Ecolabelling

Criteria development for rechargeable batteries in ICT products

Justifying a new generation of requirements to batteries based on state-of-the-art in the sector

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An exciting journey. I want to thank my parents: you are my best friends and I know that you enjoy all my accomplishments. The rays of love to Lund University: the university and the education I dreamed about. It is an honour for me to be a Lund University Global Scholarship holder. I will try to retransmit the values I felt here in my future career and daily life.

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It would be difficult to work and sometimes to live, without music. Let’s consider “Battery” by Metallica as the hymn of this research. The Swedish flat management structure – you are awesome. Thank you, Dick and Impala Malmö.

…

Something is lost on the way to creating new. To appreciate the real value – one has to pay. Sometimes to sacrifice. And in the very end, one pays with the most valuable – Time.

Communication is everything. Access to information is everything. Let’s improve batteries, making our communication tools – sustainable.

“WE’[RE]CHARGE”

IIIEE, Kullen1, 2016. Team members: Daniela, Federica, Nanda, Dima, Lara.

1 A magic place where IIIEE change agents take a journey each year – to prove their ability to defend core principles of sustainability.
Abstract

This research puts together two massive areas: voluntary certification programmes, specifically Type I ecolabelling (ISO 14024), aimed to incentivise and assist in providing customers with sustainable in all meanings products; and rechargeable batteries – inalienable element of portable electronic products. Moreover, the importance of batteries lifts up to an absolutely new level – with a rapid development of electric vehicles and energy storage systems, often used to accumulate energy from renewable energy sources.

Mass application of rechargeable batteries in consumer electronic products, first of all, increases the number of batteries on the market, and, thus, the battery waste stream. Secondly, this encourages producers to search for new chemical compounds for the creation of batteries with the increased energy density and faster recharge time.

Upcoming revision of the Battery Directive; application of new chemical compounds in cathodes production; potential risks associated with supply of such resources as cobalt and lithium; increased waste battery stream; the End-of-Life management; reaching higher rates for collection, sorting, and recycling of waste batteries; arising social conflicts around certain materials; product redesign and the necessity to be in compliance with the waste management hierarchy. All the listed aspects and challenges create a predisposition for Type I ecolabelling – to face these challenges and, thereby, to reconsider existing requirements to rechargeable batteries, initiating positive changes.

This research aims to define new potential aspects and to improve existing criteria for rechargeable batteries in portable ICT products – to meet arising environmental and social challenges, related to all life cycle stages of rechargeable batteries. To achieve this, the author conducted a research, observing background on battery technologies and the battery market; current requirements of Type I ecolabelling programmes to both – ICT products equipped with rechargeable batteries, and rechargeable batteries themselves. Numerous stakeholders, from electronics producers, waste battery collectors, and recyclers – to battery specialists and certification programmes, contributed with their view on rechargeable batteries.

The outcome of the research is the list of potential aspects of rechargeable batteries to be considered by Type I ecolabelling programmes for further implementation in the standards for mobile phones; tablets, laptops and notebook computers.

**Keywords:** Type I ecolabelling, lithium-ion battery (Li-Ion battery), rechargeable battery, product environmental properties, criteria development, sustainable development.

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Executive Summary

There is a shift in the modern environmental policy: from the “command and control” approach to a pro-active behaviour, with the focus on self-regulation, self-control, and self-organisation. The responsibilities of governments are transferred to the society. The ecolabelling, one of the new mechanisms, not only complements existing standards but “pulls” the market – towards the products with the superior environmental profile, producer responsibility, and sustainability principles.

Ecolabelling distinguishes products or services that achieved higher standards of environmental protection in comparison with those that established by law, based on the life cycle consideration approach. The objective is to assist customers in their purchase choices and to encourage producers to design and to market the products with the improved environmental profile. Ecolabelling as a market-based tool is efficient if several conditions are fulfilled, including but not limited to: a) the market functions without obvious distortions like the absence of sufficient competition amongst producers; b) ecolabelling requirements are achievable for certain – sufficient – percentage of market actors.

Evaluating a broad variety of product groups, Type I ecolabelling programmes also consider ICT products, specifically mobile phones and smartphones; notebook computers, laptops, and tablets. These devices are equipped with the rechargeable batteries what grants them autonomy and portability. Nowadays, most of the rechargeable batteries in such products are based on the Li-Ion technology. The WEEE stream significantly increases from year to year, reaching 50 Mt in 2018. The segment of waste ICT products equalled to 3 Mt in the world 41.8 Mt WEEE stream in 2014. Finally, electronic products will remain as the largest consumer of Li-Ion batteries at least until 2022.

Rechargeable batteries are a very interesting product group. Potential improvements of secondary batteries in ICT has the “win-win” nature: improved operational characteristics potentially result in less significant environmental and social impact. The increase in a number of charge-discharge cycles, as well as appropriate usage, may extend the use phase of a battery life cycle, postponing the virgin resource extraction; higher energy density may allow decreasing the battery size and weight, thus, to generate less waste.

Moreover, some challenges, associated with rechargeable batteries, may be addressed with different approaches. For example, the Li-Ion battery technology heavily relies on the use of cobalt. Cobalt is known as the material that sourced unethically – in the Democratic Republic of Congo, known as the main supplier of cobalt, the child labour is widely used for extraction of this material. Moreover, it has human and aquatic toxicity potential; and causes GHGs and SO₂ emissions during the production stage. At the same time, producers are interested to substitute cobalt with cheaper metals because this material significantly increases the cost of a battery. As the result, the Li-Ion batteries with the highest energy density contain much less of cobalt. This is en example of how the market and technological progress gradually solve a problem.

Some of the programmes developed the criteria that incorporate requirements to batteries. However, the preliminary evaluation of existing requirements to rechargeable batteries in ICT products revealed numerous weaknesses: ecolabelling programmes do not consider carefully the operational characteristics of batteries (e.g. energy density, the number of charge-discharge cycles); the restrictions on heavy metal content is based on the Battery Directive.

ISO 14024 requires Type I ecolabelling programs to review the product environmental criteria, based on such factors as “new technologies, new products, new environmental
information and market changes”. The author investigated on these factors, utilising secondary and primary sources of information. This research was conducted in collaboration with Type I ecolabelling programme TCO Certified, Sweden. The programme has a narrow focus on the IT products. Such cooperation allowed the author to receive deep insights in the sector and to utilise the programme’s resources.

Taking into account the practical nature of this research, the author formulated following research questions:

1) What new aspects should be applied to Li-Ion batteries in ICT products to decrease their environmental and social impact?
2) How could ecolabelling criteria address the new aspects?
3) What system boundaries should be considered?

To answer these research questions, the author focused attention on LCA studies on rechargeable batteries and ICT products. Moreover, various stakeholder groups – waste battery collectors and recyclers, producers, third party certification programmes were reached. Based on the collected information, the author created the ecolabelling roadmap for rechargeable batteries (Appendix I), focusing attention on the following aspects:

− The extension of the use phase – the user perspective;
− The extension of the use phase – the producer perspective;
− Battery quality based on its main operational characteristics;
− Battery content based on the materials and substances applied in the production.

Considering these aspects, the author compiled a set of possible criteria for rechargeable batteries. The criteria were sent to seven Type I ecolabelling programmes for evaluation. The list of the programmes included: EU Ecolabel (the European Union), TCO Certified (Sweden), Green Crane (Ukraine), Vitality Leaf (the Russian Federation), Swedish Society for Nature Conservation (SSNC) (Sweden), Nordic Ecolabelling (Sweden), Eco Mark Office (Japan). The specialists with the relevant experience in the criteria development gave their evaluation to the criteria based on the suggested evaluation scale. Among the specialist was Mr. Nicholas Dodd, one of the authors of the Technical Report on the revision of the European Ecolabel criteria for personal, notebook and tablet computers (2016).

Overall, all criteria demonstrated the potential for adoption by Type I ecolabelling programmes. Some of them have higher score due to the relevant experience of an ecolabelling program in the area; other criteria require more attention and deep knowledge in the area, including active communication with different stakeholder groups (e.g. the use of recovered materials in the battery production; energy density). This feedback also confirms that so far the operational characteristics of rechargeable batteries were not carefully observed. The feedback was used to adjust the criteria and to make the final suggestions.

**The list of suggested criteria**

**Criterion 1a.** A guide for a user aimed to extend battery life time. This includes information on:

− optimal battery charge (within 50-80% range);
− ambient conditions that influence a battery (e.g. temperature of a battery);
− energy saving tips (Wi-Fi usage decrease energy consumption, compared to inbuilt radio).
Preferably, if a product is sold with the pre-installed application that indicates main parameters (SoC, battery condition) and warns a user when it is necessary to charge the battery.

**Criterion 1b.** Warranty and spare parts. This includes:
- warranty on rechargeable batteries for 1 year;
- availability of spare parts (including batteries) for 5 years after stop selling a product.

**Criterion 2a.** The requirement for the design of a host device. This includes:
- possibility to disassemble, and either to repair, or to replace malfunctioning components (including batteries);
- batteries shall not be glued.

**Criterion 2b.** A guide for specialists on repairing and upgrading. This includes information on:
- how to disassemble a host product, and replace a battery in particular;
- how to upgrade and change the configuration of a host device.

**Criterion 3a.** The energy density of a battery:
- to establish minimum energy density for rechargeable batteries as 200 Wh/kg\(^3\).

**Criterion 3b.** A number of charge-discharge cycles. This includes:
- 800 for replaceable batteries;
- 1,000 for permanently inbuilt batteries (in case if it is necessary).

**Criterion 4a.** Restriction on metals in rechargeable batteries (by weight):
- mercury (Hg): < 1 ppm (0.001 g/kg);
- cadmium (Cd): < 5 ppm (0.005 g/kg);
- lead (Pb): < 5 ppm (0.005 g/kg).

**Criterion 4b.** Recycled materials in battery content:
- a battery cathode shall contain at least 5 percent of recovered materials (e.g. cobalt, lithium);
- a battery shall contain at least 10 percent of recycled plastic or other recycled materials.

**Criterion 5.** The applicant is supposed to develop and provide the Code of Conduct for the supply chain, informing all subcontractors about:
- the necessity to provide employees with adequate labour conditions, in accordance with the legislation;
- to present the complete information on how the resources are sourced.

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\(^3\) The suggested figure requires careful consideration together with the Li-Ion technology specialists, battery and electronics producers. This figure is supposed to be used for starting a dialogue with these stakeholder groups.
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<th>Definition</th>
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<tbody>
<tr>
<td>BAJ</td>
<td>Battery Association of Japan</td>
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<tr>
<td>BMS</td>
<td>Battery Management System</td>
</tr>
<tr>
<td>CE</td>
<td>Consumer Electronics</td>
</tr>
<tr>
<td>CCCV</td>
<td>Constant-Current, Constant-Voltage</td>
</tr>
<tr>
<td>CED</td>
<td>Cumulative Energy Demand</td>
</tr>
<tr>
<td>CRM</td>
<td>Critical Raw Materials</td>
</tr>
<tr>
<td>DoD</td>
<td>Depth of Discharge</td>
</tr>
<tr>
<td>EBRA</td>
<td>European Battery Recycling Association</td>
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<tr>
<td>EEE</td>
<td>Electrical and Electronic Equipment</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
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<tr>
<td>EoL</td>
<td>End-of-Life</td>
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<tr>
<td>EPD</td>
<td>Environmental Product Declaration</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>GEN</td>
<td>Global Ecolabelling Network</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
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<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
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<tr>
<td>HTP</td>
<td>Human Toxicity Potential</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
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<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
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<tr>
<td>NGO</td>
<td>Non-Governmental Organisation</td>
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<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PCR</td>
<td>Product Category Rules</td>
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<tr>
<td>PEFCR</td>
<td>Product Environmental Footprint Category Rules</td>
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<tr>
<td>REE</td>
<td>Rare Earth Element</td>
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<tr>
<td>RoHS</td>
<td>Restriction of Hazardous Substances</td>
</tr>
<tr>
<td>SDGs</td>
<td>Sustainable Development Goals</td>
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<tr>
<td>SLI</td>
<td>Starting, lighting and ignition</td>
</tr>
<tr>
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<td>State of Charge</td>
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<td>SVHCs</td>
<td>Substances of Very High Concern</td>
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<td>Single-Walled Carbon Nanotube</td>
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<td>TCLP</td>
<td>Toxicity Characteristics Leaching Procedure</td>
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<td>TETP</td>
<td>Terrestrial Ecotoxicity Potential</td>
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<td>WEEE</td>
<td>Waste Electrical and Electronic Equipment</td>
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<td>Wh</td>
<td>Watt-hour</td>
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## Abbreviation – Chemical Elements and Battery Chemistries

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<th>Abbreviation</th>
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<tbody>
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<td>As</td>
<td>Arsenic</td>
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<tr>
<td>Cd</td>
<td>Cadmium</td>
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<tr>
<td>Co</td>
<td>Cobalt</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>HBCDD</td>
<td>Hexabromocyclododecane</td>
</tr>
<tr>
<td>Hg</td>
<td>Mercury</td>
</tr>
<tr>
<td>LFP</td>
<td>Lithium-Iron-Phosphate</td>
</tr>
<tr>
<td>LCO</td>
<td>Lithium-Cobalt-Oxide</td>
</tr>
<tr>
<td>Li</td>
<td>Lithium</td>
</tr>
<tr>
<td>LMO</td>
<td>Lithium-Manganese-Oxide</td>
</tr>
<tr>
<td>NCA</td>
<td>Lithium-Nickel-Cobalt-Aluminum-Oxide</td>
</tr>
<tr>
<td>NCM</td>
<td>Lithium-Nickel-Cobalt-Manganese-Oxide</td>
</tr>
<tr>
<td>Ni</td>
<td>Nickel</td>
</tr>
<tr>
<td>Pb</td>
<td>Lead</td>
</tr>
<tr>
<td>PBB</td>
<td>Polybrominated biphenyls</td>
</tr>
<tr>
<td>PBDE</td>
<td>Polybrominated diphenyl</td>
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</table>
1 Introduction

1.1 Background

The initial task of environmental law was to establish control and regulation over pollution, caused by the industrial sector. The government approach was completely based on the “command and control” technology-based standards (Houston, 2012). Later alternative approaches with potentially greater effectiveness were developed – the market and information-based design schemes (Houston, 2012).

Modern environmental policy, aimed to “push and pull” (UNEP, 2011), with a pro-active behaviour principle, and focus on self-regulation, self-control, and self-organisation, took responsibilities from governments and transferred them to the society (“shared responsibility”), encouraging to consider issues as a complex set, but not separately (Scheer & Rubik, 2006). Ecolabelling became one of the soft tools, aimed to complement existing standards and “pull” the market (Thidell, Leire, & Lindhqvist, 2015; UNEP, 2011). Requiring low investment and, thus, being accepted by political decision-makers more willingly (Thidell et al., 2015), ecolabelling is an important part of the multiple-tool approach for setting broad environmental laws (Houston, 2012).

Ecolabelling incorporates a few types of labels. The standards from 14020 series set general principles for environmental labels and declarations: Type I ecolabelling is based on the life cycle consideration (ISO 14024); Type II ecolabelling reflects producers’ self-declared environmental claims regarding products (ISO 14021); Environmental Product Declaration (EPD), Type III ecolabelling is for business-to-business communication (ISO 14025).

In accordance with ISO 14024, ecolabels recognise environmental superiority of the product or service that achieved higher standards of environmental protection in comparison with those that established by law, based on the life cycle consideration approach. The objective is to assist customers in their purchase choices, providing them with the relevant information. At the same time, producers are encouraged to design and market more environmentally friendly products (UNEP, 2011).

Considering products and services as a single unit that causes the environmental and social impacts during its life cycle, the ecolabelling encourages the product chain actors to make improvements (Thidell et al., 2015). This includes optimisation of life cycle (design, production, consumption and disposal of products) via such measures as product redesign (“eco-design”), efficient energy and water consumption, waste reduction, information support to the customers; and more globally – focusing on the life cycle economy and diminishing of cost externalisation (Thidell et al., 2015).

Today ecolabelling programs cover different product categories: Global Ecolabelling Network (GEN) (n.d.) distinguishes 18 product categories, which include different product groups: paints and coatings, cleaning products, construction and building, office equipment and furniture, batteries, lights, home appliances, clothing and textiles, personal care products, paper products, and other. Based on functions and characteristics, some ecolabelling programs developed criteria for over 100 product groups (Thidell et al., 2015).

Some of these product groups, or their components, receive more attention on regular basis. For instance, detergents and cosmetic products are observed in terms of the potential to cause health issues and environmental impact due to a variety of chemicals in content. Building materials are constantly improved to reach higher energy efficiency.
Batteries remain a “dark horse”: not many third party certification programmes established advanced criteria for them (GEN, n.d.). However, the batteries play an exceptional role in terms of providing electronic devices with a valuable attribute of portability, and defining the future of the electric vehicle (EV) industry (Noorden, 2014). Several Type I ecotagging programmes developed criteria either for primary (non-rechargeable), or secondary (rechargeable) batteries. Criteria for electronic products, equipped with the rechargeable batteries (e.g. smartphones, laptops, notebooks), often include certain requirements to the batteries in them.

The primary batteries remain widely applied in the situations when charging is not possible or reasonable (e.g. military operations, rescue missions) (Buchmann, 2016). However, rechargeable batteries have already dominated the market with the two-thirds of the USD 71 billion world battery market in 2010 (Florez & Adolph, 2010). At that time, over 90 percent of rechargeable batteries (by weight) were sold with the equipment (RECHARGE, 2010). Nowadays this is mostly Lithium-Ion (Li-Ion) batteries (Boyden et al., 2016).

Represented by Sony in the 1990s, the Li-Ion batteries changed the market of rechargeable batteries and portable electronics, gradually replacing the nickel-based predecessors (Wang, 2014; Buchmann, 2016). Already in 2005 the Li-based technology accounted for 96 percent of cell-phone and 92 percent of laptop batteries (Wang, 2014). 1,423.9 million smartphones sold in the world in 2015, and 154.5 million laptops shipped worldwide in 2016 (Gartner, 2016).

The battery performance defines the mobility and portability of modern smartphones and laptops. But information and communications technology (ICT) products develop faster than batteries: recent improvements of battery energy density were counter-balanced with higher power consumption: more powerful devices have the same runtime as their predecessors (Florez & Adolph, 2010; Lee & Stewart, 2015). Nevertheless, the rechargeable batteries in ICT products more or less satisfy consumer needs (Buchmann, 2016), and the attention rapidly shifts to the application of Li-Ion batteries in the EV sector. To make EVs more autonomous and affordable for consumers the energy density of Li-Ion batteries and the price per kilowatt (kWh) of battery energy should be improved: so far rechargeable batteries account for the third part of the EV cost (Randall, 2016).

Nevertheless, electronic products are the largest consumer of Li-Ion batteries, at least until 2022 when, according to Ryan (2017), the EV battery market will obtain equal shares with the Electrical and Electronic Equipment (EEE) battery market, reaching together 200 GWh capacity. With the current state of development and commercialisation, Li-Sulfur, Li-Air, fuel cells and other technologies (ICM AG, 2017) are not expected to cause major breakthroughs in the battery market in 2015-2020 (Buchmann, 2016; Lee & Stewart, 2015). New lithium salts, organic solvents and electrodes will allow the Li-Ion technology to remain as prevailing for the next 10 years.

### 1.2 Problem definition

Nowadays the Li-Ion batteries are widely used as an energy source in ICT products – mobile phones, laptops, cameras, and many other products, granting them a priceless attribute – portability. Li-Ion batteries are associated with high energy density, low self-discharge rate, no memory effect, high voltage, extended life cycle, and advanced environmental profile (Dunn et al., 2015; Liang et al., 2017). And whilst ICT products are constantly improved, they remain heavily dependent on the rechargeable batteries. The latter partially defines the lifespan of a product, because batteries have limited number of charge cycles and constantly fading capacity (Balde, Wang, Kuehr, & Huisman, 2015). This inevitably leads to the End-of-Life (EoL) stage.
The ICT products become a serious contributor to the waste battery stream, often demonstrating the shortest lifespan amongst EEE.

In 2014 the world Waste Electrical and Electronic Equipment (WEEE) stream equalled to 41.8 million metric tonnes (Mt), and the ICT products (mobile phones, personal computers, calculators etc.), equipped with rechargeable batteries, contributed 3.0 Mt (Balde, Wang, Kuehr, & Huisman, 2015). It is expected that in 2018 the world waste stream will reach 50 Mt, with the increased amount of the ICT waste.

In Europe the WEEE stream is recognised as the fastest growing (EC, 2008; Boyden et al., 2016). Eurostat indicates that between 2010 and 2014 the amount of EEE put on the EU market was 8.8-9.4 Mt per year. The quantity of generated WEEE was 8.3-9.1 Mt each year (EC, 2008; Eurostat, 2016). In 2013 it was collected only 3.6 Mt of WEEE in the EU, 0.55 Mt of which were represented by ICT waste (15.3 percent) (Eurostat, 2016). The European WEEE stream is forecasted to grow to 12.3 Mt by 2020 (EC, 2008).

Kang, Chen, & Ogunseitan (2013) stress that due to the small size of the batteries, the high rate of disposal of ICT products, and “the lack of uniform regulatory policy on their disposal” makes the Li-Ion batteries a serious contributor to environmental pollution and adverse human health impacts due to potentially toxic materials.

In accordance with the WEEE Directive, when a device is disposed, the battery shall be removed and treated separately, from now on being regulated by the Battery Directive 2006/66/EC. The Battery Directive aimed to decrease the content of hazardous substances in batteries, since many of them ended up in the municipal solid waste stream (MSW), becoming the most intense source of heavy metals (Turner & Nugent, 2015). Furthermore, incorporating the concept of Extended Producer Responsibility (EPR), it has established the waste battery collection rates for each Member State, 25 percent in 2012 and 45 percent in 2016 – to prevent inappropriate management at the latest stage of life cycle.

**ICT products and Type I ecolabelling**

Type I ecolabelling programmes, developing standards for electronic products, also consider rechargeable batteries. The established requirements cover various aspects: battery content; product design; information for customers and specialists; battery performance (Appendix I). However, ISO 14024 explicitly sets that the product environmental criteria are subjects to review, based on such factors as “new technologies, new products, new environmental information and market changes”.

Potential improvements of ICT rechargeable batteries seem to have the “win-win” nature: better operational characteristics potentially result in less significant environmental and social impacts. The increase in number of charge-discharge cycles, as well as appropriate usage, may extend the use phase of a battery, postponing the virgin resource extraction; higher energy density may allow to decrease the battery size and weight, thus, to generate less waste.

The EU Ecolabel, based on the Commission Decision (EU) 2016/1371, has launched advanced requirements to personal, notebook and tablet computers: the criteria incorporate the RoHS Directive, the REACH Regulation and the Candidate List of SVHC. Blue Angel (2013; 2014; 2017) in the standard for mobile phones and portable computers pursues the ecodesign principles, and establishes requirements to battery capacity and battery lifespan. Nordic Ecolabelling (2016) in the standard for computers (including notebook computers) pre-planned the revision of the criteria for rechargeable batteries.
Based on these prerequisites, the author considers existing requirements to rechargeable batteries in portable ICT devices, to incorporate arising environmental and social challenges. This research aims to assist Type I ecolabelling programs in criteria development for rechargeable batteries, providing relevant scientific background.

1.3 Research questions and objectives

Taking into account the practical nature of this research, the author suggests the following research questions:

1) *What new aspects should be applied to Li-Ion batteries in ICT products to decrease their environmental and social impact?*

After limiting the hazardous substances in battery content, the Battery Directive 2006/66/EC has focused on collection and recycling rates, and recycling efficiency. However, other aspects may be of interest due to their potential to improve both the operational and environmental profile of rechargeable batteries, and also to cover social impacts. Type I ecolabelling programmes consider the entire life cycle of a product to find out such aspects. The author intends to observe the interconnection between battery performance and its environmental profile; battery content and the use of such crucial materials as cobalt (Co) and lithium (Li); host device design, and, finally, the EoL stage with the focus on recycling and material recovery.

The author expects that all kinds of impacts, caused by rechargeable batteries, may be diminished thanks to improved operational characteristics and the extended user phase. Type I ecolabelling could have potential to trigger changes in product design, encouraging for replaceable and repairable components. Materials, recovered during recycling, might be used in the production stage. Finally, these new aspects may also cover the user experience and behaviour patterns, making the usage of portable ICT devices more effective.

2) *How could ecolabelling criteria address the new aspects?*

The core objective of this research is to find the most significant aspects of rechargeable batteries to be utilised as the main input for further criteria development. Whilst some aspects may have great potential to withstand arising environmental and social challenges (e.g. resource scarcity, environmental impact, unethically sourced resources), there is certain risk to impose unrealistic requirements, causing unnecessary pressure on producers, and creating the market distortion.

Based on the identified environmental and social aspects of rechargeable batteries, and taking into account current legislation, the ‘state of the art’ in the battery sector, as well as the views from different stakeholders, the author will suggest criteria for rechargeable batteries.

3) *What system boundaries should be considered?*

Whilst the criteria are focused on a rechargeable battery itself, it is important to understand whether the considered system includes a host device and a charger. Siret et al. (2016) in the case of electric vehicles (EVs) exclude chargers from the system because there is no allocation of a charger per a battery or a vehicle. At the same time, all portable ICT devices are normally provided with an individual charger; however, it is often relies on a mandatory protection circuit of a Li-Ion battery and its ability to terminate the charge when the battery reaches either critically low or high levels of charge, or exposed to excessive pressure or temperature changes (Qnovo Inc., 2015; Buchmann, 2016). Finally, the environmental parameters and
performance of the secondary batteries to a large extent depends on the overall performance of the equipment they are installed in, as well as the used charger (RECHARGE, 2010).

1.4 Scope and limitation

Scope. The scope of the research is finding scientifically justified and optimal aspects of rechargeable batteries to incorporate them into the criteria, developed by Type I ecolabelling programmes. The aspects, found in this research, might be used directly – for formulation of requirements to rechargeable batteries in portable ICT devices; or to serve as scientific background for supporting a decision-making process regarding the evaluation of rechargeable battery life cycle, and development of other requirements, policies and regulations.

Literature limitation. Whilst the author utilises the newest and most recent Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA) studies on rechargeable batteries, conducted during the 2010–2017 period, it is necessary to stress that since the invention of the Li-phosphate technology in 1996 the commercial battery market was not diversified with any other new battery technology (Buchmann, 2016).

Product group limitation. The portable ICT devices group is limited to smartphones; tablet, laptop, and notebook computers. These products are usually equipped with Li-Ion batteries, used either as a single cell, or as a combination of a few cells – to form a rechargeable battery.

Voluntary certification programmes limitation. The author considers following certification programmes: EU Ecolabel; Blue Angel; Nordic Ecolabelling; TCO Certified; Korea Eco-label; Green Choice Philippines; Japan Environment Association. Eco Mark Office; EPEAT. This limitation is based on the fact whether an ecolabelling programme has developed criteria for either smartphones; tablet, laptop, and notebook computers; or rechargeable batteries.

System boundaries. After research on potential system boundaries, the author will either include or exclude certain elements (chargers, devices) from the considered system.

Information limitation. Certain information from primary sources might be restricted for public access due to a trade secret or other liabilities, therefore, the author may partially limit represented information, or avoid the usage of precise figures. In this case, the author previously warns a reader regarding any limitation.

1.5 Intended audience

Type I ecolabelling programmes are the main audience of this research. The author collaborates with TCO Certified, one of the programmes, with a narrow focus on IT products, to utilise the company’s resources for the purpose of this research. Several other ecolabelling programmes are reached during the research – to receive comments of specialists.

Furthermore, a new set of requirements to rechargeable batteries in portable ICT devices may play a significant role for a variety of other actor, including:

- Customers, and the society in general, benefit from ICT products with less significant environmental and social impacts, as well as improved operational characteristics;
- Other voluntary certification programmes, including receive the full-scale research that takes into account features and specificities of Type I ecolabelling. GEN members encourage fruitful cooperation, sharing best practices in the network;
- The producers who are eager to contribute to sustainable development, both reducing environmental and social impact, and enhancing safety and technical parameters of
rechargeable batteries; and, finally, to deliver their values to customers, assisting in their purchase choices;

- A signal for governments to reconsider legislation, establishing more stringent requirements to cut of the “tail” of products with low environmental, social, technical, and safety performance;
- Recycling companies: to reconsider recycling approaches, and to help them to influence the market of recyclables, encouraging governments to incentivise efficient recycling and material recovery.

1.6 Thesis outline

In Chapter 1 the reader is introduced to the research. The author presents the research problem and arising questions, as well as explains how the identified system boundaries and the audience of the research.

Chapter 2. The author’s approaches on gathering information are presented. The questionnaires, developed both to receive primary data and to collect feedback from Type I ecolabelling programmes, are discussed. Finally, the research design is presented.

