ENVIRONMENTAL IMPACTS OF A LOCAL CIRCULAR ECONOMY BUSINESS MODEL

A CARBON AND WATER FOOTPRINT ANALYSIS FOR SMARTPHONE REFURBISHMENT

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ABSTRACT

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Abstract
Climate change is creating harm for the environment and humanity. Companies contribute significantly to global warming and environmental destruction. Hence, to prevent the climate crisis, the traditional linear economy has been transformed. The circular economy is a way to create a sustainable economy by decreasing the environmental impacts of companies like GHG emissions, resource usage, and environmental destruction. (Bocken et al., 2016).
The growing ICT sector is an important actor in this area, particularly through the rapidly increasing amounts of WEEE, the rising GWP, and the increasing usage of resources. The inappropriate treatment of the toxic and harmful WEEE represents a growing problem (European Commission, 2020b), which can be decreased through smartphone refurbishment.
This thesis discusses the benefits and drawbacks of smartphone refurbishment as a circular economy strategy with a special focus on the analysis of carbon and water footprints. The carbon footprint and water footprint calculations are done comprehensively for the case company ASW from Belgium, which works as an optimized example. The calculations are also done for less optimized refurbishment scenarios.
The findings of the thesis suggest that smartphone refurbishment is environmentally beneficial over smartphone production. The carbon footprint of smartphone refurbishment (**6.3922 – 24.22 kgCO2e/device**) is significantly lower for every calculated scenario compared to the CF of a newly manufactured smartphone (**83.83 kgCO2e/device**). Similar, the WF of all scenarios (**1161.54 – 2946.71 L/device**) is significantly lower than the WF of smartphone production (**12075.46 L/device**). Furthermore, the refurbishment has the potential to decrease resource usage signifcantly. The thesis suggest that development and improvement of the infrastructure of smartphone refurbishment will lead to further decreased environmental impacts. Next to this, the thesis points out the research gap on the water usage in the ICT sector.

Keywords: Circular Economy, Carbon Footprint, Water Footprint, smartphone refurbishment

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LIST OF ABBREVIATIONS

ASW	A Smart World
B2B	Business to Business
BOE	Barrel of oil
BSI	British Standards
CE	Circular Economy
CF	Carbon Footprint
cF	carbon Footprint - “fossil fuel footprint”
CH4	Methane
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
EEB	European Environmental Bureau
EF	Ecological Footprint
EOL	End of Life
EPD	Environmental Product Declaration
EPR	Extended Producer Responsibility
GHG	Greenhouse gas
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
IPCC	International Panel on Climate Change
ISO	International Organization for Standards
IST	Instrumental Stakeholder Theory
L	Liter
LCA	Life Cycle Assessment
N2O	Nitrous oxide
NGO	Non-governmental organization
OECD	Organisation for Economic Co-operation and Development
OEM	Original equipment manufacturer
PAS	Public Available Specification
PFC	Perfluorocarbon
PKM	passenger-km
SF6	Sulfur hexafluoride
VW	Virtual Water
WBCSD	World Business Council for Sustainable Development
WEEE	Waste of electrical and electronic equipment
WF	Water Footprint

WRI	World Resource Institute

1 INTRODUCTION

Climate change is an increasingly important topic. The increased amount of anthropogenic greenhouse gas (GHG) emissions has caused a concentration of carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) in the atmosphere. The International Panel on Climate Change (IPCC) has identified the increased GHG emissions a side with other anthropogenic drivers as an extremely likely major cause for global warming (IPCC, 2014). Global warming is defined as a combination of rising temperatures of the sea surface and surface area. The recently published IPCC special report (2018) on *Global Warming of 1.5°C* points out the link of increasing GHG emissions to human activities. 1°C of the warming above the pre-industrial level is supposed to be caused by human influence. Scientists expect human-caused warming to keep increasing at around 0.2°C per decade. Global warming of 1.5°C is expected to be reached in between 2030-2052 if the temperature rises at the current rate. The rise above 1.5°C can cause negative impacts and risks on a physical, biological, and human scale. Physical consequences will be in the form of extreme weather conditions like droughts, floods, and changes in precipitation, but also glacier melting, coastal erosion, and sea-level rise. The biological impacts will be seen in the loss of biodiversity and the destruction of terrestrial and marine ecosystems. The effects on the human will be in the form of harm to the security of food production, general health, and living conditions. Additionally, the impacts will be seen in the form of damage to the economic system. Overall, climate change puts a risk on human and natural systems (IPCC, 2018). The IPCC (2014) report also points out that "*The risks of abrupt or irreversible changes increase as the magnitude of the warming increases*" (IPCC, 2014, p.16), which in context means that we have to start acting now to stop climate change before it is too late.

Companies have a significant impact on global warming. In this context, the term Circular Economy (CE) has recently received more awareness. CE is defined as "*an industrial economy that is restorative or regenerative by intention and design*" (Ellen MacArthur Foundation, 2013), which contrasts with the traditional linear Economy. CE business models are based on strategies for re-using, recycling, and reducing. Hence, the amount of new resources and energy for production is decreasing. Several studies point out that CE contributes to more sustainable development (Bocken, de Pauw, Bakker & van der Grinten, 2016; Homrich, Galvão, Abadia & Carvalho, 2018), supports the achievement of the CO2 emission reduction goal. Next to this, CE is expected to create economic benefits and new jobs according to modeling studies (Ellen MacArthur Foundation, 2015; European Commission, 2014). The European Union recognized the potential benefits of CE and has announced CE as one of the important strategies for tackling climate change. Nevertheless, the recently published Circularity Gap Report 2020 highlights that currently, only 8.6% of the world's businesses are working towards a

CE (Circle Economy, 2020). This fact raises the question of why the percentage is not higher.

One goal of this study is to point out the benefits of a CE. A common approach in the economy is the Carbon Footprint (CF) calculation because the primary GHG sources must be determined and controlled to reach the goal of reducing GHG emissions. The method can be used for estimating direct and indirect GHG emissions of companies, organizations, products, services, individuals, populations, governments, countries, etc. (Galli et al., 2012). CE does not only support the decrease of GHG emissions but also minimizes the overall resource usage. A limited and often underrepresented resource in the literature is water. Even though 70% of the world is covered by water, only 2.5 % from that amount is freshwater – the rest is ocean-based or saline. From this 2.5 %, much of it is not accessible because it is trapped in glaciers and snow (National Geographic, 2020). Most of the needed water for human activities like cooking, washing, agriculture, and industrial processes has to be freshwater. Therefore, water is used in every production step (Mekonnen, Aldaya, Hoekstra & Chapagain, 2011). A global survey from the World Economic Forum (2014) lists water scarcity as one of the three major risks for our systems. A tool to understand our water consumption of freshwater is the concept of the water footprint (WF) which calculates the amount of freshwater used in liters (L). The WF accounts for the direct and the indirect water use (Mekonnen et al., 2011). It is closely related to the virtual water concept. Virtual water resembles the amount of water used for the manufacturing of a product (Hoekstra, 2003). The usage of the WF helps to identify the sources of water usage and pollution, and with that knowledge, the reduction of water used in production can be supported. Many consumers are not aware of the size of their WF. Usually, they only realize their direct WF, but the indirect WF which is significantly higher is often neglected (Attari, 2014).

Both WF and CF originate from the ecological footprint (EF), which was first mentioned by Wackernagel and Rees in 1996. They describe the EF as representative of "*the critical natural capital requirements of a defined economy or population in terms of the corresponding biologically productive areas*" (Wackernagel et al., 1999, p. 377). The EF counts the direct and indirect human pressure on the earth and compares it with the planet's biocapacity (Galli et al., 2012). The EF is measured in global hectares (Wackernagel et al., 2005). The Global Footprint Network describes the CF as a part of the EF (Mancini et al., 2016). Galli et al. (2012) have been working on the OPEN: EU project, which focused on developing a 'Footprint Family' consisting of the ecological, carbon, and water footprint. The combined indicators offer the possibility of addressing the biosphere, atmosphere, and hydrosphere simultaneously. The footprint family was developed to show the far-reaching impact of humans on the planet. This study will only focus on the CF and the WF. The EF will be left out due to reasons of overcomplexity, time, and resource limitation for the study. Additionally, studies have shown that EF and CF often overlap with each other (Galli et al., 2012).

This thesis will be analyzing smartphone production as a linear economy and compare it to smartphone refurbishment as a CE. The smartphone was chosen because overall the Information and Communication Technology (ICT) sector is growing at a fast pace. Notably, the global usage of smartphones has increased immensely over the last years (Euromonitor international, 2015 in Hobson, Lynch, Lilley & Smalley, 2018). In 2005, there was an estimated number of 2.2 billion mobile cellular phone subscriptions. By 2018 this number increased to 7.85 billion. Compared to the global population, this is nearly equal to the worldwide community (Countrymeters, 2020). The CF of one device is relatively small e.g., 96 kilograms of CO2e for the iPhone 11 pro with 256 GB configuration (Apple, 2020). However, calculated on the 7.85 billion devices, this adds up to 753 billion kgCO2e. Additionally, the mobile phone market has been for a long time a primary example for the 'linear' economy, due to its way of significant resource consumption – mainly of non renewable resources - , low collection and recycling rates, short usage lifetime and little reuse, and sharing (Wieser & Tröger, 2018). The research question (RQ) that this thesis aims to answer is as follows:

> **RQ:** Does smartphone refurbishment have a lower environmental impact compared to smartphone production?

Various perspectives approach the issue of environmental impacts of a linear and a circular economy. Much research points out the benefits of a closed-loop economy, most of the authors focus on environmental benefits through CE. For example, the product life extension of electric devices contributes significantly to the mitigation of the impact on the environment (Bakker, Wang, Huisman, and Hollander (2014). Bocken et al. (2016) contribute with their research that CE product design and strategy have a positive impact on the environment. Also the research of Rashid, Asif, Krajnik and Nicolescu (2013) acknowledged that a change to a closed-loop economy will benefit the environment and will be better capable to deal with the uncertainties of the future than open-loop systems. The study of Riisgaard, Mosgaard, and Zacho (2016) on local smartphone repair businesses pointed out decreased environmental impact through the repair and increased economic benefits. The study of Zink, Maker, Geyer, Amirtharajah, and Aktella (2014) recognized smartphone refurbishment as the preferable end of life (EOL) option in terms of envicomental performance. Also Sarath, Bonda, Mohanty and Nayak (2015) mentioned recycling and refurbishment as environmentally preferable EOL possibilities for mobile phone waste. Nevertheless, some studies point out environmental trade-offs and rebound effects of CE through an increased level of other produce activities (Zink & Geyer, 2017), increased energy usage (Quariguasi & Bloemhof, 2012), inefficiency (Ardente, Talens Peiró, Mathieux, and Polverini, 2018). To answer the research question, the following sub-questions were developed:

> **SQ 1:** Does the smartphone refurbishment process have a lower CF than smartphone production?

