

DEGREE PROJECT IN ENVIRONMENTAL ENGINEERING,
SECOND CYCLE, 30 CREDITS
STOCKHOLM, SWEDEN 2017

Smartphone sustainability assessment using multi-criteria analysis and consumer survey

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Acknowledgements

I would like to thank Tahero Nori for hosting and supervising my graduation internship at Techbuddy AB. Also I would like to express my gratitude to PhD. Rajib Sinha and Monika Olsson for supervising and counselling my graduation internship. Finally, I would like to express my gratitude to all of my friends and family for support during my studies at KTH Royal Institute of Technology Stockholm.

Abstract

Sustainability is a fairly new emerging business concept for manufacturing industry and this this thesis will specifically focus on smartphone sustainability. In 2015 there were 1.86 billion smartphone users and it is estimated to increase to 2.87 billion in 2020. Currently the average lifetime of a smartphone is 21 months and according to Consumer Technology Association the technical life expectancy of a smartphone is 4.7 years. The European Commission approximated that from 17–20 kg of electronic waste is produced per person per year and that smartphones are contributors for increase of electronic waste.

Also, the smartphone manufacturing process has an impact on the people who are involved in manufacturing and resource extraction process. Related social problems include conflict minerals, issues on manufacturing campuses, health problems and excessive working hours. It is speculated that large manufacturing companies use labour market in areas that have a high risk of poverty or lacks national authority that can protect labour rights. To investigate these emerging issues that have an impact on smartphone manufacturing sustainability, a sustainability ranking criteria for individual smartphones devices and their manufactures was developed.

Furthermore, the aim of this research is to develop a ranking system using life cycle perspective and to evaluate sustainability of a smartphones upcycling, recycling, and its' social aspects. This aim will be accomplished by the following objectives: Develop evaluation system for smartphones using Multi-Criteria Analysis (MCA) to assess sustainability; comparing sustainability of smartphones Fairphone 2, iPhone 7, Samsung Galaxy S7 and LG G5, using the developed Multi-Criteria Analysis (MCA); conducting general sustainability-focused survey on consumer demand for sustainable and ethical electronics.

The method used in this research to assess smartphone sustainability was a Multi-Criteria Analysis(MCA), that was based on eco-design trends and three pillars of sustainability, – economic, environmental and social. Eco-design will be supported using EcoDesing Roadmap by Conrad Luttropp and Göran Brohammer.

In addition, with MCA method a survey was developed to briefly assess consumer behaviour in terms of choosing sustainable electronics. The results of this survey will be used as indicators, to better understand what consumer value when making a purchase decision, a survey was made considering technical and sustainable aspects. The results of this survey will be used as indicators.

Furthermore, results from this research (Table 1 MCA evaluation results) revealed that majority of chosen smartphones were lacking sustainable products aspects. This MCA ranking system also confirm that for a sustainable designed smartphone it is equally important to have well established environmental management system for the overall manufacturing process as well as the afterlife of smartphone.

Continuing, after conducting a deeper analysis with combined results from MCA, the survey revealed that the general public are willing to pay more for sustainable products, but consumers lack information about the overall manufacturers process, indicating that communication between manufacturers and consumers are very weak or even one way.

The conclusion of the study about Smartphone sustainability assessment using multi-criteria analysis and the consumer survey has provided a better understanding of the lack of transparency and complex logistics of manufacturing process of a smartphone.

The lack of qualitative data and transparency from the manufacturers' side is a major issue that creates a lot of uncertainties about smartphone manufacturing and social issues for workforce that is involved in this manufacturing process.

Key words: sustainability, smartphones, multi criteria analysis, survey, environmental management, transparency, corporate social responsibility

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List of abbreviations

CSR – Corporate social responsibility

EU – European Union

EEB - European Environmental Bureau

EPI - Environmental Performance Index is a method of quantifying the environmental performance of countries polices.

GB – Gigabyte 1000^3 bytes

HDD - hard disk drive

LCA – Life cycle assessment

iFixit - global community of people helping each other repair electronic gadgets

MCA – Multi criteria analysis is a tool of operations research that assess multiple conflicting criteria in decision making.

Micro SD- non-volatile memory card

TCO - Swedish Confederation of Professional Employees

USD – United States Dollar

USB - Universal Serial Bus

3T&G – Tin, Tungsten, tarantula and gold

Life cycle - is sequent and connected states of products or service system, beginning from material extraction and production from natural resources to final disposal. This includes extraction of raw materials, design, production, transportation and final disposal (International Organization for Standardization, 2016).

1. Introduction

Sustainability is a fairly new emerging business concept, therefore we lack uniform guidelines relevant to the specific industry, including the smartphone manufacturing industry (Supply Chain Resource Cooperative, 2012).In 2015 there were 1.86 billion smartphone users and it is estimated to increase to 2.87 billion in 2020 (Statista, 2016). Currently the average use time of a smartphone is 21 months (Walton, 2017). According to Consumer Technology Association the technical life expectancy of a smartphone is 4.7 years (Ely, 2014).The impact on global warming due to the short smartphone life span can be reduced if smartphones' life would increase to five years. This could reduce 30% of carbon dioxide emotions from smartphone manufacturing process (Tobien, 2017).

To reduce electronic waste production from smartphones, sustainable electronic solutions need to be implemented. However sustainable smartphones have a small market. Currently the most known smartphone manufacturer that attempts to implement sustainability and transparency during manufacturing process is Fairphone B.V. (The Droid Guy, 2016). Fairphone B.V. is a smartphone designed with ecological and ethical issues foremost in mind, currently they produce Fairphone 2 which is made from recycled, recyclable and responsibly sourced goods as well as minimal packaging.

In total 60,000 units of Fairphone 1 model (Joseph, 2015) were sold. According to consumer survey about 10-20% of customers are willing to pay more for sustainable smartphones meaning that there is a market for sustainable electronics (Brydolf, 2010). In December of 2015 the second generation of Fairphone 2 was released with a new benchmark for sustainable smartphones – long lasting design and fair materials (Schmidt, 2015). Fairphone 2 model has been produced since May 2016 manufacturing 40,000 units and Fairphone B.V. aims to sell 150,000 annually (Koschyk, 2016). In comparison, from 2009 to 2016 Samsung Electronics Co., Ltd. has sold 77.5 million and Apple Inc. 210 million smartphones (Satista, 2016).

Nowadays it is difficult for a consumer to compare sustainability that could support environmental benefits of a smartphone, due to the lack of qualitative data and transparency. A ranking system that can rank the sustainability of smartphones can provide useful information for consumers to make sustainable decision. In Sweden there is such a label for smartphones – TCO certificate (Brydolf, 2010). TCO – Certifies that a smartphone meets sustainability criteria such as socially responsible manufacturing, ergonomics, environment, health and safety (Brydolf, 2010). There has been criticism about this TCO certification. Therefore, an investigation was conducted to assess and compare TCO standard to Fairphone B.V. standards (Schipper, 2015). A study from Irene Schipper (SOMO) "TCO Certified Smartphones versus Fairphone" concluded that Fairphone B.V. has scored better than TCO standard, because it does not take a leading position on the social critic and Fairphone B.V. received critique about not including hazard monitoring during smartphone manicuring process (Schipper, 2015).

There are also other sustainability ranking tools available online like ECO rating 2.0, or Greenpeace ranking. Both of the previously mentioned sustainability rankings lack a specific category about smartphone sustainability ranking (International Organization for Standardization, 2016). They manly provide a general overview about sustainability that will be explained in chapter 1.3 Research Gap.

1.2 Pollution and problems caused by unsustainable smartphones

T production of smartphones involves many stakeholders and has a high demand for materials. In each manufacturing step, a smartphone creates impact on our environment and, European Commission has approximated that annually an EU citizen produces from 17–20 kg of electronic waste and that smartphones will contribute to the increase of electronic waste during the near future (Basel Convention, 2008).

Electronic waste makes up only 2 % of the landfills waste, but accounts for nearly 70 % of the toxic heavy metals in these landfills which could cause environmental problems for the local surroundings. Guiyu is the largest recycling hub in China. The air in Guiyu is polluted with heavy metals like lead and exceeds up to three times compared with industrial areas in Europe also polybrominated diphenyl ethers (PBDEs), which are flame retardants used in electronics contributes to ecosystem degradation. These high levels of lead have a profound impact on the local ecosystems like degradation of regional biodiversity (Wu, et al., 2016). The presence of free heavy metals in the environment has connection to several negative effects on humans and animals. Primal human diseases caused by heavy metal exposure are cancers, birth and immune system anomalies, mental retardation, low fertility and specific organ dysfunctions (Tchounwou, et al., 2012). Also 169 children of families whose members worked with dismantling printed circuit boards and other electronics, have been tested for lead poisoning - over 82 % of these children showed higher than average levels of lead in their blood (Wilson, 2016) .

Lastly, mining of tin at Bangka Island which is located next to Indonesia has been heavy contaminated with tin mining waste which is mainly naturally occurring sediments. Dredging for Cassiterite (SnO_2) in the island has contaminated 70 % of the coral reefs with sediments that harms coral reef ecosystem. Additionally, this contamination of sediments has created difficulties of accessing clean fresh water for the local inhabitants (Friends of the Earth Europe, 2012).

1.3 Research gap

Previously similar research has been conducted using MCA on their environmental and social impacts in the different lifecycle stages of smartphones` sustainability - Olivia Engstrand`s research “An analysis and classification of smartphones sustainability performance” (Engstrand, 2015) using MCA was based using TCO standards for IT technologies (TCO, 2017) for analysing and characterizing the performance of smartphones` sustainability. Olivia Engstrand’s research found that follow-up communication with consumers and suppliers is weak (Engstrand, 2015). Over all this previous study provides in-depth analysis about smartphone sustainability allaying substances of concert, sustainable materials, life cycle thinking, use phase, life prolonging features, end-of-life and recycling, supply chain accountability and transportation. This study is more intended towards smartphone suppliers, manufacturing process and hazardous materials used in the manufacturing process.

Furthermore, similar smartphone or electronic product sustainability ranking is provided by “Greenpeace – Guide to greener electronics” where electronics are ranked in three categories: energy, resources consumption, chemicals. Energy - where the main focus is on GHG emission management and mitigation, Chemicals - elimination of hazardous chemicals from both the product itself and manufacturing. Resource consumption - sustainable design and use of recycled materials (Greenpeace, 2012).

ECO 2.0 ranking performs a similar ranking where manufactures have to fill the questionnaire about manufacturing of their product, emissions, material usage, recyclability, hazardous chemicals and reusability (The Forum for the Future, 2017). Greenpeace and ECO 2.0- these sustainability ranking systems have not been updated and in some cases are not accessible for overview.

Overall Greenpeace, ECO 2.0 and Olivia Engstrand`s MCA ranking systems provide all available information on smartphone sustainability, but neither of these ranking systems include ranking about smartphone design in terms of promoting modularity and upcycling. In some cases, the overview of sustainability ranking is difficult to comprehend and compare. This research intends to include the smartphone design and life cycle perspective in sustainability ranking and to provide a practical overview for consumers to make sustainable purchase decisions.

1.4 Aim and objectives

The aim of the research is to develop a ranking system using eco-design perspective and to evaluate sustainability of a smartphone - upcycling, recycling, and social aspects. This will be accomplished by the following objectives:

- Developing an evaluation system for smartphones using Multi-Criteria Analysis MCA to evaluate sustainability;
- Comparing sustainability of smartphones Fairphone 2, iPhone 7, Samsung Galaxy S7 and LG G5, using developed Multi-Criteria Analysis (MCA);
- Conducting general sustainability focused survey about consumer demand for sustainable and ethical electronics.

1.5 System boundaries

The system boundaries used in the final master thesis are presented in Figure 1. This research focuses on three categories sustainability, environment and social. The environmental part is divided into two sub categories - upcycling and recycling. Upcycling category focuses on the evaluation of smartphone function prolongation, and the recycling category focuses on reducing the environmental impact of smartphone disposal by recycling its parts. Social category focuses on reduction of social issues created by resource extraction and the manufacturing process of smartphones.

1.5.1 Exclusion of economic aspect

There are two primary reasons for excluding the economic part from this research - the unknown amount of time and lack of information that would be needed to conduct a qualitative research. During the screening process, it was difficult to find qualitative and reliable data about the current economic data about smartphone sustainability. The economic aspect could have a minor influence of this research if cost of upcycling and recycling would be included. Also there is a possibility that economic aspect could prove that there is not enough information and data transparency available.