Chapter 3 consists of the background information on batteries, including historical aspects; the production process; existing and future technologies; the variety of Li-Ion based cathodes; the current situation on the battery market. The core element of the section is observation of the Type I ecolabelling criteria for rechargeable batteries in portable ICT products.

Chapter 4 consists of the literature review and analysis, aimed to assist the author in development of the holistic view on the situation in the sector. A variety of scientific researches based on LCA studies may be found in this section.

Chapter 5 reflects the data received from interviews with stakeholders. The aim is to learn the real situation on the battery market, taking into account views of various stakeholder groups.

Chapter 6 is based on the data received from secondary and primary information sources. In this section the author reflects on the used literature and conducted interviews, demonstrates which rationalities may be taken, and applied to fulfil the scope of this project. Discussing findings, the author makes assumptions and answers the research questions.

Chapter 7. The quality assurance of the found aspects and suggested criteria. The author reached several Type I ecolabelling programmes to receive their feedback on the relevance of the findings. Based on the feedback, the author adjusts criteria.

Final suggestions are in Chapter 8. The author shares last impression on the thesis topic and the research problem. The author states the aspects that are, at his opinion, may be implemented by Type I ecolabelling programmes. Overall conclusions followed-up by…

… the suggestion on further research questions and areas to work with – in Chapter 9.
2 Research design

Type I ecolabelling is, first of all, a market-based tool aimed to assist customers in their choices. Its application should be user-friendly (simple and straightforward), reliable and cost-efficient. Developing the research design, the author was guided by these principles.

2.1 ISO 14024

One of the main features of Type I ecolabelling is the life cycle consideration approach: the environmental performance of a product or service is considered on each stage of the life cycle: the extraction of natural resources, processing, and production, transportation, use, disposal stages (the EoL stage).

It is clear that LCA studies suit pretty well for the purpose of Type I ecolabelling. However, one full-scale LCA study takes a lot of efforts and time. Thereby, the author utilises conducted LCA studies on rechargeable batteries and the ICT products that are equipped with such batteries.

Whilst there are a few kinds of environmental labelling, ISO 14024 sets the principles and procedures for ecolabelling programmes of Type I. In the case of the compliance with the established requirements, the labels of this type reflect the environmental preferability of certain products over analogues within the same product category. According to the standard, “Type I environmental labelling programmes are voluntary, can be operated by public or private agencies and can be national, regional or international in nature.”

ISO 14024 requires Type I ecolabelling programs to review the product environmental criteria, based on such factors as “new technologies, new products, new environmental information and market changes”.

2.2 Collecting data

The data is collected from three areas: 1) the current stance of the battery technologies; 2) the criteria developed for rechargeable batteries by Type I ecolabelling programmes; and 3) the environmental and social impact associated with the life cycle of rechargeable batteries. The information from these areas is received from the secondary and primary sources. This was supposed to provide the author with the comprehension of how the practical aspects correspond with the theoretical and to identify “new technologies, new products, new environmental information and market changes”.

2.2.1 Secondary data

The secondary data is collected primarily from the LCA studies on the rechargeable batteries and the ICT products that are equipped with such batteries: mobile phones and smartphones; tablets, laptops and notebook computers. In the research they are often generalised to two categories: “mobile phones” and “notebook computers”. This is done for purpose since all the majority of ICT products use similar Li-Ion based battery technology.

Except LCA studies, the author utilised numerous reports of research centres, battery associations, and governmental organisations. Another crucial source is standards of Type I ecolabelling programmes. The author focuses on the programmes that developed standards either for mobile phones, or for tablets, laptops, and notebook computers; at certain stage the author made a decision to also consider standards for rechargeable batteries.
The author utilised the literature on EVs: despite the difference in scale, electric cars use the same Li-Ion battery technology. It is reasonable to consider this, however, to certain extent: the use phase of EVs may greatly reshape the environmental profile of rechargeable batteries.

### 2.2.2 Primary data

Whilst Type I ecolabelling strives to make feasible difference between ecolabelled products and analogues on the market, it is crucial not to cause any kind of market distortion, creating barriers for any group of stakeholders. For this purpose, the author made an attempt to reach stakeholders which would represent various groups and, thus, interests.

**Interviews**

In the very beginning, as a part of the brief observation of the situation in the rechargeable battery sector, the author compiled a short questionnaire – to initiate dialogues with stakeholders. The interviews were semi-structured. Receiving more information from both secondary and primary source the author modified the questionnaire, developing four variations; each of them devoted to a specific group of stakeholders:

- electronics producers;
- battery producers and technology developers;
- recycling companies;
- certification programmes.

These modified questionnaires went trough another sequence of improvements to be sent beforehand a semi-structured interviews interview. However, some stakeholders preferred to give a written response. The entire list of stakeholders reached during this research is represented in Appendix VI. The list of conducted interviews includes:

- Mr. Alain Vassart, General Secretary, European Battery Recycling Association, EBRA (EU);
- Mr. Carl E. Smith, CEO/President, Call2Recycle, Inc. (USA)
- Ms. Kristina Eriksson, Battery Manager, El-Kretsen (Sweden);
- Ms. Alyona Yuzefovich, CEO, Boxy (the Russian Federation);
- Mr. Fredrik Benson, IT and Development Officer, El-Kretsen (Sweden).

The quintessence of each interview, relevant for this research, is presented in Chapter 5 “Primary data. Views of experts and stakeholders”.

The author wants to stress an interesting fact: whilst utilisation of TCO Certified resources, as well as the name itself, in some cases gave “green light” for starting dialogues with certain stakeholders, in the end, some of them did not see the necessity to provide the author with relevant information due to their direct communication with TCO Certified. Thereby, the author had to explain that this is an independent research; despite the collaboration with the Type I ecolabelling programme, the task was to receive information as a disinterested person.

Some interviews could not be conducted within the time span, given to this research, or due to the fact that stakeholders could not share relevant information at the moment. However, a few of such interviews will be conducted post-factum, including:

- the interview with Ms. Alexandra Degher, Hewlett-Packard, Worldwide Lifecycle Assessment Program Manager. Vice-Chair of IEEE 1680.1 Workgroup on “Standard
− the interview with Ms. Pamela Brody-Heine, Director of Standards, GEC. Regarding the standard, revised by IEEE 1680.1 Workgroup (pre-planned in October-November);
− the interview with EMEA Battery program manager, Hewlett-Packard (with help of Ms. Madeleine Bergrahm, Social & Environmental Responsibility, Hewlett-Packard) (pre-planned in September);
− finally, the author participates in the 22nd International Congress for Battery Recycling, ICBR 2017, in Lisbon (Portugal). Partially, the information received at this congress will be integrated into this research post-factum, after defence.

2.3 Criteria Development

Based on the information, received from secondary and primary sources, the author identified crucial direct and indirect aspects that have influence on the environmental and social performance of rechargeable batteries. The identified aspects were used for the creation of the “Ecolabelling Roadmap for rechargeable batteries in portable ICT products” (Appendix I).

The roadmap is used to demonstrate relevant aspects and associated negative impacts, as well as the potential improvements. It also demonstrates the entire complexity of interconnections between various aspects and LC stages. Based on the identified aspects, the author formulated the criteria for rechargeable batteries.

2.4 Quality Assurance

The newly formulated criteria require verification on relevance, credibility, feasibility, the potential to cause the market distortion, and measurability which may make them either favourable or unfavourable for implementation. Criteria development is a long-term process which consists of successive phases and requires involvement of stakeholders at certain stages. This includes the feedback from various stakeholder groups. The author expects to present findings and assumptions to Type I ecolabelling programmes, and to receive their feedback on their validity and feasibility. Based on this feedback, the author will correct the assumptions, to suggest the final variant of crucial aspects and possible criteria for rechargeable batteries.

To verify the criteria, the author developed a survey for Type I ecolabelling programmes, preferably – the specialists with the experience in standardisation and criteria development. The respondents represented following Type I ecolabelling programmes: EU Ecolabel (the EU); Swedish Society for Nature Conservation (SSNC) (Sweden); TCO Certified (Sweden); Green Crane (Ukraine); Vitality Leaf (the Russian Federation); Nordic Ecolabelling (Sweden); and Eco Mark Office, Japan Environment Association (Japan).

Survey

The survey is represented in Appendix IV, and it included eight aspects of rechargeable batteries, two aspects per each category:

− The extension of the use phase – the user perspective;
− The extension of the use phase – the producer perspective;
− Battery quality based on its main operational characteristics;
− Battery content based on the materials and substances applied in the production.

The respondents were suggested to evaluate each aspects according to five attributes:
- Relevance: how relevant an aspect for rechargeable batteries;
- Differentiate: whether such aspect has any potential to differentiate between different rechargeable batteries on the market;
- Applicability: easiness of implementation;
- Measurability: how easy to measure and quantify; availability of test methods;
- Market Distortion: whether the aspect causes barriers for certain stakeholder groups.

The respondent chooses between option "High" and "Low"; also, the respondent may choose "Don't know". Finally, there is a space for comments after each section – to initiate discussions.

2.5 Developed framework

Based on the described above stages, the author compiled the final framework for the research (Figure 2-1).

![Diagram of the framework for criteria development](image)

*Figure 2-1. The framework for criteria development*

*Source: The author*
3 Background information

3.1 Rechargeable batteries. General information

The concept of a device that transforms chemical energy into electrical was created in 1800 by Alessandro Volta. Since then manufacturers were pushing further development of battery technologies, aiming to improve energy density and conversion efficiency of batteries (Smith & Gray, 2010). The vital function of batteries is energy storage that enables the cordless (portable) use of numerous electronic appliances.

It is expected that batteries will play a significant role as an energy storage for renewable energy (Rahn & Wang, 2013). McManus (2012) considers batteries as a crucial aspect for the proliferation of renewable energy sources at the community level, with a potential to change consumer behaviour patterns in terms of the national grid. But batteries still have many limitations: low energy capacity, short life cycle; finally, slow charging (Buchmann, 2016).

Besides pollution, associated with primary batteries, the Li-Ion based rechargeable batteries outperform the former in terms of efficient energy usage (Umweltbundesamt, 2013): Turner & Nugent (2015) claim that the production of an alkaline battery requires 100 times more energy than it can store during the use phase; Umweltbundesamt (2013) generalises this figure for all primary batteries as “from 40 to 500 times more”. The Federal Environment Agency in Germany recommends replacing primary batteries with rechargeable if this is technically possible (Umweltbundesamt, 2013). Nordic Ecolabelling (2015b) confirms that in most cases rechargeable batteries have a better environmental profile.

Different battery technologies find their application in various sectors. The balance between main operational characteristics (e.g. specific energy, specific power, charging time) fulfils certain requirements. For example, EVs need the rechargeable batteries with reliable performance and long life, regardless the size. In contrast, ICT products like mobile phones are equipped with the small and low-cost batteries which provide extended run-time, however, life cycle longevity is less important. Safety remains of utmost importance (Buchmann, 2016).

It is stressed that despite technologies, all batteries have similar features: they require recharging, and when energy capacity fades out, the rechargeable battery is replaced. Often, the battery’s life is shorter compared to a host device (Buchmann, 2016).

It is expected that major application of Li-Ion batteries in Europe will be EVs. Later, on a longer term basis, automotive (starting, lighting and ignition (SLI)) lead-acid batteries may be replaced by Li-Ion batteries (ICM AG, 2017): when there is need in numerous cycles, the calculations of the price-per-cycle demonstrate that Li-Ion batteries win over lead-acid (Buchmann, 2016). According to Buchmann (2016), this transition will happen faster than the advancement of the Internet.

3.1.1 Battery basics and classification

The structure of modern commercial batteries has not changed drastically: they consist of an electrolyte and two electrodes (the anode and the cathode). The chemical reaction that takes place at the electrodes and the nature of electrolyte influence the efficiency of a battery (Smith & Gray, 2010). The inactive components – steel casings, seals, and separators – ensure normal functioning of a battery cell. The active components comprise different chemical compounds which define main attributes of a battery. Some of them may cause significant environmental impact in case of inappropriate disposal (cadmium (Cd), lead (Pb), and mercury (Hg), and to a lesser degree – copper (Cu), nickel (Ni), lithium (Li), silver, and zinc).
The Battery Directive distinguishes three types of batteries: portable, industrial, and automotive batteries. Portable batteries are sealed, can be hand-carried and are neither industrial nor automotive batteries. According to European Commission (2014), approximately 75 percent of all portable batteries in the EU are non-rechargeable – for the ‘general purpose’ use, leaving the rest of the market – 25 percent – to rechargeable batteries. Industrial batteries comprise batteries, designed for the professional application, often at the manufacturing level. Here lead-acid batteries prevail on the market with 96 percent, the rest 4 percent is equally divided between NiCd and other batteries (Table 3-1). Finally, automotive batteries are used for vehicle starting, lighting and ignition systems (so-called “SLI” batteries).

Table 3-1. Battery types, based on their application and used chemistries

<table>
<thead>
<tr>
<th>Portable</th>
<th>Industrial</th>
<th>Automotive (SLI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-rechargeable (includes button cells)</td>
<td>Rechargeable</td>
<td>Lead-acid, Nickel-cadmium, Nickel-metal hydride, Lithium-ion, Lead-acid</td>
</tr>
<tr>
<td>Zinc-carbon, Alkaline-manganese, Lithium-oxide</td>
<td>Nickel-cadmium, Nickel metal hydride, Lithium-ion, Lead-acid</td>
<td></td>
</tr>
</tbody>
</table>

Source: The Battery Directive

Buchmann (2016) states that since 1996 when the Li-phosphate technology was invented, the commercial battery market has not been diversified by any new major battery system. LiCoO$_2$ (LCO) compound is widely applied for the production of cathodes, often used in the batteries for ICT products (Dunn et al., 2015). Searching for alternative options, producers try to reduce cobalt in battery content: due to its high cost and limited availability. As the result, there are already cathodes – LiNiMnCoO$_2$ (NMC) and LiNiCoAlO$_2$ (NCA) – with lower content of cobalt but the same or even higher energy density (Bernhart, 2014; Buchmann, 2016). LMO has significantly lower material costs and requires less investment but the material typically used in combination with NCM or NCA (Bernhart, 2014). Figure 3-1 and Table 3-2 demonstrate the correlation between energy density and cobalt content.
3.1.2 Battery production

Dunn et al. (2015) describes the “Cradle-to-Gate” stage with examples of core processes (Figure 3-2). The assembly of small commercial Li-Ion cells and larger EV cells is based on the same process. The significant part of production energy is used for this purpose (Gaines, Sullivan, Burnham, & Belharouak, 2011). The process consists of the following stages:

1) The coating machine is pumped with a cathode paste, made of LiCoO2 powder (80-85 percent), binder powder, solvent, and additives;
2) Coating machines covers the Al foil (20 µm thick) with a layer of paste (200-250 µm) on both sides. Drying reduces the thickness by 25-40%. The prepared foil is calendered to adjust the thickness; finally, slit to the appropriate width;
3) Similarly, the graphite paste is prepared to be put on Cu foil (the anode production);
4) The anode, separator, and cathode layers are twisted up and positioned into a case;
5) The formed cell is filled with electrolyte;
6) After safety components, valves, seals, and insulators are installed, the cell is encased;
7) The manufactured cell is charged, later conditioned and tested (up to four charge-discharge cycles to verify quality);
8) The cell is equipped with electronic circuit boards to control charging, and then packed in a case.

Figure 3-2. Battery production: the “Cradle-to-Gate” cycle with examples of processes

Source: Dunn et al. (2015)

3.1.3 Global market

Since the 1990s when Sony commercialised Li-Ion batteries, they rapidly replaced the nickel-based predecessors (Buchmann, 2016). In 1996 the total production of batteries for mobile

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**Table 3-2. Cobalt-based cathodes and energy density of batteries**

<table>
<thead>
<tr>
<th>Cathodes</th>
<th>LCO</th>
<th>NMC</th>
<th>NCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobalt, percentage from cathode mass</td>
<td>60</td>
<td>33</td>
<td>9</td>
</tr>
<tr>
<td>Energy density, Wh/kg</td>
<td>200</td>
<td>200</td>
<td>250</td>
</tr>
</tbody>
</table>

Source: Buchmann (2016)
phones was 4.9 million units; the Li-Ion, NiMH and NiCd batteries shared the market with 22, 39, and 39 percent respectively. Later, in 2005 the phone production reached 177 million units, but 79 percent were equipped with the Li-Ion batteries (and 17 percent with Li-polymer batteries). For laptops the situation is similar: in 1995 1.8 million laptops were equipped with Li-Ion (45 percent) and NiMH batteries (55 percent), however in 2005 the Li-Ion batteries led the laptop market with 92 percent (with a total production of 3.3 million units). This happened due to exact advantages of Li-Ion batteries (Florez & Adolph, 2010; Wang, 2014):

- a higher energy density;
- a greater number of charge cycles without “memory effect” and high energy density;
- as the result, battery lifetime is extended;
- just 5 percent lost of charge per month due to self-discharge (NiMH loses 30 percent);
- a broad variety of form-factors, light weight;
- a better environmental profile.

While the NiMH batteries have a few advantages (lower cost; high current; and no need for processor controlled protection circuits) (Florez & Adolph, 2010), the Li-Ion batteries became dominant on the market for both – portable devices and EVs (Wang, 2014). Appearing factories-giants (e.g. Tesla’s and Panasonic’s Gigafactory, LG Chem, Foxconn, BYD, and Boston Power) are going to triple Li-Ion battery production, reaching up to 125 GWh capacity by 2020, and only enhancing the leading role of Li-Ion battery technology (Macpherson, Bernhardsdottir, & Hayes, 2016; Desjardins, 2017). LG and Samsung also scheduled launching of Li-Ion production in Europe – in 2018 (ICM AG, 2017).

Tesla CEO Elon Musk stated that Gigafactory could triple the battery output – reaching 150 GWh (Lambert, 2016b). At the same time, China and Korea continue to invest into Li-Ion battery production (ICM AG, 2017), where this industry demonstrates linear growth: from 2.69 billion to 5.29 billion during the 2010-2014 period (Liang et al., 2017). Figure 3-3 demonstrates how greatly the Li-Ion battery industry will grow in the nearest two-three years:

![Figure 3-3. New expected Li-Ion battery production facilities](image)

*Source: Macpherson et al. (2016)*

Moreover, the European Union decided to establish “a full value chain of batteries in Europe, with large-scale battery cells production, and the circular economy, at the core”. (European Commission, 2017). The Europe’s largest Li-Ion factory, NorthVolt, is already being built in
Sweden; the planned capacity of 32 GWh is expected to be reached by 2023 (Ayre, 2017; NorthVolt, n.d.). The company assumes that there is “a long-term market for 100-150 factories of our size” (NorthVolt, n.d.).

Buchmann (2016) forecasts the 7.7 percent annually growth of the world demand for primary and secondary batteries, to reach USD 120 billion in 2019. The real growth is caused by rechargeable batteries – with the expected 82.6 percent of the global battery market in 2015. Buchmann (2016) accentuates that this demand is mostly driven by portable devices (mobile phones and tablets) so far; the battery demand for EVs was over-estimated, and the figures had to be adjusted downwards. Nevertheless, Li-Ion batteries are expected to dominate over other battery technologies in terms of their application in EVs – due to high energy density and light compact structure (Wang et al., 2017). Boyden et al. (2016) also predict that the application of Li-Ion batteries in portable electronic products will double before 2020, compared to 2013-2014 years.

In his interview to ICM AG, Christophe Pillot, Director of Avicenne Energy, provided information on trends in the Li-Ion battery market: the latter reached over 90 GWh demand in 2016, with a 25 percent growth on the average – each year during the last decade; portable devices acquired around 35 percent of the produced Li-Ion batteries (ICM AG, 2017).

3.1.4 Rechargeable batteries: Current and future technologies

The battery industry is a slow one in terms of changes and new technologies. In the last two decades, the Li-Ion batteries demonstrated just an 8 percent growth in energy density per year. Recently this has decreased to 5 percent, however, cost reduction increased to the same 8 percent per year (Buchmann, 2016). Such improvements are considered to be very slow, especially compared to the vast advancements in the microelectronics field.

Big expectations in terms of increasing the energy density are imposed on coating either cathode or anode with a thin layer of various materials; this is expected to quadruple the energy (Buchmann, 2016). Li-rich surfaces, coated with Al, C, Al, O3, and AlPO4 layers, may greatly increase discharge capacity of the coating material, reduce the irreversible capacity loss and improve their circulation rate stability and performance (Manthiram, 2013; Wang et al., 2017). The Joint Center for Energy Storage Research (JCESR) develops the concept of a “5-5-5” battery that would be “five times more powerful and five times cheaper in five years”. Oliveira et al. (2015) stress that there is no clear vision regarding the future of battery technologies: it is not clear a) how battery energy density will evolve; b) which battery technology will become dominant; and, finally, c) the amount of lithium, required for Li-Ion battery production.

Whilst Tesla is focused on the production of EVs and energy storage systems, both these niches utilise the most advanced Li-Ion technology. The company invited Jeffery Dahn, Ph.D., a pioneer in the development of Li-Ion batteries (Lambert, 2017) who also consulted Exide, Toshiba America, BYD USA (Dalhousie University, n.d.); he is a co-creator of NMC cathode that is applied in energy storage systems (Dalhousie University, n.d.; Lambert, 2016a). In his interview to The Natural Sciences and Engineering Research Council of Canada (NSERC), Jeffery Dahn explained that together with Tesla they aim to: 1) decrease the cost of Li-Ion batteries; 2) improve lifetime; 3) increase energy density.

LFP, Li-S, Li-metal

Lithium-iron-phosphate (LFP) with an olivine structure demonstrates great thermal stability but compromising with a lower conductivity that is improved with a carbon coating. The energy density of LFP (like with LMO) is lower in comparison with the layered metal oxide.
cathode materials. These drawbacks of LFP and LMO technologies are balanced by lower cost than the layered materials – in the case of high-scale production (Dunn et al., 2015).

McManus (2012) used the Recipe midpoint impact assessment methodology to evaluate the “cradle-to-gate” of LFP, comparing with the lead-acid, NiCd, NiMH, and Sodium-S batteries. It showed that LFP has a significant impact on metal depletion and GHG emissions, associated with the production of ferrite. Whilst there is no shortage of ferrite the industry is forced to process lower grade ores what causes serious environmental and economic consequences. Similar situation with manganese that is also used for the production of ferrite. This makes the overall environmental performance of the LFP-based batteries worse compared to the listed battery chemistries.

Li-metal battery prototypes have higher specific power; their energy density can reach 300Wh/kg and even higher. However, they are considered to be applied at EVs. Moli Energy introduced Li-metal anodes in the 1980s, but due to instability, they were recalled from the market in 1991 (Buchmann, 2016). Peters, Baumann, Zimmermann, Braun, & Weil (2017) assume that new batteries (e.g. Li-S or Li-O2) will trade off cycle efficiency and low energy loss for higher energy density: due to the shift from intercalation (insertion of a molecule or ion into materials with layered structures) to chemical conversion. According to Hermes (2017), Fujitsu succeeded “through proprietary materials-design technology and the discovery of factors that improve the voltage of iron-based materials” to synthesize lithium iron pyrophosphat which may become a feasible alternative to cobalt-based materials, associated with high costs and social issues. The new material allows the increasing voltage of 3.8 V, compared to the materials with cobalt in content.

However, in his interview to ICM AG (2017), Christophe Pillot states that in the next decade the Li-Ion technology will remain dominant for rechargeable batteries in portable electronic products and EVs. Li-Sulfur, Li-Air, fuel cells and other developments will not reach the mass market during this period. Though, applying new chemistries for the production of more efficient and sustainable secondary batteries, the society should be aware of potential detriment to the environments (McManus, 2012).

3.2 Regulations and batteries. Existing requirements

This section covers existing requirements to batteries, established by the EU legislation which is a driver for the European ecolabelling programs, and is often reflected by the non-EU programs; and the environmental and social criteria for rechargeable batteries in portable ICT products, set mostly by Type I ecolabelling programmes (ISO 14024).

3.2.1 EU Battery Directive 2006/66/EC

The main objectives of the Directive are to assist in the protection of the environment and to ensure correct functioning of the unified EU markets. The Directive applies to all batteries and accumulators placed on the EU market, unless, as per Article 2.2 of the Directive, they are used in specific equipment (used to protect essential national security interests and equipment designed to be sent into space).

Considering the EoL stage, the Directive addresses the pollution of soils and water (the leachates that may occur at landfills), emissions of metals to the atmosphere (due to incineration of batteries), and recycling. For this, the Directive prohibits incineration and landfilling of industrial and automotive batteries, and makes collecting and recycling compulsory for all types of batteries, setting the collection targets and the minimum recycling efficiency. The Directive requires to label batteries if certain metals exceed the limit: 5 ppm for
mercury (Hg), 20 ppm for cadmium (Cd), and 40 ppm for lead (Pb). This ensures that these metals are not deliberately added to portable batteries. The EU Member States provide annual calculations of the portable batteries, which entered the market in a given year, and the collection rate. Each EU member submits an annual report to the Commission, which also explains how the data was received.

Being under revision (European Commission, 2016b), the Battery Directive is continuously aligned with the circular economy concept (Tomboy, 2016). The task is to minimise waste and to maintain material flows within the economy as long as possible, obtaining economical, social and environmental benefits. Of special interest is finding economic and strategic incentives for material recovery. It is also planned to consider such issues as 1) business models for collection and recycling of negative value waste streams; 2) recycling capacity; 3) recycling technologies for new chemistries; and 4) legal framework for reuse (the second life).

3.2.2 Battery labelling

For a long time, policy-makers have been considering banning of primary batteries with an intense promotion of rechargeable batteries instead (Turner & Nugent, 2015), and ecolabelling was supposed to help with this (Lindhqvist, 2010). Labels were also considered as a good and inexpensive tool to improve collection and recycling rates – to avoid the release of harmful substances in disposal facilities (Lindhqvist, 2010; Turner & Nugent, 2015). Nevertheless, the EU did not implement labels or codes for batteries (except a crossed-out wheelie bin). At the same time, the Battery Association of Japan established the chemistry-based colourful marking for rechargeable batteries, Figure 3-4 (Battery Association of Japan [BAJ], n.d.).

![Figure 3-4. Rechargeable battery recycle mark in Japan](Source: BAJ (n.d.))

In addition to the labels that would cover technical characteristics (e.g. specific energy (Wh/kg), specific power (W/kg)) and environmental aspects (crossed-out wheeled bin) of rechargeable batteries, the EU battery recycling industry considers other aspects to reflect with labels (RECHARGE, 2010):

- environmental performance parameters (Primary Energy demand, Carbon Footprint);
- safety criteria (protection and/or resistance against Short-Circuit);
- chemical content (colour coding to increase the waste battery recycling efficiency).

Based on the existing demand for battery labelling, the Advanced Rechargeable & Lithium Batteries Association reported on potential ecolabelling criteria – environmental, safety, and technical – for portable rechargeable batteries (RECHARGE, 2010). The safety and technical requirements are mostly covered by existing legislation – the Battery and WEEE Directives (e.g. establishing collection systems for batteries and WEEE; collection and recycling rates), UN Model Regulation (e.g. technical performance information, energy), IEC Std 62133. To apply ecolabelling to rechargeable batteries, RECHARGE (2010) suggested next parameters:

- information on battery material composition and recycled materials in it;
- optimisation of charge-discharge cycles to increase battery durability;
− improved self-discharge rate;
− available option for repairing and/or replacing a battery, access to a resale centre;
− colour marking to assist collection and recycling processes;
− information support through online services.

General labelling of batteries partially intersects with ecolabelling, and there is still the question on how to mark batteries – to assist customers and to incentivise recycling. In parallel, new evaluation schemes like Product Environmental Footprint Category Rules (PEFCR) appear (Siret et al., 2016), expanding existing labels from a single mark to an Environmental Product Declaration. Finally, labelling practice may require improvements. For instance, Umweltbundesamt (2013) in their test with 300 batteries revealed unsatisfied labelling practices based on the Battery Directive: whilst in many cases the amount of mercury (Hg) (for a half of the tested button cells), cadmium (Cd) (for a half of zinc-coal round cells), and lead (Pb) (for a half of batteries with excessive amount of Pb) exceeded threshold, there were no relevant labels on the batteries – as it is supposed to be in accordance with the Battery Directive.

3.3 Voluntary certification programmes and their requirements to rechargeable batteries in ICT products

This section contains the information on the requirements established for ICT products by voluntary certification programmes. Most of them represent Type I ecolabelling, however, there is also a programme which is out of the GEN network – the Electronic Product Environmental Assessment Tool (EPEAT). Appendix II contains the table with the comparison of requirements of all certification programmes; it is grouped into five categories: requirements to battery content; battery quality; product design; information; and other.

