

Jenni Ylä-Mella

STRENGTHS AND
CHALLENGES IN THE
FINNISH WASTE ELECTRICAL
AND ELECTRONIC
EQUIPMENT RECOVERY
SYSTEM

CONSUMERS' PERCEPTIONS AND PARTICIPATION

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
THULE INSTITUTE, AURORA DP;
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JENNI YLÄ-MELLA

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Consumers' perceptions and participation

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Abstract

The production and use of electrical and electronic equipment (EEE) have significantly increased during the last three decades due to technological innovations and new applications of EEE. Fast technological progress, EEE becoming a part of everyday life and rising incomes have led to the situation where EEE are more replaceable than ever causing the rapid growth of waste electrical and electronic equipment (WEEE). In order to reduce negative environmental and health impacts and to improve the recovery of valuable substances from WEEE, the European Union has implemented Directives related to EEE.

In this thesis, the national implementation of the WEEE Directive and the development of the WEEE recovery infrastructure in Finland were studied. Furthermore, consumers' awareness and perceptions toward the WEEE recovery system were assessed through a survey conducted in the Oulu region. Finally, the role of consumer behaviour in storing electronics at home and its impact on the realisation of the waste hierarchy were considered.

Results indicate that the implementation of the WEEE Directive has succeeded in Finland. The legislative basis and functional WEEE recovery system with high collection and recovery rates have been enacted within a few years. The study revealed that consumers' awareness of the importance and existence of WEEE recovery system is high among the residents in Oulu; however, the high storing rates of mobile phones indicate that the proximity and the convenience of the WEEE recovery system are inadequate to motivate the return of small WEEE. Analysing the lifespan of electronics indicates that stockpiling deprives the re-use potential of mobile phones and thus hinders waste prevention. Storage also delays the return of valuable substances for recycling and risks the realisation of the waste management hierarchy. It is concluded that education and awareness raising will continue to be a crucial element in the progress towards a more environmentally conscious WEEE recovery in Finland.

Keywords: consumer behaviour, environmental awareness, infrastructure, legislation, lifespan, recovery, waste electrical and electronic equipment (WEEE), waste management

Ylä-Mella, Jenni, Sähkö- ja elektroniikkaromun keräysjärjestelmän vahvuudet ja haasteet Suomessa. Kuluttajakäsitys ja osallistuminen

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Tiivistelmä

Sähkö- ja elektroniikkalaitteiden (SE-laitteiden) tuotanto ja käyttö ovat kasvaneet merkittävästi viime vuosikymmenten aikana uusien teknologisten ratkaisujen ja sovellusten myötä. Nopea teknologinen kehitys, SE-laitteiden jokapäiväistyminen sekä elintason nousu ovat johtaneet tilanteeseen, jossa ne ovat helpommin vaihdettavissa kuin koskaan aikaisemmin. Tämän seurauksena myös sähkö- ja elektroniikkaromun (SE-romu, SER) määrä on nopeassa kasvussa. Vähentääkseen SE-romun aiheuttamia haitallisia ympäristö- ja terveysvaikutuksia sekä tehostaakseen hyödyllisten materiaalien talteenottoa SE-romusta Euroopan Unioni on ottanut käyttöön sähkö- ja elektroniikkalaitteisiin liittyviä direktiivejä.

Tässä väitöskirjatutkimuksessa on tarkasteltu SER-direktiivin kansallista käyttöönottoa ja keräysverkoston kehittämistä Suomessa. Lisäksi kuluttajakäsitystä ja -tietoisuutta arvioitiin Oulun alueella toteutetulla kyselytutkimuksella. Työssä on arvioitu myös kuluttajien roolia käytöstä poistettujen SE-laitteiden kotivarastoinnissa ja sen vaikutuksia jätehierarkian toteutumiseen.

Tulokset osoittavat, että kansallinen implementointi on onnistunut Suomessa; kansallinen lainsäädännöllinen perusta ja toimiva keräysjärjestelmä on saavutettu vain muutamassa vuodessa. Tutkimuksesta selviää, että kuluttajatietoisuus keräysjärjestelmän tärkeydestä ja sen olemassaolosta on hyvällä tasolla; matkapuhelinten korkea säilytysaste kotitalouksissa viittaa kuitenkin nykyisen järjestelmän riittämättömyyteen motivoida kuluttajia palauttamaan pientä SE-romua keräysjärjestelmään.

SE-laitteiden elinkaaren vaikutusten tarkastelu osoittaa, että varastointi estää matkapuhelinten uudelleenkäyttöä ja estää jätteen synnyn ehkäisyä. Lisäksi se viivästyttää hyödyllisten materiaalien palautumista kierrätykseen vaarantaen myös jätehierarkian toteutumisen. Siksi koulutus ja tietoisuuden lisääminen ovat tärkeässä roolissa ympäristömyötäisemmän keräysjärjestelmän saavuttamiseksi Suomessa.

Asiasanat: elinkaari, infrastruktuuri, jätehuolto, kuluttajakäyttäytyminen, lainsäädäntö, sähkö- ja elektroniikkaromu (SER), talteenotto, ympäristötietoisuus

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September 2015

Jenni Ylä-Mella

List of abbreviations

| | |
|---------------------|--|
| BAN | Basel Action Network |
| B2B | Business-to-business |
| C2B | Consumer-to-business |
| DfE | Design for environment |
| DfX | Design for X |
| EEE | Electrical and electronic equipment |
| ELV | End-of-life vehicle |
| ELY Centre | Centre for Economic Development, Transport and the Environment |
| EMPA | Swiss Federal Laboratories for Material Testing and Research |
| EOL | End-of-life |
| EOU | End-of-use |
| EPR | Extended producer responsibility |
| EPSC | Electronics Product Stewardship Canada |
| ERP | European Recycling Platform |
| ERPs | Energy-related products |
| EU | European Union |
| FLIP | Finnish Lamp Importers and Producers Association |
| HDD | Hard disc driver |
| ICT | Information and telecommunication technology |
| IT | Information technology |
| LED | Light-emitting diode |
| LHA | Large household appliance |
| LiFePO ₄ | Lithium-iron-phosphate |
| MIT | Massachusetts Institute of Technology |
| MMM | Multicriteria matrix methodology |
| NEPSI | National Electronics Product Stewardship Initiative |
| NGO | Non-governmental organisation |
| NiCd | Nickel-cadmium |
| NiMH | Nickel-metal hydride |
| OECD | Organization for Economic Cooperation and Development |
| OEM | Original equipment manufacturer/manufacturing |
| POM | Put on the market |
| PPP | Polluter pays principle |
| PRO | Producers responsibility organisation |
| PSSP | Purpose, structure, state, performance |

| | |
|--------|---|
| RoHS | Restriction of hazardous substances |
| s-WEEE | Small WEEE (all dimensions no more than 25 cm) |
| SECO | Swiss State Secretariat for Economic Affairs |
| SELT | Electronic Equipment Producers' Association |
| SERTY | The Association of Electrical and Electronic Equipment Manufacturers and Importers |
| SHA | Small household appliance |
| StEP | Solving the E-waste Problem Initiative |
| SVTC | Silicon Valley Toxics Coalition |
| TPB | Theory of planned behaviour |
| UN | United Nations |
| UNEP | United Nations Environmental Programme |
| USEPA | United States Environmental Protection Agency |
| VCN | Value-belief-norm theory |
| WEEE | Waste electrical and electronic equipment |
| WFD | Waste Framework Directive |
| 3Rs | Reduce, Reuse and Recycle |

List of original publications

This thesis is based on the following publications, which are referred throughout the text by their Roman numerals:

- I Ylä-Mella J, Poikela K, Lehtinen U, Keiski RL & Pongrácz E (2014) Implementation of Waste Electrical and Electronic Equipment Directive in Finland: Evaluation of the collection network and challenges of the effective WEEE management. *Resources, Conservation and Recycling* 86: 38–46.
- II Ylä-Mella J, Poikela K, Lehtinen U, Tanskanen P, Román E, Keiski RL & Pongrácz E (2014) Overview of the WEEE Directive and its implementation in the Nordic countries: National realisations and best practices. *Journal of Waste Management*, Article ID 457372, DOI: <http://dx.doi.org/10.1155/2014/457372>
- III Ylä-Mella J, Keiski RL & Pongrácz E (2015) Electronic waste recovery in Finland: Consumers' perceptions towards recycling and re-use of mobile phones. *Waste Management* 45: 374–384.
- IV Ylä-Mella J, Keiski RL & Pongrácz E (2015) End-of-use vs. end-of-life: When do consumer electronics become waste? Manuscript

Jenni Ylä-Mella was the main and corresponding author of all four papers.

Contents

| | |
|---|-----------|
| Abstract | |
| Tiivistelmä | |
| Acknowledgements | 7 |
| List of abbreviations | 9 |
| List of original publications | 11 |
| Contents | 13 |
| 1 Introduction | 15 |
| 1.1 Objectives and scope of the study | 16 |
| 1.2 Contribution of the original publications | 16 |
| 2 The European waste hierarchy | 19 |
| 2.1 Definition of waste | 19 |
| 2.2 Waste management options | 20 |
| 3 WEEE management and regulations | 23 |
| 3.1 Definition of waste electrical and electronic equipment | 25 |
| 3.2 Characteristics of the WEEE stream | 26 |
| 3.3 The European WEEE Directive | 30 |
| 3.3.1 Main principles | 30 |
| 3.3.2 The Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) | 31 |
| 3.3.3 The recast WEEE Directive 2012/19/EU | 34 |
| 3.4 Implementation of the WEEE Directive in Finland | 36 |
| 3.4.1 Legislative implementation | 37 |
| 3.4.2 Producer associations | 37 |
| 3.4.3 The Finnish WEEE recovery infrastructure | 38 |
| 4 Participation in WEEE recovery | 45 |
| 4.1 Convenience of recycling | 45 |
| 4.2 Awareness and incentives for recycling | 46 |
| 5 The lifespan of electronics | 49 |
| 5.1 Definitions | 49 |
| 5.2 Potential for lifespan extension of EEE | 51 |
| 6 Materials and methods | 55 |
| 6.1 Reviewing the Finnish WEEE recovery system | 55 |
| 6.1.1 Evaluating the collection network | 55 |
| 6.1.2 Assessing consumer awareness, perceptions and behaviour | 56 |

| | | |
|----------|---|------------|
| 6.1.3 | Conducting the survey | 56 |
| 6.2 | The theoretical framework of evaluating consumer awareness..... | 57 |
| 6.2.1 | The theory of planned behaviour | 57 |
| 6.2.2 | Value-belief-norm theory | 58 |
| 6.2.3 | Motivation-ability-opportunity model | 58 |
| 6.2.4 | Pro-environmental behaviour | 59 |
| 6.2.5 | The behaviour model of the survey | 60 |
| 6.3 | The conceptual background of electronics lifecycle | 62 |
| 6.3.1 | Design of electronics | 62 |
| 6.3.2 | Planned obsolescence | 63 |
| 6.3.3 | The concept of waste | 65 |
| 7 | Results and discussion | 67 |
| 7.1 | Evaluation of the Finnish WEEE collection network..... | 67 |
| 7.1.1 | Compliance with the targets of the WEEE Directive | 67 |
| 7.1.2 | Challenges and best practices for improving recovery efficiency | 70 |
| 7.1.3 | Consumers' perceptions toward convenience of the current WEEE recovery system..... | 72 |
| 7.2 | Assessment of consumers' awareness and perceptions toward WEEE..... | 73 |
| 7.2.1 | Recycling behaviour | 74 |
| 7.2.2 | Awareness and incentives for recycling..... | 76 |
| 7.2.3 | Perceptions toward re-use..... | 78 |
| 7.3 | Assessment of mobile phones' lifespan..... | 80 |
| 7.3.1 | Stockpiling of mobile phones | 80 |
| 7.3.2 | WEEE and the concept of waste..... | 84 |
| 8 | Summary and conclusions | 89 |
| 8.1 | Summary of the results of the work | 89 |
| 8.2 | Knowledge gaps and recommendations for future work..... | 92 |
| | References | 95 |
| | Appendices | 103 |
| | Original publications | 111 |

1 Introduction

Currently, wastes represent an enormous loss of material and energy resources in the developed world, such as in the European Union (EU). As a result, the EU has set its main objectives to preserve, protect and improve the quality of the environment and human health, as well as utilising natural resources judiciously. This calls for significant changes in current patterns of development, production, consumption and behaviour. To meet these objectives and ambitions, the EU has enacted a wide range of legislation as a key force for change, to contribute to sustainable waste management.

Simultaneously, the production and use of electrical and electronic equipment (EEE) have significantly increased due to technological innovations and new applications of EEE over the last decades. Additionally, fast technological progress, EEE becoming a part of everyday life and rising incomes have led to the current situation where many products, including various small and consumer electronics, are more replaceable than ever. Furthermore, the useful lifespan of existing EEE has been shortened in recent years due to an ever-quicker release of EEE products with new features (Cox *et al.* 2013, Kissling *et al.* 2012, Saphores *et al.* 2012, Schaik & Reuter 2014, Yin *et al.* 2014). In consequence, the amount of WEEE has grown immensely over the last decades (Ongondo *et al.* 2011, Pérez-Belis *et al.* 2015).

The EU implemented Directives related to electronics in order to reduce negative environmental and health impacts and to improve the material recovery of valuable substances from WEEE. The aim of the WEEE Directive is also to reduce the ever-rising amounts of electronic waste, using an Extended Producer Responsibility (EPR) approach. The WEEE Directive seeks to achieve lifecycle environmental improvements for product systems by extending the responsibilities of the manufacturer of the product to various parts of the product's lifecycle including take-back, recovery and final disposal of the product.

Setting up efficient collection schemes is necessary to ensure the achievement of the targets set in the WEEE Directive. An efficient collection system will depend on accessible and efficient collection facilities, as well as adequate and consistent guidance of consumers. However, consumers and their perceptions, as well as their recycling behaviour, play a crucial role in efficient and environmentally conscious WEEE management. When pursuing to achieve high recovery rates of WEEE, the most important factor to be considered is how to

ensure the complete participation of end-users. Therefore, improved understanding of consumers' behaviour and participation for WEEE recovery is essential for improving the efficiency of the WEEE recovery system.

1.1 Objectives and scope of the study

The subject of this doctoral research is to evaluate the current WEEE management system in Finland. In this study, the efficiency of the prevalent Finnish WEEE collection network is reviewed and, further, consumer perceptions and participation were evaluated. The objectives of the thesis were to provide answers to the following research questions:

- How the WEEE Directive has been implemented in Finland?
- How the requirements set in WEEE legislation are fulfilled in Finland?
- What are the main strengths and challenges of the Finnish WEEE recovery system?
- Are consumers aware of the possibility to return WEEE?
- What are the consumers' perceptions related to the feasibility of the current WEEE collection network in the Oulu region?
- What are the reasons for failing to return mobile phones for recycling?
- Are consumers aware of the importance of mobile phone recycling?
- What are the consumers' attitudes toward the re-use of mobile phones?
- When and why consumer electronics, *e.g.* mobile phones, become waste?
- What is the lifespan of mobile phones and how does stockpiling affect WEEE management?

The ultimate aim is to bridge knowledge gaps between the planning, realisation and management of the Finnish WEEE recovery system and contribute to an effective and resource efficient system.

1.2 Contribution of the original publications

The thesis consists of three refereed journal articles and one manuscript. The contribution of original papers to achieving the objectives of this study is explained in Figure 1.

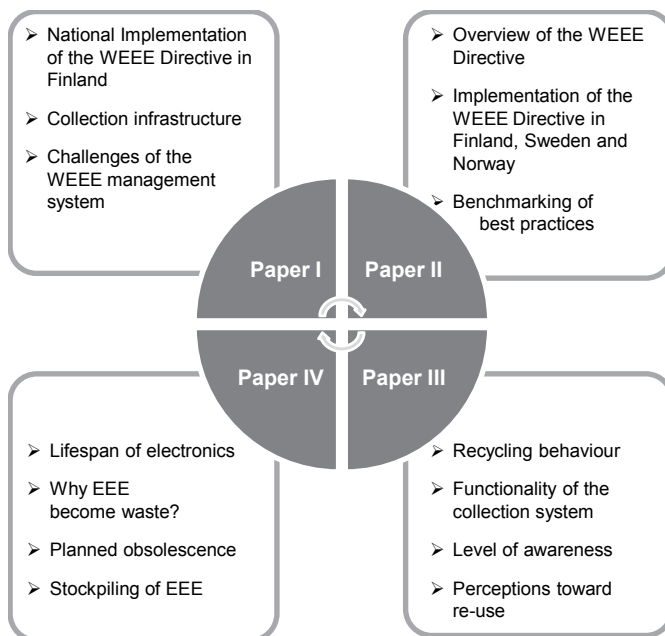


Fig. 1. Objectives of the thesis and contribution of original publications.

Papers I and II deal with the evaluation of the Finnish WEEE collection network. In Paper I, the legislative implementation of the WEEE Directive into Finnish legislation and the development of the WEEE recovery infrastructure in Finland are described. Inefficient practices existing in the current Finnish WEEE recovery system are also outlined and the challenges of its effective management, especially in the sparsely populated Northern areas of Finland, are highlighted. In Paper II, the Finnish recovery system is compared with those in Sweden and Norway in order to identify the factors defining successful and efficient WEEE recovery systems. Paper II gives first an overview of the WEEE Directive and its requirements, and then it introduces the national realisations of WEEE recovery in Sweden and Norway briefly. Finally, the comparative analysis of Nordic WEEE recovery systems is performed and best practices are identified.

Paper III examines consumers' awareness of WEEE recovery and perceptions towards mobile phone recycling and re-use. The paper reveals the results of the survey conducted in the Oulu region. Mobile phones were used as a case study of

WEEE as representatives of small high-tech devices with a short lifecycle, considerable re-use potential and substantial value of materials they contain.

Paper IV highlights the importance of the human factor in recognising waste. In the paper, it is discussed why electronic devices become waste. This key question is approached using a waste taxonomy, which argues that wastes can be classified into four categories based on the purpose, state, structure and performance attributes. In Paper IV, a review of mobile phone storage is also presented, pointing out the detrimental impact of storage on re-use potential and the realisation of the waste management hierarchy.

2 The European waste hierarchy

The waste hierarchy was launched into European waste policy by introducing it in the European Waste Framework Directive (WFD) (Council Directive 75/442/EEC) in 1975. The aim of the waste hierarchy is to protect the environment, conserve resources and minimise waste generation. The waste hierarchy indicates an order of preference for action to reduce and manage waste. Initially, the waste hierarchy had only a little impact on waste management practices. However, the European Parliament announced a new five-step waste hierarchy in the WFD (Directive 2008/98/EC on waste) in 2008. The five-step waste hierarchy is illustrated in Figure 2.

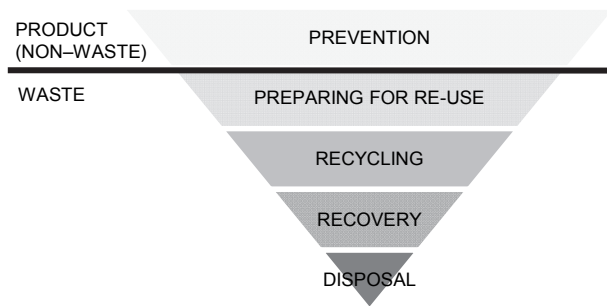


Fig. 2. Waste hierarchy (Directive 2008/98/EC).

The WFD provides that the waste hierarchy has to be implemented into Member States' national waste management laws by December 12, 2010. Furthermore, when it is applied, measures taken by Member States' should have encouraged options that delivered the best overall environmental outcome justified by lifecycle thinking (Directive 2008/98/EC).

2.1 Definition of waste

The WFD provides the general framework of waste management requirements and sets the basic waste management definitions for the EU. In the WFD (2008), waste is defined as

'any substance or object which the holder discards or intends or is required to discard'.