SQ 2: Does the smartphone refurbishment process have a lower WF than smartphone production?

Regarding the two subquestions not much research is available specially in the case of the WF of smartphone refurbishment. Ercan, Malmodin and Bergmark (2016) calculated in their study a GWP of 57kg CO2e for a smartphone using an LCA approach. A study from the European Environmental Bureau (EEB) (2019) calculated that if the product life of all smartphones in Europe would be extended to three years 4.3 megaton CO2 could be saved. The EEB states that cracked screens and weak batteries are among the main reasons for the short lifespan and quick replacement, which can be avoided through refurbishment. In the literatur an example for smartphone refurbishment could not be found but, there are examples for studies on the CF of refurbishment activities on e.g. buildings (Schwartz, Raslan & Mumovic, 2018) which point out a lower CF through refurbishment. Other smartphone refurbishment businesses communicate a reduction of GHG emissions through refurbishment from 50% (Asgoodasnew.com; 2020) up to 70% (refurbed.de; 2020).

The case company for this study is the Belgium start-up A Smart World (ASW). The company refurbishes used electronics in the form of smartphones and tablets in a local process in Belgium. In the study, a comprehensive business CF of ASW is calculated, which helps to analyze the operations of ASW as well as identifying the GHG emission hotspots. This extensive footprint will be compared to the CF of the newly manufactured iPhones of Apple. Next to the CF calculation, the WF of the refurbishment process of the case company will be compared to the WF of smartphone manufacturing.

In a second step, the CE approach will be analyzed more detailed through a comparison of different refurbishment scenarios. For this comparison, less complex CFs and WFs will be calculated for five different scenarios. These calculations only include transportation to the refurbishment facilities as well as the replacement rate of three of the most common spare parts (battery, screen, and backside). The first scenario describes the local refurbishment process from ASW, which has a 100% optimized replacement rate. The other four scenarios describe refurbishment processes in other countries with less optimized replacement rates.

This study is contributing to the research about the impacts of a CE. While the concept of CE has gained momentum, also questions started occurring: Under which circumstances are CE practices likely to succeed (social, economic, and political conditions)? When do practices lead to an environmental benefit? How can more advanced CE strategies than recycling be adopted by businesses? (Bocken, Olivetti, Cullen, Potting & Lifset, 2017b). This study will point out the positive effects of CE on sustainability through the comparison with the footprints of refurbishment to a regular smartphone production. Next to this, the benefits of the working ways of ASW compared to other refurbishing scenarios will be highlighted. Through a comparison of ASW's footprints with the estimated footprint of other refurbishing companies, the differences will be pointed out.

It is necessary to clarify that even though not every mobile phone is per definition a smartphone, in this thesis, the terms will be used interchangeably.

In chapter two, the theoretical background is presented, which introduces the concepts of a circular economy, smartphone refurbishment, carbon footprint, water footprint, and the introduction of the case company. In the third chapter, the methodologies and data collection are explained. Followed by the fourth chapter, in which the results are presented. The fifth chapter 'Discussion & Conclusion' answers the research question and points out implementations, limitations, and further research options.

2 THEORETICAL FRAMEWORK

In this chapter, first, the ICT sector and particularly the problems concerning the EOL treatments are being introduced. Afterward, the concept of circular economy is introduced generally. A special focus is put on the refurbishment strategy in the case of smartphones, which is followed by the introduction of the case company ASW. The chapter finishes with the introduction of carbon and water footprints.

2.1 Information and Communication Technology sector

Often, the ICT sector has a positive image in the minds of people concerning the aspect of sustainability. The reason for that is the transformation of significant parts of human behavior like e-commerce, smart homes or video conference, which can mitigate the impact of humanity on the environment in particular in the form of GHG emission reduction. However, the ICT sector brings some negative effects. The rapid growth of the sector comes hand in hand with the rapid demand for energy and electricity consumption (Belkhir & Elmeligi, 2018). The whole infrastructure for the functionality of electronic devices like the data centers and telecommunication networks has an immense demand for energy and electricity (Patel, 2018). The study of Malmodin, Bergmark, and Lundén (2013) estimated that by 2020 the CF of the entire ICT sector is 1.1 GtCo2e. Belkhir and Elmeligi (2018) conducted a study on the development of the GHG emissions of the ICT sector. They estimate the share of emission by 2020: data centers (45%), communication networks (24%), smartphones (11%), displays (7%), desktops (7%), notebooks (6%) and tablets (0%). Compared to 2010, the contribution of communication networks, desktops, notebooks, and displays decreased, and only smartphones and datacenters increased. They highlighted the disproportionate and drastically increasing impact of smartphones as a surprise in their results. These findings represent the importance of the analysis of the impacts of smartphone production and usage.

The fast development of ICT and namely smartphones, has led to a considerable increase in the global demand for materials for manufacturing complex devices (Belkhir & Elmeligi, 2018). Smartphones consist of around 50 different materials, including critical materials, conflict minerals, and rare elements. The ICT sector is not the only sector using these scarce and non-renewable materials. In recent years, products like wind turbines, solar panels, and electric vehicles have been on the rise. The significantly increased demand is creating a risk on the available supply. Some of the elements are only available in a specific geographic location (Valero Navazo et al., 2014). To mention some examples, Chile has 60% of lithium, South Africa 77% of platinum, and 79 % of rhodium; China has 95% of world rare earth reserves, and the USA has 81% of beryllium (OECD, 2011). While market penetration is increasing, the average usage time is decreasing. Typically, the user replaces the used phone with a new device in less than two years (Riisgaard, Mosgaard & Overgaard, 2016; Zufall, Norris, Schaltegger, Revellio & Hanse, 2020).

Waste of electrical and electronic equipment (WEEE) from, e.g., smartphones, computers, fridges, and TVs is one of the most rapid-growing waste sectors in Europe. Around 400 million mobile phones are discarded every year (Xu, Zhang, He, Li & Huang, 2016). The European Commissions estimated the annual growth rate of ICT waste to 2%. Furthermore, they stated that currently only 40% of the ICT waste is getting recycled (European Commission, 2020a). The main reasons for the frequent disposal and replacement are quick development of the technology and new models as well as the fragility of the devices (Riisgaard et al, 2016). This consequently leads to poorly organized and irresponsible disposal (Tanskanen, 2013). WEEE consists of a mix of components and materials. Due to their complexity and partly toxicity, WEEE has to be adequately managed to prevent health and environmental problems (European Commission,2020b). Therefore, the European Commission has put two legislations in place. Firstly, the Directive on waste electrical and electronic equipment (WEEE Directive) in 2003 for the creation of collection streams. The 2012 updated WEEE Directive requires 75% of the recovery of e-waste form mobile phones (Directive, 2012). Secondly, the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) in 2003, which requires subsidizing heavy metals like lead and cadmium with safer options (European Commission, 2020a). Nevertheless, the official recycles rate for mobile phones are next to a few exceptions like Sweden and Belgium low (OECD, 2011). According to estimations, the total recycling rate in Europe is currently less than 40%. Therefore, the revised European CE Action Plan integrates the electronics and ICT sector explicitly. Required actions are designed for reuse, the ‘right to repair,’ improved durability for chargers, and other additional equipment and EU vast take-back schemes for old devices (European Commission, 2020a).

Due to gaps in the law, WEEE has been frequently exported to countries with insecure landfilling and informal recycling, which is creating pollution and health problems for the local population (Ongondo, Williams & Cherrett, 2011). The origin of this practice dates back to the 1990s when recycling systems were implemented. The infrastructures were not ready to process the quantity of WEEE, and therefore countries started exporting them (Greenpeace, 2009; Wieser & Tröger, 2018). These large informal sectors for recycling have come into existence in developing countries in Asia and Africa, but also in some developed countries like Greece. Consequently, they are creating difficulties for formal recycling from WEEE (OECD, 2011). Reports state that WEEE sent to developing economies often are not pre-tested on the functionality and cause severe problems due to the insufficiency of the local recycling and waste infrastructure (Ongondo et al., 2011). Reasons for the low recycling rates in Europe are still the structure and efficiency of the recycling infrastructure (Andrae, 2018). The updated version WEEE II Directive sets stricter regulations to stop countries from exporting their WEEE to developing countries (Directive, 2012). The extended producer responsibility (EPR) has been put into place to increase the collection and recycling rates of ICT. EPR is an environmental policy, which extends the producer's responsibility to the post-consumer phase and into the EOL treatment. EPR creates a shift in the form of administrative, physical, and financial obligations from the producer side. The goal of the EPR is to decrease the environmental impact of the products. In the European Union, the EPR covers WEEE, batteries, and some vehicles (European Commission, 2014).

WEEE does not only represent harm to health and environment but also has a potential of high value from a resource point of view. Around 28% of a mobile phone consists of metals (copper 15%, cobalt and Lithium 4%, ferrous metals 3 %, and nickel 2%) (Welfens, Nordmann & Seibt, 2016). Therefore, the EOL treatment plays a crucial role. Several standard options are recycling, reuse, solid waste streams, or unused storage. These options are difficult to track for companies and governments. Reuse often happens through passing along to family and friends or selling the phones on an online platform. Putting electronics in solid waste streams and from there to the landfill or combustion is officially forbidden in most developed countries, but still, a small percentage ends up there. According to estimations, only in Germany, there are currently 124 million old phones lying unused in drawers in offices and households (Teqcycle, 2020). A consumer survey in Germany showed that 16,6% of the questioned people stored more than three devices at home (Welfens et al., 2016).

2.2 Circular Economy

Circular Economy has its beginnings in the 1970s and 1980's when the revising of the industrial processes started (Frosch and Gallapoulos, 1989 in D'Amato et al., 2017). The origins of the term and the concept of CE are much debated (Murray, Skene & Haynes, 2017). For the first time, the term CE was used by Pearce and Turner in 1990 (Andersen, 2007; Ghisellini et al., 2016 and Su et al., 2013). In 1999, Cooper stated that the current model of a linear economy, which is based on unlimited natural resources and unlimited environmental absorbing capacity for waste and pollution, should be replaced. He proposed CE because of the reduced need for raw materials and energy. But the origin of the principles and their first usage can be traced back to Boulding (1966), who developed the closed system model and referred to the limitation of the availability of natural resources for humans (Boulding, 1966). Geissdorfer, Savaget, Bocken & Hultink (2017) also connect Stahel and Reday in 1976 to the first steps of CE with their focus on industrial economics, whose work was built around waste reduction and resource efficiency, as well as the dematerialization of the economy. Already in 1982, Stahel mentioned the importance of a change of ownership to selling utilization of products (Geissdoerfer et al., 2017).