The research is focused on the ICT products. The author chose those ecolabelling programmes which have standards for mobile phones, tablets, laptops and notebook computers. The comparison covers the requirements which have direct or indirect relation to rechargeable batteries. Due to the difference in the operational capabilities and size of mobile phones and computers, there is no direct comparison between the batteries of both groups. The requirements, represented in the standards, are used to identify the aspects which are already implemented by the ecolabelling programmes. Of special interest was a background document to the standard for rechargeable batteries by Nordic Ecolabelling (2015b).

Initially, the author planned to focus exceptionally on the standards for mobile phones, laptops, notebook computers, and tablets. However, Boston Power, a battery manufacturer who supplies Asus, was certified in accordance with the Nordic Ecolabelling programme, and now its batteries carry the label (Dodd et al., 2015). Thus, the author took a decision to consider the criteria for rechargeable batteries for general use.

Type I ecolabelling (ISO 14024)

Ecolabelling became an important tool for establishing the modern environmental policy with its shift from the “command and control” approach to a pro-active behaviour. The concept of “green growth” to a high extent relies on sustainable public procurement that organically integrates ecolabelling as a tool in the system. Basically, ecolabelling “pulls out” producers and the market towards innovation, and, as the result, to the products with an improved environmental profile.
Ecolabelling incorporates a variety of labels. Within this research the author focuses on the standards from 14020 series regarding environmental labels and declarations that establish main principles for using three types of ecolabels, and in particular – on Type I ecolabelling:

- Type I ecolabelling (ISO 14024) is based on the life cycle consideration approach in accordance with ISO 14040 that establishes principles and framework for life cycle assessment. Certification is conducted by a third party that verifies whether a product or service is in compliance with the criteria established by this body;
- Type II ecolabelling (ISO 14021) establishes requirements for self-declared environmental claims (statements, symbols and graphics) regarding products. It describes the terms commonly used in environmental claims and gives qualifications for their use;
- Type III ecolabelling (ISO 14025), or EPD is mostly for “business-to-business” communication, but it is not limited to, and may be applied for delivering information to consumers. The use of the ISO 14040 series of standards is of special importance for the development of Type III environmental declarations.

Type I ecolabelling distinguishes products or services that achieved higher standards of environmental protection in comparison with those that established by law. The objective is twofold: first of all, to assist customers in their purchase choices, and secondly - to encourage producers to design and to market the products with better environmental profile. As a market-based tool, ecolabelling requires certain conditions, including but not limited to: a) the market that functions without obvious distortions (e.g. the absence of sufficient competition amongst producers), and b) certain – sufficient – percentage of market actors can fulfil the requirements established by an ecolabelling programme.

Main principles which characterise Type I ecolabelling include voluntary nature; involvement of the third party; compliance with environmental and other relevant legislation; the life cycle consideration approach; finally, selectivity: differentiation of environmentally preferable products, based on a measurable difference in the environmental impact considered as significant.

### 3.3.1 EU Ecolabel

The Commission Decision (EU) 2016/1371 on revised criteria for personal, notebook and tablet computers signalised about a new level of requirements to ICT products. A big focus is set on the restriction of hazardous substances; incentivising the design for disassembling; and provision of the customers with information.

Considering battery content, the criteria 2(a), 2(c) of the relevant standard establish restrictions based on the REACH and the CLP regulations, integrating the Candidate List of SVHCs. Certain derogation (the CLP regulation requirements) is present for Li-Ion and Li-poly batteries – in terms of applied cathode material, solvent, and salt.

The criterion 3(b) establishes the minimum battery lifetime and the quality based on the charging cycle performance. The former requires the battery to provide at least 7 hours of work after the first full charge; the latter regulates the residual energy capacity (80 percent of the initial) after 750 charging cycles for the “replaceable without tools” and after 1000 charging cycles for the “not replaceable without tools” batteries.
According to the same criterion, the producer shall provide at least 2 years of commercial guarantee for defective batteries whereas it includes energy charging problem but not the issue related to energy capacity decrease due to aging (unless there is specific guarantee provision).

With the aim to extend product lifespan and to simplify further recycling, a few requirements focus on product design: there shall be an option to replace or extract the rechargeable battery. Finally, a producer shall provide disassembly and repair instructions (criteria 3(d), 4(b)). As a part of user instruction, the customer receives information on rechargeable battery life-time extension, disassembly, and repair; the product EoL management (criteria 3(b), 6(a)).

### 3.3.2 Blue Angel

From computers, Blue Angel (2014;2017) segregates the notebook computers as portable devices which are of interest for this research. The standard for computers (Blue Angel, 2014) establishes general requirements for battery rechargeability, energy capacity, and states how to conduct life cycle test of batteries (section 3). The standard for computers and keyboards (Blue Angel, 2017) has a special section, devoted to notebook computers (section 4). Additional criterion on battery/accumulator durability requires from a battery minimum 500 charge cycles with the remaining energy capacity above 80 percent of the nominal.

Both standards state that the product design shall allow simplified disassembly to replace a battery. A producer shall provide spare parts (including batteries) for five years following the end of production. Product documents contain extended information on the battery operational characteristics, the EoL management, and instruction on disassembly.

Following the experience of the Battery Association of Japan (BAJ), Blue Angel (2017) established special requirements on marking. Such mark, except the information in compliance with EN 61960 (e.g. nominal capacity and voltage), shall indicate the metal with the greatest percentage in battery content and the substances which complicate recycling.

Blue Angel (2017) requires a producer to install computer software to keep track of battery quality: the “State of Health” based on the ratio of “full charge capacity” to “design capacity”; the “State of Charge” (SoC) and the number of charge cycles already performed. To extend the battery's lifespan, there shall be installed the software to limit charging to a value smaller than the maximum amount of usable electricity (e.g. 80 percent of the full charge capacity).

Blue Angel (2014) states that next revision will touch the requirements for battery energy capacity and for the life of batteries for portable computers.

In its standard for mobile phones, Blue Angel (2013) requires to provide the customer with the comprehensible SoC indicator and offers a test method for conducting life cycle test (section 3). Based on this test, the discharge time for the 150th battery cycle shall be minimum 3.5 hours, with the residual energy capacity – 90 percent of the nominal.

Other requirements are aimed to simplify battery extraction and replaceability, as well as further recycling. Operating instructions repeat the criterion from Blue Angel (2014; 2017). One criterion focuses on the battery safety based on existing legislation. In contrast with other ecolabelling programmes, Blue Angel does not establish any requirements for the chemicals in battery content, completely relying on the existing regulations, including the Battery Directive.

### 3.3.3 Nordic Ecolabelling

Nordic Ecolabelling (2016) incorporated social challenges, the environmental issues, and the EPR concept. The single criterion related to rechargeable batteries requires to equip a product
with the replaceable battery and to ensure availability of spare parts. During the next revision, the ecolabelling programme wants to focus on the requirements for batteries: the energy consumption, SVHCs, the environmental impact during the production phase.

**Standard for rechargeable batteries**

In contrast to the standard for computers, the set of criteria for batteries is much broader in the standard for rechargeable batteries (Nordic Ecolabelling, 2015a). The definition of rechargeable batteries is in accordance with the Battery Directive. The standard does not encompass permanently inbuilt batteries but, as an exception, it may be applied to battery chargers.

An applicant is supposed to present complete information on battery content. The standard establishes more stringent requirements on metals in content: for mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (As). If nanoparticles are used, the applicant must specify the increase in energy efficiency of the battery. A separate criterion establishes requirements on plastics in battery chargers.

The standard enforces an applicant to measure following battery operational characteristics: battery discharge; capacity; a cycle life; endurance. A variety of test with the required results is provided. Charger quality is verified through the test that is supposed to confirm that:

- the charger stops to charge the battery when it is fully charged;
- the limitation of the maximum trickle charge current;
- the limitation on the maximum no-load current.

Logically, there are no requirements on removability and upgradeability, since the standard does not cover the products equipped with the rechargeable batteries. The only design criterion is related to a battery charger for certain battery form-factors: “the charger must be suitable for use with a minimum of two battery sizes”.

Providing information, battery producer shall ensure that recyclers are aware of the nanoparticles in the content. Battery capacity is specified on a battery (mAh).

Finally, it is required from the producer to follow national regulations on packaging and battery collection, as well as to ensure that a Code of Conduct is in place - in accordance with the ten principles of the United Nations Global Compact.

Developing this standard, Nordic Ecolabelling (2015b) strived to ensure that only the best one-third of the batteries, present on the market, may receive the ecolabel.

**3.3.4 TCO Certified**

TCO Certified initiated the revision of the requirements for batteries in ICT products based on own criteria, represented in the standards for smartphones, tablets, and notebooks (TCO Certified 2015a; 2015b; 2015c). The standards have common requirements to batteries in portable electronics with a minor difference between smartphones and tablets/notebooks.

The limitation of hazardous substances is based on the Battery Directive: mercury (Hg), lead (Pb), and cadmium (Cd) (section A.6 for all standards). Additional criteria consider such specific hazardous substances as polybrominated biphenyls (PBB), polybrominated diphenyl ether (PBDE), and hexabromocyclododecane (HBCDD) in all components, including batteries.
The battery shall be rechargeable and replaceable. A producer shall provide spare parts for tablets and notebooks – for 3 years following the end of production. The availability of instructions for professionals on how to replace components.

### 3.3.5 Korea Eco-label

In both standards, for mobile phones and for notebook computers, Korea Eco-label (2012a; 2013) establishes restrictions on lead (Pb), mercury (Hg), and cadmium (Cd) in battery content, based on the Battery Directive. In addition, there is the criterion for mobile phones on nickel emission from product and its elements, including the battery pack.

The standard for mobile phones also sets the requirement on charging equipment: “The product shall have a structure in which the recharging equipment shall be used jointly with kindred model products with similar production time.” The criterion regarding product design requires the option when the battery can be extracted, and replaced. The customers shall be provided with the relevant product- and service-related information.

### Standard for rechargeable batteries

The standard Korea Eco-label (2012b) establishes requirements for the batteries used in the small household and office appliances. The criterion on the substances in content limits the amount of lead (Pb) – 40 mg/kg or less, cadmium (Cd) – 10 mg/kg or less, mercury (Hg) – 1 mg/kg or less. The Li-Ion battery capacity shall remain as 80 percent of the nominal after 400 charge cycles. No leakage shall occur. Other criteria include requirements to consumer information (the reason how the ecolabelled battery performs better in terms of environmental impact); the safety, quality, and performance – based on the national and industrial standards.

### 3.3.6 Green Choice Philippines

The ecolabelling programme limits lead (Pb), mercury (Hg), and cadmium (Cd) based on the Battery Directive; it also phases out the RoHS substances in accordance with the national legislation. The criterion on energy consumption does not repeat requirements of other programmes: “The energy consumption of portable computer power supplies shall be less than 0.75 W (watts) when plugged into a power outlet and disconnected from the computer.”

Other requirements focus on product design with the objective to extend its lifespan. A producer shall provide all spare parts and consumables for 5 years after the production has been terminated. The standard strives for modularity of product, setting the requirements to disassembly and replaceability; “The parts of the product shall be recyclable.”.

### 3.3.7 Japan Environment Association. Eco Mark

Eco Mark limits lead (Pb), mercury (Hg), and cadmium (Cd) in battery content, as well as hexavalent chromium, and specified brominated fire retardants (PBBs, PBDEs) – in accordance with the Japanese national standard. The criterion on energy consumption sets the standard energy consumption efficiency for battery-driven computers, based on their operational characteristics. The design criterion requires from batteries to be replaceable and removable (except the batteries mounted to the printed circuit boards): a special 7-stage scale is offered to classify the simplicity of battery extraction (e.g. “One-touch”, “Cutting”, and “Connector removing”).

The product-related information (including the content information) and the information on battery replacement shall be available through the website. The batteries are marked in accordance with the national legislation on the promotion of effective utilisation of resources.
3.3.8 Green Electronics Council

Green Electronics Council manages EPEAT, the environmental performance rating system for electronic products (PCs and displays, imaging equipment, televisions, mobile phones) (Electronic Product Environmental Assessment Tool [EPEAT], n.d.(a)). The EPEAT system applies the environmental criteria for mobile phones based on the standard by Underwriters Laboratories (UL) (2017); there is an on-going revision of the standard for PCs, including notebook computers (IEEE Standards Association [IEEE-SA], 2017).

The feature of the EPEAT system is its two-type criteria segregation – Required and Optional. Whilst all “Required” criteria shall be fulfilled for receiving a label, there is a grading system (Bronze-Silver-Gold) based on the compliance with the “Optional” requirements (EPEAT, n.d.(b)). The standard for mobile phones sets the mandatory restriction on heavy metals in a mobile phone battery: mercury (Hg) (less than 5 ppm) and cadmium (Cd) (less than 20 ppm).

The energy use requirements section consists of two mandatory and two optional criteria. The mandatory criteria demand the charging systems to work in compliance with the Federal Energy Conservation Standards, and the external power supply shall meet the efficiency requirements. Optional requirements include the decrease in energy consumption of charging systems and the reduced maintenance mode power.

The requirements for product design strive to make it “easy to disassemble”. The criteria segregation on “Required” and “Optional” is based on the simplicity of these operations – whether a customer needs to engage professionals and specific tools. The disassembly-related operations are supposed to be provided with the relevant instructions, another optional criterion requires to provide the instructions on the battery removability.

3.3.9 Summary

The comparison of existing requirements to rechargeable batteries in ICT products demonstrates the significance of this component in terms of environmental and social impacts. The Type I ecolabelling programmes make attempts to elaborate to enforce both product and battery redesign – either to simplify the EoL management or to decrease the hazardous potential of rechargeable batteries. Another interesting fact is that Type I ecolabelling programmes shifted attention from consumer batteries to rechargeable batteries in ICT products: just a few programmes offer standards for the former. The author grouped all requirements into five categories:

- “Content”: The requirements for battery content. Type I ecolabelling programmes stick to the existing limitation of mercury (Hg), cadmium (Cd), and lead (Pb), suggested by the Battery Directive. EU Ecolabel has already expanded the list of limited substances – based on the Candidate List of SVHCs, the RoHS Directive, and the REACH Regulation.
- “Quality”: The requirements for battery operational characteristics: energy density, a number of charge cycles.
- “Design”: The section comprises requirements for product design based on a few attributes: components removability and product upgradeability/reparability. These criteria encourage the producer to design the product that can be disassembled; the warranty, and information for professionals on how to repair a product.
- “Information”: The requirements for the information for users on how to use product and battery in the most efficient way. The consumer behaviour patterns may gradually influence battery performance, greatly extending or decreasing the use stage.
− “Other”. This section contains plans and insights, explicitly mentioned by Type I ecolabelling programmes in their standards. A few programs clearly stated what aspects of the rechargeable batteries it is scheduled to revise.

The summary of the compared standards is represented in Table 3-3. It is seen that ecolabelling programmes address the product design and to a lesser extent – the provision of users and specialists with the relevant information (evaluated as “High”). The situation with the requirements to battery content and especially – operational characteristics or “Battery quality” (evaluated either as “Low”, or no requirements at all – “red cross”).

**Table 3-3. The summary on the criteria comparison**

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<th>Source: The author</th>
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From the conducted analysis, it is seen that EU Ecolabel has the strongest requirements in terms of chemical substances in battery content. Nevertheless, it is reasonable to keep in mind that Type I ecolabelling is a very market-based tool which potentially positive impact to a high extent depends on a number of market players, able to fulfil its requirements: the list of licensees is empty (European Commission, n.d.). However, the author reached the EU Ecolabel office and received confirmation that there are a few licensees at the moment. Nevertheless, since EU Ecolabel updated the criteria relatively recently, there is not enough data on whether such requirements pay off. At the same time, EU Ecolabel utilises a powerful scientific background of numerous European research centres. Other ecolabelling
programmes are behind and often do not consider battery content at all; otherwise limiting either mercury (Hg), cadmium (Cd), and lead (Pb), or PBB, PBDE, and HBCDD (actually, only TCO Certified and Eco Mark do).

In contrast, more ecolabelling programmes established requirements for battery operational performance: EU Ecolabel, Blue Angel, Eco Mark, and EPEAT. Some basic requirements are also represented by TCO Certified, Green Choice Philippines, and Korea Eco-label.

Almost all programmes consider product design – whether it can be disassembled, repaired, and recycled. Within such requirements, the ecolabelling programmes often enforce a producer to ensure the availability of spare parts, the manuals on how to repair, and to provide additional slots for upgrades which would allow optimisation of the configuration. Roughly half of the programmes ask a producer to provide a customer with the information which may be divided into two categories: the information on the EoL handling and the information on how to extend the use phase of batteries due to appropriate usage (e.g. charging time, DoD).

Blue Angel and Nordic Ecolabelling set requirements for battery marking. Both ecolabelling programmes have also planned revision of current standards – with a focus on batteries. Their initial suggestions are presented in Appendix III.

Based on the comparison of the requirements, it is seen that battery performance has been somewhat neglected until now. Nevertheless, the ecolabelling programmes will try to use a direct interrelation between battery performance and its environmental impact. The battery performance receives especially more attention within the frame of the “circular economy”.

Criteria for rechargeable batteries as a separate product group

When it comes to the requirements for rechargeable batteries as a separate product group, so far only Nordic Ecolabelling and Korea Eco-label developed extensive criteria for them.

Nordic Ecolabelling focuses attention on the metals and nanoparticles in battery content, and on the plastics used in battery chargers. However, if there are exact values for mercury (Hg), cadmium (Cd), lead (Pb), and arsenic (As), the criterion on nanoparticles is supposed to aggregate the information and ensures that the safety measures are at the place. It is required to provide the information on the increase in battery efficiency due to the use of nanoparticles.

Extensive requirements for the quality of rechargeable batteries include battery discharge, energy capacity, a number of charge-discharge cycles, and endurance. The only design-oriented criterion covers chargers: it should be possible to charge at least two batteries at once. Battery producers are enforced to be in compliance with the local packaging and battery collection regulations. Finally, a set of aspects is specified for consideration during next revision.

The Korea Eco-label standard focuses on restriction of lead (Pb), cadmium (Cd), and mercury (Hg) in battery content and the requirement to the battery capacity.
4 Literature review and analysis

The secondary information sources reflect on a few important aspects of the rechargeable batteries: current technologies and the associated environmental and social impacts of the batteries during the entire life cycle, “cradle-to-grave”.

The word combinations used to find the relevant secondary information sources included: “Li-ion battery”, “lithium battery”, “life cycle assessment battery”. Conducting literature review, the author grouped the secondary information sources into following categories:

- “Batteries: Attributes and Content” – general information on batteries and their operational characteristics, applied technologies, advantages, and disadvantages; it also contains information on the core materials in battery content;
- “LCA and EIA” studies are of the largest interest since they demonstrate the impact of different battery technologies based on the life cycle consideration;
- “Ecolabelling” section comprises the standards of ecolabelling programs;
- “Recycling, material recovery, and reuse” includes literature which observes alternative options for the EoL management of rechargeable batteries;
- “Legislation and EPR” section covers information on the relevant EU Directives and regulations, and application of the EPR concept for waste batteries collection;
- “EVs”: whilst this sector represents the scaled-up application of Li-Ion batteries, nevertheless, the common technology may allow to take over certain research results and experience, and transfer them on rechargeable batteries in portable ICT devices;
- “Charging” aims to clarify nuances of the process which actually distinguishes the rechargeable from the primary batteries;
- “ICT” section consists of LCA studies on portable electronics: this may give image on how such studies consider rechargeable batteries in the ICT devices;
- finally, “Sustainability reports” accumulates the ICT industry leader reports on their environmental and social performance. More often companies adopt own high-scale and self-sustaining programs to produce goods in compliance with the widely adopted strategy of sustainable development: Apple with its leasing ‘Apple Upgrade Program’, aimed to close the material loops (Apple, 2017); and Lenovo’s approach to battery management, realized in ‘Lenovo Longevity Battery Technology’ (Lenovo, 2016).

Whilst most of the listed sections supplement the research, allowing to build an image on existing technologies and requirements to the secondary batteries, the LCA and EIA studies directly expose the most valuable aspects which possess the greatest potential to cause positive changes in terms of the environmental and social impacts of the rechargeable batteries.

Processing the LCA and EIA studies, the author made a decision to follow the life cycle stage order. It means that the information, obtained from the studies, is allocated in strict relation to the life cycle phases it touches; thereby, one study may be utilised for the purpose of a few sections (e.g. the use phase, the EoL management).

4.1 Life Cycle Assessment

This section contains LCA studies on rechargeable batteries and ICT products that are equipped with the batteries. The author also generalised the information on LCA studies conducted in the field – to demonstrate associated features and difficulties.
4.1.1 LCA of rechargeable batteries

This research aims to define the most crucial environmental aspects of rechargeable batteries – for the purpose of Type I ecolabelling that is based on the LC approach, and implies verification by multiple-criteria-based third party programme (ISO 14024).

The EU launched development of Product Environmental Footprint Category Rules (PEFCR), in particular for “high specific energy rechargeable batteries for mobile applications” (Siret et al., 2016). This is Type III ecolabelling, known as EPD (ISO 14025), however, it is of special interest for the research. Siret et al. (2016) also present an overview of the most crucial aspects throughout the rechargeable battery LC which are utilised for the purpose of this research.

PEFCR aims to harmonise and label based on complete LCAs, as well as to align existing Product Category Rules (PCR) (Andrae, 2016; Siret et al., 2016). Andrae, 2016 states that the PEFCR approach seems to be more reliable compared to earlier attempts to conduct LCA analysis for consumer electronic products, due to its “completeness”. The PEFCR allows to communicate LCA results for external comparisons (Andrae, 2016).

The PEFCR for rechargeable batteries was developed as a tool for communicating the environmental performance of secondary batteries: Siret et al. (2016) claim that the new evaluation system is especially of use for communicating the global warming effect of rechargeable batteries for mobile applications. Together with liquid crystal displays and printed wiring boards, batteries are the most significant sources of contribution to climate change (St-Laurent et al., 2012).

Peters et al. (2017) reviewing 79 studies on EIA of Li-Ion batteries, discovered that 36 studies provide sufficient results like exact environmental impact calculated per battery mass unit, or per Wh of specific energy. However, most of the studies use the same data sources, and only a few of them provide original data. Nevertheless, there is a variety of results due to different assumptions on the key operational characteristics of batteries (e.g. lifetime, energy capacity, or, for instance, energy consumption during the production phase of batteries).

Yu, Chen, Huang, Wang, & Wang (2014) claim that in the case with secondary batteries, pollution emissions and the environmental impact of such life cycle stages as production, recycling and disposal are of the primary interest for LCAs.

The lifespan of rechargeable batteries is significantly prolonged since they can be used repeatedly – due to numerous charging and discharging cycles. This results in potential resource savings and decreasing waste, especially if to compare with the primary batteries (Yu, Chen, et al., 2014).

So far the secondary batteries did not receive required attention – from the perspective of LCA (Yu, Chen, et al., 2014). Nevertheless, due to rapidly increasing stream of electronic products, assessment of environmental impact of rechargeable batteries, and facing the relevant sustainability challenges, come into focus. Due to their application in a wide range of portable devices, it is expected that the secondary batteries have potential to lead the battery industry, therefore it is crucial to find appropriate and reliable ways to assess the environmental and social impact the secondary batteries cause (Yu, Chen, et al., 2014).

At the same time, Peters et al., 2017, point out that existing LCAs on Li-Ion batteries often simplify battery operational characteristics in developed models, or completely disregard them (e.g. energy density, internal efficiency, cycle life). For instance, cycle life time, if considered, is
often taken as at a DoD of 80 percent: however, batteries are not discharged to SoC of 20 percent each time. Aging effect is another example: battery’s storage temperature may cause side chemical reactions which degrade a cell; and only a few LCA studies consider this effect.

These parameters play significant role in the environmental performance of batteries (McManus, M. C., 2012), and preferability of appearing battery technologies is often based on them (e.g. LFP-LTO based batteries have higher life cycle what makes them environmentally preferable) (Peters et al., 2017).

Peters et al. (2017) suggest that future LCA studies on Li-Ion batteries production shall “consider modelling energy demand during battery manufacturing”, as well as qualitative characteristics (e.g. internal battery efficiency, battery lifetime) more thoroughly. Of special attention should be cycle life assumptions – due to their significance for evaluation of the environmental performance during the entire life cycle. Nevertheless, on the average, current LCA studies adequately reflect the current state of technology.

Amarakoon, Smith, & Segal (2013) in their LCA study on application of high-energy density Li-Ion batter technologies in EVs, with a focus on a promising technology, aimed to enhance battery energy capacity – single-walled carbon nanotubes (SWCNTs); identified several ways to improve the environmental profile of Li-Ion batteries:

- Increase the lifetime of the battery: the sensitivity analysis showed that halving the lifetime of the battery greatly increases all kinds of impact for EV batteries;
- Reduce cobalt and nickel material use - due to their high toxicity (non-cancer and cancer impact potential);
- Reduce the percentage of metals by mass: metals are a key driver of environmental and toxicity impacts;
- Incorporate recovered material in the production of the battery: replacing virgin materials with recovered (especially metals) results in diminished environmental impact; requires collaboration of manufacturers and recyclers;
- Use a solvent-less process in battery manufacturing has lower energy use and lower potential to cause environmental and health impacts;
- Careful selection of active materials for cathodes: this may allow to significantly decrease the primary energy consumption for manufacturing process;
- Decrease the energy intensity of SWCNT production process.

4.1.2 Life Cycle Assessment of ICT products

The LC approach aims to methodologically investigate the entire life cycle of the products, offering a wide range of standardised approaches. However, despite the variability of the tool itself, there are certain challenges when it comes to the products under evaluation due to inconsistency in configurations. The LCA-based simulations, and then, as the result, assumptions should be carefully analysed (Andrae, 2016).

St-Laurent, Hedin, Honée, & Fröling (2012) created a LCA model to compare the difference in the environmental performance of the laptops certified by one of two voluntary certification programmes – TCO Certified and EPEAT. They discovered that both labels caused just a few changes in product design and minor influence on the environmental impact. It is explained by the fact that some requirements repeat widely adopted standards, for instance, on energy consumption or toxic substances in content. In contrast with the earlier studies, the production stage demonstrated higher environmental impact compared to the use stage (St-Laurent et al., 2012). St-Laurent et al. (2012) assume that due to short laptop life and
existing standards, the ecolabelling criteria on energy consumption do not play significant role. Based on numerous LCA studies for consumer electronic products, Andrae (2016) states for mobile phones: “it can be concluded that the use-stage electricity is currently a low contributor to mobile phone life-cycle impacts”.

The laptop life longevity is an increasingly important issue to deal with. Ecolabelling criteria should be constantly revised to actually guide toward a more environmentally friendly market segment for fast developing products like electronics (St-Laurent et al., 2012).

4.2 Li-Ion batteries aspects based on the life cycle consideration

Following the LC approach, the author considers the entire life cycle of the Li-Ion batteries, to allocate relevant aspects to each of the phases, from resource extraction, designing and production, and till the EoL management stage. The results, related to rechargeable batteries, were used as one of inputs to this research.

4.2.1 Resource extraction

Siret et al. (2016) consider raw material acquisition as the phase with the most significant environmental impact – higher than 60 percent, based on the ranking in accordance with ISO 14044. Main contributors are the anode and the cathode due to metals sulphates (e.g. cobalt sulphate), and electronic parts: chargers due to copper in content. According to Oliveira et al. (2015), together with the electricity used for manufacturing (mainly from coal), the raw material extraction causes the largest emissions of Particulate Matter (PM) (mainly bauxite, aluminum, and copper).

Whilst there is no shortage of lithium, mining of this natural resource can cause significant human health and social impacts: in particular, due to the lithium mining process, as well as the use of copper, and the impacts associated with copper mining (McManus, 2012). Nordic Ecolabelling (2015b) claims that the extraction and processing of raw materials demonstrates the highest energy consumption in the production process, and causes “the largest individual climate impact attributable to rechargeable batteries”. Oliveira et al. (2015) stress the importance of reaching more energy efficient processing.

4.2.2 Production

In this section the author considers LCA studies that cover production of both rechargeable batteries and consumer electronic products. The consideration of the latter is explained by the fact that researchers often pay some attention to rechargeable batteries as a component of a host device, thus, state how rechargeable batteries contribute to the overall impact.

Portable ICT production

St-Laurent et al., 2012, in their LCA on ecolabelled laptops, defined that the laptop production stage causes the greatest environmental impact (Andrae, 2016). Looking at the component level of notebooks, a battery is the main contributor to the environmental impact (metal depletion and the HTP) - straight after displays and mainboard (Dodd et al., 2015). The impact can be diminished either directly, by improving design and production techniques, or indirectly, by extending the use stage longevity or by reusing parts (Andrae, 2016).