2.2 Waste management options

The top priority of waste hierarchy is waste prevention. According to the WFD (2008), prevention means

'measures taken before a substance, material or product has become waste, that reduce a) the quantity of waste, including through the re-use of products or the extension of the lifespan of products; b) the adverse impacts of the generated waste on the environment and human health; or c) the content of harmful substances in materials and products'.

Due to the broad definition, various challenges complicate measuring the potential improvements in prevention especially outside the original equipment manufacturing (OEM) supply network. Sihvonen and Ritola (2015) argue that prevention should only include lifecycle phases before a product is put into the market. This can be achieved in many ways, *e.g.* using multi-lifecycle as a design objective (Rashid *et al.* 2013); enhance product's longevity by extending functionality and increasing consumer's emotional attachment to it (Fitzpatrick *et al.* 2014); or design the products fostering sustainable behaviour (Daae & Boks 2013).

After commercialisation of the product, waste prevention may be achieved through re-use. In many cases, the product's functional performance extends over the usage phase of a first user, which creates the possibility for another user to use it over again. The Waste Framework Directive (2008) defines re-use as

'any operation by which products or components that are not waste are used again for the same purpose for which they were conceived'.

The current definition highlights re-use as a product or a component, instead of material re-use. Additionally, the Directive provides re-use for the original purpose of the product; it may carry out through direct re-use or second-hand trading (Sihvonen & Ritola 2015).

When waste has been generated, the waste hierarchy gives precedence to preparing to re-use, recycling and recovery methods (*e.g.* energy recovery). In the WFD (2008), preparing for re-use means

'checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing'.

The purpose of preparing for re-use is to lengthen the product's lifespan beyond the first usage phase by enhancing the product's quality. Thierry *et al.* (1995) have defined that repair involves restoring the product to 'working order', which can be achieved, *e.g.* by rectifying activities through partial disassembly (King *et al.* 2006). Therefore, repair can be placed between direct re-use and remanufacture (Sihvonen & Ritola 2015). In addition to repair, a product can also be refurbished in order to be re-used. King *et al.* (2006) states that refurbishment of a product requires more work than repair, but less than remanufacture. Quality of the product is also expected to become higher in refurbishment than in repairing. However, Thierry *et al.* (1995) underlines that the specified quality and functional state cover only the refurbished parts or components, not the whole product.

In cases, where the products or components preparing for re-use are not possible, recycling as a material is the next advisable option. The WFD (2008) defines it as

'any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes'.

Based on the definition, recycling is seen as a process, which recovers material for the same or different purposes, depending on materials quality. In order to promote high quality of recycling, the WFD (2008) provides that separate collection of wastes shall be set up when technically, environmentally and economically practicable. The Directive incorporates reprocessing of organic material into recycling; however, reprocessing into materials that are to be used as fuels or for backfilling operations are excluded from it. Rather, they are regarded as recovery as defined by the WFD (2008):

'Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy'.

The least favoured resort of the waste hierarchy is disposal. The WFD (2008) defines it as

'any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy'.

In disposal, the safe operations have to be used. That means waste management is carried out without risk to water, air, soil, plants and animals and, further, without nuisance through noise or odours. Additionally, disposal shall not affect adversely to countryside or places of special interest (Directive 2008/98/EC).

3 WEEE management and regulations

In the mid-1990's, the environmental and health impacts of WEEE became a concern due to the burgeoning amounts and the complex mixture of materials and hazardous substances contained in EEE. Hazardous substances present in EEE are not ordinarily released during their regular use; however, they may pose hazards during inappropriate end-of-life (EOL) treatment and landfill disposal. In the mid-1990s, WEEE was typically landfilled, incinerated or recovered without any pre-treatment methods and, thus, a large proportion of hazardous substances found in the municipal waste stream came from WEEE. In consequence, some of the European forerunner countries, such as Switzerland, Norway and Sweden, began to prepare national legislation regarding WEEE management to prevent the environmental problems caused by the uncontrolled disposal of WEEE.

As a consequence of the national activities of certain forerunner countries in Europe, EU initiated the European level measures in 2000 by introducing a proposal for two Directives to reduce WEEE generation, as well as negative environmental and health impacts associated with WEEE recovery. After the legislative procedure in the EU, the Directives were implemented in 2003; the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive 2002/95/EC) bans the use of lead, mercury, cadmium, chromium, PBBs and PBDEs in EEE, while the Directive on waste electrical and electronic equipment (WEEE Directive 2002/96/EC) deals with the management of WEEE. The overview of the main contents of the WEEE Directive and its implementation in Finland (Papers I–II) are described in sections 3.4 and 3.5.

The EU with other European countries are not, however, the only ones addressing WEEE prevention and the environmental impacts of electronics. Currently, numerous outstanding initiatives exist globally, as listed in Table 1. According to Solving the E-waste Problem Initiative (StEP), approximately 4 billion people were covered by national WEEE legislation in 2014; however, legislation does not necessarily come together with enforcement and not all laws have the same comprehensive scope. Driven by the national laws, around 6.5 million tonnes (Mt) of WEEE was reported as formally treated in 2014 by national take-back systems worldwide. (Baldé *et al.* 2015) The national status of WEEE regulations of selected countries is presented in more detail alongside the WEEE quantities in Table 2, in the Chapter 3.2.

Table 1. Examples of initiatives for addressing WEEE.

| Initiative | Aims and measures |
|---|---|
| Bamako Convention | Prohibits the imports of hazardous waste into Africa. Uses similar format as the Basel Convention but may set penalties. Entered into force in 1998. In 2015, parties consist of 25 African nations. |
| Basel Convention | Keeps hazardous waste within producer countries or ones able to safely process. Does not set penalties. Entered into force in 1992. In 2015, parties consist of 182 nations and EU. |
| Electronics Product Stewardship Canada (EPSC) | Develops a solution for Canadian WEEE management since 2003. Industry-led non-governmental organisation (NGO) consists of 30 leading electronics manufacturers. |
| European WEEE Directive | Establishes collection and recycling systems for WEEE based on producer take-back. In force since 2004, adapted by 2007. |
| European RoHS Directive | Restricts use of lead, mercury, cadmium, hexavalent chromium, PBB, and PBDE in EEE. Enacted along with the WEEE Directive in 2004. Adapted also outside the EU, e.g. in China and India. |
| National Electronics Products Stewardship Initiative (NEPSI) | Develops the framework of national WEEE management system in the US since 2000. Several stakeholders, e.g. electronics manufacturers, retailers, recyclers, authorities and NGOs. |
| Reduce, Reuse and Recycle (3Rs) | Seeks to prevent creation of waste, and to further cooperation on recycling with developing countries. Allows waste export for remanufacturing. Promoted by Japan since 2000. |
| SECO/EMPA e-waste programme | Assesses and improves WEEE recycling systems by analysing the systems and exchanging knowledge on techniques and frameworks globally. |
| Solving the E-waste Problem (StEP) | Promotes re-use of recycled materials and control of WEEE contaminants. Instituted in 2007 by UN agencies and StEP partners with prominent organisations, e.g. MIT and USEPA. |
| US NGOs: Basel Action Network (BAN), Electronics TakeBack Coalition, Silicon Valley Toxics Coalition (SVTC) | Acts together for national WEEE collection and recycling programmes. Promotes internationally the “Basel Ban”, a more restrictive waste export amendment to the Basel Convention. BAN accomplishes also research and documentaries. |
| US State laws and the Responsible Electronic Recycling Act (HR 2284) | State laws for WEEE collection implemented in 25 US States. Act HR2284 proposed being a national law for controlling WEEE export and certifying used electronics for export. |
| WEEE Forum | Provides a platform for co-operation and exchange of best practices. Non-profit association of 32 European WEEE producer responsibility organisations (PROs), founded in 2002. |

3.1 Definition of waste electrical and electronic equipment

Globally, understanding and applications of the term of WEEE, or e-waste, are inconsistent both in legislation and in everyday life. In consequence, several divergent definitions have been qualified and applied in regulations, policies and guidelines by various initiatives. For instance, OECD (2001) has defined e-waste as

'any appliance using an electric power supply that has reached its end of life'.

Recently, United Nations University's Solving the E-waste Problem Initiative (StEP) has provided a white paper for launching a non-legal definition of e-waste and clarifying how the term should be used. According to the StEP (2014),

'e-waste is a term used to cover items of all types of electrical and electronic equipment (any household or business item with circuitry or electrical components with power or battery supply) and its parts that have been discarded by the owner as waste without the intention of re-use'.

The most widely accepted classification of WEEE is defined by the EU and it is applied also in this thesis. According to the Directive 2008/98/EC waste means

'any substance or object which the holder discards or intends or is required to discard'

while WEEE Directive (Directive 2012/19/EU) defines EEE as

'equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current'.

Practically, the scope of the WEEE Directive includes all electrical and electronic equipment falling under the definition of EEE, excluding only equipment intended for military purposes such as arms and munitions (Directive 2002/96/EC).

3.2 Characteristics of the WEEE stream

Production and use of EEE have increased rapidly during recent years, which have also led to the rapid growth of WEEE. Already in the 1990's, the growth rate of WEEE was 3–5% per year in the EU, which was about three times higher than the growth rate of municipal waste (European Commission 2000). Recently, the global quantity of e-waste generation has increased from 33.8 million tonnes in 2010 (5.0 kg per capita) to 41.8 million tonnes (5.9 kg per capita) in 2014. In the near future, the amount of global WEEE is predicted to grow 4–5% annually, reaching nearly 50 million tonnes (6.7 kg per capita) by 2018. (Baldé *et al.* 2015)

In 2014, 41.8 million tonnes of WEEE in total was generated. Most of it was generated in Asia (16 Mt), while the highest WEEE quantity per inhabitant (15.6 kg per capita) was generated in Europe. Regionally, the lowest total quantity of WEEE (0.6 Mt) was generated in Oceania; however, the relative quantity was almost as high as in Europe. The relative quantity of generated WEEE was lowest in Africa, where only 1.7 kg per capita was generated. (Baldé *et al.* 2015) Regional and national quantities of WEEE generation in 2014 are compiled in Table 2.

In Europe, the total WEEE generation was 11.6 million tonnes in 2014. The highest absolute quantities of WEEE were generated in Germany (1.8 Mt), followed by the United Kingdom (1.5 Mt), France (1.4 Mt) and Russia (1.2 Mt). On the other hand, the top three European countries in relative quantities were Norway (28.3 kg per capita), Switzerland (26.3 kg per capita) and Iceland (26.0 kg per capita). Simultaneously, relative quantities of WEEE generated in the countries of the Balkan region remain as low as 5–10 kg per capita. (Baldé *et al.* 2015) In case of Finland, the absolute quantity of generated WEEE was 118 000 tonnes in 2012 which means around 21.5 kg per capita.

Table 2. Regional and national details of WEEE generation and management in 2014 (Baldé *et al.* 2015, StEP 2015).

| Continent/country | WEEE generation [million tonnes] | Relative quantity of WEEE [kg per capita] | Existence of the WEEE related national regulation |
|-------------------|-------------------------------------|--|--|
| Africa | 1.9 | 1.7 | |
| Egypt | 0.37 | 4.3 | No regulation in force. |
| South Africa | 0.35 | 6.6 | No regulation in force. |
| Nigeria | 0.22 | 1.3 | National regulation in force. |
| Equatorial Guinea | 0.01 | 10.8 | No regulation in force. |
| Americas | 11.7 | 12.2 | |
| United States | 7.1 | 22.1 | State-level laws in force, but no federal mandates. |
| Brazil | 1.4 | 7.0 | National laws pending approval. |
| Mexico | 1.0 | 8.2 | National regulation in force. |
| Canada | 0.73 | 20.4 | National regulation in force. |
| Asia | 16.0 | 3.7 | |
| China | 6.0 | 4.4 | National regulation in force. |
| Japan | 2.2 | 17.3 | National regulation in force. |
| India | 1.7 | 1.3 | National regulation in force. |
| Hong Kong | 0.16 | 21.5 | National regulation in force. |
| Europe | 11.6 | 15.6 | |
| Germany | 1.8 | 21.7 | National implementation of the WEEE Directive. |
| United Kingdom | 1.5 | 23.5 | National implementation of the WEEE Directive. |
| France | 1.4 | 22.2 | National implementation of the WEEE Directive. |
| Sweden | 0.22 | 22.3 | National implementation of the WEEE Directive. |
| Finland | 0.12 | 21.5 | National implementation of the WEEE Directive. |
| Norway | 0.15 | 28.4 | National WEEE legislation in compliance with the WEEE Directive. |
| Oceania | 0.6 | 15.2 | |
| Australia | 0.47 | 20.1 | National regulation in force. |
| New Zealand | 0.09 | 19.1 | No regulative instruments in force nor proposed. |
| Total | 41.8 | 5.9 | Legislation covers ~ 4 billion people |

WEEE consists of a tremendous amount of diverse devices with various original functions, weights, sizes and material compositions. Basically, WEEE can be classified into the six categories as presented in Figure 3. (Baldé *et al.* 2015) In 2014, small equipment such as toasters, kettles, radios, toys and tools, formed the most substantial portion (31%) of all generated WEEE followed by large equipment, *e.g.* washing machines and stoves with the share of 28%. Temperature exchange equipment such as refrigerators, freezers and heat pumps (17%) and screens (15%) create also notable shares of WEEE. The rest 9% of WEEE consist of small IT devices (7%), *e.g.* mobile phones, personal computers and printers, and lamps (2%). (Baldé *et al.* 2015)

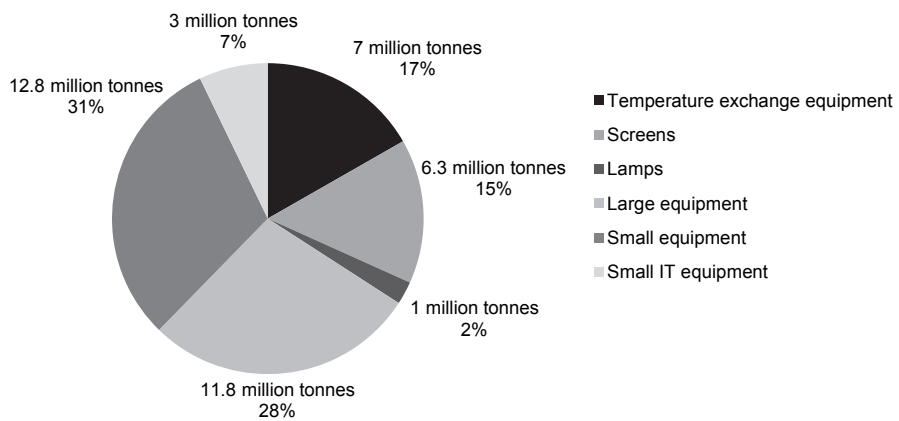


Fig. 3. Breakdown of the globally generated WEEE in 2014 (Baldé *et al.* 2015).

The material content of WEEE varies depending on WEEE categories. Iron with other ferrous metals and plastics are ordinarily major fractions of WEEE followed by aluminium and copper. Glass and miscellaneous materials may also have moderate high shares in certain categories. In addition to materials with high shares by mass, WEEE contains also high-value trace and precious metals, such as silver, gold and platinum, in concentrations higher than that in the ores commercially mined (Chancerel *et al.* 2009, Park & Fray 2009). Recently, the material composition of EEE has been examined in the UK by Haig *et al.* (2012). Based on the study, average material composition for small household appliances (category 2 of the WEEE Directive), IT and telecommunications equipment (category 3) and consumer equipment (category 4) are illustrated in Figure 4.

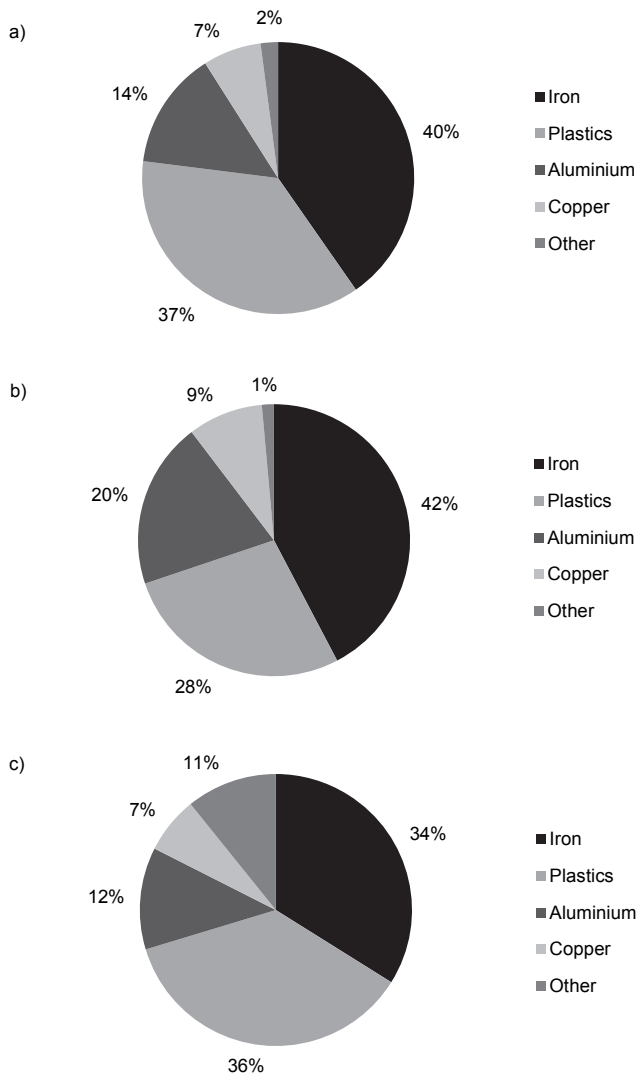


Fig. 4. Average material composition by mass for a) category 2: small household appliances, b) category 3: IT and telecommunication equipment and c) category 4: consumer equipment (Haig *et al.* 2012).

3.3 The European WEEE Directive

European Union implemented in 2003 two Directives related to electronics to reduce WEEE generation, as well as the negative environmental and health impacts associated with WEEE recovery; the RoHS Directive (2002/95/EC) and WEEE Directive (2002/96/EC). Recently, the Directives have been recast; ‘RoHS II’ came into effect in 2011 (Directive 2011/65/EU) and ‘WEEE II’ in 2012 (Directive 2012/19/EU). In the following sections, the main principles and contents of the WEEE Directives are overviewed and, further, the realisation of national implementation in Finland is introduced.

3.3.1 Main principles

The Organisation of Economic Cooperation and Development (OECD) launched the polluter pays principle (PPP) in 1972. Currently, it is one of the fundamental principles of environmental policy in the EU. As it encourages preventing and reducing pollution, it has also been included in the WEEE Directive in the form of extended producer responsibility (EPR). It is defined as an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of the product's life cycle, including its final disposal (OECD 2001). EPR policies have been adopted to manage various waste streams that require special handling and treatment, *e.g.* end-of-life vehicles, discarded electrical and electronic appliances and batteries. In the case of WEEE, EPR for the waste management phase of EEE was regulated in order to create an economic incentive for producers to move towards more environmentally sound design and manufacturing by taking into account and facilitating their repair, possible upgrading, re-use, disassembly and recycling, and, finally, the best methods of recovery and disposal. (Directive 2002/96/EC)

There are a range of approaches, from fully voluntary to mandatory, for implementing the instruments of EPR as illustrated in Table 3. In order to meet producers EPR obligations, producer responsibility organisations (PROs) are commonly constituted as a cooperation effort to provide services to manage practical affairs to its member companies.

Table 3. Optional policy instruments for EPR implementation (OECD 2001, Premalatha et al. 2014).

| Type of instrument | Examples of implementation |
|------------------------------|---|
| Administrative instrument | Minimum product and/or technical standards, restriction of hazardous substances, setting emission limits, mandatory collection and/or take-back, recovery obligations, re-use and recycling targets, disposal bans. |
| Economic instruments | Subsidies, material and product taxes, deposit-refund schemes, advance recycling and/or disposal fees. |
| Informative instruments | Environmental labelling and reports, information provisions to recyclers, consultations with authorities. |
| Voluntary industry practices | Voluntary codes of practice, environmental labelling, public-private partnerships, leasing and servicing. |

In addition to EPR, subsidiarity and proportionality are the other fundamental principles included in the WEEE Directive. Subsidiarity ensures that action is taken at the local level. In the European community context, that the member states have the capacity to take decisions and actions; however, subsidiary also authorises the intervention of the community if the member states cannot achieve objectives sufficiently (European Parliament 2010).