Over the last years, the number of scholars concerning the theoretical concept, as well as practical implementation, has increased significantly (Geissdoerfer et al., 2017). Even though the amount of popular and scholarly communication on the CE topic has increased (Kirchherr, 2018), the research field is still relatively young. It has its roots in various disciplines (Bocken, Ritala & Huotari, 2017a). Therefore, no general one definition for the still-evolving CE concept exists (Merli, Preziosi & Acampora, 2018), which can create confusion and harm the chances for international cooperation. Kirchherr, Reike, and Hekkert (2017) claim that the non-existence of a standard definition can lead to obstruction for the implementation of CE. Still, Masi et al. (2017) emphasize that the CE concept is supposed to change the complete current business models, and therefore a broad definition is helpful. Even though there is no single clear understanding or definition for CE, several different suggestions have a common understanding of the concept which all describe a "*cyclical closed-loop system*" (Murray et al., 2017, p. 372). In the following, some existing definitions of the term CE will be presented. The UK based Ellen MacArthur Foundation defines CE as "*an industrial economy that is restorative or regenerative by intention and design*" (EMF, 2012, p. 7). Geissdoerfer et al. (2017) conducted an extensive literature review on the definitions of CE and, based on their results define CE as *"a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling"* (Geissdoerfer et al., 2017, p. 766). CE can be described as an economic model to optimize resource usage through strategies like waste reduction, minimization of resources, long term maintenance of value, and closing the loop of products, parts, and materials (Morseletto, 2020). Other similar approaches are "cradle-to-cradle" (McDonough & Braungart, 2010), "industrial metabolism" (Ayres, 1994), "industrial ecology" (Graedel & Allenby, 1995; Ayres & Ayres, 2002), "blue economy" (Pauli, 2010), "biomimicry" (Benyus, 1998) and "natural capitalism" (Hawken, Lovins & Lovins, 1999).

Several strategies in the field of CE exist. They can be sorted into three main categories. The most common name for the categories is the 3R's Principle (Reduction, Reuse, and Recycle) (Su et al., 2013) or narrowing, slowing, and closing (Bocken et al., 2016), which both mean the same. The 3R's principle can be extended to the 10Rs (refuse, rethink, reduce, repair, refurbish, remanufacture, repurpose, recycle and recover) (Potting, Hekkert, Worrel & Hanemaaijer, 2017); Morseletto, 2020). Potting et al. (2017) structured the 10Rs in the subcategorize of the 3R's (see Table 1).

Table 1 The 10Rs of CE (Potting et al., 2017)

NARROWING (Reduction) Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
	R1 Rethink	Make product use more intensive (e.g., through sharing products or by putting multi-functional products on the market)
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials
SLOWING (Reuse) Extend the lifespan of the product and its parts	R3 Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfills its original function
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function
	R5 Refurbish	Restore an old product and bring it up to date
	R6 Remanufacture	Use parts of the discarded product in a new product with the same function
	R7 Repurpose	Use the discarded product or its parts in a new product with a different function
CLOSING (Recycle)	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality

A useful application of materials	R9 Recover	Incineration of materials with energy recovery

The narrowing/reduction category aims to decrease the amount of primary energy and resource usage, but also to minimize the amount of waste production through efficiency in production and consumption (Bocken et al., 2016; Su et al., 2013). Potting et al. (2017) name this category "*smarter product use and manufacture*." The narrowing category includes the refuse, rethink, and reduce principal. The **refuse** strategy aims to make the product redundant or to offer the same value on a radically different product (Potting et al., 2017). Examples for that are Spotify and Netflix, which provide both online streaming services and therefore made the former product (CD and DVD) redundant. The **rethink** strategy implies to make the product use more intensive through sharing options or by developing multi-functional products (Potting et al., 2017). Examples for the rethink strategy are self-service laundry facilities or renting platforms for clothing, kitchen equipment, building tools, or similar. The **reduce** strategy includes ambitions to increase the efficiency in the product, manufacturing process, or usage, to use fewer natural resources and materials (Potting et al., 2017). Examples for this strategy are the usage of rarer packaging material for a product, an increased efficiency in the production phase, or a renting platform for expanding the usage phase. The Product Service Systems (PSS) is a classic CE business model for the narrowing category, which offers customers the possibility to pay for the use of a product and not to own it (Suckling & Lee, 2015) and can be applied to any of the three narrowing strategies.

The slowing/reuse category is defined through the extension of the lifespan of the product and its parts (Potting et al., 2017). The slowing category includes the most different strategies: reuse, repair, refurbish, remanufacture, and repurpose. The **re-use** strategy describes the re-usage of a discarded product, which is still functioning by another consumer (Potting et al., 2017). Typical examples for this are products that are passed on to friends and family or which are sold in secondhand shops, on a flea market or online peer-to-peer platforms like eBay or Facebook groups. The **repair** strategy includes the repair and maintenance of dysfunctional products so that they can be used with their former purpose (Potting et al., 2017). Examples for this strategy are the repair offers of the original equipment manufacturers (OEM), meaning the primary product producers like the repair offers for iPhone reparation from Apple. The **refurbish** strategy means reparation and cleaning of an old product so that it is functional and as new again (Potting et al., 2017). The Ellen MacArthur Foundation's definition of refurbishment (2013) also includes cosmetic changes for the appearance of the product. An example of that is the refurbishment of ICT products like laptops, tablets, and smartphones, which can be resold to another customer. The **remanufacture** strategy characterizes the use of parts of a discarded product to build a new product with the same function (Potting et al., 2017; Cambridge Dictionary,2020a). The difference between refurbishment and remanufacturing is described as the higher complexity of the latter one (Geyer & Blass, 2010) and aims to upgrade the used phone in a condition that is like new or even better (Mugge, Jockin & Bocken, 2017). Also, for remanufacturing, the common examples are in the ICT sector. The **repurpose** strategy is defined as the usage of a discarded product or parts of it for building a new product with a different function (Potting et al., 2017). An example of that is the company Freitag, which produces bags out of old truck tarpaulins (Freitag, 2020).

The closing / recycle strategy is characterized by the "*useful application of materials*" (Potting et al., 2017) and includes recycling and recovery. The **recycling** strategy is defined as processing materials to gain the same quality (high grade) or lower (low grade) quality materials. Recycling is widely accepted as a common practice to close the loop. The benefits of recycling are that the energy to recover the materials is significantly lower than the energy needed for the extraction. Nevertheless, through inefficiency in the recycling process and factors like electricity mix, location, and collection system, the environmental benefits of recycling can be minimized or even outweighed (Allwood, 2014; Nussholz, 2017). Recycled materials can often not be applied for the same product because of lower quality, the mix of materials, or toxicities. The ultimate product chain, which is built on always reusing the same materials, is probably not possible (Potting, 2017). The **recover** strategy is described as the incineration of materials to get energy (Potting et al., 2017).

Potting et al. (2017) ranked the ten strategies for their circularity, innovation, and socio-institutional change. They stated that the lower the number, the higher is the circularity, and therefore the fewer natural resources and less environmental pressure exist. That would make the narrowing strategies the most and the closing strategies the least desirable one. Another way to rank the CE strategies is through the differentiation in 'inner and outer (Wieser & Tröger, 2016). Examples for outer circles are recycling, refurbishment and remanufacturing. Inner circles are represented through reuse, repair, and product replacement. The Ellen MacArthur Foundation points out the "power of the inner circle." It states that the inner circle has higher benefits in the form of cost savings for resources and materials, labor, energy consumption and mitigation of GHG emissions and other toxic materials (EMF, 2013). The innovation development can differ as well in three aspects: technology, product design, and revenue model. The higher the model, the higher must be the core technology development. The technology innovations for recovery and recycling are, therefore, the most complex ones. The lower the number, the higher should be the innovation in product design and revenue model. Additionally, the lower the number, the higher is the socio-institutional change to have a successful business. The Socio-institutional change involves the transformation of (un)written rules, traditions, and beliefs. Potting et al. (2017) state that the socio-institutional change is usually the most significant challenge because it involves a shift in mindset. Lüdeke-Freund, Gold & Bocken (2018) note that the closing and slowing loop strategies are clear evidence for the

CE. In contrast, narrowing the loops strategy also matches the current linear economy. The overall goals of CE are to replace more energy and resource-intensive primary production through secondary production and to reduce total consumption. The process of replacing primary production through secondary production is called cannibalization (Greyer & Blass, 2010).

ASW operates with a sustainable business model (SBM) (Schaltegger Schaltegger, Luedeke-Freund, and Hansen, 2012.) The characteristics of an SBM is that the company is creating value for a specific (sustainability) problem (Lüdeke-Freund et al., 2018). The aim of an SBM operating company is extended from only creating value for the customers to also value creation for stakeholders and the natural environment. SBMs usually do not cover the whole LC of a product but only an explicit phase, in this case, the EOL treatment. Hence, SBM creates new competition in the same market; in this example, the smartphone sector (Bocken, Short, Rana & Evans, 2014).

2.2.1 Benefits of the Circular Economy

CE offers various benefits in terms of economic, environmental, social, and resource usage (European Environmental Agency, 2016). It has the potential to guide sustainable development through decoupling from negative consequences like ecological destruction and resource exhaustion (Murray et al., 2017; Geissdorfer et al., 2017). CE allows companies to increase their productivity with the same amount of resources and to use their former waste (Hofmann, 2019). Due to the increased efficiency, lower costs for material, energy, and production occur for the company (Nussholz, 2017). Next to this, CE offers the possibility of dematerialization through changing from the traditional selling of physical goods to offering services (product as a service) (Bressanelli, Adrodegari, Perona & Saccani, 2018). Business models like leasing and rental offer the chance to change and deepen the customer relationship (Lüdeke-Freund et al., 2018). The study *'Growth within: A Circular Economy Vision for a Competitive Europe'* by the Ellen MacArthur Foundation (2015) forecasts an annual resource productivity growth by 3% through the CE in Europe.

Lately, CE has received lots of awareness and support from politics. The European Commission adopted a comprehensive 54 step CE Action Plan in December 2015 (*Closing the loop – An EU action plan for the Circular Economy*). The content of the action plan was support for a transition to a more CE in Europe for areas like product design and manufacturing, consumption, waste management, and material recovery (European Commission, 2015). In 2019 the Commission evaluated the actions conducted. By 2016, more than four million jobs had been created concerning the CE sector, the recycling rate went up, and CE business models generated €147 billion (European Commission, 2019b). In 2019, the European Commission under their president Ursula von der Leyen developed an ambitious *European Green Deal,* which strives to make Europe the first climate-neutral continent. The Commission has integrated the Green Deal in its general strategy for reaching the UN's 2030 Agenda and the sustainable development goals. Areas covered in the deal are clean and affordable energy, resource-efficient buildings, the shift to sustainable mobility. Europe should be a global leader for environmental and climate action (European Commission, 2019a). At the beginning of 2020 following the European Green Deal, the Commission implemented a revised European CE Action Plan (*A new Circular Economy Action Plan: For a cleaner and more competitive Europe*). Actions for sustainable production, product value chains, and enhanced value creation from former waste are some of the critical areas. Furthermore, the new plan demands the OEMs to produce products that are easier to disassemble (European Commission, 2020). Lately, Apple had been producing iPhones with non-removable batteries, which makes repair and refurbishment more complicated. In the future that should not be possible anymore.