In their research, St-Laurent et al. (2012) agrees that the production phase generates the largest social impact, thus, the environmental criteria for this phase could address both the social and environmental aspects. Based on the GWP100 results for a smartphone, it can be stated that the upstream processes, and exactly the production phase cause much more impact compared to the use phase (Andrae, 2016).
Battery production

Li-Ion batteries production has a significant impact for the human toxicity and freshwater ecotoxicity, to a large extent connected to waste management of plastic and other production waste (St-Laurent et al., 2012). At the same time, Siret et al. (2016) state that the production phase has a relevant significance (up to 36 percent in terms of e-mobility and eutrophication potential), less compared to the raw material extraction phase.

According to Dunn et al. (2015), the batteries with cobalt-based cathodes, and especially LCO-cathodes, are widely used in consumer electronic products. The research team from Argonne National Laboratory confirms that these cathodes are more energy- and emissions-intensive to produce. At the same time, the team admits that it is required less of high-capacity material for production of a cathode what results in their lower mass. However, these conclusions are based on public information in patents and journal articles – due to lack of publicly available data on the energy and materials consumption, thus, may be not precise.

Peters et al. (2017) observed that the model, chosen for calculation of the energy demand for battery production, has greater influence on the environmental performance of a Li-Ion battery, compared to the choice of chemistries. The models use two approaches: either the “top-down” approach that implies allocation of the gross energy demand of a facility according to economic value of the products; or the “bottom-up” approach that extrapolates energy demand of a plant on certain core processes in the technological line.

Peters et al. (2017), estimating the environmental impact of battery production, found out that average Cumulative Energy Demand (CED) and GHG emissions value are 328 kWh and 110 kg CO₂eq respectively, per 1 kWh of storage capacity.

Both research groups, Oliveira et al. (2015) and Liang et al. (2017) state that application of new technologies, including alteration of used chemistries, and improved energy profile of a battery production facility are the ways to reduce GHG emissions per kWh of stored energy. Also, they stress the importance of sourcing renewable energy for production purposes, however, it highly depends on the location where a production facility is.

Wang et al. (2017) claim: both the production and use phases are main contributors to the environmental impact of Li-Ion batteries. The production phase is associated with the most complicated processes throughout the entire life cycle of a Li-Ion battery. In their LCA study, Wang et al. (2017) stress the significance of cathode manufacturing as the main contributor to environmental impact of battery production (Figure 4-1):

- together with anode, and battery management system, cathode manufacturing causes the largest impact on metal depletion (lithium, nickel, manganese, aluminum, and copper). Production of these three components also results in significant TETP;
- L(R)NM-based cathode production requires up to 40 percent of total non-renewable energy, used for battery production;
- as the result, if energy mix is mostly represented by non-renewable energy sources, cathode becomes a major source of GHG emissions during its manufacturing;
- L(R)NM material production and cathode assembly account for 50 percent of the aquatic acidification and 47 percent of the terrestrial acid/nutria – due to usage of acid for dissolving ores and lithium extraction;
- because of a variable set of applied materials, cathode production accounts for the largest land use, required for production;
- cathode materials manufacturing accounts for the environmental impacts of 36 percent respiratory organics and 43 percent respiratory inorganics;
- the cathode process has the largest carcinogenic impact (because of the organics and metal ions in content), and has a 54 percent influence on the ozone layer depletion due to its complex process, which uses nitric acid and organic binder as raw materials.

**Li-rich battery production stage**

![Diagram showing Li-rich battery production stage]

**Figure 4-1. Damage segregation during the production stage of Li-rich battery**

*Source: Wang et al. (2017)*

Wang et al. (2017) assert that strict control over the cathode production may essentially reduce overall impact of Li-Ion batteries. Oliveira et al. (2015) state that the cathode production accounts for 36 percent of the overall climate change impact related to infrastructure; the cathode production and the plastic battery case account for 21 percent and 9 percent respectively of the overall energy intensity of production. The anode production is also an energy intense process: for complete graphitisation the synthetic graphite materials require 2,700 °C, and basic graphite – 1,100; such temperatures are achieved by using fossil fuels (Gaines et al., 2011; Dunn, Gaines, Barnes, & Sullivan, 2012).

Battery assembly and testing account for a half of used energy, and such materials like aluminum, copper, nickel, and plastics use up to one-third. The rest of materials are in small quantities in battery content, thus, consume much less energy, causing, respectively, less environmental impact (Gaines et al., 2011).

Utilising several studies, Nordic Ecolabelling (2015b) states that the production of rechargeable batteries is associated with both the most intense energy consumption, and the largest contribution to CO₂ eq emissions.

### 4.2.3 Design

Decades ago industrial ecology stressed the importance of closed systems where excessive outputs or by-products (waste) are used as an energy source or resource for another product. As the result, new resource management strategies were developed (Pawlowski, 2011):

- reducing the flow (“dematerialisation”) by introducing energy- and material-saving technologies;
- avoiding of material flow intensification due to better product quality and extended lifespan;
- looping material flows, either reusing, or recycling;
- flow substitution (“trans-materialisation”): replacement of hazardous substances with less harmful; usage of renewable raw materials instead of rare and non-renewable.

**Battery design**

Oliveira et al., 2015, considers the trans-materialisation as an important step towards cleaner production and the environmentally-friendly batteries. In terms of trans-materialisation, Oliveira et al., 2015, suggests to use more suitable non-toxic organic solvents to maximize recovery values, pre-managing the EoL stage on the earlier stages.

Kasulaitis, Babbit, Kahhat, Williams, & Ryen (2015) found that whilst the battery mass required per 1 Wh decreased by almost 50 percent (1999-2008), the mass per battery cell remained constant – the so-called “functional dematerialisation”. A producer strives to capitalise on technological improvements, increasing performance within the same form factor: technological improvements are being traded for increased functionality, following the user needs (Kasulaitis et al., 2015). If this trend is constant, it can not be asserted that dematerialisation inevitable causes decrease in energy consumption and material usage for consumer electronics (Kasulaitis et al., 2015).

Wang et al. (2017) consider substitution of cathode materials as an option to make Li-Ion batteries safer for the environment and human health: for instance, eliminate cobalt (e.g. NCM chemistry) applying, for instance, lithium-rich materials (e.g. L(R)NM). However, such substitutions should be carefully analysed beforehand: in comparison with NCM, the L(R)NM-based battery is a greater source of harm in terms of resource depletion and climate change, due to processing – calcination of mixtures of lithium carbonate and transition-metal precursors – at high temperatures (Gaines et al., 2011; Wang et al., 2017). Finally, Wang et al. (2017) forecast that lithium-rich cathodes without cobalt are a promising solution for the future Li-Ion battery market.

Oliveira et al. (2015) consider new electrode materials, renewable energy sources, and application of recyclable plastics as promising solutions to decrease the environmental impact of rechargeable batteries. Oliveira et al. (2015) see application of new materials as the way to reach higher specific energy and specific power, thus, to decrease the environmental impact of rechargeable batteries. New materials could also be applied for production of battery separators and casings.

Kang et al. (2013) stress the importance of the “Design for Environment” (DfE) strategies to make consumer electronic products safer – due to reduction of hazardous substances in their content. Wang et al. (2017) state that better battery dismantling options would allow to reach more efficient recycling, thus, diminishing the environmental impact of Li-Ion batteries.

Wesselmark & Sandberg (2017) accent that designing a battery, it is crucial to consider other system elements: the charger, a host appliance, as well as usage patterns.

**Product design**

Kasulaitis et al. (2015) explain that dematerialisation may be limited by product’s well-established and widely-adopted form factor (e.g. laptops). Further changes in the form factor are often caused by the need to increase functionality, meeting consumer’s expectations. This results in either increased (bigger smart phones) or decreased (removal of laptop optical drive)
material usage. Kasulaitis et al. (2015) suggest to focus on “translating enhanced functionality into extended product life, reduced power consumption, features that enable product recovery and recycling at end-of-life, and user-interfaces that lead the product-user to more sustainable behaviour.”

Lee & Stewart (2015) state that the screen, the processor, and radio are three typical energy drainers of a smartphone battery. Further improvements in processor and radio will probably greatly extend battery life longevity. However, no significant changes in displays which are often transmissive LCDs with a backlight. The decrease in the cost of lower-energy display technologies (for instance, Organic Light Emitting Diode (OLED)) may allow them to become dominant over other smartphone screens before 2020. On the 12th of September, 2017, Apple confirmed that a new iPhone X is equipped with an OLED display (Apple, n.d.; Hern, 2017).

And whilst processors become more energy efficient, producers constantly equip smartphones with even more powerful processors – to meet consumer’s requirements on product performance in terms of widely applied 3D graphics. At the same time, there is a constant decrease in energy used to send and receive data – by 30-40 percent each year: 4G technology allows to transmit information at a faster rate what means that the radio is used for a shorter period of time. Sending the same photo over 4G may take a quarter of the time it would take over 3G (Lee & Stewart, 2015).

Lee & Stewart (2015) stress that constant increase of a smartphone screen indirectly improves battery life: whilst a screen becomes larger in two dimensions and, but consuming more energy, this allows to increase battery volume, reaching higher energy capacity for one phone. For instance, the same model of a phone that has a 20 percent larger screen (with identical components except for display size and battery volume) may last up to 40 percent longer.

According to Qnovo Inc. (2015), unwanted degradation that may occur, for instance, during the fast charging, causes an increase in battery size. The swelling battery becomes a limiting factor in product design since producers leave more space for this.

**Safety design**

Except the constant risk profile of a battery that is based on the stochastic behaviour of the consumer (described in the 4.2.6 The use stage: the user perspective section), Wesselmark & Sandberg (2017) distinguish next root causes to energetic failure events:

- In the decreasing risk profile – the energy of the battery that is a significant driver for energetic failures, or a manufacturing fault: with time, the energy in the battery decreases, and there is less chances for a thermal runaway;
- In the increasing risk profile – the ageing effects in the battery or the build-up of internal short in the cell when the cell is cycled;
- In the bathtub profile – both a manufacturing fault and the ageing effects in the battery.

Wesselmark & Sandberg (2017) stress that cell selection based on the configuration, appropriate battery design and production are the ways to eliminate safety risks.

Nalesnik (2016) accentuates that the attractiveness of portable ICT products to high extent depends on capabilities and limitations of a rechargeable batteries, installed in them. Producers recognise the market need in very thin and light electronic devices, equipped with the battery that provides extended autonomy, faster charging, and improved battery lifespan. The annual
5 percent increase in energy density is achieved mostly due to denser packing of materials in a rechargeable battery (Qnovo Inc., 2015). According to Nalesnik (2016), in some cases, this results in compromises, and sacrificing safety.

Nalesnik (2016) refers to the U.S. Consumer Product Safety Commission: Li-Ion batteries are often the main causes recalls of laptops, smartphones, portable battery packs, and battery-powered speakers by major producers – due to risk of fire. Industries constantly look how to improve battery safety, what initiates improvements of protection circuits to more complex charging algorithms that are recognised as potential solution that does not require significant changes in battery technologies.

### Chargers. Protection circuit and charging algorithms.

**The case: Qnovo’s adapting charging algorithms**

Nordic Ecolabelling (2015b) confirms that the charger greatly affects the environmental performance of a rechargeable battery; and with a reference to Blue Angel, Nordic Ecolabelling (2015b) states that this ecolabelling programme established a criterion on chargers, and focuses on energy consumption at the end of charging. At the same time, reaching greater number of charge cycles requires heavy investments in the battery technology development. Thereby, many producers prefer to focus on firmware that limits charging to, for instance, 80 percent of battery capacity (Dodd et al., 2015).

Numerous manufacturers provide integrated circuit (IC) chips in single-wire and two-wire systems, also known as System Management Bus (SMBus) which was defined by Intel and Duracell in 1994 - for personal computers, to become a widely applied protocol for battery management (Buchmann, 2016; Wesselmark & Sandberg, 2017). The Intelligent Battery, or Smart Battery is a battery with Battery Management System (BMS). This system constantly monitors the actual status of voltages, currents and temperatures within the battery, and SoC; in case of extreme conditions, BMS indicates this and alarms (Wesselmark & Sandberg, 2017).

One of the ways to improve the charging profile is to program a charger to respond on inputs from a battery. If the charger works in compliance with an agreed message protocol, it is possible to build universal chargers which can automatically adapt the charging profile to a variety of rechargeable batteries, based on their chemistries capacities (Wesselmark & Sandberg, 2017).

According to Qnovo Inc. (2015), the battery charging approach, applied in many cases, has been in use for over a century – Constant-current, constant voltage (CCCV). CCCV recognises two phases in the charging:

- the “CC phase”: the first phase, characterised by application of a constant direct current (DC) to the battery. The battery’s voltage at its terminals increases until it reaches maximum allowable voltage (due to safety reasons);
- the “CV phase”: the second phase, when a charging electronics initiate application of constant voltage, and the charging current fades until the battery is completely charged. At this point the charging current may be neglected.

Figure 4-2 reflects a typical CCCV-based safety mechanism of a battery, showing the power path “from the wall socket to the battery” (Nalesnik, 2016). It can be distinguished three main stages of “defence” (Nalesnik, 2016):

- Stage 1: the AC adapter isolates the secondary output from the AC input and provides output voltage, current regulation, and protection – even in extreme circumstances;
- Stage 2: The power management integrated circuits (PMIC) on the mobile device regulates the voltage and current to the battery, including charging and fuel gauge functionality;
- Stage 3: finally, the protection circuit module (PCM), which provides under- and over-current/voltage and short-circuit protection.

![Basic scheme of the CCCV based protection circuit](source: Nalesnik (2016))

However, according to Qnovo Inc. (2015), CCCV is very non-flexible: it does not consider any degradation processes that occurs in a battery, as well as varying operation conditions (e.g. temperature, age). Instead, due to its straightforward character, it only enhances any present damage and accelerates capacity loss, and the fast charging causes lithium metal plating: lithium ions gather around anode instead of making their way inside. Other degradation processes include 1) the growth of thin protective layer on anode that consumes lithium ions; 2) the grains of electrodes may pulverise due to mechanical stress; and 3) the integrity of electrolyte may be damaged.

Qnovo (2015) is one of the companies who develop adaptive charging technologies which allow to optimise the charging process. Adjusting charge rate, based on the current battery charge and its condition, it is literally possible to increase battery capacity because it fades slower, and extend battery cycle life. This is achieved due to precise, fast, and energy-efficient diagnostics of a battery in real-time. Such diagnostics include, for instance, measurement of “an effective diffusion time” of lithium ions on their way between electrodes; and check-up of chemical processes in a battery (Electrochemical Impedance Spectroscopy (EIS)).

![The mechanism of Qnovo's algorithms](source: Qnovo Inc. (2015))
Whilst improved algorithms to a certain degree also rely on “pulse charging”, they, for instance, may use “a sequence of short charging pulses in relation to received diagnostic results”. Qnovo Inc. (2015) demonstrate on the example with fast charging how energy capacity greatly diminishes in case with application of CCCV, and how Qnovo's adapting charging algorithms may extend battery lifetime without capacity retention. These algorithms also imply “predictive analytics tools” that are able to predict the future state-of-health and the progression of degradation in a battery. Qnovo Inc. (2017) claims that their adaptive charging software resulted in doubled battery lifespan in over 10 million smartphones.

Tesla’s Supercharger is a great example of the 3rd generation chargers. The battery charge rate is adapted based on the current condition of a battery pack (changes due age and usage), SoC, how often a Supercharger with the increased charging speed is used, and battery temperature (Tesla, n.d.). Also a Supercharger considers the distance to be covered and respectively charge the battery; finally, the charging rate slows down when SoC increases (Tesla, n.d.).

### 4.2.4 Battery content

#### Chemical profile: Heavy metals

McManus (2012) states that the lithium based batteries are associated with an impact on human toxicity. Nordic Ecolabelling (2015b) accentuates the importance of focusing on constituent substances in battery content due to limited resources and the environmental impact, caused by resource extraction. Also, certain metals in battery content may cause serious damage to human health:

- mercury (Hg) – very hazardous to the environment, and health: accumulates in the body; volatile;
- cadmium (Cd) – hazardous to the environment, and health: accumulates in the body (the kidneys); may be carcinogenic, mutagenic or toxic for reproduction;
- lead (Pb) – hazardous to the environment, and health: toxic for reproduction; negatively affects the nervous system;
- arsenic (As) – classified as toxic (R23/R25) and hazardous to the environment (R50/53). May be present in rechargeable batteries.

The complete elimination of these metals may be problematic due to related improvements in battery performance; but their content may be limited to some extent (Nordic Ecolabelling, 2015b). For instance, cobalt has the carcinogenic potential, and it causes risks for the environment and human health; thereby, Wang et al. (2017) suggest L(R)NM – lithium-rich – materials as a good substitution for cobalt.

Examining around 300 batteries, taken from stores, Umweltbundesamt (2013) discovered that Li-Ion batteries were in compliance with the Battery Directive, having much less heavy metals in content than it is allowed. In overall, together with alkaline manganese batteries, they had the lowest content of heavy metals.

Conducting research on three types of Li-Ion batteries and metallic content in them (Table 4-2), Kang et al. (2013) discovered that next metals are present in high quantities:

- aluminum (ranging from 51 800 to 341 000 mg/kg);
- cobalt (58000 to 278000 mg/kg);
- copper (54100 to 152000 mg/kg);
- and lithium (9800 to 37200 mg/kg).
In overall, these four metals represent up to 97 percent of all metals in Li-Ion battery content: lithium and cobalt are used for the production of cathodes; copper and aluminum – as current conductors (Kang et al., 2013). Also, there are barium, chromium, silver, thallium, vanadium, zinc, and lead, but their content amount is significantly lower. The analysis did not detect antimony, arsenic, beryllium, cadmium, mercury, molybdenum, and selenium in any of the analysed Li-Ion batteries (Kang et al., 2013).

Kang et al. (2013) applied the Toxicity Characteristics Leaching Procedure (TCLP) to determine the metal content in discarded Li-Ion batteries. In two of the eight Li-Ion batteries, the amount of lead exceeded the allowable limit 5 mg/l: 6.71 mg/l and 33.10 mg/l. It may be assumed that for some other batteries lead content could exceed the threshold, but since there is a low content of Zn and Fe which influence the mobility of lead (Pb), it did not happen (Tables 4-2 and 4-3).

Table 4-1. Metallic leachates from Li-Ion batteries, based on the TCLP

<table>
<thead>
<tr>
<th>TCLP threshold</th>
<th>Li-Ion-1</th>
<th>Li-Ion-2</th>
<th>Li-Ion-3</th>
<th>Li-Ion-4</th>
<th>Li-Ion-5</th>
<th>Li-Ion-6</th>
<th>Li-Ion-7</th>
<th>Li-Ion-8</th>
</tr>
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<tr>
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<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>barium</td>
<td>100.00</td>
<td>0.13</td>
<td>0.21</td>
<td>0.25</td>
<td>0.11</td>
<td>0.38</td>
<td>0.20</td>
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<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
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<td>ND</td>
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<td>ND</td>
</tr>
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<td>0.06</td>
<td>0.11</td>
<td>33.10</td>
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<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>selenium</td>
<td>1.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>silver</td>
<td>5.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Source: Kang et al. (2013)

Table 4-2. Metallic leachates from Li-poly and smartphone batteries, based on the TCLP

<table>
<thead>
<tr>
<th>TCLP threshold</th>
<th>Li-poly-1</th>
<th>Li-poly-2</th>
<th>Li-poly-3</th>
<th>Li-poly-4</th>
<th>Smart-1</th>
<th>Smart-2</th>
<th>Smart-3</th>
<th>Smart-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>arsenic</td>
<td>5.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>barium</td>
<td>100.00</td>
<td>0.32</td>
<td>0.24</td>
<td>0.22</td>
<td>0.29</td>
<td>1.38</td>
<td>0.21</td>
<td>1.50</td>
</tr>
<tr>
<td>cadmium</td>
<td>1.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>chromium</td>
<td>5.00</td>
<td>ND</td>
<td>ND</td>
<td>0.07</td>
<td>0.08</td>
<td>0.08</td>
<td>ND</td>
<td>0.12</td>
</tr>
<tr>
<td>lead</td>
<td>5.00</td>
<td>ND</td>
<td>ND</td>
<td>0.07</td>
<td>0.10</td>
<td>ND</td>
<td>ND</td>
<td>0.05</td>
</tr>
<tr>
<td>mercury</td>
<td>0.2</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>selenium</td>
<td>1.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>silver</td>
<td>5.00</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Source: Kang et al. (2013)

Applying a variety of assessment methods, Kang et al. (2013) estimated the risks for the environment and human health, associated with metals in Li-Ion batteries content. Cobalt, copper, nickel, thallium, and silver cause the most significant impact in terms of the environment (the ecotoxicity potential and resource depletion in particular) and human toxicity. There is not enough data to estimate the contribution of aluminum and lithium to human toxicity and ecotoxicity. The list of methods, applied by Kang et al. (2013), included:
CML 2001 and EPS 2000 – abiotic resource depletion potentials; TLV, PEL, REL, and TPI – hazard-based human toxicity; CML and TRACI – human toxicity potential (HTP), freshwater ecotoxicity and terrestrial ecotoxicity potentials (TETPs) from emission to air, water and soil.

According to Kang et al. (2013), the results of assessment methods demonstrated:

- for all applied methods, cobalt, copper, and nickel contributed most to the total hazard potential;
- except only three methods, where cobalt accounted for moderate hazard potential contribution, it is often a main contributor to the total hazard potential;
- copper demonstrated a mostly large to medium relative contribution to the total potential across all methods; exception – a minimal contribution for the HTP from emission to water (the CML method);
- nickel is not the main contributor to any of the listed categories; however, it is a nontrivial contributor to the total potential for all methods: from minimal to medium (the total HTP for the TRACI method), but across all methods.

Based on the simulated landfill situation when Co, Cu, Ni, and Pb would leach out in the amounts that exceed allowable concentrations, Kang et al. (2013) demonstrate that this will negatively impact both the environment and human health. Especially in those regions that did not establish well-functioning waste collection, sorting, and recycling infrastructure.

Unterreiner, Jülch, & Reith (2016) claim that whilst Li-Ion batteries have the lowest ecological impact, compared to lead-acid and vanadium redox flow batteries, its environmental profile can be improved by over 20 percent. The authors state that some materials in battery content are “highly influential”, and the environmental impact is predominantly caused by them. In Li-Ion batteries this is gallium: it has a higher share of the environmental impact relative to its share in the battery’s content. The environmental impact could be reduced thanks to either its reduce, or substitution with other materials.

**Chemical profile: Nanomaterials**

Based on the claims that nanomaterials, applied in the production of electrodes, may greatly improve the energy density of Li-Ion batteries, Nordic Ecolabelling (2015b) permits their usage but the applicant shall prove the increase in energy density. However, Amarakoon et al. (2013) accentuate that despite progress in research on and development of SWCNTs and other nanomaterials, aimed to greatly expand the horizon of Li-Ion battery energy, the energy intensity of SWCNT manufacturing process itself is too high, and usually diminish the value of achieved improvement due to associated costs. In parallel, the studies on “using nanoscale cathode and anode materials” conducted.

**4.2.5 Transportation and distribution**

Siret et al. (2016) assert that the transportation phase in the case with secondary batteries does not cause significant environmental impact, thus, can be neglected. Based on relevant reports, Nordic Ecolabelling (2015b) concluded that even despite the fact that most batteries, in-built into laptops and smartphones, are transported from Asia to Europe, the significance of the energy used during transportation is not crucial.
4.2.6 The use stage: Producer perspective

**Operational characteristics**

Searching for advanced technologies, battery producers are in constant attempts to reach higher specific energy (longer runtimes) and improve specific power (high-current load). However, improvement of one attribute does not necessarily result in enhancement of another attribute, and there is constant need to compromise between (Buchmann, 2016).

Specific energy characterises how much energy a battery can hold (Wh/kg); specific power is the amount of energy a battery delivers per time unit (W/kg) (Buchmann, 2016). Discussing batteries, specific energy is usually mentioned as one of the main attributes that tells “how much energy a given weight can generate”.

Oliveira et al. (2015) state that the use stage environmental impact score may be expressed as “a direct function of the efficiency multiplied by the baseline contribution of producing 1 kWh”. Thereby, a low number of charge cycles and significant decrease in energy capacity are responsible for the impact during the use phase.

Similar to pharmaceutical products, any change in one attribute of battery results in side effects for other, thus, limiting market acceptance. To characterise battery as an energy storage product, the concept of the octagon battery uses eight main attributes (Buchmann, 2016): 1) high specific energy; 2) high specific power; 3) fast charging; 4) long life; 5) safe usage; 6) affordable price; 7) wide operating range; and 8) low toxicity. In addition, with age and temperature, the self-discharge increases, causing the capacity loss even if it is not used. Thereby, a battery must have low-discharge and an instant start when needed. Finally, the higher specific energy of Li-Ion batteries, the more they are reactive and unstable.

**Energy density**

Rechargeable batteries with high energy density ensure a long and optimal lifespan, resulting in the environmental and economic benefits for users, since the replacement frequency would be decreased (Nordic Ecolabelling, 2015b).

Based on GWP calculation, Wang et al. (2017) highlight that despite discrepancy between conducted LCA studies on Li-Ion batteries, the promotion of increased energy density constantly results in decrease of the environmental impact of Li-Ion batteries. Furthermore, due low energy density it is required more battery mass to provide the same energy supply, causing additional energy consumption and losses, and more frequent charging.

The research group, led by Jeff Dahn, has conducted research on “unwanted parasitic reactions” that cause degradation of a battery, and reduce its lifetime. Elimination of these reactions would result in a greatly prolonged of Li-Ion battery lifetime, allowing them to last for decades without fading energy density (ICM AG, 2017).

Peters et al. (2017) states that the energy density of Li-Ion batteries depends on:

- the capacity of active material;
- the amount of other inactive components (e.g. electrolyte).

According to Peters et al. (2017), energy density may be greatly reduced due to losses and internal inefficiencies, as well as deep discharge (when DoD drops below 80 percent, and more). This attribute greatly varies between different chemistries – for instance, weaker LFP, and more high-energy LCO, NCM, and NCA.
Peters et al. (2017) stresses that greater energy density is one of the main goals of battery producers, and “does not need to be more relevant than improving battery lifetime or charge-discharge efficiencies from an environmental point of view”.

In their LCA research on environmental impact of rechargeable batteries, Yu, Chen, et al. (2014) confirm that batteries with higher energy density and improved lifespan have less environmental impact. Thereby, the authors state that the improvements of these two attributes should be encouraged, especially on the legislative level.

**Charge and discharge cycles**

There is a strong connection between the number of charge-discharge cycles and energy consumption, as the result, shorter cycles cause uncertainty of energy consumption during the use phase, thus, generating greater impact on the Li-Ion battery. The improved cycle performance is the way to reduce the environmental impact (Yu, Chen, et al., 2014).

According to Yu, Wang, et al. (2014), commercial Li-Ion batteries allow to reach over 1,000 charge-discharge cycles. Increased number of cycles allow to increase battery energy capacity due to slower capacity retention, and, thus, fewer materials are required. The higher specific discharge capacity (mAh/g) of the cathode active material results in a lower amount of used materials for cathode production.

Based on the conducted LCA, Yu, Chen, et al. (2014) suggest to consider the figure of 200 charge-discharge cycles during the use phase as the standardised, thus, the allowable minimum for the rechargeable batteries. The figure of 300-500 cycles is recognised by the battery specialists as the current minimum for Li-Ion batteries; considering the concept of the Green Battery, the International Telecommunication Union recommended to adopt 500 cycles as the allowable minimum for a long lasting battery (Dodd et al., 2015).

However, leading notebook manufacturers (Acer, Dell, Asus, HP, and Toshiba) offer notebooks with 800-1,000 cycle batteries that can work without charging for 7-8 hours and even more. Following the demand for disassemble-ready design, it is suggested to require higher number of charge cycles from the batteries which can not be easily extracted and replaced (Dodd et al., 2015).

Whilst reaching 1000 charge cycles with the 80 percent retention (Apple with its MacBook Pro and Air models) may be up to 80 percent more expensive compared to the batteries with 300-500 cycles performance (Dodd et al., 2015), there is a strong connection between the Depth of Discharge (DoD) and the number of charge-discharge cycles of a Li-Ion battery (Buchmann, 2016; Peters et al., 2017). Table 4-1 demonstrates that if not to discharge the battery more than 50 percent, it is possible to triple the battery life cycle longevity.

**Table 4-1. Battery cycle life as a function of DoD**

<table>
<thead>
<tr>
<th>Depth of Discharge, percent</th>
<th>Discharge cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>300 - 500</td>
</tr>
<tr>
<td>50</td>
<td>1,200 - 1,500</td>
</tr>
<tr>
<td>25</td>
<td>2,000 - 2,500</td>
</tr>
<tr>
<td>10</td>
<td>3,750 - 4,700</td>
</tr>
</tbody>
</table>

*Source: Buchmann (2016)*
Such companies like Toshiba, Apple, and Asus provide their products with software that is a part of batteries’ firmware: it limits the charging to 80 percent of battery capacity what makes the battery life cycle twice as longer (Dodd et al., 2015).