The principle of proportionality introduces only obligations that are necessary to achieve, not the measures of the execution. In the case of the WEEE Directive, it describes the main principles of WEEE management financing and the establishment of principles at the community level, while the modalities of the logistics and the organisation of the take-back schemes are left to the choice of the member states. In accordance with subsidiarity, national and regional conditions have to be taken into account when collection, treatment, and financing systems for the management of WEEE are devised. (European Commission 2000)

3.3.2 The Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)

After publishing the proposal for the WEEE Directive in 2000, the legislative procedures of the EU were conducted and, in consequence, WEEE Directive 2002/96/EC was put into force in February 2003. The principal aims of the Directive are to prevent WEEE generation and to improve the re-use, recycling and recovery of WEEE in order to reduce the environmental and health impacts of WEEE. The purpose of the Directive is also to harmonise national measures in

the Member States for enhancing the effectiveness of recycling policies and eliminating disparities in the financial burden at the EU level. In order to achieve these objectives, a wide range of measures are required for operators involved in the lifecycle of EEE, including producers, consumers and, in particular, operators directly involved with WEEE treatment (Directive 2002/96/EC). Due to the extremely wide range of equipment, EEE was categorised in the Directive 2002/96/EC as illustrated in Table 4.

To ensure specific treatment and the recycling of WEEE, the Directive requires producers to oversee the finance for convenient separate collection systems, free of charge for private persons. The Directive also provides a general annual collection target for WEEE, 4 kg per capita, which had to be achieved no later than by December 31, 2006 (Directive 2002/96/EC). In addition to the collection target, certain requirements for treatment are prescribed in the Directive as targets for the re-use, recycling and recovery of WEEE. Also these specific treatment requirements of different WEEE categories (see Table 4), recovery rate up to 80% by an average weight and recycling rate up to 75% by an average weight per appliance, had to be realised by December 31, 2006. (Directive 2002/96/EC)

Table 4. The minimum targets of recovery, re-use and recycling rates in the WEEE Directive 2002/96/EC (Directive 2002/96/EC) (Paper II, published with the permission of Hindawi).

| Category | Recovery rate [w%] | Re-use and recycling rate [w%] |
|---------------------------------------|--------------------|--------------------------------|
| 1 Large household appliances (LHA) | 80 | 75 |
| 2 Small household appliances (SHA) | 70 | 50 |
| 3 IT and telecommunications equipment | 75 | 65 |
| 4 Consumer equipment | 75 | 65 |
| 5 Lighting equipment | 70 | 50 |
| Discharge lamps | - | 80 |
| 6 Electrical and electronic tools | 70 | 50 |
| 7 Toys, leisure, and sports equipment | 70 | 50 |
| 8 Medical devices | - | - |
| 9 Monitoring and control instruments | 70 | 50 |
| 10 Automatic dispersers | 80 | 75 |

In Directive 2002/96/EC, reporting requirements regarding experiences from the application of the Directive are set within five years after entry into force and, further, recasting the Directive had to be suggested, if appropriate. Also the new

mandatory targets for recovery, recycling and re-use of WEEE had to be established by December 31, 2008, at the latest (Directive 2002/96/EC). The timeline of deadlines and important dates of the WEEE Directive 2002/96/EC are illustrated in Figure 5.

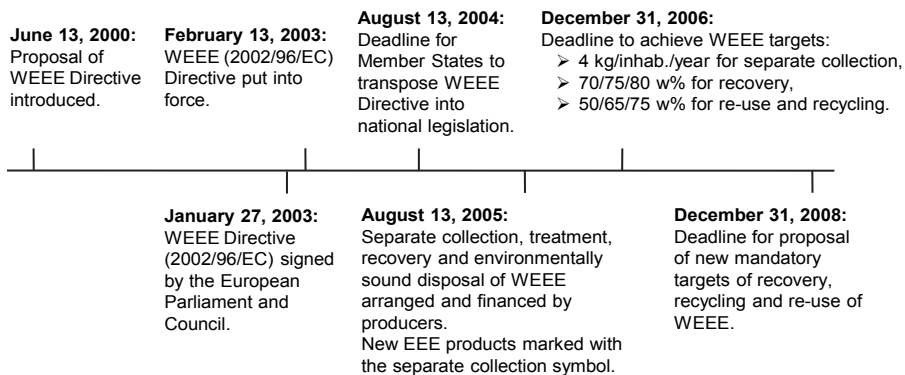


Fig. 5. Timeline of implementation of the WEEE Directive 2002/96/EC (Paper II, published with the permission of Hindawi).

Users and recyclers of WEEE have to be informed about their role in the recovery system of WEEE. In order to minimise the disposal of WEEE as unsorted municipal waste, the Directive requires labelling EEE put on the market after August 13, 2005 with the symbol of EEE shown in Figure 6. Also the requirement for producers to inform recycling operators about the material content of equipment is indicated in the Directive. (Directive 2002/96/EC)



Fig. 6. Symbol for the marking of EEE (Directive 2002/96/EC).

Despite the essential and uniform requirements of the WEEE Directive to all Member States, the transpositions of the Directive into national legislation vary

substantially. For instance, issues relating to the scope, range and type of producer responsibility, funding mechanisms and registration and monitoring are not particularly imposed by the Directive (Sinha-Khetriwal *et al.* 2006) and, therefore, more than 150 different compliance schemes exist in EU Member States (Sinha Khetriwal *et al.* 2011). National legislative implementations and/or the WEEE recovery networks have been widely investigated across Europe as can be seen in Table 5.

Table 5. Examples of the literature on the national legislative implementation of the WEEE Directive and/or the WEEE recovery systems.

| Country | References |
|----------------|---|
| Belgium | Friege <i>et al.</i> 2015, Jacobs 2008 |
| Cyprus | Kourmousis <i>et al.</i> 2011 |
| Denmark | Friege <i>et al.</i> 2015, Grunow and Gobbi 2009, Román 2012 |
| Finland | Ylä-Mella <i>et al.</i> 2014a (Paper I), Ylä-Mella <i>et al.</i> 2014b (Paper II) |
| Germany | Friege <i>et al.</i> 2015, Rotter <i>et al.</i> 2009, Rotter <i>et al.</i> 2011, Walther <i>et al.</i> 2010 |
| Greece | Achillas <i>et al.</i> 2010b, Achillas <i>et al.</i> 2010c |
| Italy | Gamberini <i>et al.</i> 2010, Gamberini <i>et al.</i> 2008, Torretta <i>et al.</i> 2013 |
| Netherlands | Melissen 2006 |
| Norway | Román 2012, Ylä-Mella <i>et al.</i> 2014b (Paper II) |
| Portugal | Gomes <i>et al.</i> 2011, Niza <i>et al.</i> 2014 |
| Romania | Ciocioiu <i>et al.</i> 2010, Popescu 2014, Torretta <i>et al.</i> 2013 |
| Spain | Mar-Ortiz <i>et al.</i> 2011, Queiruga <i>et al.</i> 2012 |
| Sweden | Bernstad <i>et al.</i> 2011, Friege <i>et al.</i> 2015, Lee and Sundin 2012, Román 2012, Ylä-Mella <i>et al.</i> 2014b (Paper II) |
| United Kingdom | Ongondo and Williams 2012, Turner and Callaghan 2007, Watson and Crowhurst 2007 |

3.3.3 The recast WEEE Directive 2012/19/EU

Based on the impact assessment of the WEEE Directive undertaken in 2008, some technical, legal and administrative challenges, *e.g.* low innovation levels in waste collection and treatment as well as distortion in competition, were observed after the first years of implementation (European Commission 2008). Based on the experience and the demand set out to propose new mandatory collection, recovery and re-use/recycling targets for WEEE by the end of 2008, the proposal for the recast WEEE Directive was introduced in December 2008. As a consequence, recast WEEE Directive 2012/19/EU was signed on July 4, 2012 and, further, the initial WEEE Directive with its successive amendments was repealed on February 15, 2014.

The main aims of the revision were to establish ambitious and appropriate collection rates for each Member State in order to increase separate collection and proper treatment. It also seeks to lower administrative burdens in the internal market by simplifying registration and reporting requirements for new equipment placed on the market and to fight illegal exports of WEEE by reversing the burden of proof on functionality for exporters. (Banti 2013) The scope of the recast Directive was clarified by defining categories as from private household ('consumer-to-business', C2B) or from users other than private households ('business-to-business', B2B), which is expected to reduce free-riding on the market.

In the recast process, EEE categories have been re-organised. According to the recast Directive, categories follow the initial ones with an extension of photovoltaic panels to category 4 over to the transitional period from August 13, 2012 to August 14, 2018. From that date onward, the Directive applies to all EEE categorized as introduced in Table 6.

Table 6. The minimum targets of recovery, re-use and recycling rates in the WEEE Directive 2012/19/EU (Paper II, published with the permission of Hindawi).

| Category | Recovery/re-use & recycling target [%] | Recovery/re-use & recycling target [%] | Recovery/re-use & recycling target [%] |
|--|--|--|--|
| | in period 1 ¹ | in period 2 ² | in period 3 ³ |
| 1 Large household appliances | 80/75 | 85/80 | |
| 2 Small household appliances | 70/50 | 75/55 | |
| 3 IT and telecommunications equipment | 75/65 | 80/70 | |
| 4 Consumer equipment | 75/65 | 80/70 | |
| 5a Lighting equipment | 70/50 | 75/55 | |
| 5b Gas discharge lamps | -/80 | -/80 | |
| 6 Electrical and electronic tools | 70/50 | 75/55 | |
| 7 Toys, leisure and sports equipment | 70/50 | 75/55 | |
| 8 Medical devices | 70/50 | 75/55 | |
| 9 Monitoring and control instruments | 70/50 | 75/55 | |
| 10 Automatic dispersers | 80/75 | 85/80 | |
| 1 Temperature exchange equipment | | | 85/80 |
| 2 Screens and monitors | | | 80/70 |
| 3 Lamps | | | -/80 |
| 4 Large equipment | | | 85/80 |
| 5 Small equipment | | | 75/55 |
| 6 Small IT and telecommunication equipment | | | 75/55 |

¹ from August 13, 2012 until August 14, 2015; ² from August 15, 2015 until August 14, 2018;

³ from August 15, 2018 onward

In the recast Directive, the more demanding and gradually evolved collection and recycling targets of WEEE are included (Table 6). Over the first three years, the recovery, re-use and recycling target remain at the previous level; however, the scope was extended to cover also category 8 (medical devices) with the target of 70% for recovery and 50% for re-use and recycling. Additionally, a separate collection rate of 4 kg/inhab./year from private households, or alternatively, the same amount of WEEE that was collected in the three preceding years if greater, have to be collected (Directive 2012/19/EU). In the period from three to seven years, all targets will raise by 5%; recycling rates ranging between 55% and 80%, and recovery rates between 75% and 85%. New categories of WEEE will be launched after seven years, with some changes in targets due to re-categorisation. Moreover, each Member State will have specific collection targets in 2019; the minimum collection rate will be 65% of the average weight of EEE put on the national market in the three preceding years or, alternatively, 85% of WEEE generated (Directive 2012/19/EU). The timeline of deadlines and important dates of the WEEE Directive 2012/19/EU is illustrated in Figure 7.

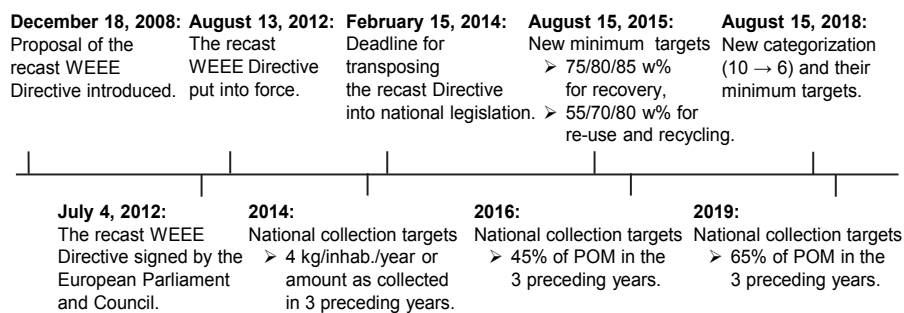


Fig. 7. Timeline of the implementation of the recast WEEE Directive 2012/19/EU (Modified from Paper II, published with the permission of Hindawi).

3.4 Implementation of the WEEE Directive in Finland

Prior to the implementation of the WEEE Directive, neither the legislative nor the operational preconditions to a nationwide, comprehensive separate collection and recovery system of WEEE existed in Finland. However, a high share of discarded metal-rich large household appliances, such as refrigerators and stoves, were already recycled in Finland through a well-established metal recycling system.

3.4.1 Legislative implementation

Producer responsibility had already launched in Finnish waste legislation in the late 1990s through the management of waste tyres (Government Degree 1246/1995), packaging (962/1997) and paper (883/1998). However, the Finnish Waste Act (1072/1993) had to be amended (452/2004) with new clauses on producer responsibility in order to harmonise Finnish legislation with the WEEE Directive. As a consequence, the Waste Act was amended in June 2004 and, further, governmental regulations of WEEE (852/2004) and RoHS (853/2004) were put into force in September 2004. Less than ten years later, the Finnish Waste Act was reformed due to the implementation of the Waste Framework Directive (2008/98/EC) and incoherence caused by several amendments. In the reformed Finnish Waste Act (646/2011), no outstanding changes in producer responsibility on EEE were made. However, the mandate of the national inspecting and controlling authority of WEEE was enhanced and, further, roles and responsibilities of various actors of WEEE were also clarified. The articles of concerning producer responsibility on EEE entered into force on May 1, 2013. Due to the adaption of the recast WEEE Directive (2012/19/EU) into Finnish legislation, the Waste Act is required to be revised again. As a consequence, the amendment of the Finnish Waste Act (410/2014) and the revised Government Degree on WEEE (519/2014) came into force in July 2014.

3.4.2 Producer associations

The majority of electronic devices sold on the Finnish market are imported (Finnish Customs 2015). Most of the producers and their representatives have transferred responsibility over discarded electronics to a producers association that, in turn, appoints WEEE recovery companies for treatment and recycling. Currently, five producer associations providing collection and recycling services for WEEE exist in Finland. Three of them, Finnish Lamp Importers and Producers Association (FLIP ry), ICT Producer Co-operative (ICT-tuottajaosuuskunta) and Electrical and Electronics Equipment Producers' Association (SELT ry), have founded together an umbrella organisation and service provider named Elker Ltd in 2004. The other two, The Association of Electric and Electronic Producers and Importers (SER-tuottajayhteisö ry, SERTY), established in 2000, and the European Recycling Platform Finland (ERP Finland), established in 2005, operate independently.

After the first years of national implementation of WEEE legislation, the EEE producers have organised rapidly. In 2005, producers associations had already more than 500 members, while four years later, in 2009, the number of members increased to over 1000. Additionally, more than 120 companies had registered to the producer register as individual producers for taking care of their producer responsibility independently. In addition to the registered producers, also free-riders exist in the Finnish market. No official information is available but it was estimated in 2011, that the share was up to 10% of EEE put in the market. (Toppila 2011: 34–35)

3.4.3 The Finnish WEEE recovery infrastructure

Various tasks such as the collection, transportation, sorting and disassembly of products, storage, selling of material fractions as well as re-usable products and parts are included in the supply chain of WEEE. In the building phase of the WEEE recovery system in Finland, two diverse structures of the supply chain were built. SERTY and ERP Finland both built their own centralised reverse supply chains, while Elker promoted a nationwide decentralised logistics network. Elker had over 30 pre-treatment stations across the country and logistics services were typically sourced from regional operators. However, producers associations have recently begun to collaborate more and, in consequence, SERTY and ERP Finland have also moved towards a more decentralised system. Additionally, most of the reception points are nowadays collectively financed by all five producers associations.

It is crucial to set up an efficient collection system because collection and transportation are ordinarily the most expensive steps of the WEEE supply chain (Lonn *et al.* 2002, Truttmann & Rechberger 2006). There are several ways to organise collection of WEEE; the most common ones are municipal sites, in store retailer take-back and producer take-back (Savage *et al.* 2006: 37–38, UNEP 2013: 51–53). Moreover, drop-off programmes, pick-up programmes and distance collection are the most commonly used methods for WEEE collection (Chancerel 2010: 37–38). In drop-off programmes, discarded devices can be returned to permanent collection centres, retailers or to containers located in public places, *e.g.* on the streets or shopping centres. Additionally, they can also be implemented as temporary collection events. Municipal collection sites are cost effective because facilities require minimal upgrading, while collection points at retail shops have been found to be successful due to high convenience for consumers

(Tanskanen 2013, UNEP 2013: 52). In pick-up systems, WEEE is collected directly from homes or offices as a regular curb-side collection or, alternatively, picked up together with other separately collected waste fractions according to a scheduled timetable (Chancerel 2010: 37–38, Tanskanen 2013, UNEP 2013: 52). In distance collection, discarded devices are sent to the collector or recycler through public postal services. It is regarded highly consumer-friendly due to easy return process for consumers; however, the costs of logistics are relatively high compared to other methods (Tanskanen 2013).

In the Finnish WEEE system, collection is arranged mainly as a permanent collection. According to Toppila (2011: 36) around 450 collection points existed around the country in 2011. In most cases, municipalities provide permanent collection points; in some cases, they are provided by private companies or social enterprises. Household devices can be brought to the collection points free of charge, while non-private users are required to have a contract with local operators to remove their WEEE straight to regional WEEE sorting and pre-treatment plants. In the case of consumer WEEE being used in companies, those can be returned to certain B2B reception points, which are managed by producer associations. They are typically located in connection with the regional pre-treatment plants (Paper I). The main stages of the WEEE recovery system in Finland are presented in Figure 8.

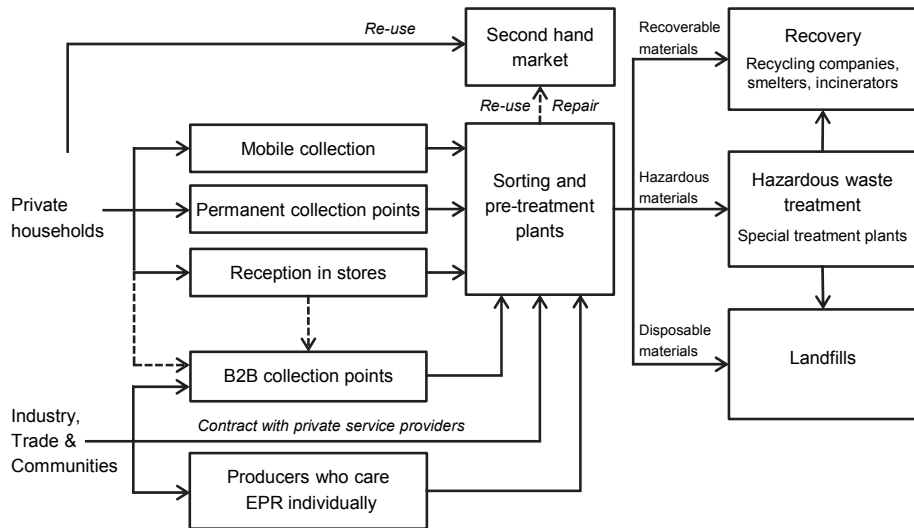


Fig. 8. The main stages of the Finnish WEEE recovery network based on Paper I (Paper II, published with the permission of Hindawi).

A permanent collection system is not efficient in all cases, *e.g.* because of the low quantities of returned devices (Kang & Schoenung 2005). Therefore, the recovery of WEEE has been organised as a mobile collection once or twice a year in the smallest or the most sparsely populated Finnish municipalities. In certain trials conducted in the most sparsely populated municipalities, consumers were also able to return their discarded devices to the retailers in association when buying a new, corresponding device.