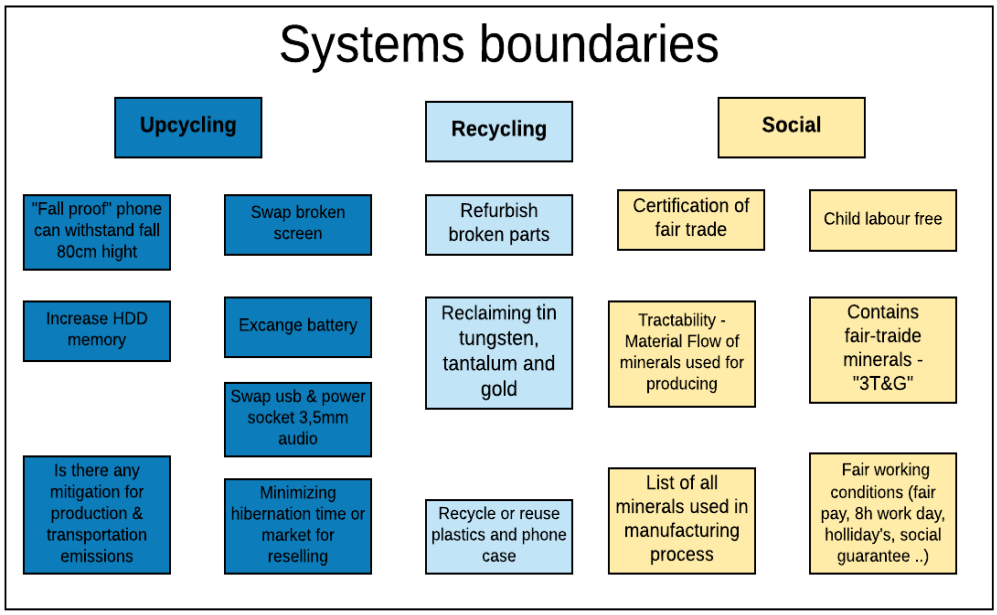


Figure 1 System boundaries of thesis research

2. State of the art

This chapter "Literature study" will exploit the latest information in smartphone sustainability, manufacturing process, environmental and social impacts. Also this chapter will explain the problems with inefficiencies of smartphone recycling, social problems related to material extraction, smartphone assembly, and usage of fair trade materials. It is important to mention the environmental burden that unsustainable smartphone production creates. And finally briefly describes the costs of smartphone manufacturing and salary of people who work at smartphone assembly lines.

Smartphones have become commodities for executing daily tasks, communication and socialization with friends and family. It has been estimated that in 2018 there will be 2.32 billion smartphone users (Statista, 2015).This increase of smartphone users creates concern for the environmental impact and sustainability problems related to the manufacturing, use and end- of – life processes of smartphones. Currently the life cycle of smartphones is linear which creates concern for future sustainability.

Sustainability is the ability to continue a defined behavior indefinitely. The three pillars of states that to achieve complete sustainability all three pillars of sustainability (i.e. social sustainability, environmental sustainability, and economic sustainability) must be stable (Daly, 1990).

2.1 Smartphone upcycling and recycling

Meanwhile, globally less than 10% of all phones are recycled (Welfens & Nordmann, 2016) Smartphone recycling is an expensive and complex issue, due to the high variety of materials, material hygiene, and components used in these devices. According to Ifixit.org mobile phone recycling companies get 0.5 USD for the raw materials in a phone, but for a reseller it is possible to get on average 20 USD per a device. Around 320 tons of gold and 7.5 tons of silver with a value of 21 billion USD are used annually for manufacturing new electronic device (Wharton School;University of Pennsylvania, 2016). On average it is possible to extract 1g of gold using 35 – 40 phones and that is equal to one ton of gold ore (Moore & Farook, 2014).The average return and handling costs for a single mobile phone return in 2006 in the USA are return incentive 3 USD, collection and shipping 1.9 USD, inspection and sorting 2.8 USD, amounting to total costs of 7.7 USD to handle a collection of a mobile phone. (Geyer & Blass, 2009)

It is possible to extract from 0.028 up to 0.037g of gold per mobile phone, using an average price of gold per gram of 12.87- 21.52 USD (Geyer & Blass, 2009) , profiting 0.47-0.61 USD per device. On its own, cell phone collection and recycling could never be done profitably, even if reverse logistics costs were to be minimized (Geyer & Blass, 2009) With the current situation with material recovery of copper and gold already make up 95% of the metal value of a mobile phone, the profit from recycling severely depends on the market value of gold and the amount of gold in a mobile phone (Geyer & Blass, 2009).

Apple Inc. recently has announced a new type of recycling method: dissembling robot called Liam which can do the reverse process of assembling. The company claims that this robot can dissemble its phones in 11 seconds, which is an amazing and fast way of recycling phones. At the same time Apple Inc. uses the same logistics system and check-up of a device before giving this device for break down to Liam, which was previously mentioned that logistics costs are still too high. This robot accepts only devices which are not older than

IPhone 5 (Urry, 2016) .The company has not taken into account the biggest issue in this industry - bad design of smart phones (make them very brittle un hard to upgrade or replace broken parts) and lack of transparency of material flow in the production of smartphones.

Furthermore, the average technical life expectancy of a smartphone is 4.7 years (Ely, 2014) , but this estimation is based on when a device becomes obsolete in today's demand for processing and functionality demand. Also the average smartphone user in the United States changes its phone to a newer model every 21 month (Walton, 2017). The reason is that newer models are coming out more often, with better upgrades bigger screens and new looks, but the most common reason to get a new smartphone is because the previous one broke with the most common problems – broken screen or battery has lost its charge (Carnoy, 2015). It has become an lifestyle of changing smartphones every time when the newest models comes out and this is creates an impact on our evironment.

With the help of "Ecological Rucksack" (ER) it is possible to estimate the entire sum of materials in kg that are taken from nature to develop a service or product subtraction the real weight of the product or service. For example, a single smartphone uses approximately 0.080 kg of materials which creates total Ecological Rucksack of 75.3 kg. Where 35.3 kg comes from raw material extraction,31.7 kg user phase, 8.2 kg production and lastly 0.1 kg collection and transportation/end of life (Welfens & Nordmann, 2016). It has been estimated that the core module contributes to 60% of the overall environmental impact, compared to a display that has 7% and a back cover 0.3% impact (Salvà, 2016).

2.2 Modularity and Smartphone design

Currently the market does not have demand for modular phones and there are only a few companies that manufacture them. In the market there are a few new modular smartphones under development like PuzzlePhone and Fairphone 1 and 2 that have raised awareness in the smartphone industry, by promoting conflict-free mineral usage and innovative design (modular). For example, life cycle assessment (LCA) was conducted on Fairphone 2 and they found that modular smartphone design will reduce global warming potential (GWP) by 30% (Salvà, 2016) (Srinivas, 2016).

It is difficult to develop a modular smartphone due to the fact that it is complicated to develop a new underlying architecture that will perform well and is cheap to manufacture. There are some more important things that should be taken into account such as durability, design of a device, life of battery and testing part in order to see how this modular device can be used (Ricknäs, 2015). It was very expensive and time consuming and it took some time for Fairphone B.V. to develop a modular design with the Fairphone 2 editions.

However, there are some modular phones that have not been launched yet, for example, PuzzlePhone, which is made by three modular compartments – brain, spine, heart (Puzzlephone, 2016).Each module can come with different purposes and upgrades for example, photo enthusiast can swap its simple module with upgraded high definition camera module. Each of this module can use other house appliances or it is possible to pair them in series and create a computer (Puzzlephone, 2016).

Furthermore, an important aspect of future modular smartphones is sustainable raw materials – gold, tantalum, tin and tungsten. These minerals should be conflict free

minerals, that their mining does not support local social issues, war and harm to human health (Fairphone B.V. c, 2016).

Gold is used in smartphones circuit boards (PCB's), because it has an excellent conductivity and resists corrosion (Gerritsen, 2016) .Tantalum is the major component of micro-capacitor (Papp, 2008). Tin is used as soldering paste to connect chip packages to the attachment points and printed circuit boards. Tungsten is used as counterweight for vibration motor (Gerritsen, 2016).

List of elements in a smartphone:

- **Electronics**: Cupper (Cu), Silver (Ag), Gold (Au), Tantalum (Ta), Nicle(Ni), Dysprosium (Dy), Praseodymium (Pr), Terbium (Tb), Neodymium (Nd), Gadolinium (Gd), Tin (Sn), Lead (Pb)
- **Casing**: Carbon(C), Magnesium(Mg), Bromine(Br), Nicle(Ni)
- **Battery:** Lithium(Li), Cobalt (Co), Carbon (C), Aluminum (Al), Oxygen (O)
- **Screen:** Indium (In), Tin (Sn), Oxygen (O) Aluminum (Al), Silicon (Si), Oxygen (O), Potassium (K), Yttrium(Y), Lanthanum(La), Terbium (Tb), Praseodymium(Pr), Europium(Eu), Dysprosium(Dy), Gadolinium(Gd). (Compoundchem, 2014)

Finally, research conducted by (Sinha, et al., 2016) has given a very good insight on the important aspects of modelling smartphone production, using and end- of- life phase. For example, life span, hibernation and modularity are some of the most important criteria for a sustainable smartphone. Recyclability should be avoided also and only used when the device cannot be used or refurbished. This part of recycling smartphones is one of the key problems due to the material hygiene and it is not feasible to recycle smartphones due their complicated hardware elemental composition (Luttropp & Brohammer, 2014) ;(Sinha, et al., 2016),.

2.3 Smartphone social impact

In 2010 the US Congress adopted the Dodd–Frank Wall Street Reform and Consumer Protection Act, in which the section 1502 states to stop the Democratic republic of Congo from using profits from trade of minerals to fund their war. It also requires that companies should provide data that they do not use conflict minerals and report this to the Securities and Exchange Commission (SEC) (U.S. Securities and Exchange Commission, 2010).

To reduce the risk of conflict minerals being imported into the EU, there is a new regulation that has been proposed in May 2017 with the aim to stop import of these minerals exported to the European Union, stop global and European Union smelters and refiners from using conflict minerals and abuse of mine workers. All companies in the EU will have to ensure that tin, tantalum, tungsten and gold come only from responsible sources. This law will come in force on the 1st of January 2021 (European Commission, 2017).

Both of these regulations can reduce or eliminate the risk of social problems related to mineral extraction, but the manufacturing process of a smartphone is still at risk. The production of a smartphone creates not only problems related towards extraction of conflict minerals, but also the manufacturing process itself. The social problems related to manufacturing are mostly related to health problems of workers who work with dangerous substances, including over excessive working hours. It should be mentioned that some companies do not have workers' union. (Lempers, 2016). The working hours' limit in China are 49 hours per week (The Telegraph, 2012) with an overtime over 8 hours, overtime rate

for the next hours is 150% of a normal hourly wage and up to 300% of a normal wage if your work was on a national holiday (Yang, 2016). Fairphone B.V. reported that their manufacturing in China on average exceeds 60 hours per a week with at least one day off (Lempers, 2016). At the same time Apple Inc. factory workers also exceed the 60 hours working week (The Telegraph, 2012).

The average working day for a factory worker includes 30 minutes' security clearance, 10.5 hours of work including 2.5 hours of overtime, 10 minute break every two hours and lunch break of 50 minutes. This investigation was conducted by a student from NYU(New York University) who worked undercover at an iPhone production site. This NYU students investigation also revealed that overtime is not voluntary (Lovejoy, 2017) and in some situations there are workers who seek for overtime, but it is due to the financial pressure of a low base salary. The living conditions of these workers at Pegatron Corporation are changing from nondescript factories and sweatshops to modern campuses of 50,000 inhabitants with Wi-Fi, television lounges, cleaning services and sport activities (Oster, 2016). Pegatron Corporation is Taiwanese electronics manufacturing company.

The base wage of a factory worker is 263 USD per month or 1.5 USD per hour. This pay can be raised, depending on a worker's performance and position. A company provides 45 USD meal subsidy per month, the cost of shared dorm room with 12 workers is 21 USD per month per a person. The monthly meal expenses for workers are between 65 – 97 USD per month (China Labor Watch, 2013).The average age of a factory workers often is young (Under age 35) (China Labor Watch, 2013), single and would rather work to save money, no skills are needed to work in this smartphone assembly's companies (Lovejoy, 2017). The average salary varies from 360 – 455 USD per month. The taxes are deducted if the income exceeds 569 USD a month (China Labor Watch, 2013). It is estimated that Apple pays 8 USD for an assembly of 16 GB iPhone 4S and 188 USD for its components (The Telegraph, 2012) and production of iPhone 7 per unit is 5 USD assembly and 219.8 USD components (Reisinger, 2016). The production costs of Fairphone 2 is 340 EURO labor and materials (Fairphone, 2016) and Samsung Galaxy S7 32GB - 255 USD (Do, 2017).