**Battery efficiency**

Improvements in battery electro-chemical performance would allow to reduce GHG emissions, caused by greater number of charge-discharge cycles during the use phase (Liang et al., 2017). To improve electrochemical performance, and, thereby, improve the environmental profile of Li-Ion batteries, Yu, Wang, et al. (2014) suggest:

- to strive for optimisation of the synthesis processes — to ensure smaller size (diameter) of material particles;
- to adopt other surface-coating agents;
- to conduct substitution of energy-efficient for energy-intensive instruments;
- to improve the synthesis processes, eliminating the most electricity-intensive steps.

**Product design**

The product design that allows to repair and replace broken components (including rechargeable batteries), as well as to upgrade the notebook or tablet, becomes one of the defining factors in terms of product life cycle extension (Dodd et al., 2015). Assessing key environmental issues and defining areas of improvement, Dodd et al. (2015) reconsidered the production and EoL phases, and suggested a) to prolong battery’s life time; b) to make batteries removable; and c) to provide users with the relevant instruction.

St-Laurent et al. (2012) consider laptop upgradeability as a viable option to extend its life cycle. In this case, the producer should ensure that upgrades are affordable and easy to do. Furthermore, computer components, including rechargeable batteries, should be easily replaceable.

Another common reason to replace a computer is its inability to function with modern computer software. It is stated that computer software design practices and marketing strategies have worsened the issue of WEEE (St-Laurent et al., 2012). According to Brownlee & Swan (2017), modern software consumes considerably more energy. It is possible to use machine learning to estimate energy use of the particular lines of code. As the result, the search-based methods for improving energy efficiency may be incorporated at the earliest stage of program development, reducing the computer central processor energy use up to 70 percent for specific tasks. The Linux operating system is famous for its optimisation for various computer configurations (St-Laurent et al., 2012); Google Inc. has focused on the OS optimisations, preventing applications from excessive energy consumption (Dent, 2017).

**4.2.7 The use stage: User perspective**

A significant amount of the environmental impact originates from the production stage of portable ICT devices, thus, longer intervals between replacement of devices are one of the approaches to decrease their annual environmental impact (St-Laurent et al., 2012). LCAs and Technical Analysis confirmed that the extension of the lifetime longevity of computers is very promising (Dodd et al., 2015). The lifetime of the battery is a limiting factor to the overall lifetime of notebooks and tablets (Dodd et al., 2015).

Yu, Chen, et al. (2014) explain that the short-lasting use stage of batteries results in higher environmental impact. The unsteady use conditions shorten the battery lifespan; the improved cycle performance may greatly decrease the environmental impact (Yu, Chen, et al., 2014).
The performance of the charger and a host appliance influence the environmental impact of rechargeable batteries (RECHARGE, 2010). Oliveira et al. (2015) narrow down this to the use stage: “The use stage is mostly dependent on the application that the battery systems are directed to”. Energy requirements of consumer electronic products (energy efficiency; power management; power supplies; user instructions) are the battery-related aspects recognised by Type I ecolabelling programmes as the area for improvements (Dodd et al., 2015).

Dodd et al. (2015) state that based on the feedback from some manufacturers, users are not that interested in the overall longevity of battery life cycle, but more like in the number of hours they can work without charging.

Energy mix and consumption

Oliveira et al. (2015) assumes that there is a strong connection between the Li-Ion battery efficiency, used energy mixes to charge it, and the environmental performance. When renewable energy becomes a significant part of an energy mix, the relevance of the use stage decreases, and the EoL stage becomes of higher concern.

Andrae (2016) explains that the overall efficiency of a mobile phone is around 65 percent due to three conversion inefficiencies: 1) charger losses, 2) conversion from/to USB connector voltage to battery voltage, and 3) battery charging cycle loss. 1.5 times more electricity is needed than what is the capacity of the battery. Depending on the product type, the typical operational electricity, required by a phone, is around 2–6 kWh per year.

Wang et al. (2017) confirm that “electricity mix and structure have a large influence on the environmental impacts of use”. The more national energy grid is based on non-renewable energy sources, the more the battery use phase contributes to the overall impact of a battery, reaching 90 percent of GWP (Wang et al., 2017). For instance, if to replace 10 percent of the coal-fired power in China with wind power or hydropower, the environmental impacts of battery use decrease by 7.9 and 8.2 percent, respectively (Wang et al., 2017). Thereby, it is vital to launch policies, aimed to encourage modernisation of national electricity mix structures and to support development of renewable energy sources. Oliveira et al. (2015) demonstrates how energy mix affects the environmental performance of a battery (Figure 4-3).

In their research, Liang et al. (2017) reference to a study that states: battery efficiency and the energy mixes used to charge it strongly influence its entire environmental performance. Nordic Ecolabelling (2015b) confirms that the energy, used for recharging, is a serious
contributor to CO$_2$ emission profile of rechargeable batteries. Siret et al. (2016) in the PEFCR for rechargeable batteries state that the use phase is defined by “energy losses due to battery and charger efficiency over battery life time”, and “country specific energy mix”. The maximal contribution of the use phase in the environmental impact is around 25 percent, based on the ISO 14044 ranking system.

Finally, Andrae (2016) demonstrates that if the production of all parts for a mobile phone shifted from fossil-based electricity to renewable energy, the potential avoidance of GHG emissions would reach 45 kg CO$_2$eq per a smartphone for two years.

**Information for clients: Changing behaviour/gaps**

Battery design is not the only one factor that defines the battery life cycle longevity. (Buchmann, 2016). The unsteady use conditions (adverse temperature, fast charging, and harsh discharge conditions) stress the battery, significantly shortening the use phase and charge-discharge cycles (Yu, Chen, et al., 2014).

Wide adoption of newer technologies (for instance, 4G) allows to reach faster transmission rates, decreasing energy consumption. But it also affects consumer behaviour who starts to send photos more often, or even videos instead (Lee & Stewart, 2015). Since the number of cellular network stations constantly grow, the distances between towers and the phone become shorter. This results in decrease of the energy consumed by the radio for transmitting data. Transmit power also decreases due to access to public Wi-Fi routers: constant usage of Wi-Fi allows to extend battery life, compared to the mobile network. Buchmann (2016) stresses that Li-Ion batteries should be stored at partial charge (approximately 50 percent SoC) in a cool place; the worst possible combination is the temperature oscillation and high voltage.

According to Wesselmark & Sandberg (2017) the stochastic behaviour of a consumer is recognised as the root cause in the constant risk profile of a battery. This means, that despite the initial risk of a thermal runaway when battery energy content is high, or ageing effect that starts to appear the closer the battery is to its EoL stage, the way of how a consumer handles the battery defines possible negative consequences during the entire life cycle of the battery.

Nordic Ecolabelling (2015b) states that it is crucial to provide users with the information on the environmental impact (e.g. climate change) of electronic products.

**Warranty**

It is stressed that extended guarantees or warranties are considered by users as producer’s confidence in product quality; this motivates consumers to strive for longer lifetimes. Whilst many producers provide warranties for notebook batteries from 6 months (Acer, LG) to 1 year (Asus, Fujitsu, Lenovo, Toshiba), some of them do not (HP) (Dodd et al., 2015).

### 4.2.8 End-of-Life Management

The significant attention is devoted to recycling and material recovery from waste rechargeable batteries. This approach corresponds with the EU waste management strategy and prioritised measures – the waste management hierarchy. The author considers as important to elaborate more on the natural resources, used as key inputs in the battery production. This, to some extent, defines the EoL management, as well as has an influence on battery design. This section also covers recycling techniques and the associated environmental impact.
According to Chancerel et al. (2016), it was reported that 72,000 t of portable waste batteries have been separately collected in the EEA area plus Switzerland in 2011. However, the identified complementary flows are estimated as 150,000-540,000 t of waste batteries in 2012.

**Reflections on key materials, used in battery production**

Keeping in mind trends in the battery production sector, described in the 3rd Chapter, it is important to stress that the Li-Ion battery technology is dependent on the materials, often sourced from a single or a narrow circle of areas:

- graphite. A crucial material for production of anodes. Around 65 percent is supplied by China, and associated with poor environmental protection practices and labour conditions (Lambert, 2016a);
- cobalt. The material, used for production of cathodes for Li-Ion batteries. Roughly a half of it is sourced from the Democratic Republic of Congo (Lambert, 2016a; Macpherson et al., 2016). The amount of cobalt, used in the battery production, will continuously grow, reaching 55 percent of the world supply in 2019 (Lambert, 2016a);
- lithium. Around 75 percent of lithium comes from so-called “Lithium Triangle”: Argentina, Chile, and Bolivia (Lambert, 2016a);
- nickel. Indonesia banned exports of nickel, and this caused the 50 percent increase of cost on the market (Lambert, 2016a).

**Cobalt**

Li-Ion battery producers compete for cobalt with the industries which heavily rely on this resource (e.g. military industry), and, thereby, are ready for significant expenses. In some cases, cobalt accounts for 60 percent of battery total cost, thus, battery producers already face difficulties with its supply. However, there is clear trend to decrease cobalt in battery content, thus, alternative incentives will be required to make the recycling of Li-Ion batteries profitable (Gaines et al., 2011). At the same time, with a reference to the Financial Times, Hermes (2017) states that the price on cobalt has doubled due to the pressure on buyers: they are forced to search for ethically sourced cobalt; the geopolitical changes can shift the scale to a much worse availability scenario as cobalt is not evenly distributed. Finally, cobalt remains as one of the most energy-intensive materials in the supply chain (Gaines & Dunn, 2015).

Chancerel et al. (2016) expect that the total content of embedded cobalt in waste laptop and tablet batteries will keep increasing until 2020, reaching 1,500 t (predominantly NMC and LCO chemistries). At the same time, there is a clear trend in the battery technology: a shift from the cobalt-rich LCO to Li-NMC chemistry. The amount of cobalt embedded in the batteries placed on the market in the European Union increased until 2013 - with 2,000 t per year, and then rapidly decreased in the following years, down to 1,000 t of cobalt. Since 2013 the NMC-based batteries prevail over LCO in laptops and tablets.

Pehlken, Albach, & Vogt (2017) modelled different scenarios for the consumption of cobalt and lithium. Taking into account currently known reserves, and based on the dominant scenario, the cumulative demand of the battery technology for these two materials will be 74–248 percent of the lithium reserves and 50 percent of the cobalt reserves by 2050. To high extent, the EV industry will shape the demand for both materials.

**Lithium**

Lithium supplies should be sufficient but cobalt and nickel are critical materials, and their supply could be strained, as well as copper and other (semi-) precious metals, used in the battery electronics (Gaines & Dunn, 2015; Oliveira et al., 2015; Peters & Weil, 2016).
However, Peters & Weil (2016) suggest to separating BMS from batteries in further assessments of resource depletion.

McManus (2012) confirms that some authors consider lithium as a scarce natural resource, claiming it as one of the main limiting factors for future battery production. However, lithium can be hardly named as a major obstacle for further growth of Li-ion battery production: its cost is roughly 2 percent of a battery pack. Despite apparent abundance of lithium, the battery industry, as the main consumer of this resource, caused an increase in the price: from 7 USD per kg to almost 25 USD per kg on the spot market at the beginning of 2016 (ICM AG, 2017).

The global lithium reserve is estimated as 39 Mt, and it is expected that demand will not exceed 20 Mt by 2100 (McManus, 2012). Gaines & Dunn (2015) envision the cumulative Li demand for smaller batteries to 2050 as 2.8 Mt; this figure decreases to 2 Mt if recycling takes place. According to Oliveira et al. (2015), the amount of lithium, required for the production of 1 kWh battery capacity, is approximately 200 grams – for the current design of Li-ion batteries in EV models. Further progress may allow reaching 160 grams per 1 kWh.

Lithium often ends up in the slag which is applied in the concrete production. If regulations or price incentive are adequately applied, lithium recovery by using a hydrometallurgical process may be justified (Gaines et al., 2011). Oliveira et al. (2015) state that the majority of studies forecast high-scale recycling to decrease the environmental impact from the extraction and production of virgin lithium. The recycling may become the largest source of lithium in the second part of the 21st century.

**Recycling and material recovery: Technologies**

Gaines et al. (2011) explain that recovery even of a single material from a multi-component product allows considering the process as recycling. The same if recovered materials are degraded – “down-cycling”. Nowadays recyclers focused on the portable electronic products, facing a diverse waste battery stream that often contains harmful substances. The shift to EV batteries is expected in the nearest future: automotive batteries will accelerate new recycling techniques, oriented on higher efficiency and obtaining high-grade recovered materials, making the recycling easier due to their size, amount, and less diverse battery chemistries (Gaines et al., 2011). Such measures as labels and bar codes, standardisation, and development of recycling-oriented design will further simplify recycling.

Gaines et al. (2011) stress that the possibility to recycle Li-ion batteries is broadly discussed, and at that moment only three companies provided enough information on how they do this: Umicore, Toxco Technologies (USA), and OnTo in a partnership with RSR (both from the USA). It is possible to recover high-grade materials from waste batteries, however, the input stream should be uniform; the recovered materials sometimes will require additional purification if to be used in the battery production again (Gaines et al., 2011).

According to Gaines et al. (2011), Umicore recycles Li-ion batteries in two stages. At first, they are melted without any pre-processing; Umicore considers this as recovery since the heat is used for powering a smelter, and the carbon is used as a reducing agent for processing metals. The output is cobalt and nickel which are sent to the second stage: the materials are refined, and the CoCl₂ is produced (Olen, Belgium). The latter is sent to South Korea to manufacture LiCoO₂ which together with virgin lithium is used for battery production. Umicore states that they reach 93 percent recovery rate for Li-ion batteries (metals 69 percent, carbon 10 percent, plastics 15 percent); not all materials are of high quality. Cobalt and nickel recovery results in energy savings (up to 70 percent) and decrease of SO₂ emissions during the production phase (Gaines et al., 2011; Dunn et al., 2012).
Toxco Technologies received a grant from the U.S. Department of Energy for recycling Li-Ion batteries in 2009. They demonstrated the Li-Ion battery recycling technology on the Tesla Roadster battery pack. The applied recycling technique implies mainly mechanical and chemical processes, so emissions are kept to a minimum. Since high-temperature processes are not used, it also allows decreasing energy consumption. As the result, about 60 percent of the battery pack materials are recycled, and 10 percent can be re-used. The 25 percent of content is presented with fluff which is landfilled; the plastic recovery will be financially viable if the amount of collected fluff increases (Gaines et al., 2011).

Other two companies, OnTo and RSR cooperated with Vehicle Recycling Partnership to demonstrate the possibility to build a new Li-Ion battery from recycled Li-Ion batteries, using the same active-material structures with minimal treatment. Applying the Eco-Bat process, they succeeded to recycle 80 percent of materials to useful products. The results were great for both cobalt and phosphate cathodes: the obtained cobalt had a much lower price compared to the market price, and the overall life cycle of the battery built with using of recovered materials was excellent (Gaines et al., 2011). They also used low-temperature processes, significantly decreasing energy consumption (Dunn et al., 2012).

Battery recycling techniques are based on three main processes: mechanical, pyrometallurgical and hydrometallurgical which are often combined to increase efficiency. The hydrometallurgical process often includes the mechanical pre-treatment (Boyden et al., 2016).

Table 4-4. Recycling processes and recovered materials

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Pyrometallurgical</th>
<th>Hydrometallurgical</th>
<th>Physical</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Materials recovered</td>
<td>Co, Ni, Cu (Li and Al to slag)</td>
<td>Metals or salts, Li₂CO₃ or LiOH</td>
<td>Cathode, anode, electrolyte, metals</td>
</tr>
<tr>
<td>Feed requirements</td>
<td>None</td>
<td>Separation desirable</td>
<td>Single chemistry required</td>
</tr>
<tr>
<td>Comments</td>
<td>New chemistries yield reduced product value</td>
<td>New chemistries yield reduced product value</td>
<td>Recovers potentially high-value materials</td>
</tr>
</tbody>
</table>

Source: Gaines & Dunn (2015)

The CRM and metal markets actors assert that more efficient recovery of CRM, REE, and valuable metals could be achieved due to manual pre-treatment and complete removal the components with further processing to recover materials (Dodd et al., 2015). They also stress that despite the Battery Directive and the requirements on collection rates, the recovery rate of Li-Ion batteries remains very low, around 5 percent in 2012-2013 years (Dodd et al., 2015). Recyclers tend to recycle the waste batteries with a high content of cobalt, nickel, and copper (Boyden et al., 2016). According to Umicore, the prerequisites for successful recycling include: 1) technical recyclability as basic requirement; 2) product design; 3) economic viability; 4) comprehensive collection; 5) transparency of real flows; 6) use of the best performing recycling infrastructure; 7) technical-organisational setup of chain (Tomboy, 2016)

Recycling and material recovery: Environmental impact

The rapid growth of the Li-Ion battery market, especially due to the shift to the EV fleet, accelerates finding the respective measures to reach adequate recycling efficiency and rates.
This can be achieved either by policies or by technology improvement what in its turn allows to reduce associated costs (Oliveira et al., 2015). Yu, Chen, et al. (2014) stress that implementing regulations, decision-makers should distinguish the difference in the EoL management for each kind of batteries; separate collection of waste batteries from household garbage positively affects the overall environmental performance of batteries (Nordic Ecolabelling, 2015b). Kang et al. (2013) claim that regulatory policies should strive to support recycling of portable rechargeable batteries and to incentivise adoption of DfE strategies – the reduction of harmful chemicals in consumer electronic products.

Applying the Eco-indicator 99 method to analyse the environmental impact of the EoL management policy for rechargeable batteries, they discovered that the incineration of Ni-MH batteries has a greater environmental impact compared to Li-ion batteries. Higher recycling rate causes a greater decrease of the Eco-indicator points for both battery types, being more obvious for Li-ion batteries, and is clearly observed when the recycle rate reaches 40–50 percent (Yu, Chen, et al., 2014). The conclusion is that battery recycling is very promising for decreasing the environmental impact of rechargeable batteries.

The recycling of Li-Ion batteries also causes the environmental impact, but Boyden et al. (2016) stress that it is beneficial for the environment, mostly due to the saving of virgin raw materials and prevention of their extraction. Oliveira et al. (2015) confirm that benefits from recycling (in particular due to the extraction of manganese, copper and low alloy steel) prevail the environmental impact caused by the recycling processes. Yu, Chen, et al. (2014) consider that the recycling of Li-ion batteries may result in higher efficiency and lower environmental loads if to carefully select the EoL treatment policies. Due to the significant impact of mining, McManus (2012) considers that recycling and material recovery “must be adopted”.

Observing how recycling affects primary production, Gaines et al. (2011) found that the recycling of aluminum, nickel, steel, and copper may result in 50 percent energy saving: from 25 percent for steel to 75 percent for aluminum and nickel. In the study, Gaines et al. (2011) received a 30 percent decrease in energy consumption for the recycling scenario; the larger percentage of high-grade materials in the output would increase this figure. Additionally, the decrease in SO\textsubscript{2} emissions from primary metal processing. The recycling makes the EoL stage one of the weakest contributors to the environmental impact. The cobalt sulphate (Siret et al., 2016), or cobalt (Dodd et al., 2015) is a significant contributor at this stage.

Table 4-5. LC energy consumption for primary and secondary material production

<table>
<thead>
<tr>
<th></th>
<th>Primary production (million Btu/ton)</th>
<th>Secondary production (million Btu/ton)</th>
<th>Reduction (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrought aluminum</td>
<td>157.3</td>
<td>40.7</td>
<td>-74.1</td>
</tr>
<tr>
<td>Cast aluminum</td>
<td>132.9</td>
<td>39.0</td>
<td>-70.7</td>
</tr>
<tr>
<td>Nickel</td>
<td>124.7</td>
<td>31.2</td>
<td>-75.0</td>
</tr>
<tr>
<td>Steel</td>
<td>38.6</td>
<td>29.1</td>
<td>-24.6</td>
</tr>
<tr>
<td>Copper</td>
<td>94.2</td>
<td>34.3</td>
<td>-63.6</td>
</tr>
</tbody>
</table>

*Source: Gaines et al. (2011)*

The recycling of Li-Ion batteries results in 51.3 percent natural resource savings when compared to landfill, as well as in decrease of energy consumption and in diminishing of
GHG emissions. Landfilling remains as of the lowest priority, causing a greater impact based on the HTP and TETP (Boyden et al., 2016).

Conducting LCA on recycling and material recovery, Boyden et al. (2016) concluded that the pyrometallurgical process is the most flexible in terms of input, but the number of recovered materials is the lowest. The output from the hydrometallurgical process completely depends on the battery type, but a larger number of materials may be extracted: according to Oliveira et al. (2015), it allows to reach 100 percent recovery efficiency for lithium and cobalt, 75 percent for iron and steel, and 94 percent for the remaining nonferrous materials. Both techniques were also estimated in terms of the environmental and health impact. The highest impact during the pyrometallurgical process occurs due to plastics incineration – for global warming potential (GWP), and electricity generation – for HTP and TETP. The hydrometallurgical process causes the most significant impacts in case of landfilling – for GWP and TETP, and due to electricity generation – for HTP (Boyden et al., 2016).

Finally, waste Li-Ion batteries transportation also causes significant impact, for instance, increasing GWP by 45 percent for pyrometallurgical processes, and HTP by 550 percent for hydrometallurgical processes in case of transportation from Australia to Europe (Boyden et al., 2016). Thereby, Boyden et al. (2016) conclude that to decrease the environmental impact of the recycling of Li-Ion batteries it is necessary: 1) to apply the low-temperature processes; 2) to recover plastics; and 3) to optimise routes, decreasing the distances between collection and recycling points.

The LCA for laptops certified by TCO Certified and EPEAT showed that HTP of the laptops labelled by TCO Certified was lower (20 percent compared to 10 respectively) – due to a higher percentage of recycling when the requirements are met (St-Laurent et al., 2012).

Li et al. (2013) demonstrate how to recover almost 100 percent of lithium and over 90 percent of cobalt, applying leaching in citric or malic acids. The authors confirm: the recovery of cobalt from waste Li-Ion batteries is more energy efficient and generates less GHGs than the production of virgin cobalt. Because the production of cobalt-rich cathodes requires more energy and causes more GHG emissions, Dunn et al. (2015) assume that cobalt recovery from waste batteries may be a “valuable technique” – in comparison to processing virgin cobalt.

Nordic Ecolabelling (2015b) recognise the importance of reusing scarce resources and saving energy, however, application of recovered metal is limited: the battery production requires materials without impurities. Wang et al. (2017) explain that the active materials in Li-Ion batteries are usually in the form of powder, and this makes recycling more complex, compared to other commercial batteries. Dunn et al. (2012) find interesting the fact that not all recovered materials from battery recycling are attributed to battery’s LCA: this is explained by open-loop recycling – when recovered materials end up in the production of other products.
5 Primary data. Views of experts and stakeholders

This section contains primary data, received from various stakeholder groups through interviews. The views, presented here, are supposed to help to create better understanding of their needs and the market itself.

After initial feedback on potential questions, the author separated and developed a compilation of questions for each stakeholder group: CE producers, battery producers, recyclers, certification programmes. Though, there was a necessity to adjust questionnaire sample for each stakeholder individually, based on the received information. The examples of questions are presented in Annex II.

5.1 European Battery Recycling Association, EBRA (EU)

An interview with Mr. Alain Vassart on 27 July 2017. General Secretary, European Battery Recycling Association (EBRA).

The author presents quintessence of the interview which is of use for this research. The presented sample was verified by Mr. Alain Vassart.

EBRA represents the companies whose main activities are battery sorting and recycling, but not collection. The market distinguishes three main battery types: automotive, or Starting-Lighting-Igniting (SLI) batteries, industrial batteries, and consumer portable batteries (rechargeable and non-rechargeable), but EBRA members are focused on the latter two.

Legislation

Comments on The Battery Directive

Whilst the Battery Directive sets collection targets for batteries – 25 percent in 2012, 45 percent in 2016, there is also another target – specifically for recyclers: recycling efficiency which is supposed to be 50 percent by average weight - for consumer portable batteries. However, the Directive is not very precise regarding segregation based on applied materials, and reaching exact recycling rates for each chemistry individually. Energy recovery is not counted in the recycling efficiency calculation.

Due to expenses and negative net income, the recyclers try not to achieve higher recycling efficiency, sticking to 50 percent threshold. Battery manufacturers and the actors who place batteries on the market pay for recycling. They are not interested to invest more than it is necessary for reaching higher recycling efficiency.

Since the batteries are often recycled together with WEEE, and there is no exact data on amount of the batteries in WEEE, it is unknown whether the 50 percent of recycling efficiency is achieved. Again, the rules for calculating recycling efficiency are not well-defined.

The Battery Directive is under review now. The first draft is expected not earlier than in 2020. The recycling efficiency may be changed, as well as the rules for calculating it - requires clarification. Some stakeholders push for increase of recycling efficiency. The Battery Directive will not enforce battery redesign, though just imposing recycling duties.

A big question is regarding how every EU Member State can reach the collection targets. At the same time, the EC may divide and change the collection rates for rechargeable and non-rechargeable batteries. The collection rate for the non-rechargeable is already very high, thereby, the collection target for the rechargeable batteries may also be increased.
The new version of the Battery Directive must - in a certain way - be flexible enough to allow innovations in the market. And innovations and changes already in the market. For instance, electrification of a car fleet in Norway, and many other countries.

Comments on the Regulation on calculation of recycling efficiency

This regulation is the first step in the right direction for establishing the rules for calculating recycling efficiency. However, there two large issues:

1) the recyclers have to report on the recycling efficiency to the Government Competent Authority of the country where they function. The reporting process has started in 2016. As the result, there is not enough data, and, thus, evidence. Moreover, they tend to keep confidentiality, and not to share the data on recycling efficiency;

2) current calculation approach is basically the establishing of the recycling balance between input and output for batteries. Recyclers often produce an alloy of various metals - cobalt, iron, nickel - output of the recycling which goes to the second refining step where another recycler can extract these materials. Thereby, in calculations it is crucial to consider what is happening during the second stage of recycling. Very often, primary recycles use “secondary” recyclers but do not correctly collect data from the latter, creating information distortion. It is necessary to decide when the fraction coming from the recycler can be considered as fully recycled, thus, being counted for recycling efficiency.

Comments on the Eco-Design Directive

Batteries are not regulated by the Eco-Design Directive. As the result, battery producers are focused exceptionally on operational characteristics – mostly on energy density and charging time which are dictated by a consumer’s need. Such aspect as, for instance, adaptation for more efficient recycling is out of priority. Thereby, it is difficult to influence battery producers in terms of battery redesign for better recycling.

Comments on the WEEE Directive

Whilst the WEEE Directive implies extraction of batteries from WEEE, for further handling in accordance with the Battery Directive, the situation on the market is different: very often the battery is kept within WEEE, thus, being recycled together with WEEE. One of the reasons is that producers of CE products create such design when it is not feasible to remove a battery, especially without breakage of the former. For instance, Apple products.

Comments on the Regulation on Conflict Minerals

So far cobalt is not covered by the Regulation on Conflict Minerals. That is why the issue with socially unsustainable cobalt (child labour) from the Democratic Republic of Congo is not really of concern of battery manufacturer today. The decrease of cobalt in battery content is mainly caused by its expensiveness what makes Li-Ion batteries too pricey. If battery producers can achieve the same low charging time and high energy density per kg of a battery by using less cobalt and, of course, more nickel, manganese, or other substitutes - they will go for it. And that is happening now.

If to compare a smartphone battery 10 years ago and today - there is clear difference in amount of cobalt in battery content. Both consumer portable and EV batteries, based on the
Li-Ion technology, contain less and less cobalt. Since cobalt is too valuable, battery producers search for alternative chemical compounds for cathodes.

**Certification programmes**

EBRA develops own certification programme for recyclers: to unify approaches on measuring the recycling efficiency, avoiding discrepancy in calculated results. WEEELABEX develops a standard for recycling WEEE, differentiating WEEE categories. RECHARGE develops a new PEFCR standard for rechargeable batteries.

**Labelling and sorting**

According to Mr. Vassart, Japan does not use colour labelling anymore. First of all, marketing agents do not like that they have less space for own labels. Another point is that today the sorting procedure is highly efficient - up to 98 percent - even without colour labelling.

In Europe some companies still apply hand sorting. The automatic sorting is either done by magnetic spectrum recognition, because each kind of battery has different magnetic response - when you let them to go through magnetic field. Or the X-Ray based approach. Today recyclers do not request more than 98 percent sorting efficiency.

Colour coding might be applied in the EU, but because of the safety reason: to simplify distinction between lead-based and Li-ion based industrial batteries - to avoid the situation when Li-Ion batteries are melted by recyclers.