2.2.2 Rebound effect of Circular Economy

Even though most literature does not address the possible risks, there are rebound effects associated with CE. Signs exist that CE can, in specific cases, enhance the overall production and consumption and hence, compensate the benefits of CE. This procedure is called "circular economy rebound" (Zink & Geyer, 2017). The two main aspects which can cause a rebound effect are (1) inadequate substitution of the CE products and (2) increased consumption due to price effects (Makov & Vivanco, 2018; Zink & Geyer, 2017). Related to (1) the inadequate substitution, Zink & Geyer (2000) explain that CE products do not automatically make a good substitution for the primary outcome. Concerning (2) price effects of CE, Zink & Geyer (2017) state that CE products can have lower quality and therefore are sold for a lower price, which in return as a consequence can lead to increased consumption. The increased use can be explained by the fact that the customer saves money by buying the cheaper CE product. Therefore, consumers can spend the saved money on more products of the same kind (e.g., clothing) or can even spend the saved money on entirely different products or services, which might not be environmentally beneficial. Another argument is that the producer is saving money due to reuse of the material and, therefore, might invest the saved money into business growth or product expansion and new offers. The CE products enter the market as substitution products and, in return, compete with the primary outcomes. The higher supply rate of the product can cause overall price effects (Zink & Geyer, 2017). Overall, based on the study by Zink & Greyer (2017) it can be concluded that the EOL treatment of the product does not play an important role if it does not cause cannibalization of sales. To prevent rebound effects, Bocken et al. (2016) propose to educate the consumers to influence their behavior as a customer in terms of avoiding overconsumption and strengthening responsible purchases. These behavioral customer changes can affect primary production. Another possible rebound effect is shown in the leasing product concept. Leasing can have advantages over selling products if the product has high durability and a higher user impact under rental (like a washing machine). However, if the product has short durability and high production and disposal consequences (like a laptop), leasing might be financially valuable but environmentally worse (Agrawal, Ferguson, Toktay & Thomson, 2012).

2.3 Smartphone refurbishment

In the literature, refurbishment and remanufacturing are frequently used interchangeably. Remanufacturing indicates the return to a new or even better condition, whereas refurbishment only includes a satisfactory condition. This study is focusing on refurbishment. Nevertheless, some of the literature used is based on remanufacturing and was still applied to this study.

Sitcharangsie, Ijomah & Wong (2019) state that remanufacturing is the most common strategy for retaining the value of discarded products and a driver for CE. Refurbishment gives the device the chance of a second usage phase because it adds new stages to the LC of the smartphone, which can be seen in Figure 1.

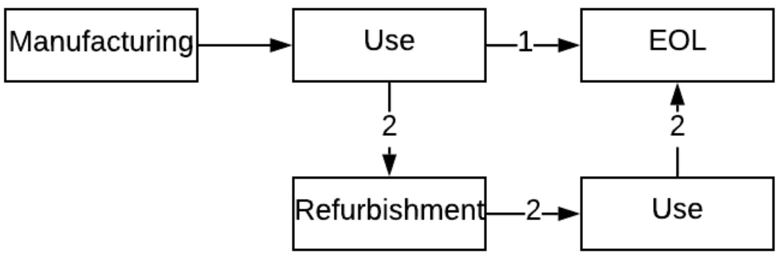

Figure 1 Life Cycle of a phone: new and refurbished (following Quariguasi & Bloemhof, 2012)

2.3.1 Benefits of smartphone refurbishment

A consensus on different studies indicates that creating a second life for products through, e.g., refurbishment leads to several positive aspects environmentally and economically (Andrae, 2016; Atasu, Guide, Van Wassenhove, 2010; Guide & Van Wassenhove, 2001). The refurbishment has significantly grown in importance over the last years. The main reasons are environmental concerns, legislation, and economic benefits (Ijomah, 1999).

The legislations are in the form of international agreements to reduce electric waste (like the WEEE Directive) and the environmental impact of products and manufacturing processes.

The Ellen MacArthur Foundation (2013) points out that refurbishment has positive economic aspects of the company because it allows them to retain the value of the former used materials and products instead of mining and production. Furthermore, due to the growing demand in the raw materials from the ICT but also other sectors like the electric mobility, the prices for raw materials have been rising (Rosenau-Tornow, Buchholz, Riemann & Wagner, 2009). There are concerns that for smartphone production essential resources like indium and palladium the future long term supply can not be guaranteed (Erdmann & Graedel, 2011; Valero Navazo et al., 2014). In these volatile markets, collecting the discarded products to retain the value or to reuse them is essential (Bakker, Wang, Huisman & den Hollander, 2014). The refurbishment process can be optimized through better product design from the beginning, which will ease the refurbishment process afterward (Ijomah, McMahon, Hammond & Newman, 2007). The decreased raw material extraction also leads to less energy usage and GHG emissions, which is a financial benefit for the company and positive for the environment (Andrea, 2016).

The study of Zufall et al. (2020) lists the different LC phases of a smartphone and the related sustainability issues related to social, ecological, and economic aspects (see Table 2).

Table 2 Sustainability issues at different LC phases of a smartphone (Zufall et al., 2020)

Life Cycle Phase	**Sustainability issues**
Resource extraction and processing	Illegal operations and harmful extraction of conflict minerals
	Bad working conditions (child labor, unsafe conditions, long working hours)
	Environmental destruction through mining
Design and manufacture	Resource and energy-intensive
	Bad working conditions (low salary, long working days)
	Toxic materials (harmful to human and environment)
	Bad product design (not reparable)
Distribution and network provision	Emissions from transportation
	The quick development of new phone models
Usage	The short lifetime of a phone
	Electricity consumption
	Collection of functional devices which are not used
End-of-life	Collection of defect devices which are not put to recycling

	WEEE illegally exported to developing countries
	Informal recycling sectors
	Bad working conditions
	Toxic materials (environmental and health problems)

Researchers analyzed several studies on the impact of the mobile phone across the whole LC. All the studies point out that the extraction and manufacturing phase is the superior phase with the highest CO2 emissions and the most significant impacts (Suckling & Lee, 2015; OECD, 2011; Ercan et al., 2016; Yu, Williams & Ju, 2010; Quariguasi & Bloemhof, 2012; Valero Navazo, 2014). Resource extraction and their processing cause 50% of GHG emissions, over 90% of biodiversity loss, and immense pressure on water resources (EC, 2020). Studies point out that the environmental impacts for the refurbishment process in the form of material and energy usage are minimal in relation to the amounts needed for a new production (Cooper & Gutowski, 2015). The energy consumed for recovering copper is only half of the amount required for primary extraction. For other metals, similar energy-saving benefits can be seen (Valero Navazo, Villalba Méndez & Talens Peiró, 2014). Furthermore, for keeping the impacts of the second usage phase low, the product should be returned in an as-new condition (Copper & Gutowski, 2015). Also, Ovchinnikov, Blass & Raz (2014) concluded that refurbishment leads to a decrease in energy consumption and increases economic benefits.

Studies show that next to the production stage the usage phase (Schischke & Kohlmeyer, 2005) has the most significant environmental impacts. Nevertheless, an extended usage phase decreases the overall environmental impact compared to a short usage phase (Geyer & Blass, 2010; Wieser & Tröger, 2017), because the short lifespan implies a more frequent replacement with a new manufactured phone. Another reason for the short life span of the phones is 'planned obsolescence', which is a built-in feature in the product design that decreases the life span of the product (Bakker et al., 2014). Therefore, the overall environmental impacts of the significant LC stages can be reduced through a long usage phase. Hence, extending life through refurbishment is environmentally beneficial (Sarath et al., 2015; Andrae, 2018). The quick replacement of the overall ICT puts enormous pressure on the resources and the waste system. Wieser and Tröger (2016) explain that the more the circulation can be slowed down, the higher will be the positive impacts on waste and energy reduction. The extension of the usage of a phone by one year can reduce the CF by 31% (Benton, Coats & Hazell, 2015).

Additionally, collecting old smartphones prevents losing resources (Ongondo et al., 2011). The value of preserving the resources through reuse is higher than the value through recycling and additionally provides less economic and environmental impacts (Netherland Circulair, 2015). The benefit of refurbishment over recycling is that the product does not have to be dismantled completely. Hence, the original energy used for primary production can be saved (Ijomah, 1999). The Ellen MacArthur Foundation (2013) demands to increase the collection rate of smartphones from 15% to 50%. From this amount, only one fifth should be recycled, and the majority should be reused or refurbished. Surveys point out that from the discarded ICT, around 60% are still functional (Cooper, 2004).

The refurbishment of smartphones decreases GHG emissions significantly. Other refurbishing companies advertise with numbers like 50% GHG emissions (Asgoodasnew.com; 2020) up to 70% CO2 emissions reduction (refurbed.de; 2020). The refurbishment of one phone can safe 14 kg of raw material and over 50 kg of CO2 emissions. If the LC of a phone gets prolonged for another year the reduction can drop by another 30 % (asgoodasnew.de; 2020).

If the numbers of refurbished smartphones increase significantly, they have the potential to replace parts of the production of new devices (Zink 2014), which would lead to cannibalization. Cannibalization means the reduction of new products manufactured because of the reuse of old devices. Much debate exists about the fact if reused phones represent a functional substitute for newly constructed products. Some assumption even predicts that buyer of reused phones tends to upgrade to a newly manufactured phone if their old one retires. This idea means that reuse positively influences the future sale of new products (Geyer & Blass, 2010). The most significant environmental impact of reuse lies in the substitution of newly manufactured devices because of the new device's need for raw and critical materials (Geyer & Blass, 2010). Even though the cannibalization is described here, currently the market of refurbished smartphones is only around 6% of the newly manufactured market (Ellen MacArthur Foundation, 2012).