According to the latest data from China Labor watch the living conditions at Pegatron that was described has worsened compared to 2013 and 2015 report: Poor housing conditions, reduced dinner break, work contract reduced from 2 years to 4 months, wages have remained the same as in 2013 (China Labor Watch, 2015).

To reduce social issues with work force it is possible to use assembly robots. Currently Foxconn has replaced 60,000 factory jobs with automated robots. The assumed costs of these robots are between 20,000 USD - 25,000 USD (Beasley, 2014).For example, McDonald U.S. has investigated that it is cheaper to buy a robotic arm with costs 35,000 USD instead of using employee with a minimum vague of 15 USD per hour (Statt, 2016).

It is estimated that by early 2030 there is a risk that robots can replace human operated jobs estimated in 38% in the U.S., 30% in the United Kingdom, 35% in Germany and 21% in Japan (Masunaga, 2017). The drawbacks of automatization are large initial investments that are needed, reduction of versatility by having a robot that can only perform a specific task. Also there is possibility of higher pollution due to the production of these machines and their maintenance (Blue, 2013). The automatization of a smartphone manufacturing could reduce

social problems that occur in the manufacturing sites, but they could create new problems for workforce by taking their jobs. But the advantages of automation are reduction of human error, possible reaction of employee costs, increased safety, reduction in production time and increased accuracy (Blue, 2013).Automation can positively affect sustainability by efficient production and efficient material usage by reduction of production errors and breakage (WHEB, 2017).

3. Methods

This research will be approached using Multi-Criteria Analysis in order to evaluate sustainability of smartphones, including their design and social measures taken to improve and understand sustainability of smartphones.The two main methods that were developed and executed for this research will consist of a survey and MCA.

3.1 Survey

The aim of this survey was to briefly assess the consumer's behaviour in terms of choosing sustainable electronics and to understand better what consumers value more in sustainable electronics – is it an ethical part or a technical part of an electronic device that is important. The results of this survey will be used as indicators for future reaserch about how the consumer chose their smartphones.

This survey also asks if consumers are willing to pay more for devices with sustainability standards and certifications and if the consumers consider the overall corporate social responsibility importnat (CSR - the image of the company's as overall sustainability and their objectives for mitigating pollution). The survey consists of nine questions. The preview of the survey is added in the Appendix I Survey - Sustainable and ethical electronics.

The results of this survey will provide a better understanding about what is valued more in sustainable smartphones from a consumer's perspective. Is it their positive impact on the people who are involved in production of smartphone (social sustainability) or value more of environmental friendly materials and its design aspect used in the smartphone (sustainable electronics).

Social sustainability is defined as:

> *"The ability of a community to develop processes and structures which not only meet the needs of its current members but also support the ability of future generations to maintain a healthy community"* (Business Dictionary, 2017)

In this study it is defined as having Fair working conditions - (fair pay, 8h working day, social benefits, holidays, safe working conditions) and corporate social responsibilities (CSR). Sustainable Electronics – electronic products that are modular, uses eco-design aspects, functions with a long-life span and is recyclable.

The data of this survey are quantitative. They show a better understanding about consumers` behavior, their values and needs. The data of this research has been quantified in excel spread sheets and translated to graphs for a better overview. The survey provides information about consumer's attitude towards sustainable and ethical electronics, willingness to pay more for these kind of products, and which aspects of sustainable design consumers value the most. The survey consisted of nine questions, eight of them were

multiple choice questions and one was grading question from the least favorable to the most favorable.

The boundaries of this survey, based “Tech Buddy AB” preferences, had to be completed in 5 minutes and should have consisted of no more than 10 questions. The preferences were based from “Tech Buddy AB” previous experience where consumers where not interested in time consuming surveys. The survey was developed using “Google Survey” tool and this was also used for survey data storage. Distribution of the survey was conducted using social media(LinkedIN , Facebook) and emails.

The target audience for this questionnaire were residents located in Sweden with age group ranging from 20 – 40 years old, with a university degree or vocational education. This include KTH Royal Institute of Technology Sustainable Technology students and tutors, service staff at large hotel (previous work place), Tech Buddy AB co-workers and partners, students from the local dorm room and others). Even though the participants of this survey where a mix of different backgrounds, a large part of them came from a background that is related to sustainable technology.

3.2 Multi-criteria analysis evaluating sustainability of smartphones (Objective 1)

MCA is a practical tool to understand better and represent a given situation, for example, evaluation of smartphone sustainability. Building up a multi-criteria analysis from online literature can present uncertainty due to the quality of literature, limited knowledge, approximation capabilities of smartphone sustainability. MCA was selected because it can provide evaluation for large amount of multiple types of information that can help with assessment for multiple types of disciplines. In this case the MCA will be used to assess smartphone sustainability using criteria that is described at the end of this paragraph (Figueira, et al., 2006).

This chapter will be divided in to these parts:

- Introduction of smartphone sustainability criteria
- Multi-criteria assessment categories
- Multi-criteria assessment evaluation road map (Fig.2)
- Sustainability ranking normalization and weighting

3.2.1 Criteria of evaluation of smartphone sustainability

Smartphone sustainability will be evaluated using eco-design, environmental and social sustainability. Eco-design will be supported using “Eco-Design Roadmap” by Conrad Luttropp and Göran Brohammer. Their research of Eco-design has developed straightforward guidelines how to develop sustainable products. In Luttropps and Brohammers book, they have divided Eco-design (ED) into ten “golden principles”: function, human resources, toxic substances, energy, material resources, economy, material hygiene, lifetime, context and information (Luttropp & Brohammer, 2014). In this research only few of these golden principles will be used (material resources, material hygiene, human resources, context and information)because these categories were more related for assessing smartphone sustainability.

The evaluation of an individual smartphone will be ranked in three categories – Upcycling, Recycling and Social. Each of these categories have subcategories where each category is

marked with three possible answers: Yes; No; Other and in some cases there is an alternative answer like “Only by technician/not feasible”.

MCA ranking formula is summarized in chapter 3.2.3 Sustainability ranking normalization and weighting. The results of this evaluation will be transferred to a sustainability grading scale, which can be found in 4.2 “MCA evaluation of smartphones results”. This ranking will determine if this smartphone leans towards unsustainability or towards sustainability, in basic terms: does this smartphone bear a positive or negative effect on Sustainability (In this research environmental and social sustainability).

The two main categories are environmental sustainability, followed by social sustainability, but the economic part is left outside in the scope of research (as it is explained in chapter 1.4 Aim and objectives). The Environmental part is divided into two categories - upcycling and recycling. Upcycling maintains functions and life span of a smartphone in order to avoid disposal (Luttropp & Brohammer, 2014). Recycling reduces unusable parts and scraps as much as possible , while at the same time giving them another life through refurbishment or claims back valuable materials for reuse and possibly closes the material loop cycle (Sinha, et al., 2016). The social part focuses on conflict free minerals, fair working conditions and certifications of sustainability (Lempers, 2016). A general overview of these categories is explained in Figure 2. “MCA evaluation road map”.

Furthermore, a simple user- friendly model was made for a quick and reliable evaluation of smartphone sustainability. Fairphone B.V.s (Lempers, 2016) research conducted on production of sustainable smartphones (Luttropp & Brohammer, 2014), (Sinha, et al., 2016), and hand book of Multiple Criteria Decision Analysis by Corporate sustainability ranking platform “Rank a Brand” provided reliable sources for gathering necessary data for smartphone evaluation (Figueira, et al., 2006).

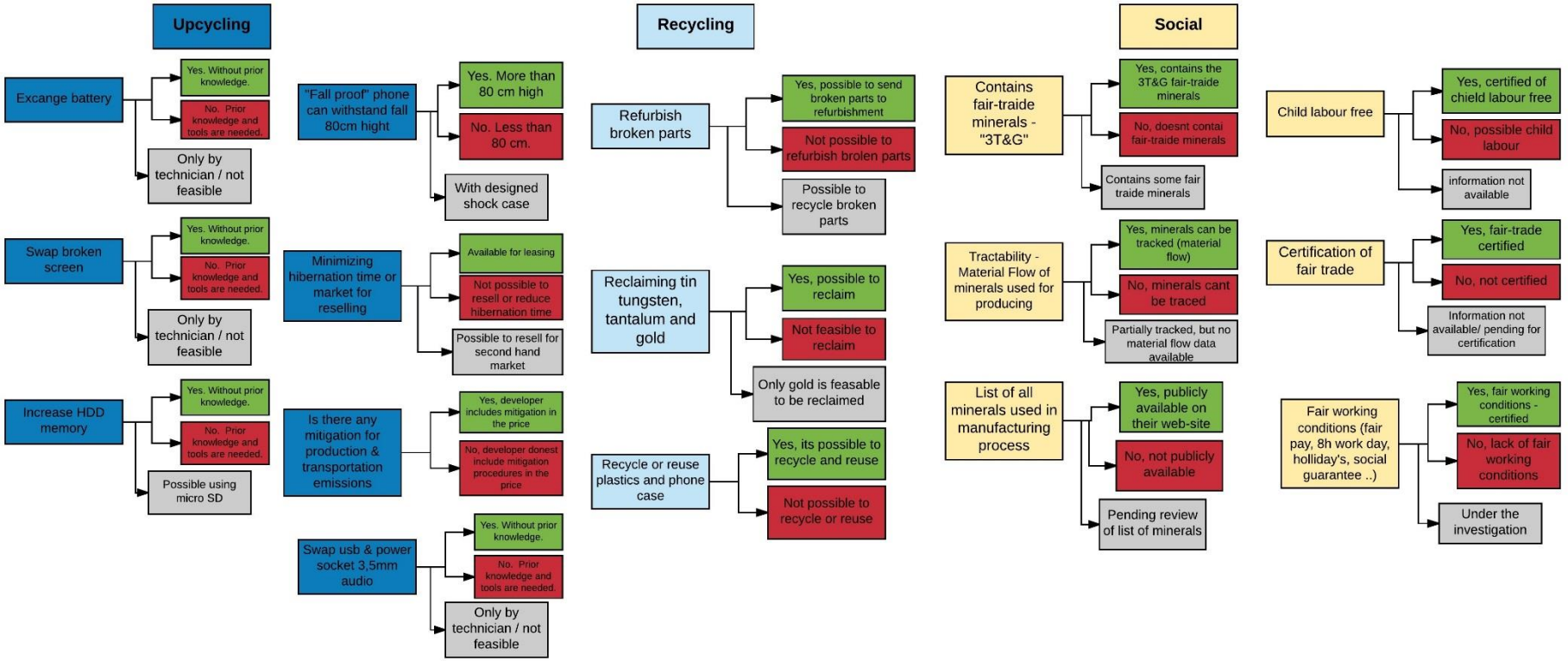


Figure 2 MCA evaluation road map

3.2.2 Multi-criteria assessment categories

This chapter describes in detail each evaluation category with a description of keys issues and their impact on sustainability. Each of these evaluation categories were developed using information from the literature study and detailed information to have a better understating about each evaluation category. Figure2. “MCA evaluation road map” provides a visual overview of each of the following categories.

Upcycling:

Exchange of batteries

The average battery lifespan is from 300-500 charging sequels and a charging sequel is defined as every time when the battery is charged under 70% (Villas Boas, 2015). After 250 charging sequels the battery capacity can drop from 10-15% (Villas Boas, 2015). This is not the issue if a smartphone has a removable battery, but many popular and high end smartphones have a built in battery which cannot be removed easily and safely without damaging the device. The reason for having an integrated battery is a space reduction and possibility to have a slimmer, lighter and faster device. The manufactures also point out that with integrated batteries people will not tinker with device by causing damage to it (Banerjee, 2015). The option of having a removable battery is important, because this will increase life span of the device, when the battery will not hold charge as a new battery (Banerjee, 2015).

Swap broken screen

The display has always been the most sensitive and fragile part of the modern smartphone. The average expectancy of damaging a smartphone’s screen by dropping it on a hard surface, statistically is the 10.4 week after purchasing.