Mr. Vassart's personal point of view: today, because recyclers do not receive so many Li-Ion batteries back from the market, recyclers like Umicore process all kinds of lithium batteries. Due to changes in applied technologies, in 10 to 20 years from now there will be more different kinds of Li-Ion batteries in large quantity. It is possible that recyclers will specialise on certain cathode chemistries. If to mix everything, it will be difficult to achieve sufficient recycling efficiency. There might appear sub-sorting of Li-Ion batteries based on applied chemistries.

And then maybe the colour coding of the lithium batteries, but only of the lithium batteries - could be of interest. Because overall structure of Li-Ion batteries despite the cathode chemistry is the same. So if to use magnetic field or X-Ray detection – it is really difficult, with the technology we have today, to make sub-sorting. But maybe in the future it will be necessary to do this. Due to uncertainties, even EBRA has no clear position on this yet. EBRA needs more information on what innovation is going to happen in the upcoming years.

**Collection**

Collection systems in the EU imply non-separate collection of batteries: a mix of everything, including alkaline, NiMH, and Li-Ion batteries. Consumers experience difficulties, recognising different kinds of batteries, either Li-Ion, or alkaline and NiMH.

In each EU Member State there is at least one battery collection system that issues tenders - to find recyclers for each kind of batteries, giving a preference to those with the lowest cost. It results in a very competitive market, since the European recycling capacity is more than sufficient. Thus, no one amongst recyclers works on full capacity. However, roughly a half of the EU Member States achieved the collection targets, and it means that there is still enough batteries to load recycling facilities. Battery collection still can be improved, however, not from the side of battery producers.
**Collected batteries fractions**

So far major amount of the waste battery mix is non-rechargeable batteries, and only a minority is represented by rechargeable. One of the reasons is the consumer’s behaviour pattern: they tend to keep either rechargeable batteries, or waste CE products with the rechargeable batteries (literally, WEEE) at home, since such batteries despite decreased energy capacity are still functional. So-called “hoarding effect”.

However, today the market is being constantly and predominantly filled with rechargeable batteries – due to rapidly increased usage of various electronic items (smartphones, laptops, electric tools etc.). At the same time, the rechargeable batteries, collected today were placed on the market approximately 10 years ago, and represent roughly 10 percent of the battery mix. In future it is expected that the proportion of waste secondary batteries will significantly increase, however, it is necessary to keep a “10 year period” in mind.

A good example with EVs: the batteries are still “on the roads”, and they may be expected to be recycled in approximately 10 years, or even later - if at the End-of-Life stage they will be utilised for the purpose of energy storage systems.

**Recycling**

Unlike the automotive batteries - due to a high content of lead, as well as straightforward and cheap recycling process that often results in positive net income, the revenues from recycling of consumer portable batteries usually do not cover expenses, thus, causing overall negative cost. Exception – the batteries with high content of cobalt.

Recycling consists of the first stage - mechanical, and then received fractions are sent either for hydrometallurgical, or for pyrometallurgical process. Recycling processes are always devoted to particular battery chemistry, thereby, there are no universal recycling process. As an exemption, a recycler can recycle two or three types of batteries, however, usually they are specialised on one type. There are many WEEE recyclers in Europe, many more than battery recyclers. Today Li-Ion recyclers do not enlarge their recycling capacity. They will do this, however, due to the “hoarding effect” – much later.

There is less than 5 percent of lithium in Li-Ion battery content, and the lithium is not really recycled. So far, BATs of battery recycling do not allow to recover materials without significant degradation.

**Main barriers for recyclers**

First of all, recyclers are not able to cover expenses of battery recycling by the revenue generated from recovered materials. Battery manufacturer or the company that place the batteries on the market have to contribute. This is a part of EPR. To increase the recycling efficiency, for example, the recyclers should be paid more due to the increased costs. Thus, a consumer will pay more for the batteries because the cost of the EoL management will be incorporated in battery price. Are the consumers ready to pay more?

Secondly, recyclers often do not know enough about innovations and application of new cathode chemistries. Battery producers tend not to share information because of commercial secret.

**Umicore: the case**

Being the largest recycler on the market, this corporation also does not invest into new recycling capacity.
Umicore recycles certain types of batteries, based on chemistry - with a focus on nickel and cobalt. Umicore recovers cobalt in Belgium, and transfers it to Korea - for producing new cathodes. However, the amount of recovered cobalt is not sufficient to cover production need, so the company definitely uses pure cobalt as well.

Umicore is almost the only one actor to recycle with further recovery of lithium. Using best available technologies, Umicore recovers lithium, however, it is too degraded to be used again in production of new batteries.

5.2 Call2Recycle, Inc. Battery collection and recycling system (USA)
An interview with Mr. Carl E. Smith on 15 August 2017. CEO/President, Call2Recycle, Inc., (USA).

Functioning on the market over 20 years, Call2Recycle, Inc. became a leading non-profit, product stewardship organisation in North America (USA and Canada) that operates a household battery recycling program. The organisation partnered with many other companies, offering solutions on battery collection and recycling.

Comments on recycling and material recovery, barriers, and financial means
In the US, recycling generally is not mandated by governments. Private organizations, both profit and non-profit, have created a quilt of programs that provide various solutions to the public. For our program, stewards fund it entirely because they feel a perceived market demand that they participate in the end-of-life disposal of their products. Until this year, our funding was entirely derived from 300 battery and product manufacturers who felt they needed to contribute to the end-of-life disposal of the batteries they put into the marketplace. But most of these payments are.

In this business environment, we define our success by continuously increasing our collections year over year. We also constantly measure: 1) the accessibility of our collection network; and 2) the awareness of our program.

The main barriers include:

- First, there are no U.S. processors of the fastest growing rechargeable chemistry: Lithium-ion. And, particularly for that chemistry, there are increasing rules and regulations surrounding their safe handling and transport.
- Second, rechargeable batteries are almost always sold with or in products. Capturing these batteries – which involves separating them from their “host” products – has increasingly made it difficult to recycle them.

At the beginning of this year, we instituted a fee-based collection service to supplement our free program. We now charge private sites (closed to public drop-off of batteries) to collect, sort and process their batteries. Already this constitute 20 percent of our total revenue.

Comments on recycling process
There is virtually no jurisdiction in North America on recycling efficiency, thus, the EU Battery Directive is used as a guide. Reporting recycling efficiency, processors does not follow any broadly accepted methodology for computing it. It always has to be independently audited and calculated, to confirm that a processor meets our minimum performance guidelines. Moreover, one major lithium ion processor located in Canada refuses to disclose their recycling efficiency.
Finally, Li-Ion battery processing efficiencies are very elusive depending on the type of Li-Ion chemistry involved. LFP, for instance, has significantly different recycling characteristics than cobalt based Li-Ion chemistries. Regarding recovered materials: lead, cadmium and cobalt are typically sold by secondary processors to suppliers who support battery manufacturers. The nickel is typically used for the steel industry and is not generally fed back to battery manufacturers. Obviously, the lead, cadmium and cobalt must be refined to ensure it is usable by these manufacturers.

**Comments on legislation and possible changes**

The U.S. Congress has generally avoided all waste issues (not just batteries) and most environmental issues. Waste and waste management policy has generally been left to the states to manage. While some states may consider EPR legislation for batteries, we don’t see any significant adoption over the next five years. EPR, in general, has lost momentum in the U.S. for a variety of reasons. For better or for worse, its adoption has mostly been seen as a way to financially support municipal governments who have been stress from increased mandates to collect and dispose of material. Policy positions such as zero waste and product stewardship have not generally resonated amongst policymakers in most state governments.

**Comments on recycling companies and their expectations**

In the US, companies generally don’t place these types of expectations on the recycling market with one exception. Lead smelters adamantly seek to avoid accidentally handling lithium-based batteries because of the tremendous damage it does to their processes. They have lobbied for legislation and other changes (e.g., make the whole batteries orange) so that this never occurs. Processors have also been concerned about safety issues, particularly the need to properly protect certain secondary chemistries when packed and shipped.

Manufacturers have strenuously opposed labelling in the US. They generally believe that they’ve been too subject to labelling requirements which, in many ways, are almost impossible to successfully implement. Fundamentally, battery manufacturers are primarily motivated by their success in selling product. Generally speaking, they believe that marking up the batteries gets in the way of the sale message that they are seeking to communicate to potential customers. They also believe that colour coating infringes on their ability to brand their batteries. Try to convince Duracell, owner of the “copper top” battery, that its batteries should be orange to better convey its chemical properties to the person who sorts (but does not buy) its batteries for recycling.

We look at processors based on their performance in three areas: 1) environmental performance; 2) recycling efficiency; and 3) costs/proceeds of their processes. We also seek proper documentation to support all three. We are vastly less concerned about the processes by which they maximize these three areas. We thoroughly assess a processor’s environmental performance as part of a broader evaluation of its capabilities. The assessment of the “environmental performance” includes: 1) verification of permits; 2) investigation on any previous environmental violations; 3) available certifications (e.g., ISO 14001); 4) validation of their downstream markets; 5) a third-party audit; data check-up from CHWMG, which is a worldwide clearinghouse of environmental data of processors which has been independently verified.

The difference in the US is that there is generally less environmental information available than in Europe, mostly because it hasn’t been mandated by government. A great example of this is the notion of recycling efficiency (RE); the EU has created a standard and the methodology to measure performance against the standard. We cannot get some processors to even tell us what they think their RE is. They claim it to be proprietary information.
In addition, we always ensure that we have at least two qualified and approved processors for each chemistry we collect and handle. Often times, this requires us to ship batteries overseas. But we never want to rely on a single organization to handle our batteries.

**Society**

Addressing the society, Call2Recycle has done some very detailed work on who recycles and why. It was discovered that Call2Recycle must appeal to someone’s value system to get them to recycle. The core message: “We know you value the environment and it’s important to you and your friends to do the right thing whenever possible. We encourage you to act on this by recycling your batteries at your local drop-off location.”

There are three stages of communication: 1) explain the importance of recycling; 2) describe how someone might act on recycling; and 3) getting them to act. You can’t skip to the third message without establishing the first two. The profile we seek to influence are those already pre-disposed to recycling, communicating to those that already recycle certain items curb-side to take the additional step to recycle batteries. We don’t waste our time and limited resources on those who simply haven’t accepted recycling as an important environmental behaviour.

Call2Recycle does not address exact figures: talking in grand numbers on such a large scale does not motivate recycling behaviour. Similarly, so far Call2Recycle did not attach the merits of recycling to broader climate change/greenhouse gas issues. It was found that consumers have great difficulty related to such numbers. Instead, those numbers tend to be highly meaningful to zealous environmentalist who already recycle and not the ones that Call2Recycle is attempting to convince to recycle.

5.3 El-Kretsen. Producer Responsibility Organisation (Sweden)


El-Kretsen is the national collection and recycling system, divided into two categories: households and businesses. The household collection is administered in co-operation with the municipalities. The collection from businesses is administered jointly with both municipalities and contracted transport carriers. Non-profit, owned by 21 trade organisations.

**General comments**

In comparison with the Battery Directive, Sweden has higher collection rates which are incorporated into national legislation – Swedish law on batteries. The habit to collect waste batteries has been fostered in the Swedish society for decades: there is a separate organisation in Sweden that promotes waste battery collection and provides information; the organisation called “Håll Sverige rent” (“Keep Sweden tidy”) exists for over 50 years, and always has been promoting waste battery collection.

However, collection rates also vary for each type of batteries: higher collection rates for NiCd, but much lower – for Li-Ion batteries, especially in comparison to sold batteries. Kristina agrees that the “hoarding” effect takes place: customers tend to keep WEEE at home. Another challenge is receiving real statistics on collected batteries.

Batteries contain less of valuable materials (metals). Ms. Eriksson agrees: when recycling is market-driven, recyclers tend to accept batteries with high content of nickel, copper, and cobalt. Kristina assumes that we need new business models for using degraded materials.
El-Kretsen enforces recyclers to extract batteries from WEEE. It is problematic to reach 100 percent. Recyclers often use manpower to extract batteries. In general, they should act in compliance with CENELEX and WEEELABEX.

Extracted batteries are sent to El-Kretsen - PRO organises transportation. This also allows to monitor how many batteries come from the WEEE stream. El-Kretsen has 2 battery sorting facilities. Downstream facilities (recycling) are chosen based on the best price and performance – through tenders.

Ms. Eriksson confirmed that product design is an important aspect: there is interconnection between product design and collection rates, however, it has even greater influence on recycling efficiency. Product redesign for better recycling (DfE, the author) is actively discussed by specialists. El-Kretsen has on-going projects with producers – “Differentiated Producer Taxes”, where product redesign is also considered. However, Ms. Eriksson says that it is difficult for El-Kretsen to influence producers.

El-Kretsen is interested not only in efficient recycling, but also in re-use of products (in their reports they provide detailed statistics on WEEE and its condition – whether it can be re-used, or repaired, for instance).

Ms. Eriksson sees next ways to improve battery collection and recycling:

- (“dream”) precise estimation of collection rate, more accurate data;
- differentiation of recycling rates for different batteries. It should be done by a combination of legislative and market-based measures (e.g. establishing functioning market for recyclables);
- provision of safety. Safety is a big issue in collection and recycling of batteries.

**Post-interview question (05 September 2017):**

Based on information from from Rebatt AS and Dakofa, Nordic Ecolabelling (2015b) states: “… Nordic Ecolabelling has found that the collection percentage in the Nordic countries is no more than 20-40% of the total number of batteries sold, which must entail that the remaining 60-80% end up going for incineration together with other household refuse or are disposed of by other inappropriate means.”:

1) Is it close to a real situation?
2) Is current high collection rate for Nordic countries achieved due to the batteries, placed on the market years ago?

Ms. Eriksson expressed confusion regarding such low figures: “The figures are not representative for Sweden”. Whilst, for instance, in Norway waste batteries were thrown away in the municipal solid waste (MSW) for a long time, it is questionable whether it has such tremendous impact on the statistics for the Nordic countries.

“In Sweden we have had over 60.00 percent collection rate the last couple of years and every “picking analysis” that has been done in the MSW has shown that the battery fraction was very low, from 0.03 percent to somewhere about 0.80 percent depending on which study you look at. We have had some historical amounts of batteries to take care of in El-Kretsen since we adopted battery collection in 2009. The consumer collection was driven by each local county back then and the stored volumes we received came rather from municipal storages than directly from the consumers.”
5.4 **Boxy. Battery collection and recycling system (Russian Federation)**

The interview with Ms. Alyona Yuzefovich, on the 3rd of August, 2017. CEO, Boxy (the Russian Federation).

Ms. Yuzefovich assumes that the market-based instruments are a good choice as the primary approach for solving environmental problems in less developed countries. The idea behind Boxy is to present waste battery collection and recycling as a complex tool to companies who will use it for marketing and team building.

According to Ms. Yuzefovich, the capacity of an average battery recycling facility in the EU is 10 tonnes. Having a dialogue with Umicore, the latter offered 3USD per 1 tonne of high-grade Li-Ion batteries, and this is without covering the cost for transportation.

**Battery recycling in Russian Federation**

Approximately 20,000 tonnes of batteries are imported to Russia every year. 500 tonnes collected every year (household batteries). The main issue is waste battery collection, but not recycling.

Companies subscribe for the service. There is one-off fee for signing a contract, and then a company pays 110 RUB per kg of a waste battery mix (mostly alkaline and zinc-carbon). The company receives a waste battery box to install it at the office, launching an official “collection point”. The income, generated from this, covers the expenses related to organising the service.

There is only one battery recycling facility in Russian Federation. The applied methods include mechanical and hydrometallurgical treatment. Since the facility was used for recycling of other products, it required some changes in a technological process, however, it was possible just to re-arrange the equipment order, changing the flow, and without additional investment. The recycling efficiency is 98 percent, but more expensive, compared to the European facilities.

5.5 **Scheduled interviews**

- The Hewlett-Packard Company. Information Technology company (USA). The interview with EMEA Battery program manager, Hewlett-Packard (USA).
- The 22nd International Congress for Battery Recycling, ICBR 2017, Lisbon (Portugal). The author attends ICBR 2017 to get in touch with representatives of the battery industry: recyclers and sorters, battery producers, policy makers.
6 Findings, analysis and assumptions

Ecolabelling implies advanced approaches for reaching positive changes in the products and services in the market. It means, that the product exposed for certification is supposed to be near, or on the top of existing production technologies and practices, often relying on the best practices in the sector.

Based on the information in Chapters 3, 4, and 5, the author developed the ecolabelling roadmap for rechargeable batteries in ICT products – Appendix I. This roadmap includes core categories to look at when the criteria are developed, as well as positive and negative factors, associated with these categories, which should be considered whenever a decision is taken.

This roadmap is used for the definition of the main aspects rechargeable batteries for the development of potential criteria. Some of the aspects are still difficult to incorporate but it is necessary to see the holistic picture – for a complex approach to solving issues.

The author finds the ICT products market as a very dynamic and harsh. The Digital Age rapidly consumes new technologies, eliminating outdated and non-efficient approaches and products, leaving space for the best. Developing new Type I ecolabelling criteria for rechargeable batteries, it is necessary to take into account that many positive changes, related to both rechargeable batteries and host devices, will occur naturally, just because of technology development. A few examples include, but not limited to:

- a shift to 4G/5G data transmission – with higher speed, thereby, a mobile phone consumes less energy. The same with public access to Wi-Fi: using such networks allows not to use in-built radio, thus, save up energy;
- an increase in display size results in a larger battery volume;
- a clear trend of shifting from fossil fuels to renewable energy sources; this affects the energy mix used both for production and during the use stage;
- whilst cobalt associated with a greatly increased cost of battery production, resource scarcity, cancerogenic potential, and even social challenges, battery producers slowly eliminate it. For instance, one of the top cathode Li-Ion chemistries – NCA – may contain just 9-15 percent of cobalt;
- finally, consumers chose best available configurations due to access to the information that is based on an experience of other users. They often chose products with the optimal “balance” between cost and performance. This eliminates performance- and cost-inefficient products from the market, greatly narrowing down potential target audience.

Finally, the author feels that launching and testing new criteria, it may be reasonable to segregate requirements on two groups: mandatory and optional, similar to what EPEAT has done. Whilst an applicant is expected to comply to the full extent with the mandatory requirements, other may be optional, and the applicant chooses a few from the suggested set – to collect minimum score for the compliance. Such solution would give more freedom and flexibility for applicants, allowing them to start transition with the most cost-efficient changes in the production technology or supply chain.

6.1 Aspects and potential criteria

The suggested aspects shall not be considered as the final. Whilst the author assumes certain values for some of the aspects, they will be reconsidered together with various stakeholders.
during a mandatory feedback stage. Nevertheless, this gives clear comprehension on the aspects which, as the author believes, are feasible for implementation.

6.1.1 Battery content

Transmaterialisation seems to be an inevitable and logical process for the Li-Ion battery technologies. First of all, development of new cathode chemistries imply the usage of various, and sometimes new, materials. Secondly, there are attempts to substitute current materials, especially the cost-inefficient like cobalt – either with such metals like, or with lithium – lithium-rich batteries. But each change may cause a sequence of consequences, and not of them positive. For instance, it is a good idea to decrease the amount of cobalt due to its price, carcinogenic potential, associated social challenges, and GHG and SO2 emissions. However, in the case with lithium-rich batteries, lithium cause a greater effect on both climate change and resource depletion. The use of recovered materials in the battery production is questionable but still has potential, especially with the development of recycling techniques.

Battery content: Heavy metals

Nowadays, all the batteries, placed on the EU market, are supposed to be in compliance with the Battery Directive in terms of the heavy metals in battery content. The Directive has already made a tremendous attempt to phase out mercury, cadmium, and lead from commercial batteries. The limits, established for heavy metals, include: mercury (Hg) – 5 ppm (0.005 g/kg); cadmium (Cd) – 20 ppm (0.02 g/kg); lead (Pb) – 40 ppm (0.04 g/kg). The author does not focus on other harmful substances since it is difficult to consider all possible criteria within one research.

Whilst recent studies like one by Umweltbundesamt (2013) demonstrate that in some batteries, represented in the market, these metals may exceed the allowable limit, however, it is an exemption: strict control in this sector will allow to completely erase commercial batteries with a prohibited level of such metals. Nevertheless, according to the same study, Li-Ion batteries possess a significantly better chemical profile: the level of heavy metals is much lower than it is allowed by the Directive. Based on the TCLP test, Kang et al. (2013) demonstrate how Li-Ion batteries are environmentally and chemically stable: from 16 Li-Ion batteries (8 Li-Ion, 4 Li-poly, and 4 smartphone batteries), only in two cases the amount of lead (Pb) exceeded the threshold; at the same time, cadmium (Cd) and mercury (Hg) were not detected in the modelled leachates.

Several the non-EU Type I ecolabelling programme reflected the Directive’s requirements on heavy metals, incorporating the same values. Nordic Ecolabelling went further, establishing stricter requirements: mercury (Hg) – 0.1 ppm (0.0001 g/kg); cadmium (Cd) – 5.0 ppm (0.005 g/kg); lead (Pb) – 5.0 ppm (0.005 g/kg); As – 10.0 ppm (0.01 g/kg). Taking into account that some applicants for ecolabelling may be outside of the EU, at least, it is reasonable to duplicate the requirement.

However, the author believes that new requirements should “pull out” from established by the Directive requirements to more stringent. Especially, this is of interest due to a variety of applied chemistries for the production of batteries. At this stage, the author suggest the following formulation of a requirement:

Criterion. Restriction on metals in rechargeable batteries (by weight):

- mercury (Hg): < 1 ppm (0.001 g/kg);
- cadmium (Cd): < 5 ppm (0.005 g/kg);
− lead (Pb): < 5 ppm (0.005 g/kg).

**Battery content: Cobalt**

The economic aspects enforce producers to look for new chemical compounds, developing alternative battery technologies. Main reasons for this are 1) to meet customer’s expectations in terms of a higher energy capacity and a faster charging; 2) to make the Li-Ion battery cheaper: to substitute cobalt in battery content with nickel, manganese, and other materials: cobalt is the main contributor to the Li-Ion battery price (Appendix VI). Moreover, cobalt is associated with the carcinogenic potential (Wang et al., 2017) and social challenges.

Cobalt is not on the agenda of the Regulation on Conflict Minerals that will be enforced in 2021, thus, its sourcing is not regulated in terms of conflict minerals. However, it is well-known that the Democratic Republic of Congo is the primary supplier of cobalt which can be hardly named as “ethically” sourced; this also undermines the economics of the mining companies that provide the market with ethically sourced cobalt (Dizard, 2017).

It seems that the market does its work, gradually eliminating cobalt from cathode chemistries. However, it is important to prepare ICT product producers to possible changes in the Regulation on Conflict Minerals, as well as to specific requirements regarding cobalt – to be deployed in the nearest future. Amongst reasons for this may be slow commercialisation of advanced battery technologies and the situation aggravation around sustainably sourced cobalt. So the question is whether phasing cobalt out of battery content will outpace increased demand on it, and, as the result, social tension, because even doubling the price for cobalt will not allow to supply existing battery producers with enough cobalt – due to its scarcity and the time needed to open new mines (Dizard, 2017).

Taking into account these facts, as well as the transboundary nature of the potential criterion, the author suggests not to impose harsh requirements regarding cobalt and its sourcing at the moment. The implementation of the Code of Conduct for suppliers may be one of the initial steps in this directions as, for instance, it was done by Umicore (n.d.). It is difficult to impose changes up-stream, especially for an ICT product manufacturer in the chain “CE producer – Battery producer – Natural resources suppliers – Other subcontractors”. But the author completely agrees with Nordic Ecolabelling (2015b): the more often each actor in the chain faces requirements on ethically sourced resources and appropriate labour conditions for employees, the more chances to cause positive changes.

**Criterion.** The applicant is supposed to develop and provide the Code of Conduct for the supply chain, informing all subcontractors about:

- the necessity to provide employees with adequate labour conditions, in accordance with the legislation;
- to present the complete information on how the resources are sourced.

**Battery content: Recycled and recovered materials**

Based on the experience of a few recycling companies who either demonstrated the possibility to (Toxco Technologies; OnTo and RSR within the Vehicle Recycling Partnership cooperation), or constantly use recyclables in the production of rechargeable batteries (Umicore), the author suggests to find the ways to incentivise this. Running ahead, the author fully realises how difficult it may be to influence the up-stream supply chain – battery producers, in particular.

Talking about cobalt-rich cathodes, it is reasonable to consider a possibility to apply recovered cobalt whose presence in waste rechargeable batteries makes their recycling profitable. In the
case, if there is a shift to lithium-rich cathodes – with the aim to reduce the price of a battery, and to diminish both environmental and health impacts – it will be necessary to reconsider the market of recyclables and applied recycling/recovering technologies. So far specialists do not forecast the shortage of lithium in the nearest future, and the overall amount of the material in battery content is quite low – less than 5 percent. The recyclers focus on more precious metals (Co, Cu, and Ni), lithium often ends up in slag. However, its market price grows from year to year, thanks to rapid development of the EV industry. Again, the shift to the batteries with higher content of lithium will require more of this metal. Last but not least, the usage of recovered metals would allow to decrease metal depletion, human and aquatic toxicities, associated with the processing stage. Finally, natural resources form a significant part of the cathode manufacturing price, requiring more attention to both recycling and material recovery (Appendix VI).

Also, here are non-active components in a rechargeable battery: a separator is normally produced from various polymers, and a battery casing, made of steel. The author suggests to incentivise the application of recyclables in these components as well.

**Criterion.** Recycled materials in battery content:

- a battery cathode shall contain at least X percent of recovered materials (e.g. cobalt, lithium);
- a battery shall contain at least X percent of recycled plastic or other recycled materials.

**Battery content: Nanomaterials**

The application of nanomaterials in general, and in the battery production in particular, has not even close reached its potential. The promised increase in battery capacity may diminish other drawbacks. However, it is important to control the situation from the very beginning, forecasting possible dangers.

The authors consider that Nordic Ecolabelling (2015b) chose a good strategy: at this stage the ecolabelling program collects statistics, requiring an applicant to provide the data on the correlation between applied nanomaterials and the battery performance (energy density).

**Battery content: Arsenic and Gallium**

Type I ecolabelling programme shall reconsider other elements and materials, used in rechargeable battery production. Often, one or two materials cause the primary environmental impact. For instance, there is the potential to improve the environmental profile of Li-Ion batteries by substitution of gallium.

At the same time, Nordic Ecolabelling (2015b) focused attention on arsenic, limiting its content to 10 ppm (0.01 g/kg) in the criteria for rechargeable batteries. Arsenic is classified as toxic (R23/R25) and hazardous to the environment (R50/53).

**6.1.2 Designing a host device**

It is difficult to trigger product redesign and to request from producers to change a form-factor. But these changes take place, and they are caused by the need to increase the functionality. Thereby, it is necessary to re-transmit this enhanced functionality into the extension of product lifespan – from reduced power consumption to the interface than changes the consumer’s behaviour.
**Replaceability, repairability, and upgradeability**

There is a strong interconnection between electronic equipment and rechargeable batteries in it: the former often defines the environmental performance of the latter. The useful life of laptops is an increasingly important issue to be addressed on the way to better environmental performance. Upgradeability, as an aspect of the design, remains as an important factor for life cycle extension. In their study on the median lifespan for 102 sampled waste batteries, Chancerel et al. (2016) found out that it is 9.8 years for waste batteries from laptops, 6.1 years - for mobile phone batteries; the same lifespan is expected for tablet batteries - 6.1 years. At the same time, laptops have the highest discard probability, compared to other electric products.

According to the conducted interviews, producers often do not design product in the way to make possible, or even to simplify an extraction of a battery without damaging the product (e.g. glued batteries). As the result, WEEE is often recycled together with rechargeable batteries despite the strict requirement to separate batteries from the former. To some extent, it also causes the so-called “hoarding effect” when consumers tend to keep WEEE at home, because a product is still functional.

Voluntary certification programmes started to implement the criteria, aimed to incentivise product redesign: when components can be replaced and upgrades are possible. However, the focus is on the hardware part of electronic products – component themselves. The efficient usage of computer resources is another crucial aspect. It is interesting to find ways how to adapt software to older computer configurations: this may help to extend the lifespan of a product since the users would be able to use the same configuration but longer. However, it is indeed difficult to influence the software industry, encouraging application developers to make programs more compatible.

**Criterion. The requirement for the design of a host device. This includes:**

- possibility to disassemble, and either to repair, or to replace malfunctioning components (including batteries);
- batteries shall not be glued.

Another crucial aspect is to provide specialists with relevant information on how to conduct repairs and modifications of the configuration. The “step-by-step” guidelines with the list of required tools should be set. The information shall be easily accessible for specialists (e.g. a producer’s website).

**Criterion. A guide for specialists on repairing and upgrading. This includes information on:**

- how to disassemble a host product, and replace a battery in particular;
- how to upgrade and change the configuration of a host device.