Until 2013, the use of retailers' take-back option was very limited in Finland due to strong resistance of the Finnish retail business. However, in accordance with the Directive 2012/19/EU on WEEE, the retailer take-back option has been extended throughout Finland. Therefore, since May 2013, end-of-life EEE devices can also be returned to the retailers in association with buying a new, corresponding device, to the store the new device is bought from. Since that date, small WEEE with all dimensions no more than 25 cm can be returned also with no purchase obligation to electronics shops of 200 m² minimum or to grocery shops larger than 1000 m² (Ministry of Environment in Finland 2011). There is no accurately dictated implementation for in-store reception in Finland; however,

shops are required to finance and organise the place, requisites and work contributions needed to receive the WEEE. Distributors may forward the received WEEE to the B2B reception points of official collection network by themselves or, alternatively, they may enrol in a distributors register in order to obtain free unloading services financed by producers associations. After registration, distributors may purchase certain combo receivers designed especially for small WEEE or get free-of-charge a special collection requisite for data WEEE, if such kinds of devices are included in the distributor's product range. According to SERTY, around 1500 distributors and shops had enrolled in the distributors' register of Finland by January 2014. In that time, around 1000 shops were expected to be still missing from the register, partly due to delayed legislation, partly due to low amounts of received WEEE and challenge to arrange a physical space for in-store collection (SERTY 2014).

From the local permanent collection points, private transportation providers contracted by producers associations transport received WEEE to regional sorting and pre-treatment stations where WEEE is manually separated for different product co-operatives, weighed and sorted. Additionally, re-usable equipment and components are sorted, stocked and delivered onwards, while recyclable devices are directed for pre-treatment. In pre-treatment, WEEE is manually disassembled to fulfil requirements for selective treatment of hazardous materials set in Annex VII of the recast WEEE Directive and, additionally, large monomaterial parts are manually separated before crushing the WEEE. Crushed WEEE is then mechanically sorted out before being delivered onwards for recovery; metals and glass to smelters or reprocessing plants, while plastics are mainly utilised as energy in incinerators. Non-recyclable parts and materials are taken to special treatment plants or for final disposal. Finally, data on operations performed in the sorting and pre-treatment stations and the quantities of various WEEE fractions are sent to producers' co-operatives.

Case: Regional WEEE recovery network in Oulu area

Oulu Waste Management Company manages the regional municipal waste management system in 13 municipalities with the total area of 15 400 km² serving around 300 000 residents. In 2015, the Oulu Waste Management Company has 73 collection points in its operating area in order to promote households recycling activities by facilitating the separate collection of domestic recyclables such as cardboard, glass, metal and paper. Additionally, seven waste stations receive for

free particular special domestic wastes such as hazardous wastes, WEEE and small amounts of waste oils. In the case of WEEE, the Oulu Waste Management Company maintains ten permanent manned WEEE reception points in its operating area with fixed opening times and guidance available on demand. (Oulu Waste Management Company 2015) The main reception point of WEEE is situated in the premises of the Waste Management Company in Oulu, where WEEE is roughly sorted by consumers to designated containers and cages in the area. Nine other reception points are situated on waste stations in rural population centres of the Oulu region, where the returned EOL devices are put into a single container or cage without sorting.

In addition to the reception points maintained by the Oulu Waste Management Company, consumers can also return their larger batches of WEEE to certain B2B reception points managed by producers associations. These B2B points are primarily intended for consumer WEEE being used in the companies, and they are located in connection with the sorting and pre-treatment plants of private service providers. In addition to companies, these points are open for distributors, who forward received WEEE to the official recovery network by themselves. In the beginning of 2014, there were only 20 shops in the Oulu region enrolled on the distributors register (SERTY 2014). All registered shops were local units of nationwide or international chains. Remarkably, most of them trade in daily consumer goods or interior decoration and building products; only one was a recognised electronics shop.

Received WEEE is transported from the Oulu Waste Management Company's collection points by private transportation providers contracted by producers associations to the regional sorting and pre-treatment plants situated in the city of Oulu. In the sorting plant, WEEE is firstly separated for different product co-operatives, weighed and sorted, and then the pre-treated devices and materials are delivered for actual treatment and material recovery mainly in Finland, as shown in Figure 9. Non-recyclable WEEE is stored until delivered to final treatment plants or disposed. Data on the quantities of WEEE fractions and all operations performed in the sorting and pre-treatment station are sent to the producers' co-operatives.

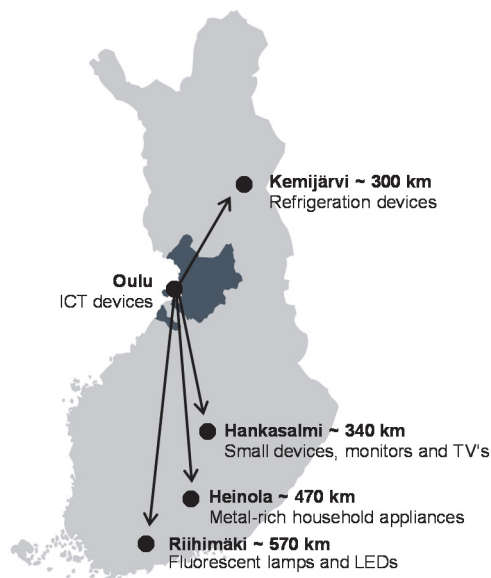


Fig. 9. The course of pre-treated WEEE from reception points maintained by the Oulu Waste Management in 2013 (modified from Figure 2 in Paper I, published with the permission of Elsevier).

In 2013, the Oulu Waste Management Company received around 1900 tonnes of WEEE. Half of the received WEEE, around 940 tonnes, was small household and consumer electronic devices. Furthermore, 593 tonnes (31%) of miscellaneous large household appliances, 355 tonnes (19%) of refrigeration devices and 17 tonnes (1%) fluorescent lamps were received. (Oulu Waste Management Company 2014)

4 Participation in WEEE recovery

Consumer attitudes and behaviour play a crucial role in efficient and environmentally conscious waste management; the existence of the WEEE collection network cannot ensure high recovery rates of WEEE but the most important factor to be considered is how to ensure the complete participation of the end-users.

4.1 Convenience of recycling

Separating dry recyclables is already a common activity amongst households in many parts of the world (Thomas & Sharp 2013). However, provision of services and the awareness of recycling are important when individuals choose to participate or not. Typically, perceptions of convenience and familiarity with local waste facilities enhance consumers' recycling behaviour (Barr *et al.* 2001, Saphores *et al.* 2006, Thomas & Sharp 2013, Valle *et al.* 2004), while inconvenience of recycling schemes and economic disincentives (*e.g.* return fees, extra trips) seem to reduce participation and recovery rates (Barr *et al.* 2001, Bouvier & Wagner 2011, Wagner *et al.* 2013). That is shown to be the case also in many WEEE recycling schemes (Saphores *et al.* 2012, Wang *et al.* 2011, Yin *et al.* 2014); however, some studies found that satisfaction with the facilities provided did not correlate with recycling behaviour but the most widespread motive for participating was legal or social norms (Miafodzyeva *et al.* 2013, Ramayah *et al.* 2012).

Wagner (2013) has studied the concept of convenience. He argues that insufficient attention has ordinarily been paid to ensure that collection systems within the framework of EPR are as convenient as possible because they are typically developed fairly rapidly. On the other hand, the term of convenience is a subjective construct and, therefore, individuals may have different perceptions regarding convenience of the collection system (Wagner *et al.* 2013). To help assess the convenience of a collection system, Wagner (2013) has identified that elementary components of convenience are knowledge requirements, proximity to the collection point/site, opportunity to drop-off materials, inducement of the collection point/site (*e.g.* desirability or availability of services), and ease of the process. According to Wagner (2013), a highly convenient collection system includes, therefore, easily obtainable and centrally located multiple collection points without any accessibility or temporal restrictions and, additionally, requires

minimal efforts to obtain and/or provide information in the course of returning procedures.

Bouvier and Wagner (2011) have studied the influence of collection facility attributes on household collection rates for TV's and computer monitors. Their results related to facilities' operation hours correlated with Wagner's findings; the more frequently facilities were open, the higher collection rates were reached. However, the results indicated that there was no correlation between the collection rates and the proximity of collection facilities but between collection rates and curbside collection. Based on the results, it seems that households served by curbside collection are less likely to transfer their WEEE to the collection facilities (Bouvier & Wagner 2011).

4.2 Awareness and incentives for recycling

In addition to an adequate and convenient collection system, recycling efforts can be raised by increasing consumers' awareness informing them about the importance of recycling and current recycling practices (Staats *et al.* 2004). Increased information and environmental awareness has been shown to enhance public participation in recycling (Ramayah *et al.* 2012, Saphores *et al.* 2012, Thomas & Sharp 2013, Valle *et al.* 2004). On the other hand, recycling is already such a strong social norm, that it hinders moves towards the more sustainable activity of reducing or preventing waste (Thomas & Sharp 2013). This becomes true especially in cases, where people do not hold sufficiently pro-environmental values to engage in other sustainable behaviours than recycling. Moreover, recycling has also been found to be used to compensate for other less sustainable behaviours, *e.g.* flying (Cox *et al.* 2013, Thomas & Sharp 2013). Therefore, in order to encourage recycling and other pro-environmental behaviours, Thomas and Sharp (2013) emphasise the importance of a greater understanding of positive and negative spill-overs in designing interventions.

Economic incentives on a large scale have not been seriously considered yet for fostering WEEE recycling (Milovantseva & Saphores 2013, Saphores *et al.* 2012); Notwithstanding, various incentives have been offered for mobile phones (Ongondo & Williams 2011b, Tanskanen 2013). Original equipment manufacturers (OEMs) may offer various incentives in order to attract consumers to participate in recycling programmes initiated by OEM. For instance, Nokia, the well-known former Finnish mobile phone manufacturer, has organised various recycling programmes with telecom operators, retail companies, environmental

NGO's and educational institutes or direct consumer campaigns over the years. In these programmes, incentives provided by Nokia, have ranged from prepaid phone cards to eco-friendly shopping bags or tree planting (Tanskanen 2013).

In addition to OEMs, also mobile phone operators and recyclers may provide incentives for their customers. Ongondo and Williams have studied mobile phone collection and recycling in the UK, especially among university students (2011a, 2011b). According to their study (2011b), numerous mobile phone take back schemes operate in the UK. Many of these schemes are voluntary and most of them provide various incentives; in addition to direct monetary payment, they include discounts or free services for mobile phone usage and certain free returning options for EOL phones. Based on the survey of Ongondo and Williams (2011a) conducted among the university students, the most popular incentives for consideration were cash payments, ease of use and convenience of service, and a contribution to charity or environment, while free airtime, texts, MP3s and ringtones were ranked the least attractive incentives.

Based on good experiences in mobile phone recovery combined with current low recycling rates of WEEE, several authors have suggested to give serious considerations for implementing economic incentives to foster WEEE recycling (Arditi 2014, Milovantseva & Saphores 2013, Ongondo & Williams 2011b, Saphores & Nixon 2014, Yin *et al.* 2014).

5 The lifespan of electronics

Lifespan is an essential parameter for accounting and analysis of material stocks and flows (Murakami *et al.* 2010). Typically, lifespan is considered constant over time in these assessments (Babbitt *et al.* 2009). However, the expectation is that the lifespan of electronics would be extended. The Waste Framework Directive (see Chapter 2.2) quotes lifespan extension as an example of waste prevention measures. In reality, several studies argue that the lifespan of electronics has narrowed recently, due to rapid technical progress and fast release of upgraded models (Cox *et al.* 2013, Saphores *et al.* 2012, Schaik & Reuter 2014). Determining the lifespan of electronics is challenging, due to the clash between expectations and reality, as well as due to inconsistent terminology and the lack of an unambiguous definition.

5.1 Definitions

In order to reduce and control the environmental impacts of energy related products (ERPs), the EU has implemented the Ecodesign Directive 2009/125/EC. The Directive makes references to lifespan, in particular to extending lifespan, but does not define it. According to the Directive, the lifespan of ERPs shall be extended through placing minimum guaranteed lifespan and time for availability of spare parts. The Ecodesign Directive (2009) defines the lifecycle of ERPs as

‘the consecutive and interlinked stages of a product from raw material use to final disposal.’

The phases of the lifecycle are (Directive 2009/125/EC):

- a) Raw material selection and use
- b) Manufacturing
- c) Packaging, transport and distribution
- d) Installation and maintenance
- e) Use
- f) End-of-life, meaning the state of a product having reached the end of its first use until its final disposal.

It is interesting to note that end-of-life (EOL) is defined differently in the European End-of Life Vehicles (ELV) Directive (Directive 2000/53/EC). In the ELV Directive, ‘end-of life vehicle’ is defined as

'a vehicle which is waste within the meaning of Article 1(a) of Directive 75/442/EEC (Waste Directive)'.

This definition indicates that an EOL product is waste that, according to the Waste Directive, is at the point of disposal. Whilst according to the Ecodesign Directive, EOL is a period of time between the end of first use and when the product is disposed. Should the first owner give or sell the product to another user, or keep it in a drawer until it is disposed, both would be part of the EOL phase. The Ecodesign Directive may assume that the device is disposed of immediately after end-of-use (EOU). This, however, is often not the case, as storage of EOU ERPs is rather common. Additionally, EOU and disposal may not coincide with loss of functionality. These factors make the interpretation of the lifespan of ERPs ambiguous. Murakami *et al.* (2009) and Babbitt *et al.* (2009) have noted three different approaches in defining lifespan:

- a) In reference to use; the length of time from the point of sale to the point of discard;
- b) In reference to ownership; the length of time a product is possessed by its first user;
- c) In reference to functionality; the length of time between purchase and product obsolescence.

It seems the beginning of a product's life is rather unambiguous; it is when its first owner purchases it. The Ecodesign Directive (2009) refers to this point as 'putting into service'. The EOL point is more open to interpretation. Figure 10 illustrates the main terms related to lifespan and EOL, and the disparity between the definitions.

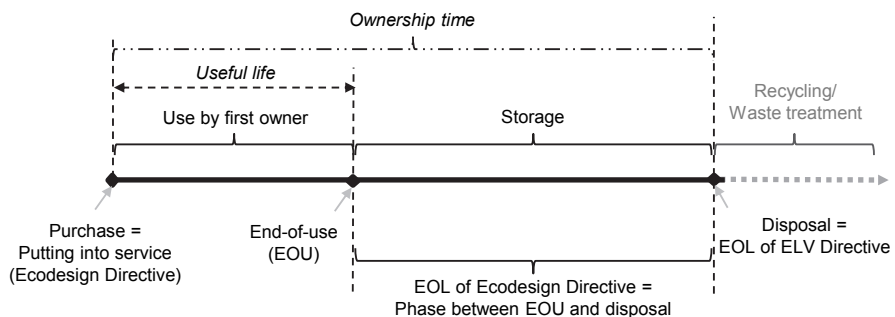


Fig. 10. Timeline for lifespan and end-of-life of ERPs (modified from Paper IV).

The assumption of this thesis is that the lifespan of ERPs begins when a product is put into service by its first owner and ends when its last holder discards it. In terms of EOL, the agreement is with the ELV Directive; *i.e.* an EOL product is that which has been disposed of, therefore, it is waste. The end of useful life, when the product is put out of use, will be called the end-of-use (EOU) phase.

It can be summarised that the lifecycle of EPRs is the length of time its constituting materials are in the technosphere, whilst lifespan is defined by its users.

5.2 Potential for lifespan extension of EEE

Consumer understanding of product lifespan has been studied by Cox *et al.* (2013), and they developed a new product typology based on product lifespan preferences. The three classes of product are ‘up-to-date’, ‘workhorse’, and ‘investment’ products. According to Cox *et al.* (2013), most consumer electronics and small EEE are considered ‘up-to-date’ products with expected lifespans of less than five years. Moreover, these products are typically discarded before the end of their functional life for reasons of keeping up with technological advances or personal feeling of success in life. A lifespan of ‘workhorse’ products is more closely related to functional durability. They are mostly used as long as they work properly; however, they are ordinarily replaced immediately when break down due to feelings of expensive or difficult repair and low cost of replacement. The third class, ‘investment’ products, have generally longer lifespan than other classes, because of consumers feelings of greater financial and/or emotional investment put into the products in the course of procurement. Consumers also tend to treat investment products carefully in use and are willing to pay for repairing because the initial investment makes the value of repair more apparent (Cox *et al.* 2013). Therefore, ‘investment’ products have highest potential for lifespan extension but also ‘up-to-date’ products can be in focus on the interest of re-use due to their short first life in use.

Regardless of the growth of EEE re-use sector over the last decades, there is still a lot of latent potential to improve the re-use of EEE (Babbitt *et al.* 2011, Kissling *et al.* 2012, Peagam *et al.* 2013) due to a number of deterring factors, such as lack of incentives, collection options and consumer awareness of re-use (Achillas *et al.* 2010a).

Achillas *et al.* (2010a) have studied promoting EEE re-use from a manufacturer’s perspective. As a small fraction (about 20%) of all EEE

components are responsible for most (about 80%) of the economic and environmental costs (the so-called Pareto's law), manufacturers have a great interest to identify those components and focus appropriate treatments on them for maximising the benefits. This can be achieved *e.g.* by using a multicriteria matrix methodology (MMM), the objectives of which are to rank components in respect to EOL potential value and identify most suitable alternative EOL management for components. According to MMM, re-use is qualified as an optimal management method for cases where components can be disassembled fast, disassembly has significant residual economic value or component provokes a heavy environmental burden when disposed of. Therefore, Achillas *et al.* (2010a) emphasise that design has a significant role towards contribute to re-use opportunities.

Kissling *et al.* (2012, 2013) have studied more in depth the generic re-use operating models for EEE, as well as success factors and barriers in re-use of EEE from the re-use operators' point of view. Their study revealed that the most important success factors are related to quality of used EEE, process practices during the preparation for re-use, and stakeholder relationships, while the least important factors were related to documentation and reporting, as well as cost and revenues. Respectively, the access to sufficient volumes of used, good-quality equipment and existing informal or illegal re-use practices were mentioned to be the most important barriers. In addition, barriers related to regulations, standards, product design and costs were also identified. (Kissling *et al.* 2013)

For improving the access to sufficient volumes of good quality EOL EEE, the EOL management practices of institutional and business-to-business (B2B) ICT devices have been studied by Babbitt *et al.* (2011), Peagam *et al.* (2013) and Peagam *et al.* (2014). According to the study of Peagam *et al.* (2013), only a small portion of B2B WEEE is collected in compliance with the WEEE Directive in the UK, Germany and France. Smaller organisations typically disposed of their EEE devices through informal arrangements while larger ones disposed them through contractors. Peagam *et al.* (2013) argues that recycling and refurbishment of B2B ICT devices seem to be commonplace in the EU; however, B2B devices seem to be entering streams where they are not reported. There are various practices and cultures related to B2B WEEE management system in EU and treatment options are highly driven by the end market for the resulting products. For instance, the re-use of B2B WEEE occurs commonly in Germany and UK, but seldom in Austria or Spain. (Peagam *et al.* 2014)

According to Peagam *et al.* (2013), the majority of B2B ICT devices reached their EOL after 3–4 years or in 3 years if the units had fixed replacement periods. Furthermore, product lifespans for B2B were noted to be shorter than for C2B and, therefore, there could be an untapped re-use potential for B2B devices (Peagam *et al.* 2013). The re-use potential and economic value of ICT devices have also been studied by Babbitt *et al.* (2011). Based on their study, especially laptops and desktop computers have a great revenue stream of re-use due to the high frequency of purchases by individuals. The resale of institutional electronic devices is not only economically worthwhile, but also extends the product lifespan by delaying equipment entering the waste stream. However, Babbitt *et al.* (2011) highlight that it is crucial to eliminate the storage phase of end-of-first-life products; immediate return to appropriate EOL management increases the re-use and refurbishment potential of EEE (Babbitt *et al.* 2011). Babbitt *et al.* (2011) took also a stand on the environmental advantages of computer leasing system; they argue that leasing by itself does not automatically ensure environmental benefits because the fixed replacement periods are typically shorter than the functional lifespan of most EEE. Therefore, the replacement cycles of EEE should be considered more case-specifically, depending on the spectrum of equipment lifespan in question (Babbitt *et al.* 2011).