To change smartphone screen, tools and prior knowledge is needed. For example, to replace a screen for Samsung Galaxy S7 use guidelines of “Ifixit .com” it will take 45 minutes, but for Iphone 7 it will need 30-60 minutes and around 8 different tools (Noronha, 2017) (Brian, 2017). This practical example shows that this common problem of fragile displays is neither practical nor sustainable. There are several options for bringing your smartphone to a designated shop where a technician can change the screen. But the range of price can vary, up to 150 USD for changing glass screen of iPhone (UBREAKIFIX, 2017).

Increase SSD (Solid-state drive)

Most of the smartphones have an internal flash memory that could vary, but some smartphones have the option to add more memory using SD (Secure digital), but some offer an alternative as cloud storage. Internal memory of a smartphone affects installed application access and processing speed. If more memory is available the data can be processed much faster (Goyal, 2016).

Swap USB, power and 3.5 mm audio jack

Universal Serial Bus (USB) socked is the most used part of a smartphone for charging, data transfer, and other auxiliaries. This part of the smartphone has a finite life span. For example, it is estimated that a micro USB socket’s lifespan should be 10,000 cycles, meaning plugging in and out will wear down the socket and it will possibly break (Kishore, 2014).

"Fall proof" phone can withstand fall 80cm high

Smartphone should be fall proof and withstand fall 80 cm minimum - according to the Fairphone B.V. an average height is from a human hand till feet (Fairphone B.V. a, 2017).

Minimizing hibernation time or market for reselling

Reduced hibernation time is an important role for a smartphone`s life cycle. It is important that a device is used or resold back to the market in order to reduce demand for production of more devices and usage of resource. Reduction of hibernation time till one year will possibly affect the resource conservation and prolong device`s function time before disposal (Sinha, et al., 2016).

Mitigation from production and transportation emissions

Manufacturers should place mitigation plans in order to reduce impact from production and transportation. They should follow the procedure of polluters pay principle (Graedel & Allenby, 2011). The manufacturers also include mitigation procedures in a smartphone`s price (Luttropp & Brohammer, 2014).

Recycling:

Refurbish broken parts

Refurbishment of broken smartphone parts can increase sustainability of smartphones and more efficient use of resource. Refurbishment of broken parts will increase longevity and reduce disposal (Intercon, 2010) (Fairphone B.V., 2017).

Reclaiming of tin, tungsten, tantalum and gold

Reclaiming valuable minerals from smartphones will reduce extraction of raw materials and by favouring circular material flow will possibly close the loop cycle of used materials (Sinha, et al., 2016) (Geyer & Blass, 2009).

Recycle or reuse plastics and phone case

Recycling or reusing of plastics and phone cases can increase sustainability and reduction of the use of virgin materials (Fairphone B.V., 2017) (Geyer & Blass, 2009).

Social:

Contains fair-trade minerals: tin tungsten, tantalum and gold

Evidence that a smartphone contains certified, fair trade minerals - gold, tungsten, tin, tantalum (3T&G). They also comply with Dodd–Frank Wall Street Reform and Consumer Protection Act at section 1502 and the new EU law of conflict minerals (European Commission, 2017) (U.S. Securities and Exchange Commission, 2010).

List of all minerals used in manufacturing process

Companies should disclose all minerals used in manufacturing of smartphones and provide data of the country of origin of these minerals (Luttropp & Brohammer, 2014). This information can provide evidence if people are involved in mineral extraction or if they have been treated fairly and if no harm was caused to them or the environment (Gerritsen, 2013).

Fair working conditions (fair pay, 8h workday, holiday's, health care)

Assure that people involved in manufacturing process are treated well which includes fair pay, 8hour workday, holidays, social guarantees and access to health care (UNESCO, 2016) (International labor office, 2003).

Child labour free

Provide that there is not any child labour involved during any steps of manufacturing process, including extraction of raw materials (UNESCO, 2016) (Luttropp & Brohammer, 2014).

Certification of fair trade

Does company have any agreements on virgin or non-virgin materials that they are certified as fair trade (U.S. Securities and Exchange Commission, 2010) (European Commission, 2017).

Tractability - Material Flow of minerals used for producing

Mineral tractability is an important part in the manufacturing process. The new legislation made in the U.S. The Dodd Frank Act's Section 1502 (U.S. Securities and Exchange Commission, 2010) and the EU regulation of conflict mineral trading (European Commission, 2017) has restriction in usage and trading of minerals that come from civil conflict zones. Companies have disclosed that mineral smelters are certified and they only use minerals which do not come from civil conflict zones. Pinpointing the material flow of minerals can positively affect the efficiency of material flow, creating a pathway for circular material flow (Sinha, et al., 2016) .

3.2.3 Sustainability ranking normalization and weighting

This part of the research will explain normalization and weighting of sustainability assessment using multi-criteria decision making. The ranking will be done numerically using score 0; 1; 2 with exception of high weighted. Example, Figure 3 Scoring of criteria.

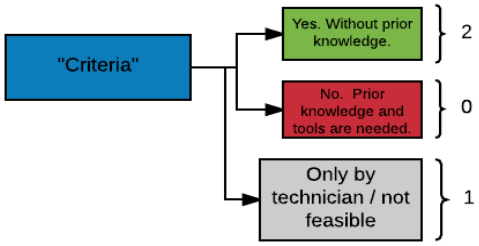


Figure 3 Scoring of criteria

Green (Yes. Without prior knowledge) represents positive impact scoring 2, grey as neutral or other scoring 1 and red (No. Prior knowledge and tools are needed) as negative impact scoring 0. The meaning "without prior knowledge refers to the user not needing prior knowledge or tools to successfully conduct an action, for example exchanging smartphone battery (open the back panel and swap batteries). The action that cannot be conducted by the user and can only be done by a certified specialist with tools, is referred as – "No. Prior knowledge and tools are needed".

Each question in the MCA form has corresponded number X_n high weighted criteria and Y_n general criteria. X_n high weighted criteria is weighed higher due to their high positive impact on smartphone sustainability, for example X_1 reparable battery will increase life span of smartphone therefore prolonging the time until a purchaser of a new smartphone. Y_n general criteria focuses on other aspects of smartphone production that could have a positive impact of suitability, for example "Certification of fair trade (Y_{12})" that is device contains materials who fair trade certified.

General criteria together with high weight criteria for each smartphone which in will translated to final score from 0 – 100% using the following formula:

$$Final\ score = \frac{\sum_i^n 1{,}5X_i + \sum_j^0 Y_j}{2 * (1{,}5i + j)} * 100\%$$

X is High weighed criteria; Y is general criteria; i is the sum of high weighted criteria that smartphone scored; j is amount of general criteria (Figueira, et al., 2006). Example:

$$51.5\% = \frac{1{,}5(2+0+1+0)+12}{2*(4+12)} * 100\%$$

Correspondingly the final sustainability score can be visualised using Figure 4 Sustainability category:



Figure 4 Sustainability category

There are four categories that are weighed higher: Exchange battery; Minimizing hibernation time or market for reselling; Tractability - material flow of minerals used for producing; Fair working conditions (fair pay, 8 h work day, holiday's, heath care). These categories were chosen because they represent great impact of smartphone sustainability according to the literature study. More information about each category can be found in paragraph 3.2.2 Multi-criteria assessment categories.

Exchange of battery (X_1) – the limiting factor of a smartphone`s life span is battery`s life. Most of our smartphones have an integrated battery for design purposes (Perry, 2011) . This is the reason why a life span depends on how many cycles of charging the battery can withstand before it loses its charge (Villas Boas, 2015). Easily accessible and changeable battery can increase life span of a smartphone (Young, 2015) by reducing the need to buy a new smartphone, which will result in reduction of environmental impact of material extraction and production processes.

Minimizing hibernation time by reselling back to the market(X_2) - having a well-established policy for second hand refurbished phones will reduce the pressure on the demand side for producing new phones and the pressure on end-of-life management (Sinha, et al., 2016).

Tractability of minerals and material flow used in production process (gold, tin, tungsten, tantalum) (X_3). It is compulsory for companies in The U.S. to follow Dodd Frank Act Section 1502 (U.S. Securities and Exchange Commission, 2010) and EU law of conflict minerals to prove the country of origin of minerals that they do not come from "conflict zones" where they can sponsor local wars, like in the Democratic Republic of Congo (European Commission, 2017).

Fair working conditions (X_4) guarantee that people involved in manufacturing process are treated fairly - fair pay, 8h workday, holiday's, healthcare (Fair trade, 2017). Workforce is a valuable asset and is a key ingredient to the long-term sustainability of the enterprise. Failure to establish can result in labour strikes, jeopardize operations and reduce efficiency and productivity of their operations (International Finance Corporation, 2016). Fair working conditions can reduce risk of poverty and positively benefit to the community (International labor office, 2003).

4. Results

In the following section the results of the study are presented. The results of the survey are followed by MCD results of four smartphones which compliments the following objectives to achieve the stated aim in 1.4 “Aim and objectives”.

- **Objective 2** Comparing sustainability of smartphones Fairphone 2, iPhone 7, Samsung Galaxy S7 and LG G5, using developed multi-criteria analysis (MCA);
- **Objective 3** Conducting general sustainability- focused survey about consumer demand for sustainable and ethical electronics.

4.1 Survey results (Objective 3)

In this chapter the author described the results of the survey on sustainable and ethical electronics, which are shown in graphs and answers. Overall, the questionnaire was answered by 80 people. The format of questions was different, starting with a possibility to choose the answers and ending with the range format, where respondents could range answers from 1 to 6 (where 1 – the least favourite, 6 –the most favourite). The purpose of the survey was only as an indicator in what people value in sustainable and ethical electronics. Some of the questions, which were in the survey, will be commented and analysed by the author. The surveys and its structure can be found in the Appendix I “Survey - Sustainable and ethical electronics”.

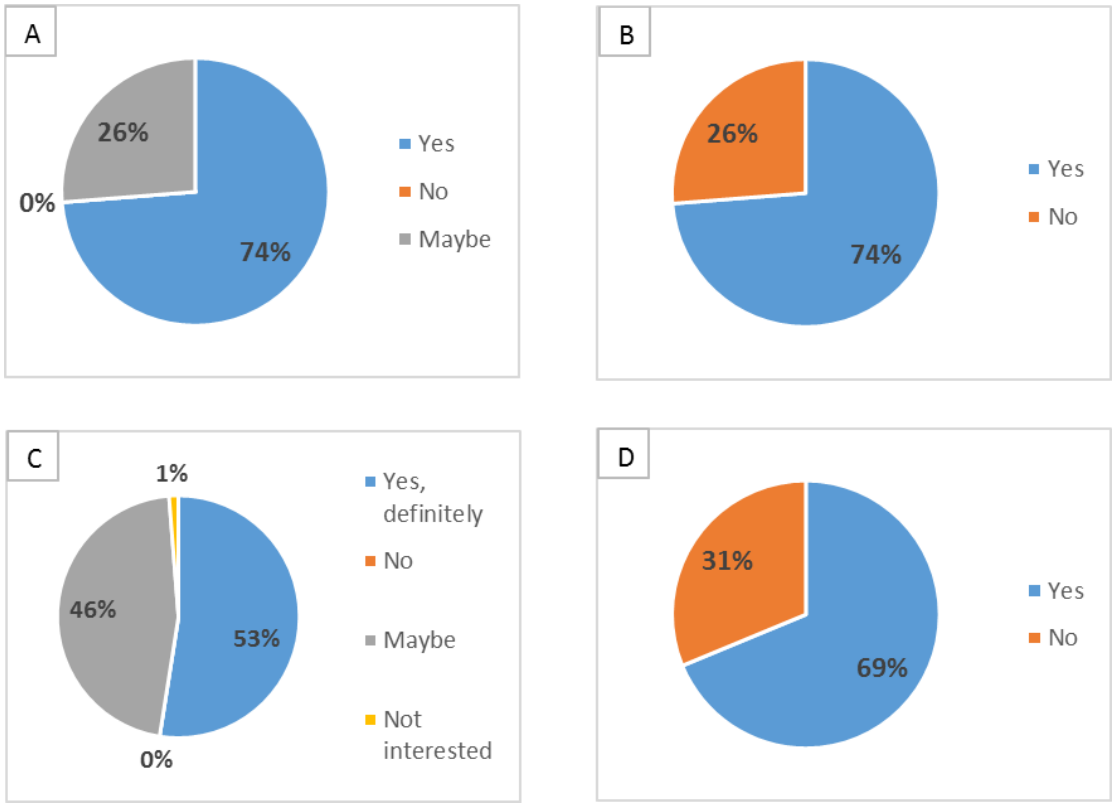


Figure 5 Survey results A) Respondents are inclined to buy sustainable and ethically manufactured electronics by taking into account wellbeing of the workforce and environment. B) Willing to pay more for a device that has a fair-trade or sustainable electronic. C) Interested in buying fair-trade electronic, products with a sustainable electronic label, or other similar products. D) Retailers should offer a separate department to promote, fair-trade electronics and electronics with sustainability label