**6.1.3 Extending the use phase: Producer perspective**

Battery producers strive to please consumers and their expectations regarding battery performance. This is done by increasing the energy density and decreasing the charging time. A greater energy density also allows to diminish battery size, however, it makes a battery more unsafe. Faster charging time means higher stress for a battery what accelerates the process of degradation and, thereby, leads to the decrease of battery capacity. Improving certain battery characteristics it is necessary to ensure that other are not unacceptably diminished.
**Energy density**

EU Ecolabel requires a producer to equip a product with the battery that can provide at least 7 hours of autonomous work after the first full charge. The programme considers different scenarios of usage, distinguishing energy demand over a period of time.

It might be complex, and even unnecessary, to establish a strict threshold of minimal energy density: to some extent, smartphone and laptop producers apply similar Li-Ion technology with certain variations, being guided by cost efficiency. Moreover, variety of form-factors and models makes it even more difficult. At the same time, small changes in cathode chemistry seem to occur more often nowadays. Thereby, the requirement on a minimal number of work hours seems to be logical and more flexible. Finally, the author finds it difficult to set an exact value for energy density. Thereby, the figure suggested below is set for starting a dialogue with stakeholders and defining more appropriate figure, or even the formulation of the criterion (e.g. a number of hours of autonomy for a device).

It is also important to distinguish the low- and high-class products within one product lineup: the former may be equipped with the rechargeable batteries of lower class – with the decreased nominal energy density, for instance. This might be done with the aim to cover different groups of the target audience. Potentially, it may be necessary to establish similar gradation for the criterion on energy density. On the other hand, Type I ecolabelling strives to distinguish the market segment of the best products, thereby, it may have the sense to focus on high-end products.

**Criterion. The energy density of a battery:**

- to establish minimum energy density for rechargeable batteries as 150 Wh/kg.

**Charge cycles**

It is stated that policy-makers should encourage the use of the rechargeable batteries with higher energy density. The number of charge cycles is another crucial aspect that may result in a longer service life with lower environmental loads. Considering the minimum number of charge cycles based on the existing Li-Ion technologies, various sources suggest different figures: from 200 to 500 cycles. At the same time, ICT producers claim that their batteries provide from 800 to 1,000 charge cycles.

Requiring the exact number of charge-discharge cycles might have been justified. However, such criterion should distinguish the products which are equipped with permanently inbuilt batteries and with the removable batteries. Moreover, an ecolabelling program shall decide whether the products with inbuilt batteries can be certified: for instance, EU Ecolabel requires an increased number of cycles in this case.

The number of minimum charge-discharge cycles should be justified. The author suggests Type I ecolabelling programmes to gather more information from current and potential licensees on the rechargeable batteries they install into products. The Ecodesign Implementing Measure Regulation requires manufacturers to provide a declaration on battery lifetime for notebook computers: “(a) the minimum number of loading cycles that the batteries can withstand (applies only to notebook computers);” , thereby, such information should be available.

It is explained that some producers prefer to focus on battery’s firmware that limits SoC, thereby, increasing the number of charge cycles: this does not require heavy investments as it is in the case with reaching, for instance, 1,000 charge cycles what may be up to 80 percent
more expensive compared to the batteries with 300-500 cycles performance; and is based on inefficiency of user’s behaviour patterns. This approach allows to double the battery life cycle.

**Criterion.** A number of charge-discharge cycles. This includes:

- 600 for replaceable batteries;
- 800 for permanently inbuilt batteries (in case if it is necessary).

### 6.1.4 Extending the use phase: User perspective

**Information for clients**

“‘The environmental movement’s biggest mistake has been to say, ‘Do less. Tighten your belts. Consume less,’” Hans-Josef Fell, a prominent Green Party politician (Germany) said. “People associate that with a lower quality of life. ‘Do things differently <…> – that’s the message.” (Kunzig, 2015). Whilst it is difficult to influence consumer’s behaviour patterns, in the end, the overcoming of so-called “behaviour gap” would result in a significant impact in case of success. For this, it is important to demonstrate users how beneficial for them may be exact actions which, by the way, not often require strong will and lots of efforts.

There is a strong connection between the DoD and the battery capacity retention of a Li-Ion battery: deep DoD results in a shorter lifespan. Moreover, if the battery is constantly influenced by high voltage and temperature changes, this will enhance degradation processes and aging. Following basic recommendations on the battery charging and the conditions for its usage, it is possible to preserve the initial battery capacity, thereby, extending battery lifespan and product autonomy.

**Criterion.** A guide for a user aimed to extend battery life time. This includes information on:

- optimal battery charge (within 50-80% range);
- ambient conditions that influence a battery (e.g. temperature of a battery);
- energy saving tips (Wi-Fi usage decrease energy consumption, compared to inbuilt radio).

**Warranty**

Whilst HP does not provide any warranty for notebook batteries, other major market players do. For instance, Acer and LG – 6 months; Asus, Fujitsu, Lenovo, and Toshiba – 1 year (Dodd et al., 2015). Whenever producer provides warranty, consumers are more confident regarding product quality and often strive for longer lifetimes in the case with batteries (Dodd et al., 2015).

At the same time, the energy of the battery is a significant driver for energetic failures: with time, the energy in the battery decreases, and there are fewer chances for a thermal runaway. From the very beginning, the risk of such thermal runaway to a high extent may be caused by a manufacturing fault.

**Criterion.** Warranty and spare parts. This includes:

- warranty on rechargeable batteries for 1 year;
- availability of spare parts (including batteries) for 5 years after stop selling a product.
7 Suggested Criteria. Quality Assurance

The author compiled a set of possible criteria for rechargeable batteries and sent it to Type I ecolabelling programs for further evaluation. This feedback will be used to adjust the aspects, and to present the final suggestions in the next section. The list of respondents and ecolabelling programmes includes:

- EU Ecolabel (the European Union): Mr. Nicholas Dodd, Scientific & Technical Project Officer, Joint Research Centre (JRC), European Commission;
- TCO Certified (Sweden): Mr. Stefan Carlberg, Criteria Development Manager;
- SSNC (Sweden): Ms. Liv Södahl, Coordinator of “Shop Environmentally Friendly” (Handla Miljövänligt) Network and Administrator of Bra Miljöval butik;
- Green Crane (Ukraine): Ms. Svetlana Perminova, Head;
- Vitality Leaf (the Russian Federation): Ms. Yulia Gracheva, Head;
- Nordic Ecolabelling (Sweden): Mr. Ove Jansson, Ecolabel Officer;
- Eco Mark Office, Japan Environment Association (Japan): Mr. Ryo Ohsawa, Criteria & Certification Section, Manager.

The author wants to stress that the consideration and evaluation of criteria require certain background and deep analysis. The specialists often had no deep knowledge in the area. The task was to receive the initial view on what could be of interest, based on the fruitful experience of these specialists. However, there is one exemption: Mr. Nicholas Dodd who is a co-author of the technical report on the revision of the European Ecolabel criteria for personal, notebook and tablet computers; his answers were highlighted to differentiate from other views. Where the respondents left any comments, the author presents them after the relevant criterion.

The legend:

- **Low** – low score (in contrast with other categories, the lower score in the “Market Distortion” category is desirable);
- **High** – high score;
- **DK** – “Do not know”, the respondent does not know.

Table 7-1. Criterion. A guide for a user aimed to extend battery life time

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*Source: The author*
EU Ecolabel: Mr. Dodd stresses that “Some models include a software that optimises the battery charge. This can be established as a default setting. The drawback is that this reduces the operational time of the product in hours, so to meet consumer expectations the energy density of the battery would have to be increased”;

Vitality Leaf: Ms. Gracheva accentuates that such criterion was not established in the Vitality Leaf standard for mobile phones;

SSNC: Ms. Södahl suggests other possible variants of this criterion: 1) a charger that stops charging at X %; 2) an application on the phone that reminds you of how to use your battery wisely; 3) a competition between consumers: who has the oldest battery; a small reward to those who use the same battery for X years. The problem is that the information, provided with a product, is often neglected by consumers; it is reasonable to reconsider the criterion, with a certain focus on making the information for users more interesting;

Nordic Ecolabelling: Mr. Jansson thinks that users do not use the information in a guide on a daily basis.

The author agrees that often users neglect the instructions they receive together with a product. The author finds interesting the idea to pre-install on mobile phones and notebook computers relevant programs which would indicate basic information on the battery condition (SoC, the charge cycles before the battery capacity fades below 80 percent) and warn the user when it is desirable to recharge the battery (when the SoC is 50 percent).

Table 7-2. Criterion. A guide for specialists on repairing and upgrading

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Source: The author

Vitality Leaf: Ms. Gracheva explains that such criterion is easy to implement for various types of electronic products;

Nordic Ecolabelling: Mr. Jansson assumes that specialists use a guide better than users; it is difficult to give any answers regarding market distortion;

Eco Mark Office: Mr. Ryo Ohsawa referenced to the programme’s standard to demonstrate how a similar criterion was formulated.

Therefore, the author suggests to leave the criterion without changes.
Table 7-3. Criterion. The requirement for the design of a host device

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Source: The author

Producers may use the “planned obsolescence”; also it is difficult to trigger changes in terms of product form-factor. The criterion on battery removability seems to be a considerable solution, thereby, the author leaves it without changes.

Table 7-4. Criterion. Warranty and spare parts

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Source: The author

- EU Ecolabel: According to Mr. Dodd “Battery warranties usually address faults with the battery (e.g. failure to charge) rather than degradation related to patterns of use, which are the more likely reasons for early discard of the product and/or the need to change the battery”;
- Nordic Ecolabelling: Mr. Jansson explains that Nordic Ecolabelling considers this area as a difficult one to have information on. It feels that this does not have any big impacts. It is also a discussion on the price for the spare parts and how easy the user can use the warranty;
- Eco Mark Office: Mr. Ryo Ohsawa referenced to the programme’s standard to demonstrate how a similar criterion was formulated.

The thermal runaways and other failures may occur at the earliest stage either due to manufacturer’s fault or because of the inconsistency in the behaviour patterns of the user. Moreover, despite the longevity, the warranty triggers positive changes in user’s behaviour. As the result, the author suggests to consider this aspect together with producers based on the statistics from repair services that may collect the data on battery failures and main causes.
Table 7-5. Criterion. Number of charge-discharge cycles

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<td>Eco Mark Office</td>
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Table 7-6. Criterion. Energy density of a battery

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<th>Source: The author</th>
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<td>Eco Mark Office</td>
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</tbody>
</table>

Source: The author

- SSNC: Ms. Södahl asked whether the presented quantities of charge cycles greatly differ from the average battery;
- Vitality Leaf: Ms. Gracheva assumes that it may be difficult to establish such requirement in terms of “Applicability”; to measure this aspect it may be necessary to use tests which are not available in certain regions.

The author assumes, based on the available standards (IEC 61960) and further development of the express tests for measurement of charge cycles, such criterion should not be an obstacle. However, the exact number of minimum charge cycles is questionable. At the moment, the author suggests to reach the producers and discuss possible thresholds. Preliminary, the author increases the values up to 800/1000 charge cycles respectively.

Table 7-6. Criterion. Energy density of a battery

- EU Ecolabel: Mr. Dodd explains “To measure the energy density (or hours of operational usage) a benchmark software is generally used, but this raises issues of comparability based on the target market segment for the product/patterns of use, and also the specification of the software user simulation scenarios.”

This criterion is of high significance. The author suggests to continue the discussion on it with stakeholders – battery specialists and producers, as well as electronic product producers. Preliminary, the author increases the value up to 200 Wh/kg based on Chapter 3.
Nevertheless, this criterion is debatable due to the figure itself. The author suggests ecolabelling programmes to carefully consider this criterion – together with stakeholders.

Table 7.7. Criterion. Restriction on metals in rechargeable batteries (by weight)

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<th>Relevance</th>
<th>Differentiate</th>
<th>Applicability</th>
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Source: The author

- SSNC: Ms. Södahl stressed that this question requires relevant knowledge;
- Vitality Leaf: Ms. Gracheva noticed that the situation is different for the countries where the RoHS Directive is applied or not applied;
- Eco Mark Office: Mr. Ryo Ohsawa referenced to the programme’s standard to demonstrate how a similar criterion was formulated.

Based on the studies, the rechargeable batteries seem to have the potential for more stringent requirements to heavy metals in batteries. Taking into account experiments with the batteries, the Battery Directive did not completely stop commercialisation of the batteries with higher content of either lead (Pb), or cadmium (Cd). The allowable minimum for mercury (Hg) may be potentially decreased as it is done by Nordic Ecolabelling.

Table 7.8. Criterion. Recycled materials in battery content

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<tr>
<th></th>
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<th>Applicability</th>
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</table>

Source: The author

- SSNC: Ms. Södahl considers that this criterion is very relevant, but difficult to comply with; it is suggested that the percentage could start low and grow as the supply becomes of higher quality and easily accessible;
– EU Ecolabel: Mr. Dodd explains that “there are some traceability systems for the verification of plastics content, but it may be more difficult to verify cobalt and lithium content”;

– Eco Mark Office: Mr. Ryo Ohsawa stated “It does not require the use of recycled materials. Trade-off with flame retardancy” – seemingly referring to the programme’s standard.

The author considers that this criterion is one of the most complex to implement. Most of the respondents find this criterion as a difficult one to apply and measure. Nevertheless, the experience of the largest battery recyclers demonstrates that recovered materials are used in the production of new batteries. The author suggests to discuss this criterion with stakeholder groups which include recyclers and battery producers.

**Summary**

In general, at this stage, all criteria demonstrated the potential for adoption by Type I ecolabelling programmes. Some of them have higher score due to the relevant experience of some of the ecolabelling programmes in the area. The criteria on battery content and operational characteristics logically have a higher quantity of the “Do not know” answers. It is explained by honest answers of ecolabelling specialist who had no relevant background for judging the criteria. It does not mean that they are not viable. Instead, they require more attention and further research, including active communication with different stakeholder groups (e.g. the use of recovered materials in the battery production; energy density). This feedback also confirms that so far the operational characteristics of rechargeable batteries did not receive proper attention and were not deeply investigated.
8 Conclusions

The author conducted research on the aspects for rechargeable batteries in portable ICT products. The ecolabelling roadmap for rechargeable batteries was created: it represents the main aspects associated with each stage of the rechargeable battery life cycle. Based on the processed information, the author defined several the most crucial and feasible for implementation aspects:

- The extension of the use phase – the user perspective;
- The extension of the use phase – the producer perspective;
- Battery quality;
- Battery content.

For each of the identified aspects the author developed at least two criteria that a) have a numerical value; b) can be measured. The criteria are presented and discussed in Chapter 8.

Defining the system boundaries, the author considered a host device due to the fact that it greatly influences both operational and environmental performance of rechargeable batteries. Chargers themselves are not considered in this study, however, they also have a significant impact on the batteries; instead, the author elaborates on charging algorithms.

Finally, the developed criteria were presented to several Type I ecolabelling programmes – to receive feedback from specialists with the relevant knowledge in the standardisation area. This feedback was used to verify the criteria and, in some cases, to adjust them. Overall, the specialists estimated the criteria as relevant and important. Nevertheless, some of the criteria require more attention and further involvement of different stakeholders – to avoid the market distortion.

Developing next generation of criteria for rechargeable batteries, the author suggests to focus on:

- operational characteristics of batteries;
- product redesign and integration of the DfE concept;
- battery content, especially in terms of the use of recyclables;
- social impacts – arising challenges, related to ethically sourced cobalt, and potential scarcity of certain resources.

The final list of suggested criteria

Criterion 1a. A guide for a user aimed to extend battery life time. This includes information on:

- optimal battery charge (within 50-80% range);
- ambient conditions that influence a battery (e.g. temperature of a battery);
- energy saving tips (Wi-Fi usage decrease energy consumption, compared to inbuilt radio).

Preferably, if a product is sold with the pre-installed application that indicates main parameters (SoC, battery condition) and warns a user when it is necessary to charge the battery.
Criterion 1b. Warranty and spare parts. This includes:

- warranty on rechargeable batteries for 1 year;
- availability of spare parts (including batteries) for 5 years after stop selling a product.

Criterion 2a. The requirement for the design of a host device. This includes:

- possibility to disassemble, and either to repair, or to replace malfunctioning components (including batteries);
- batteries shall not be glued.

Criterion 2b. A guide for specialists on repairing and upgrading. This includes information on:

- how to disassemble a host product, and replace a battery in particular;
- how to upgrade and change the configuration of a host device.

Criterion 3a. The energy density of a battery:

- to establish minimum energy density for rechargeable batteries as 200 Wh/kg\(^4\).

Criterion 3b. A number of charge-discharge cycles. This includes:

- 800 for replaceable batteries;
- 1,000 for permanently inbuilt batteries (in case if it is necessary).

Criterion 4a. Restriction on metals in rechargeable batteries (by weight):

- mercury (Hg): < 1 ppm (0.001 g/kg);
- cadmium (Cd): < 5 ppm (0.005 g/kg);
- lead (Pb): < 5 ppm (0.005 g/kg).

Criterion 4b. Recycled materials in battery content:

- a battery cathode shall contain at least 5 percent of recovered materials (e.g. cobalt, lithium);
- a battery shall contain at least 10 percent of recycled plastic or other recycled materials.

Criterion 5. The applicant is supposed to develop and provide the Code of Conduct for the supply chain, informing all subcontractors about:

- the necessity to provide employees with adequate labour conditions, in accordance with the legislation;
- to present the complete information on how the resources are sourced.

\(^4\) The suggested figure is debatable and requires careful consideration together with the Li-Ion technology specialists, battery and electronics producers. This figure is supposed to be used for starting a dialogue with these stakeholder groups.
9 Further study

Finalising this research, the author felt that at least several aspects – for instance, charging technologies, battery energy density and charge cycles – operational characteristics were somewhat neglected by ecolabelling programmes until now. These require much more attention and even a separate study. Actually, the same may be said almost about each aspect. Nevertheless, this study provides the reader with the insight on the potential aspects of rechargeable batteries to be used by Type I ecolabelling programmes.

Returning to the charging of rechargeable batteries, the author wants to stress that this aspect is connected to several areas: user behaviour and ambient conditions; chargers, from the first to the third generation; charging algorithms and battery firmware; finally, the electro-chemical performance of the battery itself. Again, in parallel with basic CCCV algorithms, new technologies appear to be immediately adopted – for instance, inductive charging. Summarising, this exact aspect requires a multiple approach to observe all interconnections and the most optimal options to address it within ecolabelling criteria.

Whilst the author stressed the importance of the use phase in the life cycle of rechargeable batteries, the EoL stage inevitably comes afterward. Some specialists find a tremendous potential in the secondary use or rechargeable batteries – as energy storage systems. However, this only postpones the stage when it is necessary to apply the recycling and material recovery approaches. The author suggests to investigate more on how the recycling and material recovery may diminish the environmental and social impacts, associated with the first stages of the life cycle. Of special interest is the use of recovered materials in the production of new batteries: “to what extent recovered materials are degraded?”, “how to remove impurities?”, “what are the optimal recycling and recovery techniques?”, “what tools could help to improve recycling and recovery efficiencies?”.

Considering the substances used for the battery production, some ecolabelling programs already made first steps in this direction. Last year’s revision of the criteria for notebook computers for the purpose of the EU Ecolabel resulted in advanced requirements that incorporate the RoHS Directive, the Candidate List of SVHC and the REACH Regulation. This is also explained by the EU’s focus on chemical substances, thus, a powerful scientific base is aggregated. Other ecolabelling programmes may reconsider own requirements to substances in batteries, utilising the experience of partners.

In the case, if an ecolabelling program revises current criteria for rechargeable batteries, the author suggests to consider a possibility to launch a monitoring system for tracking the impact: to see whether updated requirements trigger any changes or accelerate the redesign processes in the area. For this, it is required to organise appropriate data collection and to involve stakeholders (e.g. licensees). One of the drawbacks of Type I ecolabelling as a tool is that it is difficult to evaluate either positive or negative impact on the environment.

Following the circular economy principles, new business models appear. Some of them are based on well-known leasing – providing a client with service instead of product. For instance, Apple has launched “Apple Upgrade Program” for their phones: the cost of a phone is spread out over 24 months; in addition, a customer may upgrade it to a newer model after 12 payments, as well as to repair (the cost is included in the fee). Such “take-back” approach allows the company to save up to 1900 kg of aluminum and 800 kg of copper from 100.000 iPhone 6 devices (Apple, 2017). The author suggests to look closely at new business models and their application in the sector of ICT products from the environmental point of view.
Bibliography


Appendix II – Comparison of Type I ecolabelling criteria

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I. Certification System and Standard
   A. Scope

II. Substances of Very High Concern (SVHCs)

III. Quality

IV. Design

V. Removability, Upgradability, Recyclability

VI. Information for users and/or 3rd parties

Other relevant criteria or views

EC Eurolabelling Criteria

The product group of personal and portable electronic devices incorporates computers, computer monitors, personal digital assistants, mobile phones, electronic readers, hybrid devices, TV sets, video players, audio players, navigation systems, industrial electronic systems, industrial electronics equipment, radio equipment (mobile and fixed), wireless devices, telecommunications systems, wireless access points, wireless controllers, network equipment, television, entertainment and video equipment (including that used for broadcast and media production and distribution), cameras, camcorders, mass storage devices, fax machines, facsimile equipment, e-book readers, and navigation systems. In this context, devices used in cars and other mobile transport equipment, as well as parts and subassemblies for these devices, are also covered. The product group does not include consumer devices, equipment, and parts designed to be used exclusively in the professional or business environment. The scope covers the raw materials and components that are used in the production of the device, as well as the device itself. The objects of the criteria are to ensure the long-term usability and the sustainable removal of such devices, particularly by promoting the use of the most recycable components. For a device to be considered for this Ecolabeling, it must meet the requirements of the following test procedure in Appendix 3.3. Recyclable Design. For recycling purposes it shall be possible to extract the battery separately from the rest of the device. The battery capacity shall be measured in accordance with Standard EN 62133:2003, Parts 3 and 4 respectively.

Blue Angel Criteria

The product group of personal and portable electronic devices incorporates computers, computer monitors, personal digital assistants, mobile phones, electronic readers, hybrid devices, TV sets, video players, audio players, navigation systems, industrial electronic systems, industrial electronics equipment, radio equipment (mobile and fixed), wireless devices, telecommunications systems, wireless access points, wireless controllers, network equipment, television, entertainment and video equipment (including that used for broadcast and media production and distribution), cameras, camcorders, mass storage devices, fax machines, facsimile equipment, e-book readers, and navigation systems. The objects of the criteria are to ensure the long-term usability and the sustainable removal of such devices, particularly by promoting the use of the most recycable components. For a device to be considered for this Ecolabeling, it must meet the requirements of the following test procedure in Appendix 3.3. Recyclable Design. For recycling purposes it shall be possible to extract the battery separately from the rest of the device. The battery capacity shall be measured in accordance with Standard EN 62133:2003, Parts 3 and 4 respectively.

i. Rechargeable battery replacement: The rechargeable battery pack shall be easy to replace by one person following the standard operating procedure provided by the manufacturer. The device shall not be designed in a way that it is impossible to replace the rechargeable battery packs. For notebooks, the maximum discharge time for cycle 150 shall be 90% of the rated capacity. For business or enterprise products the BAPCo Mobilemark 'Office Workstation' shall be designed as to allow easy access to the following basic user information: - the status of the battery charge, - the number of charge and discharge cycles during the lifetime of the device. The product shall be designed to meet the requirements of the following test procedure in Appendix 3.3. Recyclable Design. For recycling purposes it shall be possible to extract the battery separately from the rest of the device.

ii. The applicant shall provide a minimum two year warranty for defect-free devices.

iii. The mobile phone shall have an internal state-of-charge indicator. The battery shall display the current state of charge during use and during charging. This indicator shall be displayed upon completion of the charging process, display a red signal as the battery reaches the critical level (as specified in criterion 3.5.2), and the red signal shall be displayed for at least 5s. In this case partial charging shall be set as the default charging mode.

iv. The following indications on user instructions and devices for recycling shall be provided: - The product shall be delivered during cycle 150 shall be equal to 90% of the rated capacity. The minimum discharge time for cycle 150 shall be 3.5 hours and the capacity measured during this test procedure in Appendix 3.3. Recyclable Design shall meet the requirements of the following test procedure in Appendix 3.3. Recyclable Design. The battery capacity shall be measured in accordance with Standard EN 62133:2003, Parts 3 and 4 respectively.

v. The mobile phone shall have an internal state-of-charge indicator. The battery shall display the current state of charge during use and during charging. This indicator shall be displayed upon completion of the charging process, display a red signal as the battery reaches the critical level (as specified in criterion 3.5.2), and the red signal shall be displayed for at least 5s. In this case partial charging shall be set as the default charging mode.

vi. Rechargeable battery packs shall not be used in devices where the rechargeable battery can be changed without tools.

vii. The rechargeable battery replacement: The rechargeable battery pack shall be easy to replace by one person following the standard operating procedure provided by the manufacturer. The device shall not be designed in a way that it is impossible to replace the rechargeable battery packs. For notebooks, the maximum discharge time for cycle 150 shall be 90% of the rated capacity. For business or enterprise products the BAPCo Mobilemark 'Office Workstation' shall be designed as to allow easy access to the following basic user information: - the status of the battery charge, - the number of charge and discharge cycles during the lifetime of the device. The product shall be designed to meet the requirements of the following test procedure in Appendix 3.3. Recyclable Design. For recycling purposes it shall be possible to extract the battery separately from the rest of the device.

viii. The mobile phone shall have an internal state-of-charge indicator. The battery shall display the current state of charge during use and during charging. This indicator shall be displayed upon completion of the charging process, display a red signal as the battery reaches the critical level (as specified in criterion 3.5.2), and the red signal shall be displayed for at least 5s. In this case partial charging shall be set as the default charging mode.

ix. The battery shall be designed to allow easy access to the following basic user information: - the status of the battery charge, - the number of charge and discharge cycles during the lifetime of the device. The product shall be designed to meet the requirements of the following test procedure in Appendix 3.3. Recyclable Design. For recycling purposes it shall be possible to extract the battery separately from the rest of the device.

x. The mobile phone shall have an internal state-of-charge indicator. The battery shall display the current state of charge during use and during charging. This indicator shall be displayed upon completion of the charging process, display a red signal as the battery reaches the critical level (as specified in criterion 3.5.2), and the red signal shall be displayed for at least 5s. In this case partial charging shall be set as the default charging mode.

xi. Rechargeable battery packs shall not be used in devices where the rechargeable battery can be changed without tools.
4.4 Battery/Accumulator Capacity

The battery/accumulator capacity shall be calculated and remaining capacity shall be measured in accordance with the requirements set out in Appendix A Determination of Battery/Accumulator Durability.

The applicant shall - from the date of placing the computer on the market or, at least, from the date of filing the application until, at least, 6 years after production ceases - make these software tools available for free-of-charge download on its website as well as inform about these tools in the computer product documents. Provided that the computer is placed on the market with a pre-installed operating system the software tools described above-described must also be pre-installed in the delivery for a period of at least 5 years after the end of production.

4.4.1 Battery/Accumulator Marking

The applicant shall mark the software tools for battery/accumulator status reading and for battery/accumulator protection according to para. 4.5 (Battery/Accumulator Protection). The software shall be able to stop the battery/accumulator’s charge to a value smaller than the maximum amount of usable electricity (e.g. 80% of the full charge capacity). Doing so will extend the battery/accumulator’s life.

4.4.2 Battery/Accumulator Protection Software

The devices to be Blue Angel eco-labelled must be so designed as to ensure easy accessibility to the replaceable components and expansion interfaces (e.g. IC sockets plug-in connectors). For this purpose, it must be possible to open housing parts, change and battery covers easily and without expert knowledge.

4.4.3 Battery/Accumulator Status and Protection Software

The batteries/accumulators must be so designed as to allow the user to easily replace the batteries/accumulators without the need for expert knowledge.

4.6 Longevity and Charge cycles

The battery/accumulator (or battery/accumulator pack) must be marked in accordance with standard EN 61960 providing at least the following information:

- nominal capacity (Ah);
- nominal voltage;
- type designation;
- date of manufacture (may be coded);
- indication of the maximum energy (in watt hours) the battery/accumulator may provide in a certain time period (e.g. tin, phosphorous).

The battery/accumulator (or battery/accumulator pack) shall be designed to be handled by battery recycling firms.

4.7 Information on the software tools for battery/accumulator status reading and for battery/accumulator protection according to para. 4.5 (Battery/Accumulator Protection). The software shall be able to stop the battery/accumulator’s charge to a value smaller than the maximum amount of usable electricity (e.g. 80% of the full charge capacity). Doing so will extend the battery/accumulator’s life.

4.8.1 Battery/Accumulator Status and Protection Software

The device to be Blue Angel eco-labelled must be so designed as to ensure easy accessibility to the replaceable components and expansion interfaces (e.g. IC sockets plug-in connectors). For this purpose, it must be possible to open housing parts, change and battery covers easily and without expert knowledge.