2.3.2 Drawbacks of the smartphone refurbishment

To reach the stage of a sufficient refurbishment rate to subsidize new phone production, refurbishing companies have to overcome several barriers. The refurbishment company has to balance several complicated and risky aspects like timing, quantity, and quality of the discarded phones (Ijomah, 1999), knowledge to disassemble the various phone models, reverse logistics, possible problems in the matching of the materials and spare parts and uncertainty in the processing times (Sitcharangsie et al., 2019). Reversed logistics, which is the return of the used mobile devices from the customer back to the company (Cambridge, 2020b), represents a barrier for refurbishment and the general resource recovery. Costs for reverse logistics occur from collection & shipping, the inspection & processing, and a possible return incentive for the previous owner (Guide & Van Wassenhove, 2001). The motivation for reuse and recycling on the company side is mostly market-driven or comes from legislations. Only a few companies are environmentally or voluntary, motivated. (Geyer & Blass, 2010). When phones are collected by a refurbishing company, they have to be checked for the ones that can be refurbished and phones that can only be recycled. Hence, reuse and recycling are never entirely independent of each other (Geyer & Blass, 2010). Recycling is not mandatory economically successful compared to financially beneficial reuse (Suckling & Lee, 2015). In most countries, consumers return the phone without any charge. But collecting enough is one of the biggest challenges for refurbishing companies. Therefore, some companies started to offer consumers money in return for their old devices (Xu et al., 2016).

Another barrier is the cooperation with the OEM. Most of the refurbishments, reuse, and recycling is not done or coordinated by the OEM, but by third-party companies (Geyer & Blass, 2010). OEMs do not necessarily support refurbishments because of the fear of cannibalization (Atasu, Guide, Van Wassenhove, 2010; Guide & Li, 2010, Andrae, 2018). Therefore, obtaining the original spare parts from the OEM can be difficult due to missing cooperation. (Zink & Greyer, 2017). In the example of Denmark, only a few of the repair shops are certified by the OEM's for the phone reparation (Riisgaard et al., 2016).

Another current problem is inefficiency in the refurbishment process and transportation. But if the refurbishing rate would increase substantially, the infrastructure and efficiency would simultaneously increase. Then refurbishing a smartphone would have the same beneficial effects as a prolonged usage (Andrae, 2018)

Another problematic comes from the consumer side. Often the understanding of the importance of responsible treatment of ICT is missing. Hence, owners of used phones tend to leave the unused phone in the drawer or just put it into regular house waste. Monetary incentives can boost awareness and increase the collection rate of old ICT devices (Welfens, Nordmann & Seibt, 2016). Another obstacle is missing trust from the customers in the quality of the refurbished phones. Studies have shown that a local shop can be essential to increase reliance (Riisgaard et al., 2016). But even if the problematic concerning trustworthiness is overcome, people tend to be willing to spend a lower amount of money on refurbished phones compared to new ones. In general, price management is a possible boundary for a successful refurbishment business (Liang, Pokharel & Lim, 2009). The low sales price (Osibanjo & Nnorom, 2008) and high labor costs in western countries (Riisgaard et al., 2016) can make the remanufacturing of mobile phones unprofitable.

This aspect leads to the possible drawbacks of the refurbishment industry. Some producers purchase components from countries with lower labor costs to reduce costs and simply assemble these parts (Goodship, Stevels & Huisman, 2019). Furthermore, several studies pointed out that many of the phones for reuse were sold to developing countries (Osibanjo & Nnorom, 2008; Geyer & Blass, 2010). Exports from Europe often go to Africa, Eastern Europe, and the Far & Middle East. Refurbisher from the USA export to Latin America, Asia, Africa, and Eastern Europe (Geyer & Blass, 2010). The shipping of the used devices to developing countries is directly related to passing on hazardous materials (Osibanjo & Nnorom, 2008). WEEE, which is exported to developing countries, "disappears." The standards in developing countries like Asia, South America, or Africa are not as high as in Europe and, therefore, does not suffice the European Standards (Huismann, 2003). Thus, exports were heavily criticized and are now under stricter regulations (Salhofer, Steuer, Ramusch & Beigl, 2016), which can be seen in Annex VI "*Minimum requirement of shipments*" of the WEEE Directive. This section specifies regulations for shipments to ensure that the items shipped are functioning electrical and electronic equipments and not WEEE (Directive, 2012).

2.3.3 Rebound effect in the smartphone refurbishment

Smartphone refurbishment can also lead to a rebound effect. A study by Zink & Geyer (2017) analyses the impact of refurbished smartphones. In the study is assumed that all smartphones are sold to a developing country whose inhabitants would otherwise not be able to buy a smartphone. Therefore, the study compares the impact of no smartphone to a refurbished smartphone and achieves the result that the refurbished smartphones cause a CE rebound effect. Quariguasi & Bloemhof (2012) point out that refurbishment is not useful if newer phone models have a significantly lower energy consumption. Nussholz (2017) specifies that energy efficiency is dependent on the impact of the process for refurbishment and included other consequences like transportation to the workshops. Products with an intensive production phase and less influence in the user phase, are well suitable for refurbishment. But products with a high impact in the user phase are not predestinated for a refurbishment process. Fortunately, products are becoming increasingly more and more energy-efficient, which makes them more suitable for a refurbishment process.

Even though, refurbishment brings various benefits, Ardente et al. (2018) point out that there is a point when remanufacturing becomes inefficient. This point is reached when the old device performs (environmentally) much worse compared to a new appliance. For example, if the energy consumption of the refurbished phones is significantly higher than of a more modern device than the environmental benefits of the refurbishment process could break even with the environmentally harmful aspects of the higher emissions in the usage phase. Also, the expected lifetime of a refurbished device can be significantly shorter than a new model. On the example of remanufacturing phones, Quariguasi and Bloemhof (2012) showed that remanufacturing has a positive impact under the condition that the refurbished parts do not have a significantly shorter lifespan than the added new elements.

Another problem in the smartphone industry is that producers develop new models so frequently that the refurbished smartphones are counted quickly as old phones, even though they are still in good conditions (Zufall et al., 2020).

Another crucial part of a successful reduction of the environmental impact of a smartphone through refurbishment is the following user phase. The longer the overall time of usage until a new replacement, the more the environmental impact of the refurbishment can be balanced (Streicher-Porte et al., 2009).

2.3.4 Smartphone components

The production of a smartphone makes up to around 85-95% of its total CF, because of the energy-intensive mining and the built-in electronics (Belkhir & Elmeligi, 2020). As mentioned previously, the smartphone consists of a variety of different resources and materials. Included are conflict minerals (like tantalum), rare earth elements (like Lanthanum (La), Praseodymium (Pr), Gadolinium (Gd), Terbium (Tb) and Dysprosium (Dy)) and toxic materials (like lead, arsenic), which are connected to environmental and health risks (OECD, 2010). The primary critical metals included in phones are antimony, beryllium, palladium, and platinum. 'Critically of metals can change according to the demand, availability, supply, and usage of these metals (OECD, 2011).

The following section explains the smartphone components to create a better understanding of the refurbishment process and to realize which raw materials and resources are needed for a smartphone refurbishment.

Battery
Most of the smartphone batteries have lithium-ion batteries, which consist of lithium cobalt (positive electrode) and graphite (carbon) (negative electrode). Some other batteries are composed of different metals. An ideal replacement for cobalt is manganese. The case of the battery is usually made of aluminum (Compound Interest, 2014).

Four different battery types can be used for smartphones: Nickel-cadmium (NiCd), Nickel-metal-hydride (NiMH), Lithium.ion (Li-ion) and Lithium Polymer (Li-Pol) (Gizbot, 2016). The Lithium-ion battery is by far the most common. The demand for lithium has been increasing drastically in the last years, mainly due to the rise of electric vehicles. Lithium extraction happens all over the globe. The five biggest lithium producing countries are Australia, Chile, Argentina, China, and Zimbabwe (Barrera, 2019). The extraction process puts pressure on the environment mainly through the vast amounts of water used and polluted (Katwala, 2018). Cobalt is another critical element in the battery, which is mostly found in the Democratic Republic of Congo. The cobalt mining creates substantial environmental, social and political problems in the country examples are acid dumping, child labor and corruption (Smedley, 2014).

There are two good reasons why batteries should be treated appropriately, meaning recycling or refurbishing at the EOL. The first one is that inappropriately disposed batteries in the landfill or in incineration harm the environment. Therefore, the EU Commission also developed the Battery Directive (EC, 2018). The second reason is that the amount of the metals in the battery is 100 times higher than in the ground. Usually, minerals are found with less than 0.01% quantity on Earth (Valero Navazo, Villalba Méndez & Talens Peiró, 2014). Therefore, recycling can be seen as urban mining and batteries should not be put in the WEEE (Smedley, 2014).

Batteries are often the first component that does not function properly anymore (Osibanjo & Nnorom, 20008). A difficulty is that producers do not make it easy to change the battery by yourself. For example, since the iPhone 7, the iPhones are waterproof, but the new casing makes it also even more challenging to change the battery (Apple, 2020).

Front /Screen
The glass of the screen is usually made of aluminosilicate glass, which is a mix of alumina (Al_2O_3) and silica (SiO_2). Additionally, it contains potassium ions, which strengthen the glass. For the glass to function as a touch screen, a transparent film of indium tin oxide (a mixture of indium oxide and tin oxide) is used. The screen contains small amounts of various rare earth elements (like Yttrium, Lanthanum, Terbium, Praseodymium, Europium, Dysprosium, and Gadolinium), which produce the colors in the screen (Compound Interest, 2014).

Casing
Most of the cases are made of plastics. They can include other compounds like bromine to add flame retardants or nickel, which reduces electromagnetic interference. Instead of plastic magnesium compounds can also be used for the casing (Compound Interest, 2014).

Electronics
The electronics consist of various elements. Copper, gold, and silver are the majority of metals used for the micro-electrical components. Copper is also used for the wiring inside the phone. Tantalum is mostly used for the micro capacitors. Nickel is one of the essential parts of the microphone. Other elements like Praseodymium, gadolinium, and Neodymium are composing the magnets in the microphone and speakers. For the vibration of the phone, Neodymium, terbium, and dysprosium are used. The chip in the phone consists of pure silicon. Oxygen is added to develop non conducting areas. Other elements like antimony, arsenic, phosphorus, and gallium are added to manage the electricity. For the soldering process, tin and lead are used. Lead can be subsidized with a mix of copper and silver (Compound Interest, 2014).

2.3.5 Consumer acceptance of refurbished smartphones

An essential aspect of the success of refurbishment is the consumer. Van Weelden, Mugge, and Bakker (2016) researched the issue of consumer acceptance for refurbished smartphones. Both based their studies on the Engel Kollat Blackwell (EKB) Model of Consumer Behavior (EKB) (Engel, Kollat & Blackwell, 1968). The EKB model describes the consumer decision as a problem-solving task in several phases: pre-purchase phase, orientation phase, evaluation phase, and post-purchase phase. The model of the different phases in the consumer decision process can be seen in Figure 2.