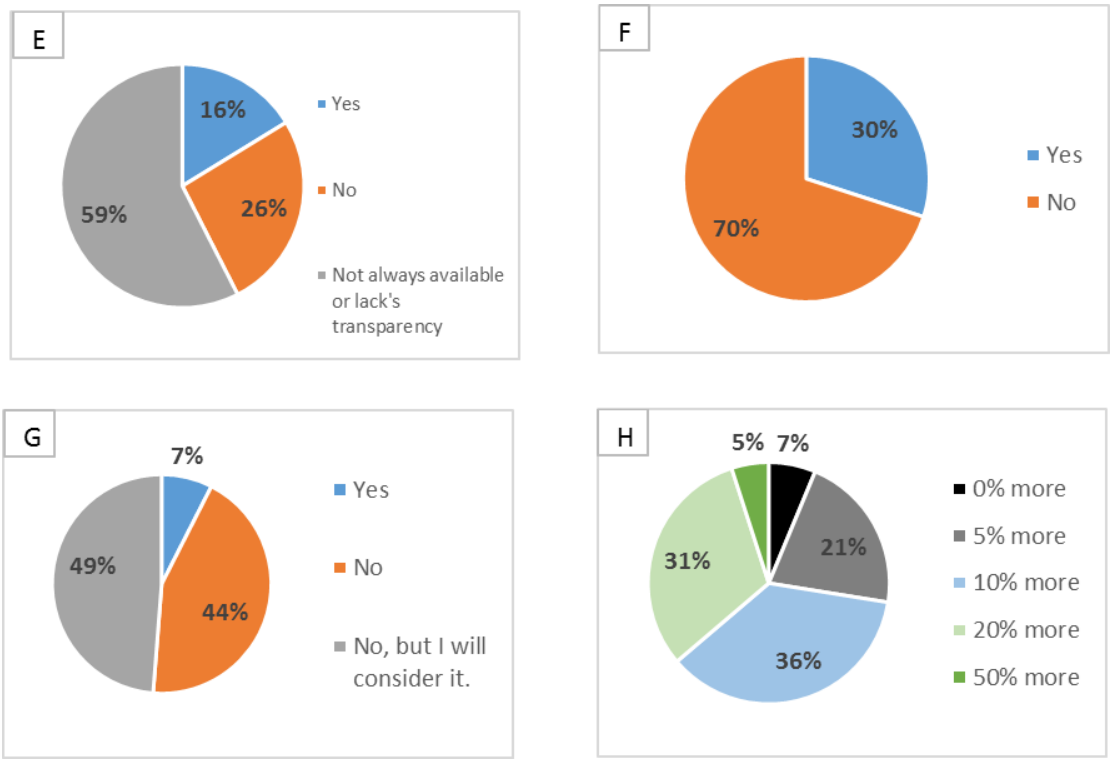


Figure 6 - Survey results. E) Considers company's/manufactures overall sustainability. F) Read a company CSR (corporate social responsibility report), before buying their products. Used brand sustainability ranking assessments from rankabrand.org. G) Used rankabrand.org to asses if the product would guarantee that it is ethically sustainable. H) How much more money consumers are willing to pay more for sustainable products.

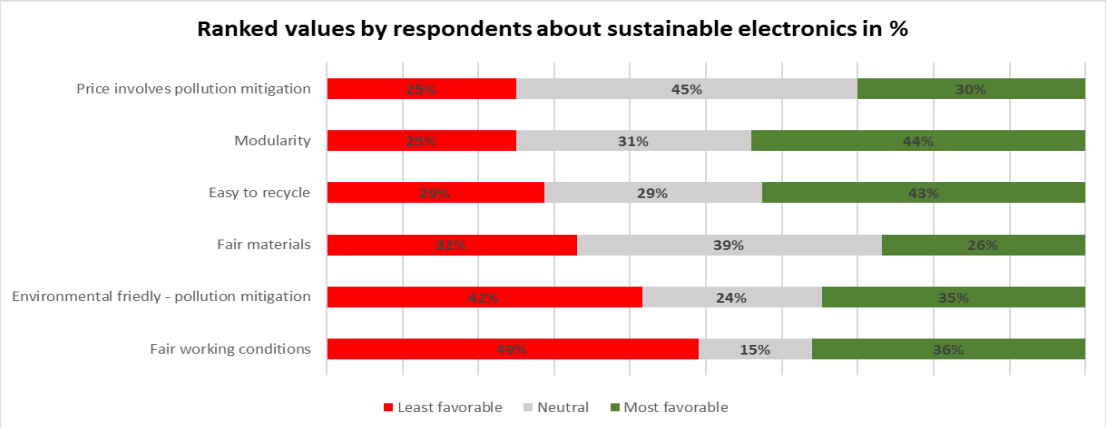


Figure 7 Consumer sustainability aspects from least to most favourable

Fig. 5 A and B illustrates that 74% of respondents are inclined to buy and pay more for sustainable and ethically produced electronics. C illustrates that more than half of the respondents - 53% -have interest in buying fair-trade electronics and less than half - 46% will - consider, but have decided for buying fair-trade electronics. This survey was oriented for consumers/respondents in Sweden, so there is a clear connection to the environmental performance index (EPI), which is quite high. (Environmental Performance Index, 2016).This can be interpreted that the Scandinavian countries are putting environmental protection as their priority, rather than their personal needs.

Fig. 5 C concludes that 53% consumers are inclined to buy Fair trade electronics and products with sustainable electronic label and 46% will consider of buying these products. This illustrates that the level of environmental awareness is increasing, and that there is a need in the market for sustainable electronics (Cohen, 2015). Fig. 5 D illustrates that 69 % of consumers would prefer to have a separate department for Fair trade and Sustainable electronics. That means there are not enough initiatives from retailers advertising more sustainable electronics.

Fig. 6 E illustrates that 26% respondents were not considering manufactures sustainability and 59% replied there is not enough information available or that manufacturing process lacks transparency. These kind of pie charts illustrate undeniable lack of the necessary information about electronic industry and its transparency (Supply Chain Resource Cooperative, 2012) .

Fig. 6 F confirms that 70% of respondents have not read company's CSR before buying electronic goods, indicating that their priority was the product, but after better advertising and more information the data could possibly change (Agarwal, 2013).

Fig. 6 G represents that only 7% of consumers have used rankabrand.org which is a platform that ranks company sustainability, therefore 49% of respondents will consider using rankabrand.org to investigate sustainability of their purchase. Although the environmental awareness is increasing (Cohen, 2015), there is lack of readily available tools for assessing sustainability of electronic products. Lastly pie chart H Illustrates that majority of consumers are willing to pay 10 – 20% more for sustainable electronics were 36% of consumers are willing to pay 10% more and 31% willing to pay 20% more for sustainable electronics. This result is complying similar research conducted in 2010 that 10-20% are willing to pay more for sustainable electronics (Brydolf, 2010). In addition, a study showed that doubling payment of sweatshop workers would only increase the cost of product the by 1.8% (Dosomething.org, 2015).

Fig. 7 illustrates ranking of sustainability aspects that consumer value, from least to most favourable aspects of sustainability. According to the consumers 49% ranked Fair working conditions and 42% Environmental friendly, that the company has considered pollution mitigation in their manufacturing, being the least favourable aspects that will impact consumer choice. The most favourable aspects about sustainability were modularity 44% and easy to recycle 43%. Lastly ranked as neutral, the price of a product involves mitigation of pollution and fair material use, were ranked to be neither least nor most favourable.

Recycling and modularity was ranked to be most favourable, as it was discussed previously. Modularity is a part of upcycling process where materials are returned back to the supply chain to be reused, reverse the need for further raw stock materials and reducing waste (Intercon, 2010). Recycling does extend lifespan of material, but finally they are likely still destined for a landfill, by stretching out waste stream and make the reduced lifecycle costs of the material. Modularity, as it was mentioned, prolongs the lifespan of materials and reduces the need for raw materials (Intercon, 2010).

Fair working conditions were ranked the least favourable by 49% of participants, which could indicate that participants are not fully aware about working condition issues in electronic goods manufacturing industry (Facing Finance, 2015). Working conditions in Chinese factories consist of excessive working hours, often with no compensation for

overtime and with an average workers age from 18-21 years old. There are reports that villages surrounding manufacturing plants have an increased risk of respiratory problems (Facing Finance, 2015).

4.2 MCA evaluation of smartphones results (Objective 2)

The following chapter summarizes smartphone sustainability raking applying Multi-criteria analysis evaluating sustainability of smartphone from chapter *3.2 Multi-criteria analysis evaluating sustainability of smartphone(Objective 1).* MCA was conducted on the following: LG G5, Fairphone 2, iPhone 7 and Samsung galaxy S7. The selected models were based their design features (modularity) and their amount sold in the market. More information about the MCA evaluation can be found in Appendix II MCA - evaluation of smartphones check list.

Table 1 "MCA evaluation results" summarizes the results of for four evaluated smartphones using fifteen categories (criteria's) from chapter 3.2.2 Multi-criteria assessment categories . Furthermore, the results are summarised using chapters 3.2.3 Sustainability ranking normalization and weighting formula and final score is "weighted" and the converted to "Normalized results" in percentage.

Table 1 MCA evaluation results

Categories/Smartphones	**LG G5**	**Fairphone 2**	**iPhone 7**	**Samsung Galaxy S7**
Exchange battery(X_1)	2	2	0	0
Swap broken screen(Y_1)	0	2	0	0
Increase HDD memory(Y_2)	1	1	0	1
Swap USB & power socket 3,5mm audio(Y_3)	0	2	0	0
"Fall proof" phone can withstand fall 80cm high(Y_5)	0	1	0	0
Minimizing hibernation time or market for reselling(X_2)	1	0	1	1
Is there any mitigation for production & transportation emissions(Y_6)	2	0	2	2
Refurbish broken parts(Y_7)	1	2	2	1
Reclaiming of 3T&G(Y_8)	1	0	1	1
Recycle/reuse plastics & phone case(Y_9)	0	0	2	2
Tractability - Material Flow of minerals used for producing(X_3)	0	1	0	0
List of all minerals used in manufacturing process(Y_{10})	0	2	0	0
Fair working conditions (fair pay, 8h workday, holiday's, healthcare.) (X_4)	0	0	0	0
Child labour free(Y_{11})	0	0	0	0
Certification of fair trade(Y_{12})	0	2	0	0
Total, not weighted:	8	15	8	8
Weighted:	**9.5**	**16.5**	**8.5**	**8.5**
Normalized Result:	**30%**	**52%**	**27%**	**27%**

Further chapters contain detailed results from MCA analysis and evaluation using the criteria that were described in chapter 3.2 Multi-criteria analysis evaluating sustainability of smartphone (Objective 1), sub-chapter 3.2.2 Multi-criteria assessment categories. Furthermore, Table 1 "MCA evaluation" results summarizes further analysed chapter results in normalized values and Figure 2 "MCA evaluation road map", helps to sort out evaluated categories for a better overview of results in Table 1.

4.2.1 Upcycling

Battery

Fairphone 2 and partially LG G5 had modular design incorporated and the battery was easily accessible and no prior knowledge was necessary. Samsung Galaxy 7 (SG7) (iFixit, 2016) and iPhone 7 (iP7) (iFixit, 2016) - removal of the battery for these models was not possible. Only with the specific tools and prior knowledge was there a possibility to change it. Easily accessible and removable battery can increase a smartphone` lifespan. Batteries have a life span of 300-500 charging cycles (one charging cycle is charge when battery is below 70%) On average battery capacity can reduce by 15-22% after 1st year (Villas Boas, 2015) (Carnoy, 2015) . The replacement of a broken screen; USB and power socket, 3,5mm audio was only possible for Fairphone 2, due to its modular and innovative design (iFixit, 2015). The rest of the smartphones required to use tools and prior knowledge, to know how to disassemble and reassemble a phone once again. Lastly, increase of hard disk space was for FP2, LG G5 and SG7 using micro SD slot, but iP7 (Arena, 2016) did not have a micro SD slot to add some extra space. These aspects can have an impact on a smartphone`s lifespan, therefore, increased life span of a smartphone possibly will reduce its environmental impact (Arushanyan, et al., 2014). EEB also claims that measures taken in order to increase products lifespan will positively impact the efficiency of resource; therefore it will improve environmental performance (Chris van Rossem, 2006).