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4.4.6 Battery/Accumulator Protection Software

The batteries/accumulators must be so designed as to allow the user to easily replace the batteries/accumulators without the need for expert knowledge.
Notebooks 5.0
TCO Certified
Certification Standard
>
Notebook computers with a display size to the battery is sold together with a charger as part of the application where the battery is sold together with a charger as part of the appliance.)

O1 Nanotechnology
Nanoparticles may be present only in electrode material in the battery for the purpose of improving the energy efficiency of the battery. Nanoparticles are present in electrode material, the applicant must specify the extent to which the energy efficiency of the battery is improved.

O2 Requirements applicable to plastic in battery chargers
If the rechargeable batteries are sold together with a charger, the charger must fulfill the following requirements:
- The plastic in the casing must not be labelled in accordance with ISO 11469.
- The plastic in the casing must not be chlorinated plastic.
- Chlorinated plastic must not be added to the plastic in the casing and cables.
- Chlorinated plastic must not be added to the plastic in the casing and cables.

O3 Longevity and Charge cycles
Li-ion/LiP batteries and cells:
The conditions during capacity testing must be in accordance with the, of the time of application applicable, IEC 61960 standard for Li-ion/LiP cells and batteries applicable at the time of application.
Cycle life testing:
- All tested batteries must meet the following requirements:
  - The discharge time for cycle 700 must be at least 30 minutes (correspond to 50% of remaining capacity)
  - The discharge time for cycle 800 must be at least 3.5 timer hours (correspond to 70% of remaining capacity)
- Initial capacity testing:
  - All batteries that undergo testing must meet the following requirements:
    - At least one of the 5 cycles performed in the test must involve a discharge period of at least 5 hours.
    - All (4) tested cells/batteries must comply with the requirement.
Endurance testing:
Endurance testing must comply with the conditions described in table 4 and the tested-cells/batteries must meet the requirements stated in table 5. Cycles 1-50 are repeated until the required number of cycles has been reached for the tested battery type. The required number of cycles for the different battery types are listed in.

A.6.4 Hazardous substances (in relation with A.6.4 Hazardous substances)
The limit value for batteries is 0.005% for mercury, 0.002% for cadmium and 0.004% lead per kilogram, according to EU Directives 2006/66/EC.

A.6.5 Environment
Monitor A.6.5.1
2. The brand owner shall guarantee the availability of spare parts for at least three years from the time that production cease. Instructions on how to replace these parts shall be available to professionals upon request.

A.6.6.1
X

- The maximum trickle charge current must on average be < C/20, based on the lowest battery capacity that the charger is recommended to charge.
- The maximum no-load current must on average be < C/50, based on the lowest battery capacity that the charger is recommended to charge.

TCO Certified
This document contains requirements, test methods and references for Notebook computers with a display size ≥ 10.1.
4.2 The capacity of battery

The charging capacity by battery type should be satisfied the following criteria.

- Rechargeable Alkaline-Manganese battery shall be 40% or more of rated capacity indicated in the battery in regard to the charge capacity after a 25 times charging and discharging cycle test, and during test, no leakage shall occur.
- Nickel-metal hydride battery and Lithium secondary batteries shall be 60% or more of rated capacity indicated in the battery in regard to the charge capacity after a 400 times charging and discharging cycle test, and during test, no leakage shall occur.

4.3 Battery

The content of lead (Pb), cadmium (Cd), mercury (Hg) and their compounds in the batteries of products shall comply with EU Directive 2006/66/EC.

X

4.4 Environment-friendly design

The product shall be designed and manufactured by considering resource- and energy-saving, reduction of pollutant emission and hazardous substance use, recycled material use, substance use, using recycled materials, improving recyclability, resource- and energy-saving, reduction of pollutant emission and hazardous substance use, recycled material use, and hazardous substance use, using recycled materials, improving recyclability.

X

4.5 Battery for power supply

The service life warranty of batteries for power supply shall be at least one year.

X

4.6 The emission of nickel

Nickel release amount from product surface of battery, case, and the 2nd battery pack (replacement module) shall be below 300 μg/cm² when destroyed, and the area of the skin shall be less than 1 cm²/week.

X

4.7 The structure of recharging equipment

The product shall have a structure in which the recharging equipment shall be used jointly with lithium-ion model products with simple production time.

X

5.1 Quality related criteria

- Quality related criteria or views
- The standard covers the cell that is able to be used for personal use for the small sized portable power for office or home. This includes rechargeable Alkaline-Manganese batteries, Nickel-metal hydride batteries, and Lithium secondary batteries.

X

6. Consumer Information

The certification reason that relevant products contribute to reduction of environmental effects should be marked.

X

6.3 Quality related criteria

- Quality related criteria or views
- These sets of criteria and industrial standards, heavily rely on the national and industrial standards, thereby, the author does not present them here.
### Mobile Phone and Laptop Computer

#### Energy Use Requirements

**10.1 Mobile phone battery charging system efficiency**

- **10.1.1 Required** – Battery Charger Systems
  - a) Test report demonstrating that the product meets:
    1. The DCR maximum 24-hour charge and maintenance-energy (WH) until June 13, 2018.
  - b) If the product is declared to conform in a country or region with different efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.

- **10.1.2 Optional – Reduction in energy consumption of battery charging systems**
  - a) Test report demonstrating a 10%, 20% or 30% reduction in:
    1. The DCR maximum 24-hour charge and maintenance-energy (WH) until June 13, 2018.
  - b) If the product is declared to conform in a country or region with different efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.

- **10.1.3 Required – External power supply energy efficiency**
  - a) Test report demonstrating that the external power supply meets the efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.
  - b) If the product is declared to conform in a country or region with different efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.

- **10.1.4 Optional – Reduced maintenance mode power**
  - a) Test report demonstrating that the external power supply meets the efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.
  - b) If the product is declared to conform in a country or region with different efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.

**11.3.2 Optional – Battery removability instructions**

- a) Demonstration that the removal of batteries covered by this criterion by qualified repair service providers or authorized repair providers is achievable without the use of tools for removal of the battery alone (i.e. use of tools to get to the battery is acceptable)
- b) URL for manufacturer’s website containing information on how to obtain removal instructions in accordance with 11.3.2

### Information for users and/or 3rd parties

The three supplier(s) selected shall provide the necessary instructions or guidelines to the manufacturer from one or more of the following categories:

- **Printed circuit board assemblies**
  - Integrated circuits
  - Printed circuit boards
  - Display
  - Batteries
- It is acceptable for the supplier to provide the disclosures, or for the manufacturer to include the disclosures in the final product, after the manufacturer has produced the disclosures as output by the manufacturer’s own reporting. If the manufacturer provides the disclosures, the data can either be either be provided to such supplier, or aggregated.

**11.3.2 Optional – Supplier removability information**

- The suppliers selected shall provide the necessary instructions or guidelines to the manufacturer from one or more of the following categories:
  - Print circuit board assemblies
  - Integrated circuits
  - Printed circuit boards
  - Display
  - Batteries
- It is acceptable for the supplier to provide the disclosures, or for the manufacturer to include the disclosures in the final product, after the manufacturer has produced the disclosures as output by the manufacturer’s own reporting. If the manufacturer provides the disclosures, the data can either be either be provided to such supplier, or aggregated.

### Longevity and Charge cycles

- **11.4 Ease of disassembling mobile phone**
  - a) Demonstration that the mobile phone housing in removable or detachable to allow access to the reparable primary circuit board and battery by a qualified repair service provider or authorized repair provider without causing damage to the mobile phone that would preclude re-use or refurbishment.
  - b) If the product is declared to conform in a country or region with different requirements of the Federal Energy Conservation Standards for Battery Charger Systems.
  - c) Documentation that information on how to recycle used batteries is provided in electronic or printed format, or on the battery.
  - d) Documentation specifying who are the appropriate parties to remove the battery.

### Removability, Upgradability & Recyclability

**11.3.1 Required – Battery removability/placement by qualified repair service providers or authorized repair providers**

- a) Instructions demonstrating how qualified repair service providers or authorized repair providers can remove and replace batteries that can provide primary power without damage that would preclude re-use or refurbishment of the mobile phone.
- b) If the product is declared to conform in a country or region with different efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.

### Design

**11.4.1 Required – Case of disassembling mobile phone**

- a) Demonstration that the mobile phone housing in removable or detachable to allow access to the reparable primary circuit board and battery by a qualified repair service provider or authorized repair provider without causing damage to the mobile phone that would preclude re-use or refurbishment.
- b) If the product is declared to conform in a country or region with different efficiency requirements of the U.S. DOE Efficiency Regulations for External Power Supplies for "Maximum Power in No-Load Mode (W)" for direct EPS in accordance with Table 10.2 in the criterion.
- c) Evidence that the adhesives used are not used or do not prevent removal of listed components.
- d) Documentation that information on how to recycle used batteries is provided in electronic or printed format, or on the battery.
- e) Documentation specifying who are the appropriate parties to remove the battery.
- f) URL for manufacturer’s website containing information on how to obtain removal instructions in accordance with 11.3.2
This Eco Mark product category applies to notebook PCs, desktop PCs, all-in-one PCs (a PC with integrated monitor), CRT monitors, LCD monitors, keyboards, and mouse devices. This product category also includes thin clients*1 and tablet PCs*2.

**Thin client:** A terminal that is attached to an organization’s information system network. Thin clients possess only the essential functions, while application software, files and other assets are managed by a server. Normally, thin clients do not have an internal magnetic disk or other means of storage.

**Tablet PC:** A personal computer that emphasizes features such as portability and viewing ease for business applications and that is treated as a type of notebook PC.

Cadmium, lead and mercury shall not be added as prescribed constituents. Applies to single-cell batteries. Does not apply to solder and so forth used to interconnect single-cell batteries. The percentage content of lead, cadmium, hexavalent chromium, mercury, and specified brominated flame retardants (PBBs, PBDEs) shall not exceed the reference values enumerated for these specified substances in JIS C 0950, a Japanese Industrial Standard that specifies the method for indicating the content of specified substances contained in electrical and electronic equipment.

If an applicable substance qualifies as an exception under content marking rules, the content information shall be disclosed on a website. This item does not apply to batteries that equipment users are not supposed to remove. This item does not apply to batteries that equipment users may remove.

Information on battery replacement shall be provided. This does not apply in instances where, for example, batteries are mounted to a printed circuit board or other component that is not supposed to be removed by equipment users.

For equipment that has a secondary battery, information or labels shall be provided in accordance with the Law for the Promotion of Effective Utilization of Resources so as to (1) communicate that the equipment has a secondary battery, and (2) promote the use of secondary batteries as a recyclable resource.

### Certification System & Standard

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Substances of Very High Concern (SVHCs)</strong></td>
<td><strong>Quality</strong></td>
</tr>
<tr>
<td><strong>Battery Content</strong></td>
<td><strong>Design</strong></td>
</tr>
<tr>
<td><strong>Longevity and Charge cycles</strong></td>
<td><strong>Removability, Upgradability &amp; Reparability, Recyclability</strong></td>
</tr>
<tr>
<td><strong>Information for users and/or 3rd parties</strong></td>
<td><strong>Other relevant criteria or views</strong></td>
</tr>
</tbody>
</table>

#### CRITERIA

The PC shall be equipped with a power switch and power consumption in the off state shall be less than 1W. If the computer is required to operate other functions (functions to supply power to a clock, monitor modem or LAN wake signals, monitor battery charge, and illuminate LEDs to notify equipment users of equipment status, etc.) when the power switch off, power consumption shall not exceed 5W.

<table>
<thead>
<tr>
<th>Type of power source and the class of element means</th>
<th>Charge</th>
<th>Rechargeable</th>
<th>Battery</th>
<th>Category</th>
<th>Standard energy consumption efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery-driven computers</td>
<td>A or B</td>
<td>B or C</td>
<td>B</td>
<td>A or B</td>
<td>5W or less</td>
</tr>
</tbody>
</table>

**Batteries shall be replaceable and removable by equipment users.** This does not apply to batteries that are mounted to printed circuit boards or other components that are not supposed to be removed by equipment users. This item applies to batteries that equipment users are not supposed to remove. This item does not apply to batteries that equipment users may remove.

#### Certification System & Standard

Appendix III – Future criteria for rechargeable batteries

Here is the list of the criteria to be considered in the future by two Type I ecolabelling programmes – Nordic Ecolabelling and Blue Angel.

*Table. Rechargeable battery aspects to be considered in the future*

<table>
<thead>
<tr>
<th>Blue Angel</th>
<th>Computers</th>
<th>Battery content</th>
<th>Performance</th>
<th>LC phases</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Additives in plastic</td>
<td></td>
<td>Battery capacity and life (port. PCs)</td>
<td></td>
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<tr>
<td></td>
<td>(phthalates)</td>
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<tr>
<td></td>
<td>Exclusion of substances on the Candidate List of SVHC from the licensed product</td>
<td></td>
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<td>Production: Energy consumption &amp; evaluation of carbon footprint.</td>
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<tr>
<td></td>
<td>Requirements for the use of recycled plastics in the manufacture</td>
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<tr>
<td></td>
<td>Requirements on the battery (in general)</td>
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<td></td>
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</tr>
<tr>
<td>Nordic Ecolabelling</td>
<td>Computers</td>
<td>Substances substitution. Further limitation on heavy metals. Solvents in production</td>
<td>Quality: Number of charge cycles w/o capacity retention</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Production: Requirements on energy consumption</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Consumer information based on collection rates</td>
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<tr>
<td></td>
<td>Rechargeable Batteries</td>
<td></td>
<td>Transportation: requirements to certain rechargeable batteries</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Consumer information on optimum use/charging</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Blue Angel (2014); Nordic Ecolabelling (2015a; 2015b)*
Appendix IV – Samples of questionnaire for interviews

The questionnaire samples utilised for receiving primary data from stakeholders.

1. Questions to CE producers

Objective: to understand trends, upcoming changes => to measure achievable upper threshold for establishing new requirements by voluntary certification systems (implies communication with R&D departments).

Producer and battery suppliers

Q1. Does the company have control over (or influence on) upstream stages of battery life cycle?

Q2. How effectively can the company influence a battery supplier in term of battery redesign?

Material Recovery and Re-use

Q1. Does the company consider a shift to a business model when disposed products are reprocessed to recover materials for their further application in production?

Q2. What is done and/or planned in this area?

Future

Q1. The company’s view on application of eco-design in terms of secondary batteries. How to co-integrate it into the overall design of a product?

Q2. Matt Kohut (Lenovo) in 2009 asserted that “the manufacturers are trading capacity for longevity” (http://blog.lenovo.com/en/blog/3-year-batteries). How could we describe the current trend in terms of the secondary battery technology development?

Legislation

Q1. What changes does the company foresee in terms of the battery legislation? Both: the EU legislation and voluntary certification systems.

Q2. How would it influence the company relation with a battery supplier?

[Note: For instance, the Battery Directive (1991) phased out hazardous metals from battery content; next version of this Directive (2006) incentivised battery collection and recycling. What can be expected as the next step, taking in account the Circular Economy approach].

Currently applied secondary battery technologies

Q1. What battery technology is used? Any planned shifts to newer technologies?

Q2. What are the main advantages of the applied technology?

Q3. Does it greatly affect component/product price?
Battery related issues with products

Q1. What is the percentage of problems (technical issues), related to secondary batteries - in company’s CE products? Any statistics?

2. Battery producers and technology developers

Objectives: to understand what producers can actually achieve, improving operational characteristics of secondary batteries. To see the difference between theoretical high-level performance batteries and commercially viable product.

Q1. Current trends in secondary battery production for small-scale application (portable electronics):

- What materials and technologies are applied?
- Main trends in the nearest future. Transmaterialism as a solution? [Note: shift to new, more sustainable and cost-effective materials].
- Expected prices per kWh battery.

Q2. What operational characteristics are expected to be improved, and to what extent - in terms of secondary batteries for portable devices (the octagon battery concept): 1) high specific energy; 2) high specific power; 3) affordable price; 4) long life; 5) safe usage; 6) wide operating range; 7) low toxicity; 8) fast charging.

Q3. Application of recovered materials in secondary battery production:

- Does the company find this economically viable and attractive?
- Does it allow to reach required product quality?
- If the company applies: what is the percentage of recovered materials in battery content?

Q4. Does the company control up-stream stages and processes? For instance, in terms of conflict minerals and resource scarcity. Down-stream processes?

Q5. What sustainability aspects (environmental and social) are considered by the company during battery life-cycle? [Note: Conflict minerals, resource scarcity].

Charging algorithms

Q1. Can we adjust algorithms to regulate charging process more efficiently? How ‘flexible’ and adjustable the charging algorithms are?

Q2. In general, more info on the charging algorithms.

Q3. Reasoning for and potential of applying so-called ‘smart chargers’.

Future

Q1. How the company imagines application of eco-design in terms of batteries?
3. Recycling companies

Objectives: to understand trends, recyclability potential, main drivers to recycle (legislation and/or profitability), and problems; views on REE, conflict/scare minerals and resources.

General questions

Q1. What is the current situation with recycling and material recovery: how does a company estimates own success and market/legislation readiness?

Q2. Main barriers in the secondary battery recycling area.

Q3. What are financial means? As I know, the EPR approach does not function in all states in US. [Note: In the EU the Battery Directive became a powerful driver for incentivising recycling, and regulating battery market, establishing Extended Producer Responsibility and setting collection targets. At the same time, if there is no regulation, recycling is completely market-driven: recyclers prefer to recycle batteries with high content of cobalt, copper, nickel.]

Process

Q1. Applied technologies, current recycling efficiency, and what can be achieved in the nearest future [Note: if it is possible, any statistics].

Q2. Quality of recovered materials. Can battery producers use them again for battery production, or the materials are too degraded?

Legislation

Q1. What changes does the company foresee in terms of the battery legislation? Both: national legislation and voluntary certification systems (for instance, EPEAT establishes certain requirements to rechargeable batteries in mobile phones).

For instance, the Battery Directive (1991) phased out hazardous metals from battery content; next version of this Directive (2006) incentivised battery collection and recycling. What can be expected as the next step, taking in account the Circular Economy approach.

Q2. What do recycling companies expect (measures) for simplification of collection, sorting and recycling procedures? [Note: maybe additional labelling of batteries? E.g. colour codes in Japan].

Q3. What would you suggest or consider as Best Available Techniques (BATs) in the secondary battery recycling sector?
Society

Q1. How does Call2Recycle explains the society that it is necessary to collect and recycle batteries? What kind of a message is sent?

4. Certification programmes

Objectives: to understand trends and upcoming changes in the requirements to cells/secondary batteries

Q1. Revising requirements to batteries in IT products. What battery life-cycle stages and environmental/social aspects are of the most interest for the programme?
Appendix V – Survey for Type I ecolabelling programmes

Survey: Criteria for rechargeable batteries in smartphones and laptops

I. Preliminary information and assistance.

Section 1.

This poll aims to gather feedback from the specialist, experienced in Type I ecolabelling - on aspects of rechargeable batteries in portable ICT devices (e.g. smartphones, laptops).

Received information will be utilised for the purpose of a research in this field on criteria development for the rechargeable batteries.

Researcher: Dmytro Kapotia, Candidate in MSc in Environmental Management and Policy, IIIEE, Lund University

Estimated time: 10 minutes.

Section 2.

Respondent information:

− Name and surname
− Position
− Organisation

Section 3

Instruction

A respondent is offered to go through 4 blocks of criteria:

1) Direct extension of life time (a rechargeable battery and a host device);
2) Indirect extension of life time;
3) Battery operational characteristics;
4) Battery content.

Each block contains 2 aspects, considered essential to rechargeable batteries.

It is not expected that the respondent has a solid background on rechargeable batteries. However, certain information is presented almost for each aspect.

There are 5 criteria for assessment:

− Relevance: how relevant an aspect for rechargeable batteries;
− Differentiate: whether such aspect has any potential to differentiate between different rechargeable batteries on the market;
− Applicability: easiness of implementation;
− Measurability: how easy to measure and quantify; availability of test methods;
− Market Distortion: whether the aspect causes barriers for certain stakeholder groups.
The respondent chooses between option "High" and "Low". Due to lack of certain information or any controversy, the respondent may choose "Don't know". Finally, there is a space for comments after each section.

II. Questions

Section 4.

1. Direct extension of life time. Rechargeable batteries

Background: Following basic instructions, a user can greatly extend battery life cycle during the use phase.

Aspect 1A. A guide for a user, aimed to extend battery life time.

This includes information on:

- optimal battery charge (within 50-80% range);
- ambient conditions that influence a battery (e.g. temperature of a battery);
- energy saving tips (Wi-Fi usage decrease energy consumption, compared to in-built radio).

Section 5.

1. Direct extension of life time. Host devices

Background: To make fixes and upgrades possible. For repair services.

Aspect 1B. A guide for specialists on repairing and upgrading.

This includes information on:

- how to disassemble a host product, and replace a battery in particular;
- how to upgrade and change configuration of a host device.

Section 6.

2. Indirect extension of battery life time

Background: It has been mentioned that WEEE is often recycled with batteries despite regulation, because products can not be disassembled. The product design, oriented on easiness of dissemble, allows to pre-manage the End-of-Life stage of rechargeable batteries.

Aspect 2A. Requirement for design of a host device.

Requirement on:

- disassembly, a possibility to replace malfunctioning components, including batteries; not glued.
Section 7.

2. Indirect extension of battery life time

Background: It is studied that product warranty increases consumer’s careful attitude to products. Availability of spare parts may extend the use phase, postponing the End-of-Life stage.

Aspect 2B. Warranty and spare parts.
- warranty on rechargeable batteries for 1 year;
- availability of spare parts (including batteries) for 5 years after stop selling a product.

Section 8.

3. Battery operational characteristics

Background: Based on conducted studies, and taking into account similar criterion by EU Ecolabel (750/1000 based on easiness of battery removability).

Aspect 3A. Number of charge-discharge cycles:
- 600 for replaceable batteries;
- 800 for permanently in-built batteries (in case if it is necessary).

Section 9.

3. Battery operational characteristics

Background: Trying to fulfil customer’s expectations on product - and a rechargeable battery in particular - performance, battery manufacturers increase energy density and decrease charging time.

Aspect 3B. Energy density:

To establish minimal energy density for rechargeable batteries as 150 Wh/kg.

Section 10.

4. Battery content

Background: Further limitation on metals in battery content. The Battery Directive establishes next limitations (by weight): Hg - 5 ppm; Cd - 20 ppm; Pb - 40 ppm.

Aspect 4A. Restriction on metals in rechargeable batteries (by weight):
- Hg: < 1 ppm;
- Cd: < 5 ppm;
- Pb: < 5 ppm.
Section 11.

4. Battery content

Background: each 5th cathode produced in the world contains cobalt, recovered by one of the world largest recyclers - Umicore. Usage of recovered cobalt and lithium would allow to decrease GHG emissions, associated with the battery production, decrease resource depletion.

Aspect 4B. Recycled materials in battery content.

- a battery cathode shall contain at least X percent of recovered materials (e.g. cobalt, lithium);
- a battery shall contain at least X percent of recycled plastic, or other recycled materials.

III. Final part

Section 12.

Final reflections

If you have any final comments, or reflections on proposed criteria for rechargeable batteries, please, share them. Perhaps, you would suggest to consider other aspects.

IV. Outro

Section 13.

Thank you for your time!

Please, do not hesitate to reach me for any clarification, or further dialogue!

Best regards, Dmytro Kapotia

Contact information:

Tel.: +46 72 038 80 31

E-mail: dmtr.kpt@gmail.com

Figure 1 demonstrates how a section with a question and suggested answers look like. The respondent estimates five main attributes for each aspect. The attributes may be evaluated either from “High” to “Low”, or as “Do not know” if the respondent finds difficult to estimate a criterion.
1. Direct extension of life time. Rechargeable batteries

Background: Following basic instructions, a user can greatly extend battery life cycle during the use phase.

Aspect 1A. A guide for a user, aimed to extend battery life time.
This includes information on:
- optimal battery charge (within 50-80% range);
- ambient conditions that influence a battery (e.g., temperature of a battery);
- energy saving tips (Wi-Fi usage decrease energy consumption, compared to in-built radio).

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance</td>
<td></td>
<td></td>
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<tr>
<td>Differentiate</td>
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<td>Applicability</td>
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<td>Measurability</td>
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<tr>
<td>Market Distortion</td>
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</table>

Your reflections, if any:

Your answer

![Image of survey form]

Figure 1. An example of a question from the survey for ecolabelling programmes

Source: The author
Appendix VI – Costs associated with Li-Ion cathode production

According to Bernhart (2014), cobalt is the main contributor to cathode price. Due to the highest content of cobalt, LCO material is the most expensive. NCM and NCA each require similar investments in equipment, have higher energy density compared to LMO. LMO has significantly lower material costs and requires less investment but the material typically used in combination with NCM or NCA.

The advantage of LFP is the low material costs which are counterbalanced by its higher energy cost (50-100% more than for NCA or NCM) and quality cost; it also requires larger investments (~15%).

Finally, natural resources form a significant part of the cathode manufacturing price, requiring more attention to both recycling and material recovery.

![Figure 1. Manufacturing costs of the Li-Ion cathode production based on the applied chemistry in 2015 year, percentage](image)

*Source: Bernhart (2014)*
### Appendix VII – List of contacts

The list of the stakeholders the author had pleasure to contact during the research. The ecolabelling specialists are highlighted with the blue colour.

<table>
<thead>
<tr>
<th>Name</th>
<th>Position, Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. Alain Vassart</td>
<td>General Secretary, European Battery Recycling Association (EBRA)</td>
</tr>
<tr>
<td>Ms. Alexandra Degher</td>
<td>Worldwide Lifecycle Assessment Program Manager, HP Vice-Chair , 1680.1 WG on criteria for computers (EPEAT)</td>
</tr>
<tr>
<td>Ms. Alyona Yuzefovich</td>
<td>CEO, Boxy. Battery collection and recycling service</td>
</tr>
<tr>
<td>Mr. Carl E. Smith</td>
<td>CEO, Call2Recycle, Inc.</td>
</tr>
<tr>
<td>Mr. Fredrik Benson</td>
<td>IT and Development Officer, El-Kretsen</td>
</tr>
<tr>
<td>Mr. Hans Wendeschlag</td>
<td>Sustainability Manager, HP</td>
</tr>
<tr>
<td>Mr. Jeff Omelchuk</td>
<td>Executive Director, EPEAT, Green Electronics Council</td>
</tr>
<tr>
<td>Ms. Kristina Eriksson</td>
<td>Battery Manager, El-Kretsen</td>
</tr>
<tr>
<td>Mr. Kristofer Sundsgård</td>
<td>Country Manager (within Sweden), Stena Recycling</td>
</tr>
<tr>
<td>Ms. Liv Södahl</td>
<td>Coordinator of “Shop Environmentally Friendly” (Handla Miljövänligt) Network and Administrator of Bra Miljöval butik, SSNC</td>
</tr>
<tr>
<td>Ms. Madeleine Bergraham</td>
<td>EMEA Social &amp; Environmental Responsibility, HP</td>
</tr>
<tr>
<td>Ms. Maria Wessemark</td>
<td>Battery specialist, Intertek</td>
</tr>
<tr>
<td>Ms. Naoko Tojo</td>
<td>Ph. D, Senior Lecturer, Deputy head of department, IIIEE, Lund University</td>
</tr>
<tr>
<td>Mr. Nicholas Dodd</td>
<td>Scientific &amp; Technical Project Officer, Joint Research Centre (JRC), European Commission</td>
</tr>
<tr>
<td>Mr. Niclas Rydell</td>
<td>Head, Standardisation Department, TCO Certified</td>
</tr>
<tr>
<td>Mr. Ove Jansson</td>
<td>Ecolabel Officer, Nordic Ecolabelling</td>
</tr>
<tr>
<td>Ms. Pamela Brody-Heine</td>
<td>Director of Standards, EPEAT, Green Electronics Council IEEE WG 1680.1 on standard for laptops and PCs</td>
</tr>
<tr>
<td>Mr. Paul Reynolds</td>
<td>Product Stewardship Manager, HP</td>
</tr>
<tr>
<td>Mr. Stefan Carlberg</td>
<td>Criteria Development Manager, TCO Certified</td>
</tr>
<tr>
<td>Mr. Stephen Fuller</td>
<td>Criteria Development and Compliance Manager, TCO Certified</td>
</tr>
<tr>
<td>Ms. Svetlana Perminova</td>
<td>Head, Green Crane</td>
</tr>
<tr>
<td>Mr. Thomas Hedin</td>
<td>Sustainability Manager/R&amp;D, Lenovo</td>
</tr>
<tr>
<td>Mr. Thomas Lindhqvist</td>
<td>Ph. D, Senior Lecturer, IIIEE, Lund University</td>
</tr>
<tr>
<td>Ms. Yulia Gracheva</td>
<td>Ph. D, Head, Vitality Leaf</td>
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</tbody>
</table>