All in all, the main challenges of increasing re-use rise from the contradiction between WEEE legislation and manufacturers' benefits. Recently, increased motivation for re-use is provided in the European WEEE legislation; however, re-use may be a conflict of interest for producers; better environmental image may increase the total sales or, on the contrary, sales volumes of new equipment may be reduced due to re-use in parallel with increased WEEE collection costs. It has also been proposed that the image of re-use hurts the brand image of high-tech fashion conscious devices (Herold 2007: 124–125).

6 Materials and methods

Various theories, concepts and methods were applied in this doctoral study to review the Finnish WEEE recovery network, evaluate consumer awareness, perceptions and behaviour and, finally, to analyse the lifespan of consumer electronics and the impacts of storage on the realisation of the waste hierarchy.

6.1 Reviewing the Finnish WEEE recovery system

The review is based on a study of the network infrastructure and evaluation of consumer awareness through a survey conducted as a questionnaire in the Oulu region in 2013.

6.1.1 Evaluating the collection network

The review of the network is based on personal professional experiences and academic research conducted over the course of 10 years in Finland. The evaluation study, presented in Papers I and II, was explorative in nature while resting on a literature review and personal notifications from Finnish, Swedish and Norwegian real-life experiences. Notifications from various representatives of national authorities and WEEE operators were conducted through personal encounters in professional positions, e-mail enquiries, semi-structured personal interviews carried out during company visits, and person-to-person discussions in public events related to the topic of the thesis. By way of illustration, thematic issues discussed in the semi-structured interview conducted during the company visit in El-Kretsen, Sweden, are summarised in Appendix 1. The aim of the evaluation of the Finnish WEEE collection network was to provide answers to the following research questions:

- How the WEEE Directive has been implemented in Finland?
- How the requirements set in WEEE legislation are fulfilled in Finland?
- What are the main strengths and challenges of the Finnish WEEE recovery system?
- Are consumers aware of the possibility to return WEEE?
- What are the consumers' perceptions related to the feasibility of the current WEEE collection network in the Oulu region?

6.1.2 Assessing consumer awareness, perceptions and behaviour

Consumers' awareness, perceptions and behaviour related to the current WEEE recovery system, recycling and re-use of electronic waste, especially mobile phones, were investigated through a survey and reported in Paper III. The survey was a descriptive case study supported by quantitative analysis. Mobile phones were selected as a case study device as they represent a typical, small, high-tech consumer device with a short lifecycle and substantial contents of valuable materials. The objective of Paper III was to provide answers to the following research questions:

- What are the reasons for failing to return mobile phones for recycling?
- Are consumers aware of the importance of mobile phone recycling?
- What are the consumers' attitudes towards the re-use of mobile phones?

6.1.3 Conducting the survey

The survey was conducted by a questionnaire distributed to arbitrarily selected respondents in a large work community (50 copies) and households across the city of Oulu with the postal codes of 90230 and 90540 (100 copies). The questionnaires were requested to be returned anonymously in prepaid return envelopes through public postal services, and the received responses were analysed by IBM SPSS Statistics, version 21.

The questionnaire consisted of 19 multiple-choice or open-ended questions. The first part of the questionnaire (questions 1–3, 4b and 19) was related to respondents recycling behaviour and convenience of the current WEEE recovery system in the Oulu area. In the second part of the survey (questions 4a, 5 and 8–11), consumers' awareness related to WEEE recovery and legislation were investigated by asking their perceptions toward mobile phone recycling. Also the level of knowledge regarding legislative issues and national implementation was enquired about. The third part of the questionnaire (questions 6 and 7) explored monetary incentives for returning old mobile phones and consumers' perceptions toward mobile phone re-use. Respondents were also required to indicate factors impacting their willingness to re-use mobile phones. The questionnaire is in Appendix 2.

6.2 The theoretical framework of evaluating consumer awareness

The behaviour model of the survey is based on the theories of planned behaviour (TPB) developed by Ajzen (1991) and value-belief-norm (VBN) by Stern (2000), improved with models of motivation-ability-opportunity-behaviour by Ölander and Thøgersen (1995) and pro-environmental behaviour by Kollmuss and Agyemang (2002).

6.2.1 The theory of planned behaviour

The theory of planned behaviour rests on the assumption that people, in essence, are rational by nature and they apply available information systematically. The basis of TPB is that people try to reach a consistency between personal knowledge, attitudes and behaviour. Therefore, the central factor of TPB is the individual's intention to perform certain behaviour. A simplified representation of TPB is illustrated in the Figure 11.

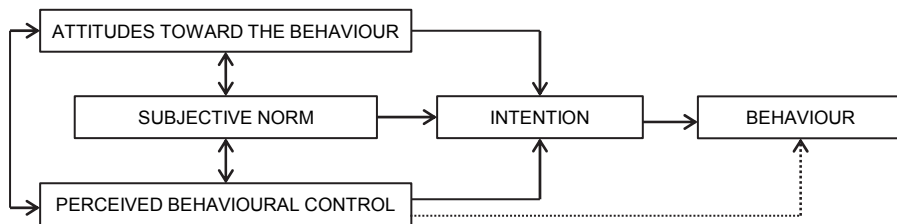


Fig. 11. A schematic representation of TPB (Ajzen 1991).

According to TPB, behaviour is driven by three independent determinants of intention; attitudes toward the behaviour, perceived social pressure or subjective norms and perceived behavioural control over the action, which is assumed to reflect the person's past experiences. The stronger these factors are, the more likely they are to form a behavioural intention to do the action and, ultimately, act. All of these determinants are driven by the individual's salient beliefs; therefore, changes in beliefs are required in order to influence individuals' behaviour. It is assumed in the TPB theory, that external variables, such as personality characteristics or demographic variables, can affect the person's behaviour only indirectly. Therefore, they are regarded as less stable and are ordinarily excluded from TPB. (Ajzen 1991)

6.2.2 Value-belief-norm theory

In the value-belief-norm (VBN) theory developed by Stern (2000), value theory has been linked to norm-activation theory. According to VBN theory, personal norms are activated when individuals believe that adverse consequences violate something they value and they would share the responsibility for those consequences by taking certain action. (Stern 2000) Figure 12 illustrates the causal chain of VBN.

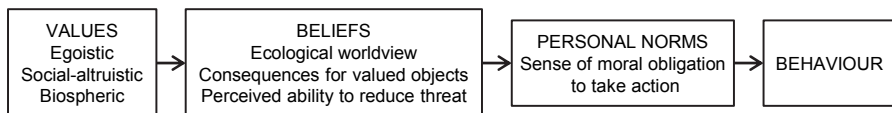


Fig. 12. Variables in the VBN theory of environmentalism (Stern 2000).

The VBN theory recognises that moral motivations, including personal values, beliefs, and norms, have a strong causal influence to the environmentally significant behaviour. These causal factors vary across behaviour and individuals, and may also interact with each other. Attitudinal causes are typically the most predictive for behaviours not strongly limited by context or individuals' capability, whereas contextual factors and personal capability induce more variance for expensive and/or difficult behaviours (Stern 2000). In sum, VBN argues that individual choice about pro-environmental actions is driven by personal norms, an internalised sense of obligation to act in a certain way.

6.2.3 Motivation-ability-opportunity model

Ölander and Thøgersen (1995) argued that motivation, ability and opportunity should be taken into consideration when determining consumer behaviour. Motivation is the first component of the model; it consists of beliefs, attitudes and social norms affecting the intention to perform certain behaviour. Apart from the motivation, acting in certain way requires also the abilities, *e.g.* knowledge or habits, to perform. Although ability is a precondition for a desired behaviour, it may also be a risk for failure due to 'old habit' in a changing situation. The other precondition for the performance of the behaviour is opportunity. The illustration of Ölander and Thøgersen's motivation-ability-opportunity model for consumer behaviour is presented in Figure 13.

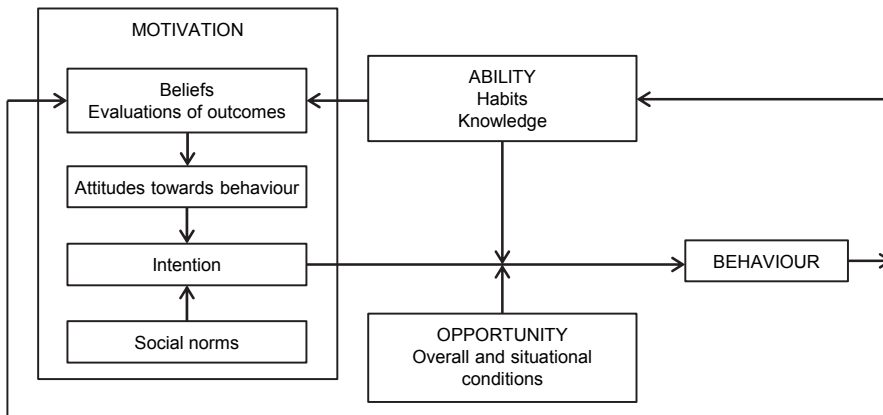


Fig. 13. The motivation-ability-opportunity-behaviour model (Ölander & Thøgersen 1995).

Ölander and Thøgersen (1995) emphasise that individuals may perceive the same conditions in divergent ways and, thus, they experience existing opportunities variously. In time, people may also to change their beliefs or abilities because of experiences and learning process.

6.2.4 Pro-environmental behaviour

Numerous theoretical frameworks explaining complex relationships between environmental knowledge, environmental awareness and pro-environmental behaviour have been developed. However, no definitive explanation has yet been found. The Kollmuss and Agyeman (2002) model takes into account positive and negative factors influencing pro-environmental behaviour and explains how they influence each other and, ultimately, behaviour. A simplified illustration of this model is presented in Figure 14.

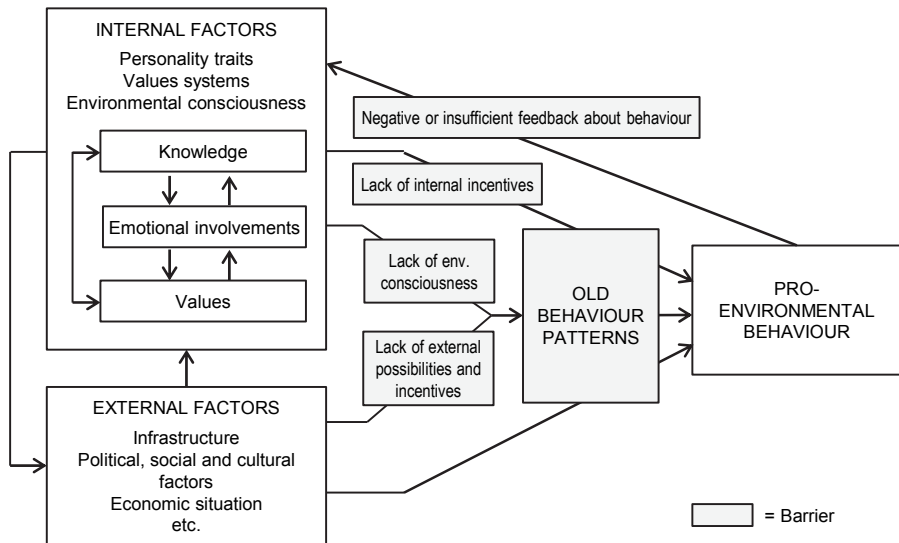


Fig. 14. A simplified representation of model of pro-environmental behaviour (Kollmuss & Agyeman 2002).

The central concept of the model is ‘pro-environmental consciousness’, a complex internal factor consisting of environmental knowledge, values and attitudes together with emotional involvement, which is embedded in general personal values and moulded by other internal and external factors. According to Kollmuss and Agyeman (2002), the factors inherent in the model and their synergies have varying roles over the course of a person’s development process. The most significant positive influence on pro-environmental behaviour is attained with synergistic action of internal and external factors. On the other hand, several potential barriers hindering the pro-environmental behaviour have also been included in the model; old behaviour patterns being the most important one. (Kollmuss & Agyeman 2002)

6.2.5 The behaviour model of the survey

The above-mentioned theories and models emphasise numerous variables influencing the individual’s behaviour. However, they are not employed as such in this study but, rather, the most suitable viewpoints are applied for the basis of the survey. The behaviour model applied in the survey is presented in Figure 15.

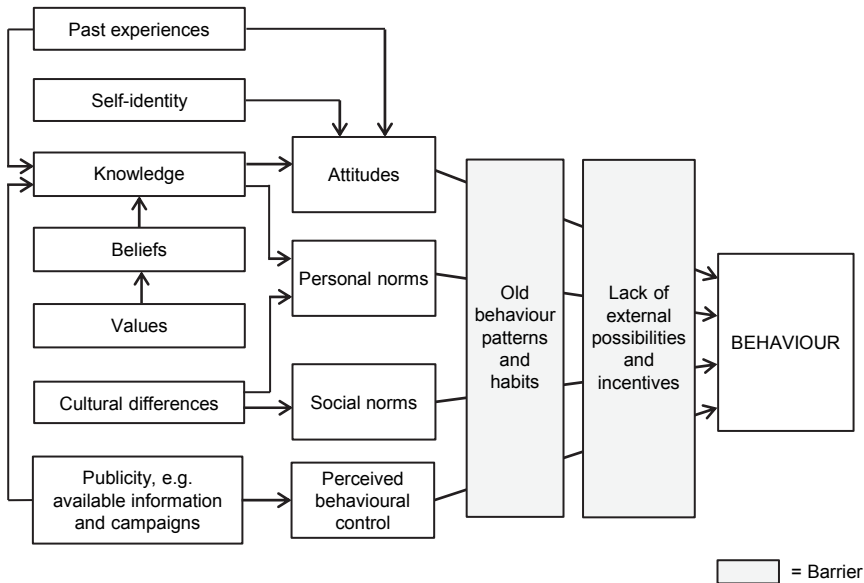


Fig. 15. The behaviour model of the survey.

The theoretical basis of the model rests on the assumption of TPB that people are rational by nature and they pursue consistency between their personal knowledge, attitudes and behaviour. Furthermore, the model agrees with VBN theory assuming that values have strong causal influence on the individual's knowledge and, thus, attitudes and personal norms. In the model, an individual's attitude, personal and social norms and perceived behavioural control affect their behaviour. The model includes also certain variables (*e.g.* opportunity and ability) inherent for models of motivation-opportunity-ability-behaviour and pro-environmental behaviour in the model, as it is believed that the convenience of the WEEE recovery infrastructure, incentives, and old habits patterns also influence the individual's behaviour.

This behaviour model was developed in order to apply it when creating a sensible questionnaire for conducting the survey, rather than to examine the relevance or the functionality of the model.

6.3 The conceptual background of electronics lifecycle

This study also focuses on the lifespan of consumer electronics and the impact of storage behaviour on the realisation of the waste hierarchy, using mobile phones as a case study. Stockpiling mobile phones and its implications on lifespan is discussed in Paper IV seeking to provide answers to the following research questions:

- When and why consumer electronics, *e.g.* mobile phones, become waste?
- What is the lifespan of mobile phones and how does stockpiling affect WEEE management?

As presented in section 5.1, the key determinants of when electronics become waste are design features and human behaviour, which are described in this section.

6.3.1 Design of electronics

A product design begins with a product definition, which specifies the features a product will have after the completion of the development process. Ordinarily, features include *e.g.* what the product will be used for, how it will function, what its properties will be, and what kinds of cost and aesthetic attributes the product will need. In addition to the product definition list, the designer needs also to consider various other product attributes. (Graedel & Allenby 1995: 186–189) The paradigm for later considerations is called ‘Design for X’ (DFX), where X may be (Graedel & Allenby 1995: 186–187):

- *Assembly* – consideration of assemblability, *e.g.* ease of assembly, error-free assembly and common part assembly;
- *Compliance* – consideration of the regulatory compliance required for manufacturing and field use, *e.g.* topics as electromagnetic compatibility;
- *Environment* – consideration of relevant environmental factors integrated with product design;
- *Manufacturability* – consideration of how well a design can be integrated into factory processes, *e.g.* fabrication and assembly;
- *Material logistics and component applicability* – considerations of factory and field material movement and management, as well as the corresponding applicability of components and materials;

- *Orderability* – considerations of corresponding manufacturing and distribution;
- *Reliability* – considerations of operations under variable ambient conditions, e.g. electrostatic discharge and corrosion resistance;
- *Serviceability* – consideration of how to facilitate initial installations, as well as the repair and modification of products;

Of these, especially Design for Environment (DfE) is used in order to improve the environmental profile of electronics. The idea behind DfE is to ensure that all relevant and ascertainable environmental considerations and constraints are integrated into a manufacturer's design process resulting in a product realisation. In terms of extending the lifecycle of electronics, the key DfE strategies are design for re-use, repair and refurbishment, intended to extend or improve functionality.

The reverse strategy, aimed at shortening the functional life of electronics is built-in, or planned obsolescence.

6.3.2 Planned obsolescence

In current competitive markets, producers face remarkable challenges maintaining high rates of sales; the more reliable and long-lasting products they have, the longer the replacing cycle and slower the rate of sales growth in saturated markets is. This so-called 'durables problem' creates pressure to incorporate planned obsolescence into products in order to promote shorter replacement cycles for durable products. (Guiltinan 2009)

The objective of planned obsolescence is to stimulate consumers' to replace their products by influencing either the shape of the product or the consumers' mental attitude (Packard 1960: 53–67). Packard (1960: 55) have categorised obsolescence into three different types:

- *Obsolescence of function* – existing product becomes outmoded when a product with better performance is introduced;
- *Obsolescence of quality* – a product breaks down or wears out at a given time;
- *Obsolescence of desirability* – a product is still sound in terms of quality and/or performance, but the styling or some other changes make it less desirable.

Respectively, Guiltinan (2009) has divided planned obsolescence mechanisms into the physical and technological part; the physical part fosters the replacement is to shorten the products' time in use through a certain physical mechanism and, thus, corresponds to the obsolescence of function and quality defined by Packard (1960: 55). According to Guiltinan (2009), alternative physical mechanisms for planned obsolescence are limited functional life design, design for limited repair or design aesthetics lead to reduced satisfaction. When the mechanism of design for limited repair is applied, appliances are designed to be non-repairable. This mechanism is based on the suggestion that the price of repair for consumer electronics encourages disposal and, thus, a household replaces appliances rather than repairs them. The idea of design aesthetics lead to reduced satisfaction rests on, *e.g.* use of pristine and polished surfaces, which damaged quickly in everyday use and, thus, increase consumer's dissatisfaction and probability of premature disposal. (Guiltinan 2009)

Even faster replacement cycles can be achieved by fostering technological obsolescence. This type of obsolescence is called also voluntary obsolescence or "planned obsolescence of desirability" as phrased by Packard (1960: 55). Packard's expression refers to the marketing strategy of "making people buy new things, even though the old ones work just fine". Consumers voluntarily render their device obsolete for no other reason than wishing to replace it with a newer model. (Packard 1960: 68–77) According to Guiltinan (2009), technological obsolescence mechanisms include design for fashion and design for functional enhancement through upgraded features; both intensify consumers' dissatisfaction towards their existing products. It is argued that technical product obsolescence is clearly a more significant driver for replacement due to its voluntary nature (Guiltinan 2009).