Minimizing hibernation time or a market for reselling

This will lessen stress on the demand for manufacturing new smartphones, reduce the stress on the end-of-life management (Sinha, et al., 2016). It could, as previously mentioned, improve sustainability (Chris van Rossem, 2006) and boost positively the development of efficiency in the market for second hand smartphones (Sinha, et al., 2016). Currently the recovery of materials like copper and precious metals (gold) already make up 95% of the value of metal, the profit from recycling severely depends on the market value of gold and the amount of gold in a mobile phone (Geyer & Blass, 2009).

Apple Inc. has created a good system where old Apple Inc. products including smartphones can be returned back to the company in exchange for discount or vouchers for a new Apple Inc. product. The company refurbishes these devices with a 1-year warranty and sell them on the official website (Apple Inc., 2017). Fairphone 2 is designed in a more unique way, so that this phone will last for 5 years and hibernation should not occur, but there is not enough information to confirm this.

Fairphone 2 has been produced in small quantities - currently 40.000 units and could reach up to 150.000 units per a year (Koschyk, 2016) compared to the other smartphones, like LG G5 that sold 1.6 million units in its first month of release (Benson, 2016). LG Electronics Inc. and Samsung Electronics Co., Ltd. has not established a system like Apple Inc., but they have established coopoeration with third party e-waste management companies in each country (LG Electronics Inc., 2016) (Samsung Electronics Co., Ltd., 2016).

Mitigation strategy from production & transportation emissions

Apple Inc. (Apple Inc., 2017), Samsung Electronics Co., Ltd. (Samsung Electronics Co.,Ltd., 2016)and LG Electronics Inc. (LG Electronics Inc., 2016) have established programs for emission mitigation.

LG Electronics Inc. conducted an LCA on their smartphone products, the result of which indicated that 60-80% environmental impact comes from production phase and 4% from transportation and that their goal is to reduce 40% all GHG emissions by 2020 (LG Electronics Inc., 2016).

Samsung Electronics Co., Ltd. has managed to reduce GHG emissions by 57% from the production process. Transportation emissions from road or railroad have reduced from 1%-0.4%, airline emissions have increased from 26%-42.5% and shipping emissions have reduced from 73%-57.1%. Emissions by airplane have increased by 16%, due to the increase of sales and its business activities (Samsung Electronics Co.,Ltd., 2016).

Apple Inc. in their mitigation plans focuses on using only renewable resources in their production processes and travelling more environmentally friendly by 2018. They also investigated that 77% of emissions com from manufacturing process and 17% comes from transportation (Apple Inc., 2017).

Fairphone B.V. has not established an environmental management system similar to other companies, but incorporating modular design in FP2 will reduce the Global warming potential (GWP) by 30%. They have conducted LCA on FP2 where the biggest emitter was production with 82.1% GWP, but transportation contributed 6.8% GWP mostly from air freight (Salvà, 2016).

4.2.2 Recycling

Refurbish broken parts, reclaiming of tin, tungsten, tantalum and gold, recycle/reuse plastics and phone case.

Apple Inc. has developed a new recycling method - dissembling by using robot called Liam. This robot has the potential to disassemble a smartphone in 11 seconds. It is estimated that this technique can recover 0.3 kg of gold, 55 kg of tin, 3.5 kg of tungsten, 2.5 kg of tantalum and 1900 kg of aluminium from 100,000 iPhone 6 devices. They are planning to move to closed-loop supply chain and use only renewable or recycled materials. Through these recycling programs, in 2015 Apple was able to recover 30500 T of e-waste material for reuse, this includes steel, plastics, glass, aluminium, copper, cobalt, zinc, lead, nickel, silver, tin and gold (Staff, 2015) (Apple Inc. b, 2016).

Samsung similar to Apple wants to incorporate circular economy in their mining, but this is still in an early development stage. SG7 design uses 100% recycled aluminium (Samsung Electronics Co., Ltd., 2016). In their sustainability report there was not any information about 3T&G recycling and reuse, but there is a management plan for e-waste recycling. Furthermore, LG Electronics Inc. has an e-waste and recycling program, but the data do not specify what kind of minerals are reclaimed and at what amounts. There was not enough data to draw a conclusion about LG Electronics Inc. reuse and recycling (LG Electronics Inc., 2016). Finally, Fairphone B.V. are also going towards a circular economy approach, they actively investigated the most effective way of recycling. The investigation concluded that modularity promotes the recovery of gold, copper, silver, cobalt, nickel, palladium, platinum,

gallium, indium and zinc can from 80 to 98% (Fairphone B.V., 2017). More investigating is needed to fully understand the benefits of modularity and the most efficient way of recycling. Fairphone B.V.is actively working with investigations and promotions of smartphone recycling.

4.2.3 Social

Tractability - material flow of minerals used for producing

As it was discussed in the previous chapter, Apple Inc. has established successful material flow from e-waste mining in order to promote their way towards closed loop material flow. Currently Apple Inc. is actively investigating in their supply chain to assure that all of their smelters and refiners comply with their diligence requirements. The manufacturers material supply line is very complex and they have provided data of all mineral country of origin (Apple Inc. b, 2016). LG Electronics Inc. is actively investigating their supply lines to assure that 3T and G come from smelters are certified to be conflict mineral free. They found out that in 2015, 68% of their smelters comply with a conflict free mineral strategy. Samsung Electronics Co., Ltd. is also investigating their supply chain to assure their products contain conflict free 3T and G. From April 2016 all supply of tantalum comes from certified smelters. Finally, they are actively investigating the risks that conflict minerals are creating for the local miners and environment (Samsung Electronics Co., Ltd., 2016)

Fairphone B.V. has achieved traceability of tin, tungsten, tantalum and gold. They have established the country of origin of these four minerals and conflict free mineral refineries. FP2 tungsten comes from Rwanda; gold comes from Lucanas in Peru and this gold has received a Fair Trade certificate; tin and tantalum comes from Democratic Republic of Congo. To assure that materials are conflict free, Fairphone B.V. is iTSCI system of “bagging and tagging” to trace the minerals journey from extraction points to the producer (Gerritsen, 2013) . Fairphone B.V. will also continue the investigation for the rest of the minerals that are used in the manufacturing of smartphones.

The intensive investigation of mineral traceability can be the result of the Dodd Frank Act's Section 1502 on conflict minerals and possibly the new EU regulation conflict minerals in order to combat use of conflict minerals (European Commission, 2017) (U.S. Securities and Exchange Commission, 2010) . In the case of Fairphone B.V., investigation of the country of origin of these minerals and material flow was their own initiative. Also the material flow of minerals in Samsung Electronics Co., Ltd., Apple Inc. and LG Electronics Inc. lacks transparency compared to Fairphones B.V. open information flow. Substances of concern like conflict minerals are an important sustainability aspect to improve the sustainability performance (OECD, 2011).

Fair working conditions and child labour.

Fairphone 2 with local NGO’s are participating in activities to increase working conditions in their assembly lines. They have set a target that factory workers should not work more than 60 hours per week and have one day off every week. Fairphone B.V. found out that in July 2016 factory workers worked more than 60 hours/week and this was due to delays of materials. Fairphone B.V. indicated that this was not due to their business, but it was the others ‘company’s responsibility which also use the same factory. Overtime hours are paid 150% more than for regular days and overtime in off days or holidays are doubled and tripled. Fairphone B.V. is transparent of disclosing information about working conditions

and they have to work closely with the local institutions to improve the working conditions (Lempers, 2016).

Samsung Electronics Co., Ltd. has been accused of exploiting child labour, pupils at the age 15 (Reisinger, 2014) and health degradation of their workers. There are 200 documented cases with 76 deaths from chronicle diseases (leukaemia, lupus and lymphoma) in the former Samsung semiconductor and LCD employees (Lee, 2016) . There are reports that Samsung and Apples external supplier of cobalt is exploiting child labour (Wakefield, 2016). To counter the problem of exploitation of child labour, Samsung will provide free of charge ID scanners to their suppliers to account for workers and reduce chance of child labour. They are working on a management system to reduce occupational disease problems for their workers and contractors (Samsung Electronics Co., Ltd., 2016).

Apple Inc. also has been accused of over exploitation of their workers. The journalists revealed that an assembly worker had to work 18 days in a row, despite his requests for a day off. Factory workers regularly exceed 60 hours per week schedule (The Guardian, 2014). Apple Inc. reported that they have improved their working conditions through their supply chain and since 2016 98% comply with a maximum 60 hours work week and one day off (Apple Inc., 2017).

According to their sustainability report LG Electronics Inc. is actively promoting fair working conditions in their supply chain and the welfare of workers` health. The third party audit is ongoing in order to investigate the situation of fair working conditions (LG Electronics Inc., 2016).

According to the fair labour association a regular workweek shall not exceed 48 hours and the sum of regular and overtime hours shall not exceed 60 hours per a week. Children under the age of 15 or before completion of compulsory education should not be employed (Fair Labor Association, 2012).Fair working conditions are a crucial part of well-being, development and economic growth. Well managed labour can have a positive impact on the local social stability which can benefit to the local economy by business investments of foreign investors (International labor office, 2003).

Fairphone B.V. has not received ISO 14001, but they have received stronger certificate for their smartphone FP2, the Blue Angel, for its product lifetime extension, low electromagnetic radiation and active promotions of take back initiatives and recyclable design (Salvà, 2016).

4.2.4 Comparative results between MCA and survey

After conducting a deeper analysis with combined results from MCA, survey revealed that the general public are willing to pay more for sustainable products but consumers lack information about the overall manufacturers` sustainability. Meaning that communication between manufacturers and consumers is very weak or even does not exist (Open Market, 2015).

Manufacturers also could not become fully sustainable when their products have been designed to have a short life span and a fragile design (Sulleyman, 2017).Small scale manufacturers could possibly lack the ability of a well-established environmental management system, like in the case with Fairphone B.V. Their product Fairphone 2 promotes future smartphone design as being one of the first modular smartphones where all parts can be replaced easily without prior knowledge. Theoretically Fairphone B.V. has

designed a recycling system for Fairphone 2 (Fairphone B.V., 2017), but due to the small scale production of only 40,000 units (Koschyk, 2016) the recycling of these smartphones could be expensive using Fairphone individually designed recycling platform. In comparison from, 2009 - 2016 Samsung Electronics Co., Ltd. has sold 77.5 million and Apple Inc. 210 million smartphone (Satista, 2016).

The best case scenario would be when Apple incorporates modularity with durability in their design, with combination of their smartphone recycling program of circular material flow and e-waste mining. In addition, their recycling of smartphones using robots could reduce the need for raw material and excessive work force. It is estimated that by early 2030 there is a risk that robots can replace human operated jobs from 38% in the U.S. 30% in the United Kingdom, 35% in Germany and 21% in Japan (Masunaga, 2017).

The automation of smartphone manufacturing could also reduce social problems that occur in manufacturing sites, but it could create new problems for workforce such as losing their jobs. The advantages of automation are reduction of human error, possible reaction to employee costs, increased safety, reduction in production time and increased accuracy (Blue, 2013). This aspect of automation should be investigated over a long period of time, it could have an impact on our population and lifestyle (Groover, 2017).

The MCA analysis of each smartphone model, indicated that there is lack of transparency in understanding the complicated material flow. In most cases when the production is increased it is difficult to pin point the origin of each material used in the production process. Fairphone B.V. has fairly transparent material flow, but it still needs to determine all the materials used in the production process.

5. Discussion

This chapter discusses and assesses findings from this thesis. The first chapter will discuss the quality of data involved in this research. Further chapter will discuss the credibility of this study and the present study results with other studies. The last chapter will discuss about implications of this research and possibility to expand the study in the future.

5.1 Data quality

Collection of qualitative data for this research has been challenging due to the lack of qualitative data availability. Most of the data collected for this research can be described as quantitative data. In some cases, the data lacks the needed transparency for making an objective conclusion. This research also contains information that comes from tech news blogs creating a possibility of subjective and unreliable data.

A large part of the data used for MCA analysis was retrieved from official smartphone manufactures, annual sustainability report. After analysing this data, uncertainties regarding the data transparency and data quality were not fully disclosed in these sustainability reports. For example, LG Electronics Inc. annual sustainability report lacked data about material quantity used from their electronic waste (e-waste) management system (LG Electronics Inc., 2016).