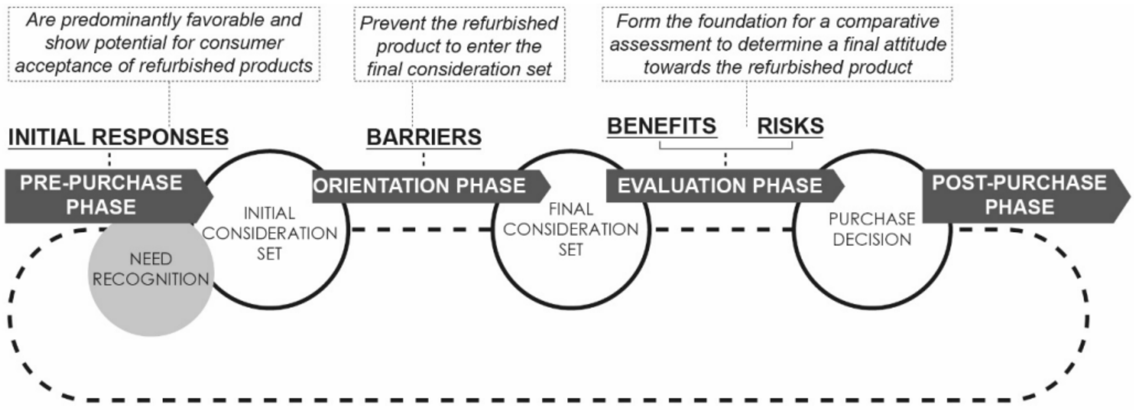

Figure 2 Model of the consumer decision-making-process showing the main factors influencing consumer acceptance of refurbished mobile phones (Van Weelden et al., 2016)

In the pre-purchase phase, which represents an initial reaction without much consideration, the consumers showed a general interest in refurbished smartphones.

In the orientation phase, two main barriers for refurbished smartphones were found: 'lack of awareness* and 'misconception of refurbishment concept.' Therefore, refurbished smartphones are often not even taken into consideration when buying a new phone, because consumers did not know about refurbishment or if they knew they associated second-hand phones to refurbished smartphones. The second-hand image comes alone with a perceived risk of damage and bad quality. Another encountered problem in the orientation phase is 'lack of availability' because refurbished phones are often not in the usual retail stores or on the webpage of the known phone producers available. The fourth factor in the orientation phase is that refurbished products 'lack the thrill of newness', which describes a minor barrier because of missing new functionalities as well as an emotional barrier concerning the unpackaging and the feeling of purchasing something new.

In the evaluation phase, the consumer's perceived risks and benefits of a refurbished smartphone were weighted. The study of van Weelden et al. (2016) figured out that the perceived high risks while purchasing a refurbished product are the main barriers to consumption. The main risks are performance risk, financial risk, time risk, and obsolescence risk. Performance risk describes the fear that the phone breaks quicker. The financial risk means the perception that the price of the refurbished phone is too high because it might break easier. Time risk is the fear that the phone has to be returned because of a technical defect or something similar and that the buyer has, as a consequence, no phone for some time. The obsolescence risk describes the problem of outdated technology, especially regarding the quickly developing world of smartphones. These risks could be limited through the fact that the EU law compels refurbishing companies to have a one-year warranty for their products (European Parliament, 1999). The main perceived benefit is financial because of the lower price of refurbished smartphones. The environmental benefit of a refurbished smartphone can be a factor for deciding for a refurbished product (Michaude and Llerena, 2011) but usually only plays a minor role in the eyes of the consumer (Van Weelden et al., 2016).

Van Weelden et al. (2016) describe a range of factors that can influence the risk-benefit balance. They divided them into three categorize: personal, contextual, and product-related. Personal means familiarity or trust in their ability to judge the quality of the phone. Contextual factors can be a warranty, the price, the image of the seller and the brand, and the shopping experience. The product category includes information about the performance of the phone, the usage history, and the outer appearance.

Mugge, Jockin and Bocken (2017) did follow-up research on the study of van Weelden et al. (2016), in which they formed six different customer groups: (1) casual supporter, (2) sustainable enthusiast, (3) conservative critic, (4) susceptible follower, (5) proud power-user, and (6) expert techie. The analysis showed that three of the groups (casual supporter, sustainable enthusiast and susceptible follower) were suitable for refurbished smartphones due to their interest in environmental issues. Additionally, these three groups did not show a high interest in the newest technological updates. This overlaps with the results of van Weelden et al. (2016) that consumers of refurbished smartphones are more interested in functionality than new technologies or an outstanding appearance. In many cases, the functionality gets overrun by the perceived risks. Therefore, the most crucial aspect is to convince consumers that the refurbished smartphones meet the minimum requirements for functionality (Van Weelden et al., 2016). An element that influences this factor negatively is that no official guideline for refurbishment exists, and therefore the quality between the different refurbishing companies can vary drastically (Sharma, Garg & Sharma, 2016).

Riisgaard et al. (2016) mention that a possible problem of CE is that the consumption of the products is private. In contrast, the consequences of the use of environmental impacts are societal issues. Hence, the connection between behavior and societal problems should be found. For smartphones, an economic incentive for either selling the discarded devices to refurbishment companies or buying the refurbished smartphone for a lower price compared to a new device can connect these two areas. Overall, the price is the main driver. Val Weelden et al. (2016) stated that "If money did not matter, they would all decide for a new phone." The willingness to pay for a refurbished smartphone is lower than for a new product (Mugge et al., 2017). One reason for that is the perceived risks concerning the quality of the refurbished products (Guide and Li, 2010). A factor which effects in the opposite direction is the lower ecological impact of a product, which has become an important criteria in the decision process of the consumer (Laroche, Bergeron & Barbaro-Forelo, 2001) and eco-certification are a credible sign for a decreased impact (Berghoef & Dodds, 2013). The use of a eco-certification increases the willingness to pay (Harms and Linton, 2015).

2.4 Carbon Footprint

In the following two chapters, the concept of carbon and water footprint is explained as well as the standard used for the calculation in this thesis.

Even though the 'carbon footprint' has become a widely used concept for calculating the amount of GHG emissions, a clear definition of 'what exactly is a CF?' is missing. The most common understanding is that CF is representing gaseous emissions that are linked to climate change and human activities like production and consumption (Wiedmann & Minx, 2008). As a result of a comprehensive literature review, Wiedmann & Minx (2008) suggest the following definition: "*The carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that are directly and indirectly caused by an activity or is accumulated over the life stages of a product*"(Wiedmann & Minx, 2008, p.5). The CF is based on Life-Cycle thinking. But the difference to an LCA is that the CF only assesses a single indicator, the Global Warming Potential (GWP). The GWP describes how long a GHG molecule will stay active in the atmosphere (Eurostat, 2014).

While conducting a CF, it is crucial to set boundaries of the study. The defined boundaries decided which aspects and indicators are being included in the CF. The boundaries of the footprint must be indicated to provide consistency, transparency, and accuracy. Several initiatives and standards exist for calculating the CF of a product. The benefits of using standards are cost reductions for the company and transparency, comprehensibility, and comparability for outsiders (GHG Protocol, 2004). The three most known standards are the PAS 2050, ISO TS 14067, and GHG Protocol product standards. The International Organization for Standards (ISO) published the first version of the ISO TS 14067. It offers guidelines for the CF calculation as well as for the treatment of specific GHG emissions. The instructions are based on the ISO 14040 and ISO 14044, which are the Standards for LCAs (Garcia & Freire, 2004; ISO, 2018). The Public Available Specification (PAS) 2050 developed by the British Standards (BSI) was first used in 2008 and then revised in 2011. The guidelines are as well based on the ISO standards for LCAs (BSI, 2011; Garcia & Freire, 2014; Weidema et al., 2008). It is generally based on the ISO standards and in alignment with the PAS 2050 (Garcia & Freire, 2014). By now, several standards like the Product Standard and the Corporate Standard exist (GHG Protocol, 2020b). An additional standard is the Climate Declaration which is a single-issue declaration highlighting the CF of a product. The Climate Declaration should be published for products which have an Environmental Product Declaration (EPD). This concept was developed by the International EPD System. Similar to the other standards, the Climate Declaration is also based on the ISO standards (EPD, 2020; Garcia & Freire, 2014). The European Commission also worked on environmental footprint pilots between 2013-2016. A Product Environmental Footprint and an Organisation Environmental Footprint pilot were tested. Differences to other standards like ISO 14044 are that the EC decides which impact categories have to be analyzed and which methods must be used. This should lead to a more harmonized and fair approach (Kerkhof, Terlouw, Vieira, Alexandre & Bagard, 2017). This study will be working with the GHG Protocol Standard.

The Global Footprint Network, which conducts annually 'National Footprint Accounts', sees the carbon Footprint as one aspect of the EF. Mancini (2016) is working on a carbon Footprint (cF) which is a measurement within the EF which accounts for the "*amount of bio-productive forest land required to sequester anthropogenic carbon dioxide emissions at world average sequestration rate, to avoid CO2 accumulation in the atmosphere*" (Mancini et al., 2016). This cF should not be confused with the CF, because the cF is used explicitly as an equivalent for the 'fossil fuel footprint' or as the 'CO2 area' or 'CO2 land'. CO2 land is defined as "*The demand on biocapacity required to sequester (through photosynthesis) the carbon dioxide (CO2) emissions from fossil fuel combustion. … it includes the biocapacity typically that of unharvested forests, needed to absorb that fraction of fossil CO2 that is not absorbed by the ocean*" (in Wiedmann & Minx, 2008, p. 4).

Some scholars also identified the limitations of the concept. Research points out that CF can be oversimplified because they mainly focus on one indicator, the CO2 emissions. In comparison, an LCA includes various other factors. But according to the current situation in the world in which the focus is on carbon emission reduction and global warming, the CF is focusing on the most crucial aspect.

2.4.1 GHG Protocol Standard

The GHG Protocol Initiative has been developed by the US-based World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), which resembles a group of 170 international companies and is based in Geneva. The Initiative was started in 1998 with the mission to develop internationally accepted standards for accounting and reporting of GHGs. They consist of different stakeholder relationships between companies, non-governmental organizations (NGO's), policymakers, and others. The Initiative developed two standards (1) *GHG Protocol Corporate Accounting and Reporting Standard*, which included a step by step guide for reporting the GHG emissions of companies and (2) *GHG Protocol Project Quantification Standard*, which is a guide for analyzing the GHG mitigation projects. The GHG Protocol Corporate Accounting and Reporting, which is used in this study, is based on the five principles: relevance, completeness, consistency, transparency, and accuracy.