The incentives for obsolescence are compounded in the fields of industry where rapid product development is embedded into the competitive environment. Grout and Park (2005) have argued that companies cannot even survive in the competitive market unless their products exhibit planned and known obsolescence. They have also found that consumer demand may be greatest for the outputs of those particular companies who engage in excessive research and development programmes (Grout & Park 2005). On the other hand, the managerial dilemma regarding 'willingness to cannibalise' occurs in the competitive market; if a company will not cannibalise its own product's sales, its competitors will. It is ordinarily more affordable for companies to retain

customers than to acquire new ones; therefore, self-cannibalising may be a necessity for a company's survival. (Guiltinan 2009)

6.3.3 The concept of waste

Most of the waste taxonomies are classified by their state (*e.g.* solid, liquid or gaseous), by origin (*e.g.* process, household or packaging waste), or by certain characteristic (*e.g.* inert, combustible or hazardous). However, this only results in fragmentation rather than in an explanation of the concept of 'waste.' In order to provide a framework to explain the concept of waste, a methodology for the classification of waste based on the PSSP language was developed at the University of Oulu, Finland, and introduced by Pongrácz (2002) and Pohjola and Pongrácz (2002). The ontology of PSSP language can be presented as follows (Pohjola & Pongrácz 2002):

1. Views the world as being consisted of real things and abstract things, the former being descendant of the generic real thing.
2. Argues that the generic real thing – and thereby all real things – can be represented as objects having attributes of *Purpose*, *Structure*, *State*, and *Performance*.
3. The above list of attributes is argued to be necessary, and also sufficient.

The ontology behind the PSSP language is useful when analysing the concept of waste. Man-made things, artefacts, have been made for a certain purpose and they are expected to perform their assigned purpose. In essence, *Performance* evaluates the goodness of the artefact with respect to the *Purpose*, while *Structure* is understood as unit structure, and is thought of as made of parts and the links in between. *State* denotes material properties, and the location and relation within the environment. As a consequence, Pongrácz (2002: 82) argued that wastes can be categorised into four classes, summarised in Table 7.

Table 7. Classes of waste (Pongrácz 2002: 82).

| Class | Definition | Illustration |
|----------|--|---------------------------------------|
| Class #1 | Non-wanted things created not intended, or not avoided, with no purpose. | Process wastes, discharges, emissions |
| Class #2 | Things that were given a finite purpose, thus destined to become useless after fulfilling it. | Single use, disposable products |
| Class #3 | Things not able to perform with respect to the intended purpose due to change in structure or state. | Obsolete, spoiled, broken products |
| Class #4 | Things able to perform, but their users fail to use them for their intended purpose | Products that go beyond their target |

This taxonomy also explains the reasons why waste was formed. The description of waste as ‘a thing, which the owner failed to use for its intended purpose’ highlights the fact that a thing became waste because of the wrongful action of the owner, whereas waste emission can be described as ‘a thing to which its producer has not assigned a *Purpose*’ pointing out the error of the producer. Further, ‘a thing which is not performing in respect to its original *Purpose* due to a structural change’, explains the reason why the thing became waste. Based on this classification, Pongrácz (2002: 93) has offered the definition for waste as

‘Waste is a man-thing that is, in the given time and place, in its actual structure and state, not useful to its owner, or an output that has no owner and no purpose.’

This definition also emphasises the dynamic nature of the concept of waste; the same thing can be waste or non-waste for different people and in different places and times.

7 Results and discussion

The two key subjects of this doctoral study are the functioning of the Finnish WEEE collection network and the participation of consumers in the WEEE recovery and issues affecting it such as awareness and perceptions.

7.1 Evaluation of the Finnish WEEE collection network

The evaluation of the Finnish WEEE collection network is the subject of Papers I–III. In Paper I, the legislative implementation and the development of the Finnish WEEE collection infrastructure is examined. Paper I also analyses current collection practices and the challenges of its effective management from a resource efficiency point of view. In Paper II, the Finnish system is compared with those in Sweden and Norway in order to identify the factors defining successful and efficient practices. The evaluation also takes into account consumers' perceptions towards the convenience of the current collection network presented in Paper III.

7.1.1 Compliance with the targets of the WEEE Directive

According to the original WEEE Directive 2002/96/EC, a separate collection of WEEE had to be arranged by August 2005 and a general collection target (4 kg per capita) as well as treatment requirements, recovery, and recycling rates up to 80 w% and 75 w% had to be realised by the end of 2006 (Directive 2002/96/EC). After the recast of the Directive in 2012, the recovery, re-use and recycling targets remained at the same level until August 2015; however, the scope was extended to cover also medical devices with the target of 70% for recovery and 50% for re-use and recycling.

On the grounds of the study presented in Papers I–II, it can be argued that Finland has succeeded in setting up a functioning WEEE recovery infrastructure in a short time as the amounts of collected WEEE have exceeded the target of 4 kg/inhab./year since 2006. The collection rate has been over 9 kg/inhab. in Finland since 2007, which is also the new country-specific collection target for Finland that came into effect in 2014 (Ministry of Environment in Finland 2014). According to the latest official data from the Finnish producer registration system reported to the EU, close to 53 000 tonnes or some 9.8 kg/inhab./year of WEEE

were collected separately in Finland in 2012 (Eurostat 2015). Figure 16 illustrates the relative quantities of officially collected WEEE in Finland during 2005–2012.

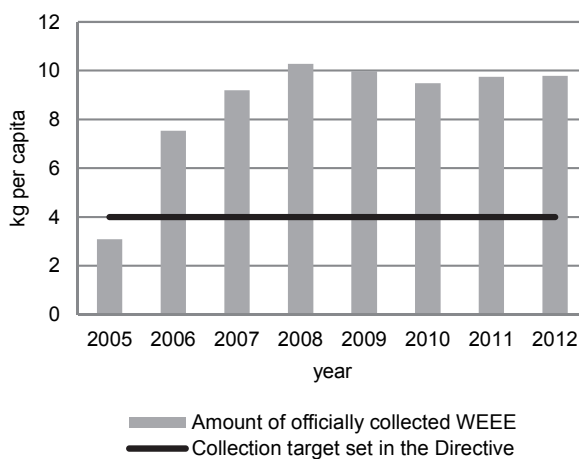


Fig. 16. Amounts of collected WEEE per capita in Finland in 2005–2012 (Eurostat 2015).

In addition to high tonnages of collected WEEE, good recovery percentages have also been achieved in Finland. The collection amounts and recycling and recovery rates in Finland in 2012 are compiled in Table 8.

Table 8. Amounts of collected WEEE and achieved recovery and recycling targets in Finland in 2012 (Eurostat 2015).

| Category | Amount [tonnes] | Portion [%] | Actual recovery /target [%] | Actual re-use and recycling/target [%] |
|---------------------------------------|-----------------|-------------|-----------------------------|--|
| 1 Large household appliances | 26803 | 50.6% | 91/80 | 89/75 |
| 2 Small household appliances | 1912 | 3.6% | 88/70 | 85/50 |
| 3 IT and telecomm. equipment | 7640 | 14.4% | 90/75 | 89/65 |
| 4 Consumer equipment | 14214 | 26.8% | 93/75 | 91/65 |
| 5a Lighting equipment and | 268 | 0.5% | 89/70 | 88/50 |
| 5b Gas discharge lamps | 850 | 1.6% | - | 90/80 |
| 6 Electrical and electronic tools | 684 | 1.3% | 94/70 | 93/50 |
| 7 Toys, leisure, and sports equipment | 83 | 0.2% | 87/70 | 86/50 |
| 8 Medical devices | 23 | 0.1% | 91/70 | 83/50 |
| 9 Monitoring and control instruments | 101 | 0.2% | 85/70 | 82/50 |
| 10 Automatic dispersers | 395 | 0.7% | 99/80 | 83/75 |
| Total/average | 52972 | 100% | 91.4% | 89.4% |

In 2012, the re-use and recycling rate was 89.4% and around 2% of WEEE was recovered as energy. The total recovery rate of WEEE in Finland was, therefore, close to 92% (Eurostat 2015). Re-use, category-specific recycling and recovery targets set down in the WEEE Directive were also fulfilled in every category. High recovery rates and total tonnages of collected WEEE do not, however, describe the total effectiveness of the recovery system. When collection amounts are compared to the EEE amount put on to the market (POM), there is still room to improve collection rates. Therefore, new collection rates were introduced in the recast Directive based on national consumption levels. Member states' collection rates in 2012 as a percentage of the average weight of EEE put on the market in the three preceding years and forthcoming targets are gathered in Figure 17.

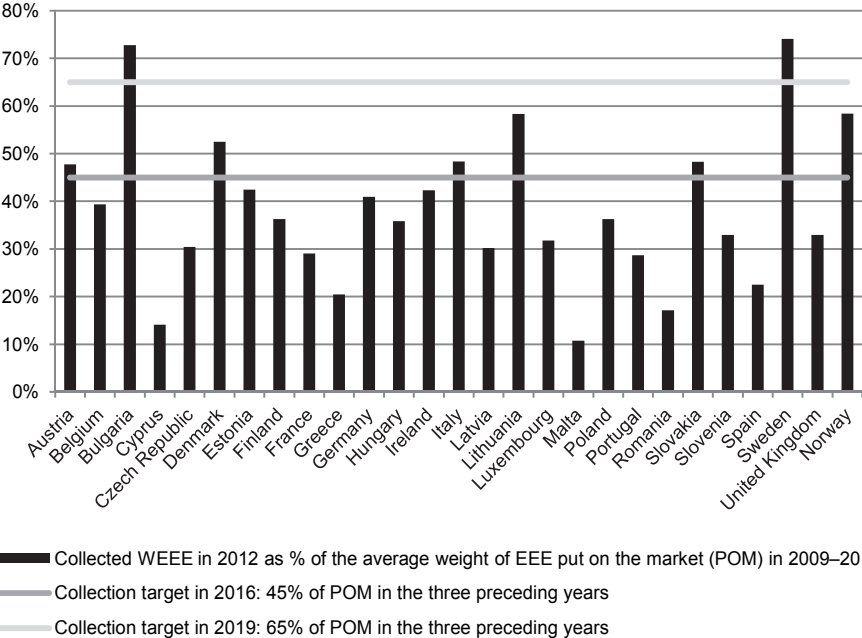


Fig. 17. Collection rate for WEEE in 2012 as a percentage of the average weight of EEE put on to the market in the three preceding years (2009–2011) in the EU and Norway (Eurostat 2015).

According to EU statistics (Eurostat 2015), seven of the current EU Member States and Norway have already achieved the 45% target in 2012; Sweden and

Bulgaria even exceeded 65% (Eurostat 2015). On the contrary, three Member States have collection rates lower than 20%. In case of Finland, the collection rate was 36% in 2012. It is a good average level compared to other Member States; however, considerable collection improvements are still needed to achieve the 45% target set for 2016 and 65% set for 2019 (Eurostat 2015). The alternative collection target for 2019 and onward is 85% of generated WEEE.

In order to illustrate the future WEEE quantities need to be collected in Finland to fulfil future collection targets, some rough estimation can be undertaken based on the latest WEEE data from 2012. According to StEP (2015), 118 000 tonnes or 21.5 kg per capita of WEEE was generated in Finland, while the amount of EEE put on to the market was 138 000 tonnes (25.4 kg per capita). If there are no significant changes in the Finnish population and no remarkable positive or negative effects in the economic situation affecting remarkably the amounts of EEE put on to the market in Finland, it can be estimated that the annual collection quantities of WEEE should be from 16.5 kg (45% target of 3 preceding years POM) to 18.5 kg (65% target) per capita in 2016 and 2019, which will be some 90 000-100 000 tonnes as an absolute quantity of WEEE. That means the quantities of collected WEEE in 2019 should be double compared to 2012. Estimated quantities follow the earlier estimations calculated by Huisman (2010).

7.1.2 Challenges and best practices for improving recovery efficiency

Despite the principal goal of the WEEE legislation to prevent waste generation and promote re-use, the current WEEE recovery system does not promote re-use and/or refurbishment of EEE in Finland. It seems that the re-use potential of returned devices is lost in the collection and transportation phases due to inadequate guidance and careless handling. Therefore, in order to enhance re-use, an establishment of a testing and refurbishing system is needed, to provide verification on the quality of the returned devices. In previous years, certain efforts have existed in Finland but the national markets of refurbished EEE were rather restricted and, recently, activities have gradually waned over the time. Therefore, changes in consumer attitudes are required in order to expand the market of re-used and/or refurbished EEE in Finland.

Although Finnish WEEE legislation provides a reasonable opportunity to return discarded appliances for recovery throughout the country, the main

challenges of the WEEE collection network are related to long transportation distances and sizes of permanent collection points; the physical space of collection cages are strongly limited in the smallest reception points of the collection network. Moreover, the amounts of returned WEEE may vary substantially due to larger batches of WEEE from rural households. Limitations in the physical space lead to careless handling and/or inappropriate storing conditions in the reception points while waiting for transportation. Therefore, the cost-effectiveness of the collection and transportation phases could be improved by using suitable containers and implementing sorting opportunities also in the smallest points (Gamberini *et al.* 2009, Krook & Eklund 2010).

Also long transportation distances bring challenges to managing the WEEE recovery system effectively. In particular, appliances containing only few valuable components but high transportation and treatment costs, such as refrigerators and other large household appliances, may even have negative recycling value. Therefore, the decentralised pre-treatment stations network should be improved across the country and, further, collection and transportation stages of WEEE need to be optimised from a cost-effectiveness point of view.

In addition to challenges in the WEEE recovery network in operation, some challenges occur also in the legislative implementation and monitoring the realisation of producers' responsibilities. Finnish legislation underlines free return of WEEE for private consumers and households, while industry, educational institutes and communities may have to pay for it. However, Finnish producer associations experience that some companies are still using the free-of-charge channels reserved for private consumers. Moreover, some free- and easy-rider companies, who have not registered yet to the producer register and do not attend to their responsibility, still exist in Finland (Toppila 2011: 35) although the Finnish national inspecting and controlling authority of WEEE (ELY Centre Pirkanmaa) has informed and guided the companies over the years. Therefore, more information and publicity on prevailing practices and recent changes of WEEE legislation are still needed for companies.

The other remarkable challenge of the current system is the competitive collection points outside the official network. Only the most valuable WEEE is received in these unofficial collection points; low or negative value WEEE is left at the responsibility of producers associations. As a consequence, the operational costs of the official system have increased and, thus, the cost-effectiveness of WEEE recovery network under producer responsibility decreased. In order to restrict this tendency, the producer's right of precedence to organise waste

management covered by producer responsibility has been included in the reformed Waste Act in 2012. As a result, other operators may establish parallel collection systems for EOL products, only if those are managed in cooperation with the individual producer or certain producer association. Due to the transitional period of the law, it has had no noticeable effect yet on the amounts of officially collected WEEE; however, the amounts and the profitability of WEEE received by producers associations are expected to rise in the near future.

When the Finnish WEEE recovery system was compared to those in Sweden and Norway in Paper II, certain best practices for improving resource efficiency were identified from the Swedish and Norwegian systems. Firstly, the Swedish system is optimised from an efficient material flow point of view. The other key issue is the one dominant service provider for the whole of Sweden; by controlling the whole WEEE recovery chain, El-Kretsen is able to offer practical and cost-effective solutions and optimised transportation services. The highly standardised system at the national level also clears the roles and provides efficient ways for all stakeholders to operate (Lee & Sundin 2012).

The best practices identified from the Norwegian system are related to the parallel routes of WEEE from household and industry. It enables more flexibility to select optimal recovery routes and, thus, improves the efficiency of the recovery system by promoting the re-use of B2B devices. The other benefit of the Norwegian system is linked to better control of EEE and WEEE flows and accurate calculations of WEEE leaking outside the recovery system due to comprehensive statistics of non-member countries of the EU.

All in all, reasonable nationwide possibilities and an efficient management of the WEEE recycling system are still not enough for creating a sustainable system; consumers' understanding and recycling behaviour regarding the return of EOL devices have also an outstanding influence on the effectiveness of WEEE recovery. Finns are typically highly aware of environmental issues and, therefore, are also willing to take advantages of established WEEE recovery systems. Therefore, strong civic support of environmental protection can be seen as one of the main strengths of the WEEE recovery system in Finland.

7.1.3 Consumers' perceptions toward convenience of the current WEEE recovery system

Although the total tonnages of WEEE collected in EU are at a good level, the returns of appliances lighter than 1 kg are very low (Huisman 2010). This is

especially true for small high-tech appliances such as mobile phones (Chancerel 2010: 102–103, Polák & Drápalová 2012, Tanskanen & Butler 2007), which is the case also in Finland; Toppila (2011: 76) has evaluated that only 80 000 mobile phones were returned to the official recycling in 2009 and, at the same time, up to one million mobile phones not in use were stockpiled at Finnish homes annually.

Several studies have shown that the convenience of the WEEE collection system has a positive influence on public participation and, hence, recovery rates (Bouvier & Wagner 2011, Saphores *et al.* 2012, Yin *et al.* 2014). Based on the survey presented in Paper III, local residents return their old mobile phones to the recovery system through several routes in the city of Oulu. Permanent collection points, especially Rusko Waste Centre, are most commonly used, although other returning options are also available. Respondents regarded that the current system is simply to use; however, most of the respondents (66%) did not take a stand on the convenience.

A high non-responding rate and common storing habit of respondents (see Chapter 7.2.1) indicate that proximity and the convenience of the current permanent collection point network are inadequate in promoting the return of small WEEE (s-WEEE). This is, however, expected to change in the near future due to the mandatory retailer take-back for s-WEEE which came into effect in May 2013. There is no statistical data available yet for supporting this assumption; however, numbers of in-store reception points and amounts of received s-WEEE are expected to rise rapidly as soon as consumers become more aware of this return option. In order to increase the public awareness, nationwide information campaigns provided by Finnish authorities, producers associations and retailers would be, therefore, recommended.

7.2 Assessment of consumers' awareness and perceptions toward WEEE

Assessment of consumers' awareness and perceptions toward WEEE recycling and re-use as well as the current recovery system is based on the survey conducted in the city of Oulu in 2013 and presented in Paper III.

In total, 150 questionnaires were distributed and 53 responses were received; hence, the response rate was 35%. Most of respondents lived in one or two-person households (74%) and had a polytechnic or university degree (79%). Age distribution varied widely and evenly segmented for age ranges of 20–34 years, 35–50 years, 51–64 years and above 65 years. Most of the respondents were full-

time workers (53%) or pensioners (26%) but also some part-time workers (9%), students (6%) home makers (4%) and one entrepreneur participated in the survey.

7.2.1 Recycling behaviour

In the survey, the frequency and reasons for changing mobile phones were enquired about. Majority of the respondents (57%) replace their mobile phones every 2–3 years; however, every third stated to use their mobile phones longer, up to 10 years. Furthermore, 9% of respondents changed their mobile phones during the course of the first two years, while none of them admitted to changing a mobile phone more often than once a year. The most common reason (72%) for changing the mobile phone was that the old one stopped working properly. Mobile phones were also changed if the latest models had novel features (32%) or if mobile phones were company-owned (17%).

Most of the respondents (85%) had unused mobile phones at home. In total, 30% stated to have one extra phone at home and, in addition, almost half of respondents admitted to having 2–5 phones not in use. The number of mobile phones stored at homes is illustrated in Figure 18.

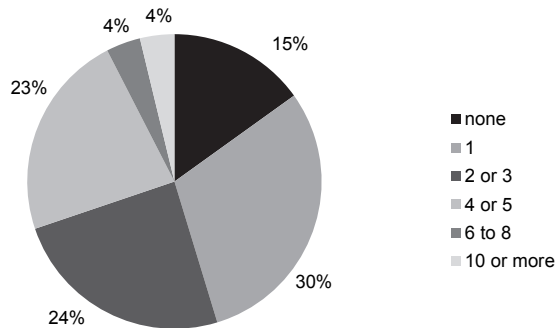


Fig. 18. Number of disused mobile phones stored at home (respondents R=53) (modified from Paper III, published with the permission of Elsevier).

When asking the reasons for failing to return mobile phones for recycling, 70% of all, or 82% of those respondents who had mobile phones at homes, told that they just keep at least some of the phones at home. Every fourth respondent stated to give at least one old phone to children, relatives or friends and 28% of them have taken old mobile phones to the recycling centre. Only a few of them have sold an unused mobile phone onward while 13% of respondents have left it at the store

when buying a new one. None of respondents stated to have disposed them with mixed waste. The fate of the old mobile phones is illustrated in Figure 19.