During the data collection it was difficult to understand the data provided from each company's sustainability report and in some cases data was not fully available. The structure of their reports did no provide a clear overview of sustainability performance. It also proved

that there are no clear guidelines on how to develop transparent annual sustainability reports.

Transparency about mineral tractability was an issue, Fairphone B.V. was the only company that could provide data about the country of origin on tin, tantalum, tungsten and gold and their flow throughout the supply chain.

Furthermore, the survey that was conducted in this research lacked information about participant's country of origin, age, gender and education which could have impact of the survey results. Some assumptions were made, based on the information that was provided from the survey.

It is important to understand that modularity is new concept and still needs a full examination to better understand positive and negative effects. As time comes and more information will be available more accurate conclusions can be made.

Finally, since the implementation of Dott-Frank act and EU conflict free mineral policy manufacturers are obliged to comply with "conflict free minerals" and assured that all the suppliers do not import "conflict minerals" or devices that contains "conflict minerals" . This could reduce unsustainable mining of "conflict minerals", but due to the complex logistics and lack of transparency, raw materials could be difficult to trace.

5.1.1 MCA ranking data gap – product quality

A product's history and its' previous predecessors pay a significant role in product development. Apple Inc., Samsung Electronics Co., Ltd. and LG Electronics Inc. have well established smartphone production line and well tested quality for their electronics, giving them an advantage in quality product production and consumers trust in brand. Fairphone 2 is a new product on the market with a short history with previous predecessor Fairphone 1 which possibly can make the quality of the smartphone questionable and also the brand is unknown for the general market. Even though Fairphone 2 scored higher in sustainability rank, there are still many unknowns about the brand quality and the Fairphone B.V. environmental management program.

5.1.2 Survey result data gap

This survey lacks the information available about geographical location, gender, age and education. Geographical location can influence participant's behaviour, due to the economic welfare on the country. According to EPI (Environmental Performance index) countries with high economic welfare like Sweden, Norway and Finland has higher EPI ranking than countries with a lower economic welfare indicating that the economic welfare can influence consumer's behaviour towards sustainable electronics (Shirley, 2017). Education can greatly influence the results of the survey, because the higher level of education of a participant- the greater policy support towards environmental protection (UNESCO, 2016). In conclusion this survey assumes that in age group from 20 – 40 years old, living in Sweden and has either a university degree or vocational education.

The desired target group can have an impact on survey results, due to the fact that this survey was conducted in high economic welfare like Sweden and with highly educated target group. Possibly that this target group has a desire to consume more electronic goods compared to other European countries that have a lower economic welfare.

5.2 Credibility of the study

Credibility of the study has been influenced by the data availability and manufactures transparency. For example, iPhone 7, Samsung Galaxy S7 and LG G5 performed low due to the lack of data or transparency compared to Fairphones 2 where most of the data was easily accessible and had elaborate explanation. It is important to mention that compared to larger manufactures Fairphone B.V. is a small enterprise, therefore data collection is less complicated.

Fairphone 2 has proven that it can be a more sustainable and transparent smartphone than others manufactures. Will Fairphone 2 smartphone keep up with supplying sustainable manufacturing and mineral extraction when up scaled to the same level as other manufactures life Apple Inc. and Samsung Electronics Co., Ltd?

5.3 Compare the present study results with other studies

Similar research has been conducted using MCA to analyse smartphone sustainability: "An analysis and classification of smartphones sustainability performance" by Olivia Engstrand. Similar conclusion can be drawn related to data availability and its effect on the smartphones performance in MCA approach. The data availability has an important part for evaluation of smartphone sustainability, therefore in this research it has a significant impact on the results of each smartphones sustainability. Furthermore, after data screening a connection that can be drawn is that the smartphone industry is lacking a united standardization of data reporting. This would allow more accurate research to investigate smartphone sustainability.

5. 4 Implications of results

This research found out that manufacturing of sustainable smartphones is complex, due to complicated logistics routes and large involvement of stakeholders. Currently the data transparency and tractability has a significant downside for affecting qualitative research. Using the available data and information that was provided from each company's environmental management report it was difficult to draw solid conclusions.

After performing MCA on four smartphones it can be assured, that modularity can have a positive impact on sustainability of smartphone if the manufacturing process can also be done in a sustainable way. Data screening also provided a better understanding on social issues that stimulate unsustainable smartphone manufacturing. Also, the economic part of smartphone manufacturing outside Europe does not provide solid economic and social benefit. The biggest issue in the manufacturing process is the violation of labour rights related to work health and safety and over excessive working hours. Moving manufacturing closer to Europe or into Europe, could possibly affect sustainable smartphone production, due to the laws and regulations in the EU. Some data even provided evidence that in the near future automation of manufacturing will become more feasible.

Furthermore, the survey that was conducted in this research concludes that there is a demand for sustainable electronics and that consumers are willing to pay 10 -20% more for these products. Consumers, when asked about sustainable electronics, value modularity and ease of recycling as the most favourable aspects. Least valued ranked aspects were fair working conditions and impact on the environment. It's possible to assume that the general

public lacks the necessary information for making sustainable choices, but more research is needed to complement this finding.

5.5 Possibility to expand the study in the future

There is a need for future investigation about the upscaling effects of modular smartphones and the impact on sustainability. More importantly, it should be investigated whether fair trade mining would be possible if Fairphone B.V. production process was upscaled to the same level as Apple Inc. and Samsung Co., Ltd. Furthermore, it would be necessary to investigate economic and environmental benefits of smartphone manufacturing in Europe. Find of what are the driving factors that will enable moving manufacturing back to Europe.

6. Conclusion

The aim of this research is to develop a ranking system using eco-design perspective and to evaluate sustainability of a smartphone - upcycling, recycling, and social aspects. Furthermore, there are two main objectives that have been researched. First main objective for assessing smartphone sustainability was to:

- Compare sustainability of smartphones Fairphone 2, iPhone 7, Samsung Galaxy S7 and LG G5, by using developed multi-criteria analysis (MCA).

After analysing four smartphones, most of the smartphones lacked the ability for modularity and ease of repair. Also, there is not enough available data about upscaling manufacturing of sustainable smartphones like Fairphone 2, and its ability to remain transparent and sustainable. A well establish and working environmental management system is more important than having modular design. If combined Fairphone B.V. modular design and Apple Inc. circular material recycling management, can possibly produce a product that is sustainable and made from recycled materials. It is important to address the possibility for improving working conditions of smartphone manufacturing to move manufacturing to Europe instead of manufacturing in China. This would allow making manufacturing process more transparent and creating a safer working environment.

Transparency of smartphone manufactures was the major issue, for retrieving reliable and transparent data. *Also some of the data analysis was difficult to process due to lack of data tractability (point source), data quality and the methods of how the data was collected and analysed.* Data about upcycling and recycling part was difficult to analyse due to lack of data transparency in manufactures sustainability reports. Furthermore, the social aspects were very briefly described in these manufactures sustainability reports and did not fully comply with third part research that was conducted about social problems related to smartphone manufacturing process. There is evidence of social problems at smartphone manufacturing facilities. If the smartphone manufactures could become more transparent this would possibly solve problems that hindrances smartphone manufactures to become more sustainable.

- Conducting general sustainability - focused survey about consumer demand for sustainable and ethical electronics.

The majority of survey responders are inclined to buy and pay 10 – 20% more for sustainable, and ethically produced electronics. Also when asked about which aspects of sustainable electronics consumers value the most it was modularity and recyclability. The least valued aspects were fair working conditions and impact on the environment.

Conclusion of the study about Smartphone sustainability assessment using Multi-Criteria Analysis and consumer survey has provided evidence about the lack of transparency of manufacturing of a smartphone device and how we smartphones users take this technology for granted.

Even though consumers fully do not understand the complex logistic that each component and building material is going through, these devices have a strong impact on our daily life and the people who are involved in the manufacturing process. As long as process of smartphone manufacturing will be a closed process it is difficult to discuss about sustainability of these devices. To possibly tackle this issue of transparency and data quality the responsible authority must conduct public audits in these companies, but this could have a resistance from manufactories about corporate secrets.

6.1 Recommendations for smartphone users

This chapter summarizes recommendation for smartphone users how to make sustainable decisions purchasing and improve current devices sustainability.

- Reduce hibernation time – if there is a possibility to resell old smartphones to the second hand market. This action can positively contribute to the reducing of producing of new smartphones for the market that does have it. (Meaning it is sustainable to sell old smartphone to the second-hand market).
- Currently the average smartphone lifespan is 21 months, before a new smartphone is bought. If the smartphones functionally are not compromised, using the smartphone longer than the average lifespan, could reduce need for production of new smartphones therefore reduce stress on production process.
- Choose smartphones with easily accessible and removable battery. This can increase smartphones lifespan, because the battery is one of the key factors that limits the lifespan of smartphone.
- Conduct a short background research on company sustainability and their transparency related towards the desired electronic product that will be bought.

6.2 Recommendations for Tech Buddy Sustainable Electronic production.

- Environmental management eco-design. To have that specific electronic product be sustainable and environmentally friendly it needs to be designed using eco-design aspect. Also, important part is that manufactures have fully functional environmental management and that includes pollution mitigation management of manufactured production use phase and end of life phase.

- Modular design, that can be easily repaired or upgraded by the consumer without excessive prior knowledge and tools

- If an Environmental management program is too expensive it is possible to outsource it or if it the enterprise is a “start-up” possibly could, share it with other “start-up” or similar companies with similar products.

- A sustainable electronic product should be produced locally, in this case Europe, due to the fact that Europe has well established directives and guidelines for environment and labour protection. Also producting product locally will have a positive impact on the local economic progress.

- To avoid end-of-life scenario for functioning product and increase material conservation a well-established, trustworthy second hand marked will have a positive impact on product sustainability.

- The manufacturer should include costs of pollution mitigation following the principle – polluter pays.

- Transparency is an important part of achieving reliable data exchange and consumers trust.

- Well established data collection and accountability of data will help with calculation of products impacts to the environment.

- Product has to be designed in a way that consumers can recycle it easily and without prior knowledge.

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Appendix I Survey - Sustainable and ethical electronics

Questions

1. Would you be more inclined to buy electronics that had been produced ethically, i.e. reduced pollution and ethically manufactured with regards to the wellbeing of the workforce, than other products?
    a. Yes
    b. No
    c. Maybe
2. In order from most important to least, what are the more important aspects that a sustainable electronic label should consider?
    I. Fair working conditions - (fair pay, 8h work day, social benefits, holidays, safe working conditions)
    II. Environmental friendly electronics - (No pollution or reduced pollution to air, water and soil)
    III. Products price involves pollution mitigation - (Carbon offsetting and other)
    IV. Fair Materials are used in this product (Minerals with a Fair Trade label - Gold, Tantalum, Tin, Tungsten).
    V. This device is modular - (easy and with our prior knowledge to swamp broken parts)
    VI. Easy to recycle - material hygiene
3. Are you willing to pay more for a device that has a ‘fair-trade’ or ‘sustainable electronic’ label, than a non-sustainable?
    a. Yes,
    b. No
4. Are you interested in buying ‘Fairtrade electronic’, products with a ‘sustainable electronic’ label, or other similar products?
    a. Yes, definitely
    b. Maybe
    c. No
    d. Not interested
5. How much more would you consider paying if the product would guarantee that it is ethically sustainable.
    a. 0%
    b. 5%
    c. 10%
    d. 20%
    e. 50%
6. Should retailers offer a separate department to promote,” Fair-trade electronics" , "Sustainable Electronic label"?
    a. Yes
    b. No
7. When buying a new electric device/appliance do you consider the company’s overall view on sustainability beforehand?
    a. Yes
    b. No
    c. Not always available or lacks of transparency

8. Have you ever read a company's CSR (corporate social responsibility report), before buying their products?
    a. Yes
    b. No
9. Have ever used brand sustainability ranking assessments from rankabrand.org?
    a. Yes
    b. No
    c. No, but I will consider it, when buying electronics devices next time

Appendix II MCA - evaluation of smartphones check list

This chapter contains data with references for MCA smartphone analysis: LG G5, Fairphone 2, iPhone 7 and Samsung Galaxy S7. It is divided in to five columns: Criteria, Answer using Figure 2 "MCA evaluation road map" as guidelines, score which is analysed and summarised in Table 1 MCA evaluation results, remarks and source with reference.