In the literature, the different boundaries are referred to as "tiers" or "scopes" of the carbon footprint (GHG Protocol, 2004; Matthews, Hendrickson & Weber, 2008). Scope 1 is *Direct GHG emissions*, which come from sources that are owned or controlled by the company. Scope 2 is *Electricity indirect GHG emissions,* which occur, for example, from the usage of electricity on the organization site, which is provided externally. Scope 3 is *Other indirect GHG emissions*: the emissions from this scope occur as a consequence of the reporting organization, but the source of the emission is neither owned nor controlled by the organization. Examples for this category are the usage and end of life phase of products or services. Even though the GHG Protocol describes scope 3 as an optional category, many studies show that scope 3 contains the major part of GHG emissions (Larsen, Pettersen, Solli &Hertwich, 2013; Matthews et al., 2008), which indicates the importance of that category. The boundaries also must state which emissions are being analyzed. Over the years, there were discussions if the CF should only calculate CO2 emissions or all carbon-based emissions or all GHG emissions, including non-carbon based gases (Wiedmann & Minx, 2008). The GHG Protocol Standards are based on the Kyoto Protocol, whose target is to reduce GHG emissions. The Kyoto Protocol includes the six primary GHG, which are Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF6) (UNFCCCC, 2008). These six mentioned gases are the most common and in the GHG Protocol standard necessary to include gases. The GHG Protocol Corporate Standards mention that if other additional GHG emissions are measured they should be reported separately (GHG Protocol, 2004). The CF is usually calculated in CO2 equivalents (CO2e) (Wiedmann & Minx, 2007), which is a metric measure that offers the possibility to compare the different GHGs. The GHGs are converted into the corresponding equivalent of carbon dioxide. These equivalents are based on GWP (GHG Protocol, 2004).

2.4.2 Instructions for the GHG Protocol

There are two main approaches for calculating the CF: the Process Analysis and the Environmental Input-Output analysis. The PA is a bottom-up method that takes the whole life cycle into account. It is recommendable to use for smaller-scale studies like of one product. Environmental Input-Output analysis represents a top-down approach. This approach is useful for creating more comprehensive examinations because it also takes other impacts into account and therefore creates a broader picture. This approach is rather recommendable for meso level analysis like a whole sector and not only a single product (Wiedmann & Minx, 2008). Therefore, for this study, the PA approach was chosen because it focuses on a micro-level analysis. An important aspect that must be kept in mind while doing a CF is to avoid double counting. This can happen easily when the whole supply chain or LCA is being analyzed. Double counting can cause problems in terms of carbon trading and offsetting. Additionally, it falsifies the data and results (Wiedmann & Minx, 2008).

2.5 Water Footprint

Freshwater is needed for nearly every human process because saltwater is not useful for many activities like drinking and cooking, but also for washing, agriculture, and industrial processes. Even though freshwater on land is continuously replenished through water cycles, it is not unlimited. The water systems in the world are affected by two mechanisms. The first and more known one is global warming and its effects on global temperature rise as well as evaporation and precipitation patterns. The second mechanism is global trade (Chapagain & Hoekstra, 2008). They explain this mechanism on an example between America and the Netherlandes. Through the consumption of an American product in the Netherlands, the Netherlands affects water consumption in the United States. Over 4 billion people live in areas with a high rate of water scarcity in at least one month of the year (Mekonnen &Hoekstra, 2016 in Hoekstra 2017). The discussion about the limited water resources has three different aspects: production, trade and consumption. The production is discussed under the aspect of local efficiency. The global trade is discussed in the light of worldwide resource efficiency and the consumption perspective analyses the water use efficiency of consumers (Hoekstra, 2017).

Due to the limitation, it is essential to know: how much freshwater is annually available and how much freshwater the human is consuming (Mekonnen et al., 2011)? The concept of the water footprint (WF) answers the second part of the question. The WF was developed to indicate the consumption-based freshwater usage. It is closely related to the virtual water (VW) concept, which was first used by Tony Allan in 1997. VW resembles the amount of water used for the manufacturing of a product. The term virtual is used to point out that far more water is used during production than in the final product itself. The WF and VW both refer to the amount of water used for a product. But the WF can create a more comprehensive picture because it can additionally indicate the source of the water, the time and location when it was used. Additionally, the WF can be applied wider not only for a product but also for individuals, companies, cities, or countries (Haie, Rodrigues Freitas & Castro Pereira, 2018; Hoekstra, 2003).

The Water Footprint (WF) concept was first introduced by Hoekstra in 2002. (Hoekstra, 2003). The WF was developed because of rising water problems (Haie et al., 2018). The WF calculates direct and indirect usage and pollution of freshwater along the supply chain over the whole production in a volumetric measure. Therefore, WF can be a comprehensive indicator of freshwater resource usage. The WF indicates the source and amount of the used freshwater as well as the pollution. But the WF does not explicitly show the local environmental impact, because this varies a lot depending on the vulnerability of the local source (Mekonnen et al., 2011).

2.5.1 Water Footprint Assessment Manual

The Water Footprint Network developed a standard for calculating the WF, which is called the 'Water Footprint Manual'(Mekonnen et al., 2011). The Water Footprint Manual classifies water sources into different categrories and scopes which can be seen in Figure 3. First off all, the WF can be divided into three groups: the blue, green, and grey wf. The blue WF calculates the consumption of surface and groundwater. The term 'Consumption' in this context refers to lost water through evaporation from one specific catchment area. The water may return to another catchment area or the sea or stay in a product. The green water footprint refers to rainwater sources, which evaporate or are incorporated into the product or service. The grey water footprint addresses the polluted water. Next to this the WF manual also differs between a direct and an indirect WF, which has the same distinction as on the CF. In the context of a business, the direct WF represents '*the volume of freshwater consumed or polluted due to the business's own operations*.' The indirect WF is '*the volume of freshwater consumed or polluted to produce all the goods and services that form the inputs of production of the business*.' In the WF, the amount of freshwater required to reach the status quo of natural background concentrations and water quality standards is calculated. Therefore, the WF analyses data for direct and indirect use including both times the green, blue, and grey footprint.

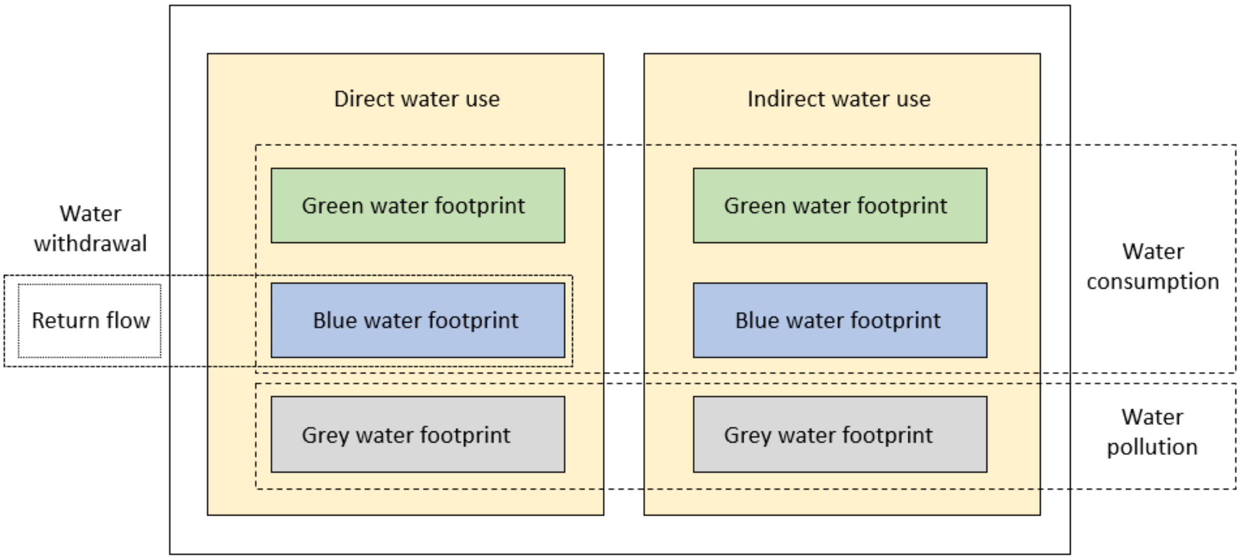

Figure 3 Relationship of different scopes (Mekonnen et al., 2011)

Other terms in this context are the water consumption, which accounts for the same areas as the WF except that it leaves out the grey water footprint. The water pollution accounts only for the grey WF of the direct and indirect use. The water withdrawal calculates the total amount of blue water taken from the source, which means only direct use. The complete WF shows a more comprehensive picture of the water usage than water withdrawal, or other calculations (Mekonnen et al., 2011).

Human water consumption can be explained on the example of a river basin, which is also often called the catchment area. The basin resembles the entire area of the river and its tributaries. The yearly precipitation leaves the basin because of evapotranspiration and run-off. Evapotranspiration describes the processes of evaporation and transpiration. Humans can alter the processes of the run-off and evapotranspiration. The green water describes the usage of evaporative water for agriculture and forestry. Bluewater consumption shows human use through abstraction of the run-off flow. The following figure 4 shows the green and blue water footprint and its differences in more detail.

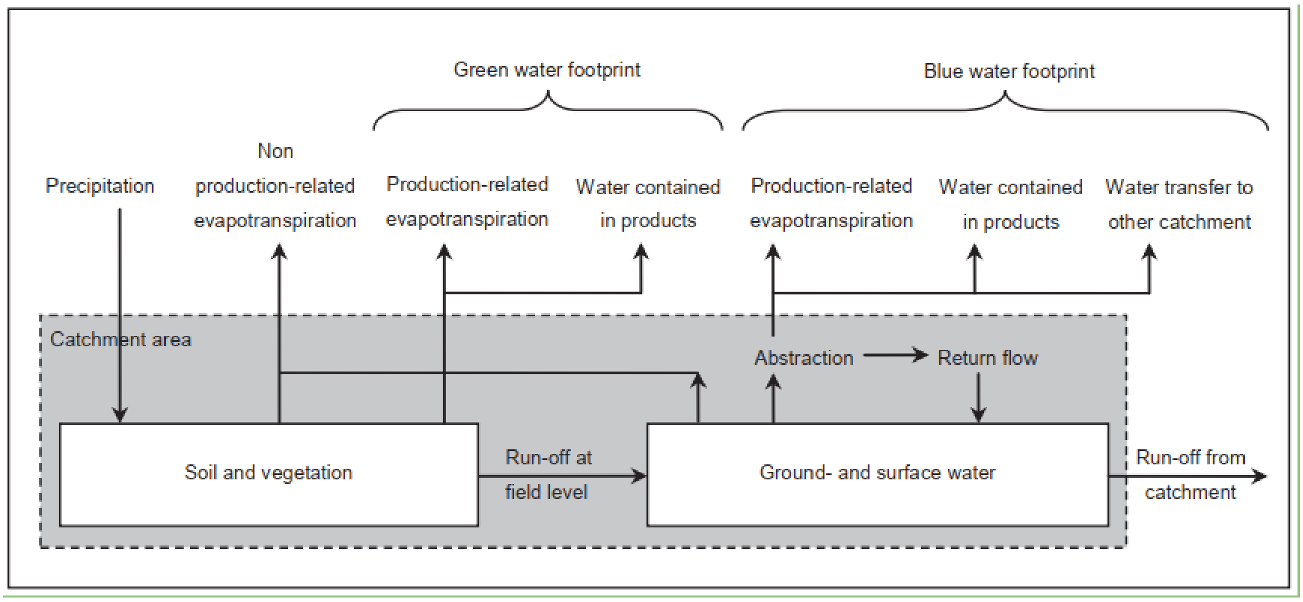

Figure 4 The green and blue WF in relation to the water balance of a catchment area (Mekonnen et al., 2011, p. 20)