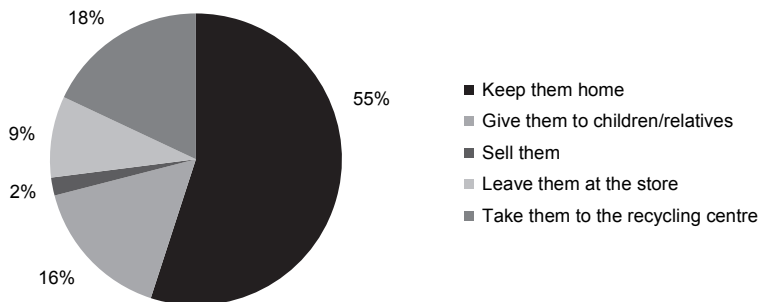


Fig. 19. The fate of the old mobile phones (responses n=82) (modified from Paper III, published with the permission of Elsevier).

Various reasons for not returning old mobile phones were given. More than half of respondents (55%) keep them as a spare phone, while 38% admitted that end-of-use phones lay at homes because they have not gotten around to returning it yet. Only a few respondents felt that recycling was troublesome; however, 17% of them did not know where to take old phones. Reasons for not returning the mobile phones are summarised in Figure 20.

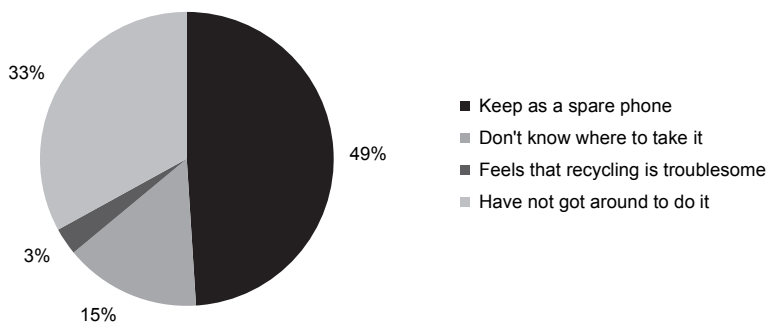


Fig. 20. Reasons for not returning old mobile phones (responses n=60) (modified from Paper III, published with the permission of Elsevier).

The relation between the number of stored phones and the reasons for not returning them was examined in more detail. Respondents, who stated to keep phones only in reserve, have fewer phones at homes (2.7 phones) on average than

the respondents keeping phones for some other reasons (up to 4.3. phones at homes). On the other hand, 8% of respondents argued to have only spare phones at home although the number of unused phones was higher than the number of persons living in their households.

When an old mobile phone was returned for recycling, the main collection point of Oulu Waste Management Company's Rusko Waste Centre (23%) was the most commonly used. Also collection points in certain working places (6%), in-store reception (6%) and special collection campaigns through public postal services (4%) were occasionally used.

The survey results showed that mobile phones are typical 'up-to-date' products defined by Cox *et al.* (2013); they have short lifespan and are discarded before the end of their functional life. Most of disused mobile phones are kept at home as spare phones rather than returning immediately for recycling. As stockpiling at home seems to be especially common for personal electronics in every-day use, it was hypothesised that one of the key reasons for stockpiling may be the personal attachment to the device. In the case of mobile phones, people tend to personalise their mobile phones and, therefore, they may become a strong representation of personal identity and style (Cox *et al.* 2013, Cui *et al.* 2007, Vanden Abeele *et al.* 2014). As a consequence, it takes time for this attachment to subside before the owner is willing to finally discard the device, although it is probable that spare phones will never be used again due of the fast technological progress.

7.2.2 Awareness and incentives for recycling

When asking about the importance of recycling old mobile phones almost 95% of respondents agreed with the statement. Moreover, the majority (78%) of them argued more specifically for the reasons. Recycling was considered to be important due to material recovery (51%); not only in the form of metal recycling, but also due to re-use potential. Environmental protection was also mentioned often (38%) in the responses. Further, hazardous materials were the main concern of 28% of respondents while, on the other hand, economic value was also highlighted several times (28%). Reasons for the importance of mobile phone recycling are summarised in Figure 21.

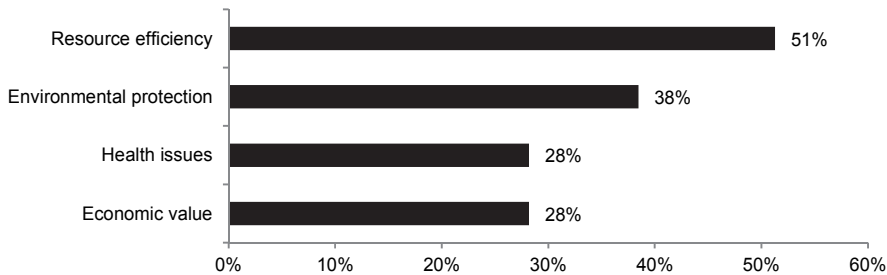


Fig. 21. Motives for recycling old mobile phones (respondents R=39) (Paper III, published with the permission of Elsevier).

More than half of the respondents (57%) were aware of the effective Finnish WEEE legislation. The practical realisation of legislation was even more familiar; more than 95% of respondents were aware that households may return their WEEE free of charge to the official collection system. When asking if respondents had seen the symbol used for marking EEE in their mobile phones or its supplementaries (Figure 6), 43% of respondents agreed to have seen it, while as many as 36% responded negatively to the question. Moreover, 64% of respondents identified the main thoughts of the symbol correctly; the rest 36% did not take a stand on the issue.

Respondents were also asked about the monetary incentive that would motivate them to return old mobile phones through a fictional deposit system. One third of respondents claimed that 5 euro would be a sufficient deposit. Altogether, nearly 60% of respondents argued, that they would return old mobile phones through a deposit system with 10 euro maximum, whereas a 20 euro deposit would please up to 70% of respondents.

Based on the survey, it can be concluded that the current WEEE collection system in the Oulu region is well-known among the local residents. However, only some of them have used it by now; in other words, knowledge of importance and existence of recovery systems in itself does not bring about pro-environmental behaviour. As an illustration of this, up to 85% of the all respondents still store their disused mobile phones at home for a possible future use, although up to 35% of all motives for mobile phones recycling were linked to resource efficiency.

In order to reduce stockpiling, consumers' have to be motivated to return their disused extra phones for recycling. Firstly, consumers have to be made aware that there is still value in the product that could be recovered and, then, they need to

be offered compensation for action. Providing a reimbursement might be a sufficient reminder and incentive to return old phones for recycling especially for those, who fall into the ‘have not got around to do it yet’ category. Monetary incentives could be a good option as up to half of respondents claimed to be satisfied with fairly reasonable (max. 5 euro) monetary incentives. Therefore, it would be advisable to consider the implementation of economic incentives for fostering mobile phone recycling in Finland.

7.2.3 Perceptions toward re-use

Respondents were asked about their willingness to buy a used mobile phone; half of the respondents answered positively with certain reserves. A cheaper price was the most important prerequisite (41%) for buying a used phone and, moreover, it was also the most commonly cited reason (38%). Other common factors in decision-making were novel features (23%) and knowing the last owner (19%). In total, 15% of respondents regarded age as a prerequisite for buying, however, only 4% of respondents considered it as the most relevant factor. Five respondents did not define the most important prerequisite at all. The importance and frequency of certain prerequisites for buying a used mobile phone are compiled in Figure 22.

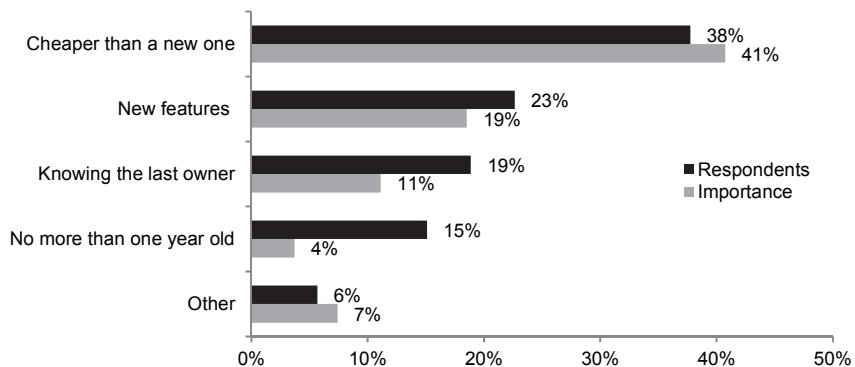


Fig. 22. Importance of prerequisites for buying a used mobile phone (respondents R=27, prerequisites n=53) (Paper III, published with the permission of Elsevier).

Respectively, 49% of respondents were not willing to buy a used mobile phone. In total, 73% of them argued specific reasons, as illustrated in Figure 23. Reliability (32%) was the most common reason; 47% of respondents agreed on this. Due to fast technical progress, a short span (21%) and the existence of new budget models (21%) were also the prevalent reasons. Valid warranty (16%) or certain specific features (7%) were also mentioned; however, it is remarkable that only one respondent stated to be suspicious toward information security issues.

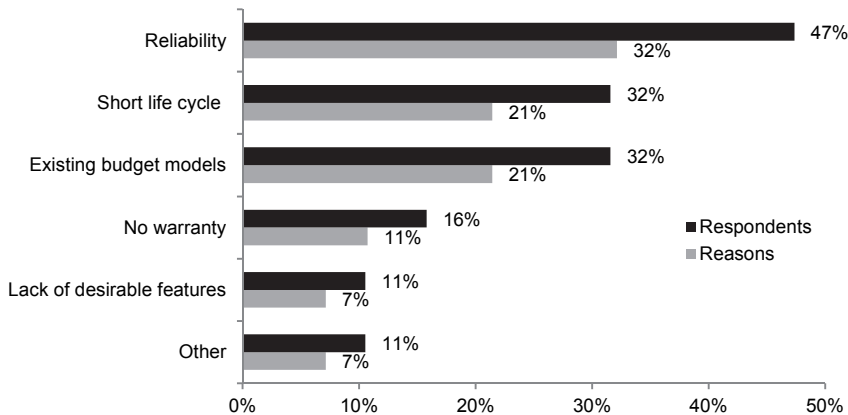


Fig. 23. Reasons for not buying a used mobile phone (respondents R=19, reasons n=28) (Paper III, published with the permission of Elsevier).

Opinions concerning reasonable prices for used mobile phones were also enquired about. As a result, 78% of those who were compliant to mobile phone re-use were willing to pay 50% of the original price at the most. Additionally, 15% were ready to pay up to 80% or 300 euro.

All in all, it seems that a half of the respondents have an open mind about the re-use of mobile phones if certain prerequisite requirements are fulfilled. However, it seems that Finnish consumers have unrealistic expectations of new features, valid guarantee time and low prices of used mobile phones and, therefore, the supply and demand do not meet at this moment. In order to provide verification on the quality of the used device and to enhance re-use, the establishment of a testing and refurbishing system needed to be developed.

7.3 Assessment of mobile phones' lifespan

The end-of-life stage of electronics, consumer stockpiling behaviour and the impacts of the storage behaviour on the realisation of the waste management hierarchy have been the focus of Paper IV. Further, the question of when electronics become waste has been approached using PSSP language.

7.3.1 Stockpiling of mobile phones

The lifespan of mobile phones depends on various reasons, *e.g.* economic conditions, cultural behaviour, and even market strategy for sales; however, the typical lifespan for mobile phones in service is from one to five years (Huisman *et al.* 2007, Jang & Kim 2010, Milovantseva & Saphores 2013, Murakami *et al.* 2009, Polák & Drápalová 2012, Yin *et al.* 2014). The user's age is significant in terms of lifespan; younger people tend to replace their mobile phones more regularly (Ongondo & Williams 2011a) while elder keep the phones longer (Jang & Kim 2010, Murakami *et al.* 2009). The common consensus of surveys is that most users replace their mobile phone within 2 years (Murakami *et al.* 2010, Ongondo & Williams 2011a). The background of this short lifespan is the fact that in many countries mobile phone contracts are signed for 2 years.

On the other hand, the short usage time of mobile phones creates also a re-use potential of functional devices. If people would deliver their functional EOU mobile phones to the recovery system without unnecessary delays, there is a reasonable chance to find a second user who could still use them. Unfortunately, this is not always the case. Currently, there seems to be an immense resource potential stored at homes, waiting for the storage phase to end (Bouvier & Wagner 2011, Polák & Drápalová 2012, Saphores *et al.* 2009, Toppila 2011: 75–76).

The results of the survey in Oulu (Paper III) presented in Chapter 7.2 also indicate that people stockpile their EOU mobile phones at home. The results correlate several other surveys conducted across the world summarised in Table 9.

Table 9. Characteristics and key results of the selected surveys related to mobile phones and consumers recycling behaviour (Paper IV).

| Survey, country | Implementation; no of respondents | Key results |
|--|--|---|
| Ylä-Mella et al. 2015, Finland (Paper III) | Questionnaires; 53 respondents | Awareness is high but not translated to behaviour; proximity and convenience of the recovery system are inadequate; more publicity and up-to-date information needed. |
| Yin et al. 2014, China | On-site interviews and web-site survey; 1035 respondents | Environmental awareness is low; the most of EOL mobile phones were stored at homes or recycled ineffectively; Establishment of a reasonable WEEE recycling system is vital in order to improve the recycling rates. |
| Milovantseva & Saphores 2013, USA | Knowledge Networks' online research panel; 3156 respondents | Recycling rate of EOL mobile phones is only 20% although variety of convenient recycling options exists; implementing economic instruments should be considered in order to increase WEEE collection. |
| Li et al. 2012, China | On-street interviews and questionnaires; 346 respondents | Differing consumption patterns was the most effective indicator in the WEEE recycling system; WEEE value was the most critical factor when choosing a recycling method; more research for pricing schemes and consumption patterns are needed before regulating WEEE. |
| Jang and Kim 2010, Korea | Questionnaires; 1090 respondents | 14.5 million mobile phones have been retired annually in Korea over the period of 2000–2007; a large fraction of EOL phones are stored at home since only 5 million phones have been collected annually; more effective collection and raising awareness are needed. |
| Ongondo and Williams 2011a, UK | Internet survey for university students; 2287 respondents | Around 3.7 million mobile phones are stockpiled by UK university students; students are aware of the take-back services but only moderate numbers have used those; monetary incentives have the greatest influence over student's willingness to utilise take-back services, followed by convenience and ease of use of services. |
| Murakami et al. 2009, Japan | Survey, 2002 respondents (6707 mobile phones) | Estimated 167 million mobile phones "hibernating" in stocks in Japan. These phones in stock make up 45 % of the aggregated amount of EOL mobile phones in Japan. |
| Tanskanen and Butler 2007, Global | Nokia employee intranet survey; 733 respondents | Mobile phones are rich in metals allowing economically viable recycling; low return rates are one of the main bottlenecks in the recycling; raising awareness and providing easy take-back options are key factors in increasing the returning rate of WEEE. |

Based on the results of the surveys summarised in Table 9, it can be concluded that people prefer storing their EOU mobile phones at home. Typically 40% to 60% of respondents intended to keep the EOU mobile phone at home when they procured a new one; up to 77% respondents agreed this habit in the survey reported by Tanskanen and Butler (2007). However, 18% of respondents of that particular survey mentioned that they use those phones occasionally. EOU mobile phones have also been sold or donated for re-use; from 9% (Murakami *et al.* 2009) to 39% (Li *et al.* 2012) of old phones were channelled straight into the second hand market, while retailers take-back and in-store collection seems to be functional only in Korea (Jang & Kim 2010). The fates of EOU mobile phones in these particular surveys are summarised in Figure 24.

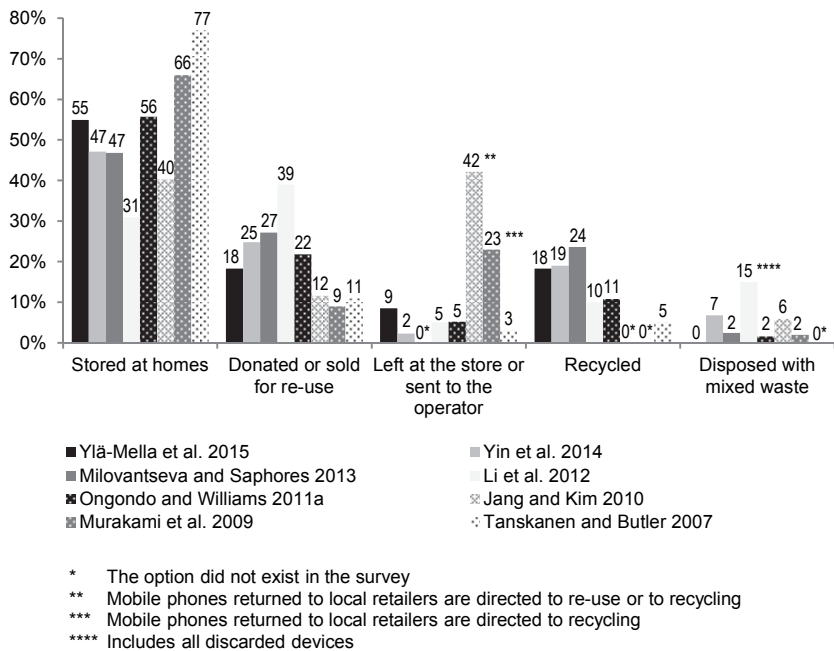


Fig. 24. The fate of used mobile phones according to the results of the selected surveys (Paper IV).

In the context of the selected surveys, it seems that a functional in-store collection system reduces the quantities of phones sold and donated for direct re-use. On the other hand, the results indicate that the successful implementation of retailers

take-back promotes returning of mobile phones to the recovery and, thus, reduces stockpiling at homes.

The stockpiling of phones was often justified by keeping as a spare phone. However, when the major reason for replacement was enquired, 44% (Yin *et al.* 2014) to 72% (Paper III) of respondents mentioned malfunctioning of phones as a main reason. Because of this contradiction, it is unclear, if stockpiled mobile phones are functional or not. Stockpiling of EOU mobile phones have become more common in recent years. According to Murakami *et al.* (2009), while only 20% of old mobile phones were stored at Japanese homes in 1996, over 60% were stored in 2006. Furthermore, they have estimated that stockpiled phones make up 45% of the aggregated amount of mobile phones in Japan (Murakami *et al.* 2009); additionally, the corresponding share in Korea is estimated to be up to 65% (Jang & Kim 2010).

Lack of knowledge is also commonly mentioned as a reason for keeping phones at home; up to 46% of respondents did not know where to return those (Yin *et al.* 2014). Alternatively, Wagner (2009) proposed that stockpiling occurs due to the inconvenience of the WEEE recovery systems, households' sufficient storage capacities and perceived value of stored phones.

Sabbaghi *et al.* (2015) noted the knowledge gaps regarding the reasons of consumer storage behaviour. In order to clarify the reasons for stockpiling behaviour, they concentrated on determining design features, *e.g.* age, brand and capacity, that may affect storage behaviour in case of computer hard disc drives (HDD). They found that the storage time was in relation to age; the minimum storage time belonged to HDDs with the age of 4–6 years old. Storage was found to be more likely for younger devices due to consumers' feeling that the devices have not been used long enough. The study also revealed that, the higher the capacity and initial purchase price of HDD, the more likely they end up in storage. (Sabbaghi *et al.* 2015) It can be argued that all these factors apply to mobile phones as well and, therefore, the following key reasons are suggested that promote mobile phone stockpiling:

- *Short usage time;*
- *Multi-functionality;*
- *High storage capacity;*
- *High purchase price.*

In addition to the initial purchase price, the extra costs of purchased content also add to the economic value of mobile phones. The sentimental value of phones is

also notable; photos and other memories captured on the phone may add to its worth. Although many surveys pointed out the stockpiling phenomenon, only few have captured the extended role of mobile phones. Additional uses (camera, music player, game console, alarm clock, etc.) may also account for the reluctance to cede ownership. The Japanese survey by Murakami *et al.* (2009) is one of the few, which have highlighted the multi-functionality of mobile phones. According to the study (Murakami *et al.* 2009) the main reasons for stockpiling phones are related to personal information security, content that is difficult to transfer (apps, music, etc.) and captured memories, such as photos or messages. The monetary investment in the device has a secondary role; however, as pointed out in Paper III, even a small monetary compensation could motivate consumers to hand over their EOL devices.