LG G5

Criteria	Answer	Score	Remarks	Source
Exchange battery(X_1)	Yes, without prior knowledge	2	Replaceable battery using a modular slot	(La, 2016)
Swap broken screen(Y_1)	No, knowledge and tools are needed	0		(Zalmanowitz, 2016)
Increase HDD memory(Y_2)	Possible using micro SD	1	Up to 2 terabits can be added to phones memory using micro SD memory card.	(La, 2016)
Swap USB & power socket 3,5mm audio(Y_3)	No, knowledge and tools are needed	0		(iFixit, 2016)
Life span up to 5 years(Y_4)	Possible for an upgrade to increase life span	1	There is no data that this smartphone can last for 5 years. Although it is possible to exchange battery that can prolong smartphones life span.	(La, 2016)
"Fall proof" phone can withstand fall 80cm high(Y_5)	No, less than 80 cm	0	No data available - manufacturer has not conducted fall prove tests.	
Minimizing hibernation time or market for reselling(X_2)	Possible to resell for second hand market	1	Possible for re-sell in second hard market. LG has not established market for refurbished smartphones.	(LG Electronics Inc., 2016)
Is there any mitigation for production & transportation emissions(Y_6)	Yes, developer includes mitigation in the price	2	There is an environmental management system emplace for emissions accounting and mitigation plan for emission reduction.	(LG Electronics Inc., 2016)
Refurbish broken parts(Y_7)	Possible to recycle broken parts	1	LG Electronics mentions that it is possible to recycle your old smartphones using third party contract firm.	(LG Electronics Inc., 2016)
Reclaiming of 3T&G(Y_8)	Only gold is feasible to be reclaimed	1	No data available about mineral recycling. External suppliers can recycle gold from old smartphones.	(LG Electronics Inc., 2016)
Recycle/reuse plastics & phone case(Y_9)	No possible to recycle or reuse	0	No data available for smartphone plastic recycling.	(LG Electronics Inc., 2016)
Tractability - Material Flow of minerals used for producing(X_3)	No, minerals can't be traced	0	There is data available about mineral tractability and material flow, but future plan is to establish tracking system for major minerals.	(LG Electronics Inc., 2016)
List of all minerals used in manufacturing process(Y_{10})	No, not publicly available	0	No data available.	
Fair working conditions (fair pay, 8h work day, holiday's, heath care.) (X_4)	Under the investigation	0	There is investigation using third party members, for improving fair working condition.	(LG Electronics Inc., 2016)
Child labour free(Y_{11})	Information not available	0	LG has established goal for protection labour rights. No data available about child labour incidents.	(LG Electronics Inc., 2016)

Fairphone 2

Criteria	Answer	Score	Remarks	Source
Exchange battery(X_1)	Yes, without prior knowledge	2	No tools needed. Easily accessible.	(Fairphone B.V., 2016)
Swap broken screen(Y_1)	Yes, without prior knowledge	2	No tools needed. Easily accessible.	(Fairphone B.V., 2016)
Increase HDD memory(Y_2)	Possible using micro SD or similar slot	1	Up to 64 gigabits can be added to phones memory using micro SD memory card.	(Fairphone B.V., 2016)
Swap USB & power socket 3,5mm audio(Y_3)	Yes, without prior knowledge	2	Using tool, fillips screwdriver and possibly T5 torx screwdriver.	(Fairphone B.V., 2016)
Life span up to 5 years(Y_4)	Yes, designed to last 5 years	2	Fairphone B.V. provides a five year guarantee on all parts and also home repair.	(Fairphone B.V., 2016)
"Fall proof" phone can withstand fall 80cm high(Y_5)	With designed shock case	1	Fairphone 2 design so that back case is serves as protective layer and holds the battery in place.	(Fairphone B.V. a, 2017)
Minimizing hibernation time or market for reselling(X_2)	Not possible to resell or reduce hibernation time	0	Fairphone B.V. does not have a big market share and design of this phone, is made to last for an indefinite amount of time.	(Hebert, 2015)
Is there any mitigation for production & transportation emissions(Y_6)	No, developer doesn't include mitigation procedures in the price	0	No data available about emission mitigation from transportation and production.	
Refurbish broken parts(Y_7)	Yes, possible to send broken parts to refurbishment	2	Fairphone B.V. has established a program for broken spare part refurbishment.	(Redu, 2014)
Reclaiming of 3T&G(Y_8)	Not feasible to reclaim	0	Still under the investigation by Fairphone B.V.	(Ballester, 2017)
Recycle/reuse plastics & phone case(Y_9)	No possible to recycle or reuse	0	Still under the investigation by Fairphone B.V.	(Ballester, 2017)
Tractability - Material Flow of minerals used for producing(X_3)	Partially tracked, but no material flow data available	1	Established point source of minerals – gold, tin, tungsten and tantalum.	(Gerritsen, 2013)
List of all minerals used in manufacturing process(Y_{10})	Yes, publicly available on their web-site	2	Easily accessible data about all minerals used in smartphone production.	(Fairphone B.V. and The Dragonfly Initiative, 2017)
Fair working conditions (fair pay, 8h work day, holiday's, heath care.) (X_4)	No, lack of fair working conditions	0	Fairphone B.V. is helping its suppliers by organizing events related labour unions for improving working conditions. There was no clear data that Fairphone B.V. has implemented and improved working conditions.	(Fairphone B.V. b, 2016)
Child labour free(Y_{11})	Information not available	0	No data available about child labour.	(Fairphone B.V. c, 2016)
Certification of fair trade(Y_{12})	Yes, fair-trade certified	2	Gold used in Fairphone 2 has been Fair-trade certified and pending for Fair-trade certificate of tungsten in Rwanda.	(Gerritsen, 2013) (Solution Network, 2012)

iPhone 7

Criteria	Answer	Score	Remarks	Source
Exchange battery(X_1)	No, knowledge and tools are needed	0	Prior knowledge and tools are needed for exhaling battery. Battery removal involves dangerous procedure that can damage smartphones internal mainframe and will smartphones factory guarantee.	(Reisman, 2017)
Swap broken screen(Y_1)	No, knowledge and tools are needed	0	Prior knowledge and tools are needed for exhaling battery. Battery removal involves dangerous procedure that can damage smartphones internal mainframe and will smartphones factory guarantee.	(Noronha, 2017)
Increase HDD memory(Y_2)	No, knowledge and tools are needed	0	Not possible to add more internal memory.	(GSM Arena, 2017)
Swap USB & power socket 3,5mm audio(Y_3)	No, knowledge and tools are needed	0	Prior knowledge and tools are needed for exhaling battery. Battery removal involves dangerous procedure that can damage smartphones internal mainframe and will smartphones factory guarantee.	(Havard, 2017)
Life span up to 5 years(Y_4)	No, designed to last less than 5 years	0	Apple Inc. expects that owners will change smartphones every 2-3. According to technology newspaper, Apple Inc. produces smartphones which will last for that period of time.	(McGoogan , 2017)
"Fall proof" phone can withstand fall 80cm high(Y_5)	No, less than 80 cm	0	No data available.	
Minimizing hibernation time or market for reselling(X_2)	Possible to resell for second hand market	1	Apple Inc. has developed second hand market for their products. In the future Apple Inc. wants to only use refurbished spare parts and phones, to reduce need for virgin materials.	(Apple Inc. a, 2017)
Is there any mitigation for production & transportation emissions(Y_6)	Yes, developer includes mitigation in the price	2	Apple Inc. has established environmental management program to reduce carbon foot print form production and transportation.	(Apple Inc. b, 2016)
Refurbish broken parts(Y_7)	Yes, possible to send broken parts to refurbishment	2	Apple Inc. has developed second hand market for their products. In the future Apple Inc. wants to only use refurbished spare parts and phones, to reduce need for virgin materials	(Apple Inc. a, 2017)
Reclaiming of 3T&G(Y_8)	Only gold is feasible to be reclaimed	1	Apple Inc. is developing material re-claiming from old smartphones to enable material recycling towards a circular material flow.	(Apple Inc. b, 2016)
Recycle/reuse plastics & phone case(Y_9)	Yes, it's possible to recycle and reuse	2	Progressive management of reclaiming of plastic aluminium, glass and other materials.	(Apple Inc. b, 2016)
Tractability - Material Flow of minerals used for producing(X_3)	No, minerals cannot be traced	0	There has been established awareness for not use minerals from DRC and received minerals from not certified smelters.	(United States Securities and Exchange Commission; Apple Inc., 2015)
List of all minerals used in manufacturing process(Y_{10})	No, not publicly available	0	No data available	(Apple Inc. b, 2016)
Fair working conditions (fair pay, 8h work day, holiday's, heath care.) (X_4)	Information not available	0	Apple has not fully disclosed the code of conduct for fair working conditions, and multiple investigations have been done, claiming bad working conditions in manufacturing areas.	(The Guardian, 2014) (China Labor Watch, 2013) (China Labor Watch, 2015)
Child labour free(Y_{11})	No, possible child labour	0	Evidence of possible child labour involved in manufacturing process.	(Wakefield, 2016)
Certification of fair trade(Y_{12})	No, not certified	0	No proof of fair trade, but there is evidence of movement towards fair trade, like with not using certified mineral smelters and mining minerals from DRC.	(Apple Inc. b, 2016)

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Criteria	Answer	Score	Remarks	Source
Exchange battery(X_1)	No, knowledge and tools are needed	0	Prior knowledge and tools is needed for exhaling battery. Battery removal involves dangerous procedure that will damage smartphones internal mainframe and will smartphones factory guarantee.	(Lionheart, 2017)
Swap broken screen(Y_1)	No, knowledge and tools are needed	0	Prior knowledge and tools is needed for exhaling battery. Battery removal involves dangerous procedure that will damage smartphones internal mainframe and will smartphones factory guarantee.	(Lionheart, 2017)
Increase HDD memory(Y_2)	Possible using micro SD or similar slot	1	Up to 256 gigabits can be added to phones memory using micro SD memory card.	(Samsung Electronics Co., Ltd. c, 2017)
Swap USB & power socket 3,5mm audio(Y_3)	No, knowledge and tools are needed	0	Repair manual not available.	
Life span up to 5 years(Y_4)	No, designed to last less than 5 years	0	There is no data available about smartphones lifespan, but the life span of this smartphones strongly depends battery life.	(Sharma, 2016)
"Fall proof" phone can withstand fall 80cm high(Y_5)	No, less than 80 cm	0	No data available.	
Minimizing hibernation time or market for reselling(X_2)	Possible to resell for second hand market	1	Possible for re-sell in second hard market. Samsung Electronics Co., Ltd. has not established market for refurbished smartphones.	
Is there any mitigation for production & transportation emissions(Y_6)	Yes, developer includes mitigation in the price	2	They have identified the emissions from production and transportation. They do not have clear mitigation about how they will reduce emissions.	(Samsung Electronics Co., Ltd. b, 2016)
Refurbish broken parts(Y_7)	Possible to recycle broken parts	1	Samsung has established e-waste collection and recycling, but no quantifying data is available.	(Samsung Electronics Co., Ltd. b, 2016)
Reclaiming of 3T&G(Y_8)	Only gold is feasible to be reclaimed	1	No data available about reclaiming 3T&G, but possible external recycles can recycle gold.	(Samsung Electronics Co., Ltd. b, 2016)
Recycle/reuse plastics & phone case(Y_9)	Yes, it's possible to recycle and reuse	2	Conducts recycling of plastic form the mobile phones.	(Samsung Electronics Co., Ltd. c, 2012)
Tractability - Material Flow of minerals used for producing(X_3)	No, minerals can't be traced	0	There is data available about mineral tractability and material flow. Guarantee that they do not use conflict minerals from Democratic Republic of Congo.	(Samsung Electronics Co., Ltd. b, 2016)
List of all minerals used in manufacturing process(Y_{10})	No, not publicly available	0	No data available.	
Fair working conditions (fair pay, 8h work day, holiday's, heath care.) (X_4)	No, lack of fair working conditions	0	No direct conformation from Samsung of good working conditions. There have been reported cases where people who work at Samsung factories are suffering from work related disease. Also cases where Samsung is forcing 16hours workdays.	(Miyoung, 2012)
Child labour free(Y_{11})	No, possible child labour	0	Samsung's official Code of Conduct states that no child labour under 15 years old. But in BBC news agency claims that they decupling this situation, but using external suppliers who possibly use child labour.	(Samsung Electronics Co., Ltd. d, 2015) (Wakefield, 2016) (Reisinger, 2014)
Certification of fair trade(Y_{12})	No, not certified		No data available.	

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