7.3.2 WEEE and the concept of waste

It can be argued that the main objective of the WEEE Directive is waste prevention. However, in order to prevent waste, it is needed to know the reasons why EEE became waste. This question has been answered using the taxonomy of waste presented in Chapter 6.3.3, Table 7. An analysis of *Purpose, Structure, State* and *Performance*, as well as the state of technical development of EEE is required when determining why EEE turns to waste.

Most WEEE falls into Class #3 or Class #4. The most typical representatives of Class #3 are not functional due to damage in *Structure* or improper *State*, and they are referred to as end-of-life (EOL) products. An increasing number of functional devices is, however, end-of-use (EOU), and can be considered waste Class #4. The relation between the product lifespan and Classes of WEEE is illustrated in Figure 25.

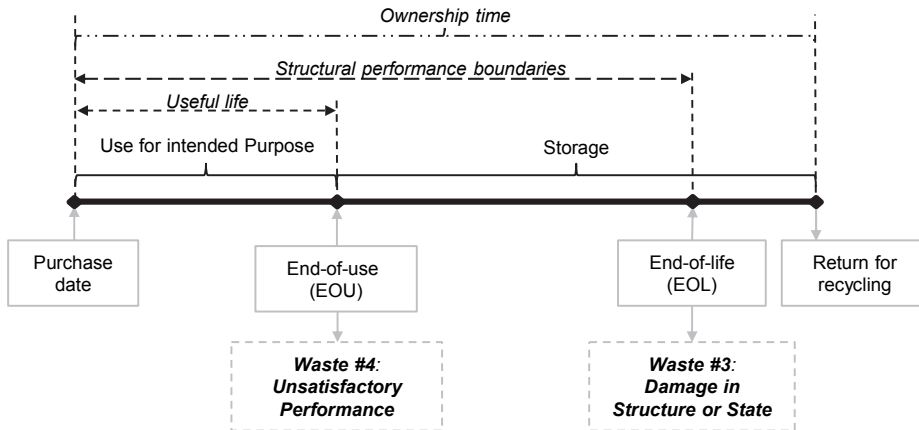


Fig. 25. The relation between the product lifespan and classes of WEEE (modified from Paper IV).

EOU products of Class #4 fulfil the description ‘their owner fails to use them for their intended purpose’. It is not because of structural or other damage, which hampers the performance but the user’s raised expectations of the product performance have changed, *e.g.* due to planned obsolescence. Ordinarily, the requirements for enhanced performance are brought by market forces by introducing newer, superior models with novel features. When newer models appear on the market, the dissatisfaction with the ‘older’ model grows, until the users make a decision for replacement (Pongrácz *et al.* 2005). While EOL devices are typically disposed of and/or recycled due to failures in functionality, EOU devices have a potential of extending lifespan through re-use with or without upgrade or refurbishment. Class #2 represents disposable products, such as non-rechargeable batteries. As well, if disposable is understood as cheap, and short-term convenience, in the survey of Cox *et al.* (2013), respondents considered some “workhorse” EEE, such as cheap, supermarket brand electronics (*e.g.* kettles, toasters) as ‘semi-disposable’. Because they are cheap to replace, repair is ordinarily not considered. Based on these considerations related to a product’s lifespan, the classes of WEEE are summarised in Table 10, contrasted to the EEE product types of Cox *et al.* (2013).

Table 10. Classes of waste by Pongrácz (2002: 82) compared to EEE product classes by Cox *et al.* (2013) (Paper IV).

| Class | Classes of Waste | Classes of EEE products |
|----------|---|---|
| Class #1 | Non-wanted things created not intended, or not avoided, with no purpose; e.g. process wastes, discharges, emissions | Not included in the product typology |
| Class #2 | Things that were given a finite purpose thus destined to become useless after fulfilling it; e.g. single use, disposable products. | Some of the 'workhorse' products may belong in this category because their lifespans are related to functionality and lifespan expectations are shaped by the price of the product. |
| Class #3 | Things not able to perform with respect to the intended purpose due to change in structure or state; e.g. physically broken products. | 'Workhorse' products are expected to perform reliably in use. They are typically used as long as they last and discarded immediately when broken. |
| Class #4 | Things able to perform, but their users fail to use them for their intended purpose; e.g. because no longer fashionable. | 'Up-to-date' products are typically replaced before they break due to feeling of 'out-of-date'. |

Because the user's decision to change *Purpose* is a dynamic process, understanding the structure of an artefact is significant for EEE. *State* describes the physical attributes of the materials contained in EEE; aside from the obvious solid, liquid, gaseous types of state, the attribute includes also consideration of the material's lifecycle. Most materials have a limited life cycle and their performance declines toward the end of it. For example, non-rechargeable batteries become waste when battery chemical is degraded to such a low level that it cannot provide required power anymore.

Likewise, in the course of numerous charging cycles of rechargeable batteries, unwanted side reactions take place in the anode and cathode causing the gradual degradation of the battery over the time (Zheng *et al.* 2015). Occurrence of performance losses varies depending on the rechargeable battery types and number of recharge cycles. In the most optimistic cases, the number of recharge cycles may rise up to 400 for NiMH and NiCd batteries; however, the more realistic expectation is 50 recharging cycles (Parsons 2007).

Figure 25 also highlights that stored devices may lose their functionality in storage. Storage time and conditions influence, *e.g.* on battery performance and lifespan prediction. According to Sarasketa-Zabala *et al.* (2014), the long storage time switched the main degradation mechanism of LiFePO₄/graphite batteries and, then, accelerates the cell performance loss. In addition, capacity fade is even

faster at high storage temperatures due to temperature dependent chemical reactions (Sarasketa-Zabala *et al.* 2014, Zheng *et al.* 2015).

Typical artefacts that turn to waste due to short life cycle are, *e.g.* ‘up-to-date’ class EEE, toys and fashion clothing. A main purpose of these products is being topical and/or trendy with limited time in use; thus, their long functionality is a secondary role. In other words, technological obsolescence is built into these products. For instance, in the case of consumer electronics, owners may choose to use it only for a short period when it is fashionable or up-to-date although the technical specifications would last longer in order to keep up with technological advances or personal feeling of success in life.

8 Summary and conclusions

8.1 Summary of the results of the work

The production and use of EEE have significantly increased over the last three decades due to technological innovations resulting in the tremendous amounts and diversity of EEE with various functions, weights, sizes and material compositions. Fast technological progress, EEE becoming a part of everyday life and rising incomes have led to the current situation where consumer electronics are more replaceable than ever. Furthermore, an ever-quicker release of EEE products with new features shortens the useful lifespan of existing EEE. As a consequence, the amount of WEEE has grown vastly during the last decades, growing threefold faster than other municipal waste streams.

In order to reduce negative environmental and health impacts and to improve the material recovery of valuable substances from WEEE, the EU has implemented the WEEE Directive by using an Extended Producer Responsibility approach (EPR). The principal aims of the Directive are to prevent WEEE generation and to improve the re-use, recycling and recovery of WEEE by requiring producers to oversee the finance for convenient separate collection systems, being free of charge for private persons. It also provides certain annual collection, recycling and recovery targets for WEEE in order to ensure adequate treatment for generated WEEE:

In this study, the implementation and efficiency of the WEEE Directive in Finland was examined. The implementation of the WEEE Directive in Finland and the efficiency of the WEEE collection network were considered in Papers I and II. To achieve the required recovery rates set in the WEEE Directive, the most important factor to be considered was how to ensure the complete participation of the end-users. Therefore, consumers' awareness and attitudes towards WEEE recovery and re-use were investigated in Paper III. Finally, the importance of the human factor in recognising waste was considered in Paper IV. In Paper IV, the storage habit of consumer was also analysed and its impact on the realisation of the waste hierarchy.

The review of the Finnish WEEE collection network (Paper I–II) reveals that the implementation of WEEE Directive has succeeded in Finland; legislative basis has been enacted, collection infrastructure has been set in the course of the given implementation period and the current collection target has been exceeded.

The collection rate has been over 9 kg/inhab. in Finland since 2007, standing within the top third in Europe despite the large sparsely populated areas in the Northern and Eastern parts of Finland. Furthermore, good recovery percentages have also been achieved in Finland as category-specific recycling and recovery targets set down in the WEEE Directive were also fulfilled in every category. However, upcoming targets for 2016 and 2019, collection target as a percentage of devices put on to the market and re-use/preparing for re-use target of 5%, have not yet been achieved. Therefore, the current system has to be improved in the near future. The study showed that inefficient practices exist especially in the collection stage (*e.g.* careless handling, mixing of EEE categories). Moreover, the current collection system does not promote re-use; no separate collection, testing or refurbishment systems for functional devices have been developed in parallel with the collection system.

In addition to a reasonable opportunity to return end-of-life appliances for recovery throughout the country, another important issue is to ensure consumers' participation. The evaluation of consumers' recycling behaviour, awareness and perceptions was conducted through a survey (Paper III). The survey was based on the theories of planned behaviour and value-belief-norm, improved with models of motivation-ability-opportunity-behaviour and pro-environmental behaviour. The aim was to find out consumers' awareness and perceptions related to the feasibility of local returning possibilities of WEEE, the reasons for failing to return mobile phones to the recycling system and, finally, consumers' perceptions toward mobile phone re-use.

Various studies have proven that consumers' perceptions of convenience and familiarity with local waste facilities enhance recycling behaviour. The results of our survey showed that the current WEEE recovery system in the Oulu region is well known among the local residents; however, only some of them have used it by now. This indicates that knowledge of the existence of recovery systems and importance of recycling in general does not bring about pro-environmental behaviour by itself. Furthermore, the results indicate that proximity and the convenience of the current permanent collection network are inadequate in promoting the return of small WEEE in particular, such as mobile phones.

The survey also revealed that most of the respondents stored their end-of-use (EOU) mobile phones at home rather than returning them immediately for recycling. The results showed that more than half of the respondents had two or more mobile phones at homes not in use. The most common reason for this was keeping them as spare phones, followed by laziness to return them to recycling.

The relation between the number of stored phones and the reasons for not returning them was also examined. Respondents, who stated to keep phones only in reserve, have fewer phones at homes (2.7 phones) on average than the respondents keeping phones for some other reasons (up to 4.3 phones at homes).

The results related to stockpiling mobile phones at home correlate with several other surveys conducted across the world. Based on the results of various surveys evaluated in Paper IV, people prefer storing their EOU mobile phones at home rather than returning them for re-use and/or recycling; typically 40% to 60% of respondents intended to keep an old mobile phone at home when they procured a new one. A reasonable share of used mobile phones had also been sold or donated for re-use, while the portion of phones left at stores or sent to operators for recycling was substantially lower, typically less than 10%.

Consumers' stockpiling habits led to considering the lifespan of electronics such as mobile phones in Paper IV. It seems that mobile phones are typical 'up-to-date' products with expected lifespans of two years and, ordinarily, are discarded before the end of their functional life. The short first-life of mobile phones, on the other hand, creates a re-use potential of functional devices because a considerable share of consumers would be willing to use mobile phones beyond their up-to-date time. If people would deliver their functional EOU mobile phones to the recovery system immediately when buying a new one, there would be a reasonable chance to find a second user who could still use them. Unfortunately, this is not a case and with every day of storage, these devices become less and less trendy and thus the probability that they will be re-used decreases. Moreover, functional EOU devices may even lose their functionality during long storage, partly because the technology they are based on becomes obsolete and/or undesirable changes occur in their structure or state. Considering that most consumers keep mobile phones for two years, it was approximated that keeping old mobile phones in storage for longer than a year essentially turns them waste.

Ultimately, purposeless storing deprives functional devices the potential of re-use, as well as delays the return of valuable materials for recycling, thus risking the realisation of waste management hierarchy. In order to change the current situation, education and awareness-raising will continue to be crucial elements in the progress of improving recovery efficiency and move towards a more environmentally sound WEEE recovery.

8.2 Knowledge gaps and recommendations for future work

The efficient WEEE collection network and high recovery rates are essential not only for reducing the negative environmental and health impacts associated with WEEE, but also for ensuring the recycling of high-value trace and precious metals contained in WEEE in accordance with the European circular economy strategy. It was concluded that although the national WEEE implementation has succeeded in Finland in the compliance with the targets of the WEEE Directive, it does not, however, describe the total effectiveness of the recovery system. When collection amounts are compared to the amount of EEE put on the market, there is still a lot of room to improve collection rates. In particular, collection rates of small WEEE are currently low and, therefore, there is still need for further research and network development in order to improve the proximity and convenience of the system.

Moreover, the results of this thesis have revealed that the current recovery system does not promote re-use. The key challenge is that, currently, end-of-use (EOU) devices are not distinguished from end-of-life (EOL) devices. While EOL devices are disposed of and/or recycled due to failures in their functionality, functional EOU devices carry the potential of extending life through re-use. Interpretations of end-of-life and end-of-use scenarios with reference to ownership, structural performance and disposal times conducted in this thesis illustrated that total ownership is a not a good indicator of the usefulness of the device, neither of its lifespan, due to the high probability of them being stored after first use. Therefore, future research should focus on exploring reasons why consumer electronics are stored at home. In the case of mobile phones, more information related to consumers' perception toward additional features of smart phones and its impact on stockpiling habits is needed.

As consumers' stockpiling habits of used EEE indicates the reluctance to cede ownership and the phenomenon seems to be especially common for personal electronics in every-day use, it can be argued that one of the reasons for stockpiling is the personal attachment to the device. Therefore, more efforts are needed to enhance the conditions for promoting users' willingness to hand over their phones for re-use. It is suggested, that it could be achieved by establishing services, *e.g.* for purging, transferring and delivering personal data from old phones when users are changing phones and, additionally, for fine-tuning and upgrading in order to make used mobile phone more desirable for the second user.

These services are currently missing, and this gap needs to be tackled both technically and organisationally in order to fuel a real change.

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Appendix 1

Company visit to El-Kretsen, Sweden

14.9.2007

Interviewed person: Logistic manager Martin Seeger
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Thematic issues discussed in the semi-structured interview conducted by Dr. Ulla Lehtinen from University of Oulu, Dept. of Industrial Management:

1. Operating model in Sweden
 - WEEE collection network; *e.g. number of permanent collection points, the role of municipalities, the financing system;*
 - Transportation and WEEE treatment; *e.g. categories of WEEE, service providers' collection and operating areas depending on WEEE segments;*
 - Open procurement of services; *execution of competitive tendering and tendering terms, e.g. required quality and environmental standards.*
2. WEEE operators and service providers in Sweden
 - Nationwide main operators and their market shares;
 - The role of social enterprises.
3. Execution of B2B WEEE treatment
4. Re-use of WEEE
 - Re-use operators;
 - El-Kretsen's role in consumers' guidance.
5. Nordic collaboration
 - Cooperation possibilities between Finland, Sweden and Norway.
6. Operators and service providers in Northern Sweden
 - Existing sorting and pre-treatment plants;
 - Market situations and business potential for Finnish companies.

Appendix 2

Questionnaire

31.1.2013

Please, choose and mark the most appropriate option or write the answer to the reserved space. You can choose one or more option, when needed.

Mobile phone recycling

1. Do you have old and unused mobile phones at home? If yes, how many? _____

2a) What do you do with old and unused mobile phones?

- 1. I keep them at home (please, answer also question 2b)
- 2. I give them *e.g.* to my children/friend
- 3. I sell them
- 4. I leave them at the store when buying a new one
- 5. I take them to the recycling centre (please, answer also questions 2c and 2d)
- 6. I dispose them with mixed waste

2b) If you keep old mobile phones at home, please give a reason why?

2c) If you have taken your old phones to the recycling centre, please tell where and where did you hear about this opportunity from?

2d) In your opinion, was it was simple or troublesome to take old mobile phones to the recycling centre? Why?

3. If you have not taken your old mobile phones to the recycling centre, what is the reason?

1. I keep it as a spare phone
2. I don't know where to take it
3. I feel that recycling is troublesome
4. I have not got around to do it yet
5. Other, what? _____

4a) In your opinion, is it acceptable to put an old mobile phone to the mixed waste bin?

1. Yes
2. No

4b) Have you ever disposed of a mobile phone with the mixed waste?

1. Yes
2. No

What do you know and think about mobile phone recycling?

5. In your opinion, is recycling mobile phones important? If yes, why?

6. Imagine that a deposit system similar to returnable bottles was operational for mobile phones. What would be the sum of money (min. € - max. €) that would motivate you to return your old mobile phone through the deposit system?

7a) Would you be willing to buy a used mobile phone?

1. Yes
2. No

7b) What would be your prerequisites for buying a used mobile phone? If you choose more than one, please, underline the most important option.

1. Mobile phone is no more than one year old
2. It has features that my current one does not have
3. It is cheaper to buy a used phone than a new one.
4. I know the last owner/I buy it at first hand
5. Other, what? _____

7c) How much would you be willing to pay for a used mobile phone (max. € or % from original price)? _____

7d) If you would not be willing to buy an old mobile phone, please, indicate why.

8. Have you heard about the Finnish Government Decree related to the waste electrical and electronics equipment (WEEE)?

1. Yes
2. No

9. Have you seen this symbol on your mobile phone? If yes, where? What does it mean to you?

10. In your opinion, is it true, that you have to pay a recycling fee when returning a used mobile phone to the collection point?

1. Yes
2. No

11. Have you heard about mobile phone recycling campaigns arranged in Finland?

1. Yes
2. No

12. If you have heard about it, have you participated in the campaign?

1. Yes
2. No

Background information

13. Gender

1. Female
2. Male

14. Age

1. under 20 years
2. 20 - 34 years
3. 35 - 50 years
4. 51 - 64 years
5. over 65 years

15. What is your highest education?

1. Comprehensive/elementary/middle school
2. Upper secondary school/Grammar school
3. Vocational school
4. College degree
5. Vocational high school degree
6. University/Other institute of higher education degree
7. Other, what? _____

16. What is your occupation?

1. Student
2. Full-time worker
3. Part-time worker
4. Entrepreneur
5. Homemaker or stay-at-home mum/dad
6. Unemployed
7. Pensioner
8. Other, what? _____

17. How much is your household's total gross income per month?

1. under 2000 €
2. 2000 - 3999 €
3. 4000 - 5999 €
4. 6000 - 7999 €
5. Over 8000 €

18a) How many persons belong to your household? _____

18b) How many of them are under 18 years old? _____

18c) How many mobile phones you have in your household? _____

18d) How many of them are company-owned phones? _____

19a) How frequently you change a mobile phone?

1. More often than one year
2. 1 - 2 years
3. 2 - 3 years
4. Less frequently; how seldom? _____

19b) What is your most common reason to change a mobile phone to a newer one?

1. The old one doesn't work anymore
2. Company-owned phones are changed regularly
3. The latest phone models have novel features
4. Other, what? _____

Original publications

- I Ylä-Mella J, Poikela K, Lehtinen U, Keiski RL & Pongrácz E (2014) Implementation of Waste Electrical and Electronic Equipment Directive in Finland: Evaluation of the collection network and challenges of the effective WEEE management. *Resources, Conservation and Recycling* 86: 38–46.
- II Ylä-Mella J, Poikela K, Lehtinen U, Tanskanen P, Román E, Keiski RL & Pongrácz E (2014) Overview of the WEEE Directive and its implementation in the Nordic countries: National realisations and best practices. *Journal of Waste Management*, Article ID 457372, DOI: <http://dx.doi.org/10.1155/2014/457372>
- III Ylä-Mella J, Keiski RL & Pongrácz E (2015) Electronic waste recovery in Finland: Consumers' perceptions towards recycling and re-use of mobile phones. *Waste Management* 45: 374–384.
- IV Ylä-Mella J, Keiski RL & Pongrácz E (2015) End-of-use vs. end-of-life: When do consumer electronics become waste? Manuscript

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531. Pouke, Matti (2015) Augmented virtuality : transforming real human activity into virtual environments
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