The Water Footprint Assessment combines several activities. It is used to quantify and locate the WF of a specific entity, which can be e.g. a process step, a product, a consumer, a consumer group, a business, a business sector, or the whole humanity. Next, the environmental, social, and economic sustainability of the WF is assessed. It is important to notice that the WF assessment does not tell what to do, but rather helps to understand the whole picture. The WF is used to calculate the footprint of a single process step. To calculate the WF of a complete product (good or service), the different WF of the different steps must be calculated. To calculate the WF of an individual consumer, the WF of the various consumed products has to be added up. Finally, to estimate the WF of a community of consumers, the different individual consumer WF have to be added together (Mekonnen et al., 2012).

Additionally, next to the Water Footprint Assessment Manual, an ISO Standard (ISO 14046:2014 *Environmental Management – Water Footprint – Principles, Requirements, and Guidelines)* exists for calculating the WF. Different froo the Water Footprint Assessment, ISO does not differ between blue, green, and grey footprints but focuses on the whole life cycle with an LCA approach (ISO,2014). Another method is called the Available Water Remaining (AWARE) and calculates with an LCA perspective on the water resource depletion. AWARE focuses on local and regional water use and conditions (Ansorge and Beránková, 2017). The WFA has been used on various global studies of the years with topics of national consumption of countries (Hoekstra and Hung, 2002). The WF origins from the agricultural field but has expanded to the industrial areas. (Hoekstra, 2017).

In earlier stages, the green and blue water footprint were not distinguished by each other. The differentiation from a consumptive WF to a green and a blue footprint came from Falkenmark (2000) in Hoekstra 2017). The first study in that context was done by Chapagain (2006b). Chapagain et al. (2006b) also introduced in the same paper the grey WF under the name 'dilution water footprint', which was later renamed to grey WF as a consequence of some misinterpretations of the first name. (Hoekstra, 2017). In the beginnings, the grey WF was limited to pollution through nitrogen. Nowadays, several other water quality parameters can be calculated with the grey WF including metals, pesticides, nutrients, and dissolved solids (Hoekstra, 2017).

2.5.2 Instructions for the Water Footprint Manual

At the beginning of the WF assessment, the goal and the scope must be defined. To set the goal, in the beginning, helps planning and to coordinate the future steps and the focus of the study. For the scope, the inventory boundaries must be set. These boundaries describe what will be included and what will be excluded from the assessment. This is very similar to the boundaries which had to be set for the CF. The scope of interest for this study is the direct and indirect WF. The direct WF is also called operational WF. The indirect WF represents the supply chain WF. Traditionally, the supply chain WF was not included in the corporate WF. But as in the CF, the indirect WF is for most companies larger than their operational WF and, therefore, should be included to show a comprehensive picture. Another distinction in the corporate WF is between the WF directly associated with the product and the overhead WF. The overhead WF is related to water consumption, which is needed for running a functioning business, but not straight forward related to the production of a specific product. The following table 3 shows a list of various components of the business WF and which section they belong to.

Table 3 Example of WF for a refurbishment business (Mekonnen et al., 2011)

	Operational	Supply chain
WF directly associated with the production	• water consumed or polluted during the production process • water thermally polluted through the use for cooling	• water footprint of other inputs used in production

of the business's product (s)		• water footprint of other items bought by the company for processing their product
Overhead	• water consumption or pollution related to water use in kitchens, toilets, cleaning, or washing working clothes • business property cleaning causes water consumption (blue) or pollution (grey)	• water footprint or infrastructure (construction materials and so on) • water footprint of materials (paper, office materials, IT) • water footprint of energy (fuel, gas, electricity) • water footprint of transportation for general use (office materials, cars and trucks, fuels, electricity and so on) • food and beverage consumption

The scope must indicate which processes along the supply chain will be included. The WF Assessment Manual generally suggests including all 'significant' operations (Mekonnen et al., 2011). There is no one definition of significant. The manual indicates that every process which contributes to more than one percent to the WF can be account as substantial. Supply chains seem to be never-ending because of the variety of inputs in the different processes. Nevertheless, only a few steps contribute to the total WF of the final product. In industrial sectors, the highest contribution generally comes from pollution (grey WF). Another aspect that has to be decided is if labor and transportation are included. Labour is required for nearly every production process and can occur in the direct and indirect WF. The employee's food, clothing, drinking water, etc. could be included in the WF. But including the employee's data can lead to double counting if the user phase is also included because all workers can also be consumers, which creates a loop. Therefore, it is common practice to exclude labor.

The WF assessment can be done on different spatiotemporal levels (Table 4). Level A describes global averages, which are generally represented annually and have the lowest level of detail. This data can is quite unspecific but can be well used for awareness-raising and comparisons. Level B data is used for national, regional, or catchment specific assessments. The data time period is also annual or monthly. The information of Level B data is more precise than Level A and hence can be well used for hot spot identification. Level A and B data can be found in literature and databases. Level C data represented a small catchment or a specific area and is, therefore, more precise. The data has to be empirically collected.

Table 4 Spatiotemporal explication in water footprint accounting (Mekonnen et al., 2011, p.12)

	Spatial explication	Temporal explication	Source of required data on water use	Typical use of the accounts
Level A	Global average	Annual	Available literature and databases on typical water consumption and pollution by product or process	Awareness-raising; rough identification of components contributing most to the overall water footprint; development of global projections of water consumption
Level B	National, regional or catchment specific	Annual or monthly	As above, but the use of nationally, regionally or catchment specific data	Rough identification of spatial spreading and variability; knowledge base for hotspot identification and water allocation decisions
Level C	Small catchment or field-specific	Monthly or daily	Empirical data of (if not directly measurable) best estimations on water consumption and pollution, specified by location and over the year	Knowledgebase for carrying out a water footprint sustainability assessment; formulation of a strategy to reduce water footprints and associated local impacts

2.6 The case company: A Smart World

A Smart World was founded in July 2018 in Belgium. The startup with six employees buys used smartphones, refurbishes, and resells them. From a CE perspective, the case company uses the slowing the resource loop strategy. This strategy offers (environmental) benefits because for producing a secondary product, fewer resources, energy, and workforce are required compared to an original product from raw materials (Castellani, Sala & Mirabella, 2015). The average life cycle of the smartphones becomes extended through the refurbishment and the following second user phase. ASW aims to operate only locally. ASW buys most of the used phones from Belgium companies. They pick the phones up themselves by car and bring them to the workshop, where the phones are refurbished. A small number of used phones are bought from individuals. They usually sent the phones via Bpost to the office of ASW. The workshop and the office of ASW are in the same building, and they are in Genval near Brussels. During the refurbishment process, ASW works to optimize the operation and, therefore, to replace only the necessary parts. Hence, if a phone has a scratch on the back, it will not be repaired because the scratch does not influence the functionality of the phone. After the refurbishment, the ready phones are brought to the storage from BME in Genk, which is around 100 km away from the office. The phones stay there until they are sold. The transportation from there to the customer is done via Bpost. Generally, ASW buys more phones from companies and sells more to individuals. The individual customers do not only live in Belgium but the whole of Europe. The reason that the company does not sell the refurbished phones back to companies is that they are only working with a small quantity currently. Companies usually want to buy a more significant number of the same model so that every employee would get the same phone. Therefore, ASW cannot fulfill this need at the moment.

3 DATA AND METHODOLOGY

The collected data, methods, and calculations are presented in the following section. The research is based on comparing the CF and WF of different refurbishment scenarios to smartphone production. The main reason for using the footprints instead of an LCA is the simplicity of the footprints. A complete LCA of smartphone manufacturing and refurbishment provides a great amount of data, but to understand the most important aspects more simplicity is needed. Furthermore, much of the data for an LCA would have not been available.

The CF explicitly was chosen because the essential data for comparing the environmental impact of manufacturing and refurbishing mobile phones are the GHG emission and energy usage. The literature review of Suckling and Lee (2015) about LCA's of smartphones points out that most of the studies are only assessing the impacts of energy usage and GWP of mobile phones. Hence, comparable studies and literature for the CF calculation are available. The CF has gotten most of its publicity from nongovernmental organizations, businesses, and individual initiatives instead of scientists. Since a CF is "catchier" and simpler. Nowadays, every person can easily use one of the online CF calculators to calculate his or her CF (Weidema, Thrane, Christensen, Schmidt & Lokke, 2008). Hence, the communication to companies and individuals who are not experts in environmental impact assessments is more natural with the footprints. The GHG Protocol Standard was explicitly chosen due to its popularity. According to CDP, which is a non-for-profit charity organization working on a global disclosure system for businesses and countries about their environmental impact management system (CDP, 2020), in 2016 over 90% of the Fortune 500 companies worked with the GHG Protocol directly or indirectly (GHG Protocol, 2020a). GHG Protocol (2020b) claims to be the worldwide most used CF accounting standard.

Even though the GWP is one of the most important aspects concerning the environmental impacts of smartphone manufacturing and refurbishment, Moberg et al. (2014) note that the GWP alone does not represent all the important environmental impacts. A more comprehensive study is needed to gain a border understanding of all the environmental impacts of mobile phones. Therefore, the WF was additionally chosen. Overall, water usage is a very underrepresented topic in the ICT sector and every other field except agriculture. The reason behind that could be that e.g. in the United States, 85% of water consumption is needed for irrigation and livestock. 8% is used for domestic and commercial usage, 4 % for industrial mining, and 3% for thermoelectric power (McMahon & Price, 2011). Nevertheless, attention should be paid to this area, because the ICT sector is rapidly growing (Belkhir & Elmeligi 2018).

The data for the research was collected between January and March 2020 to quantify the GHG emissions caused as well as the water usage during phone refurbishment. The case company data are based on the data from December 2019.

It is not based on the whole year, due to the reason that ASW is a growing start-up and their operations had immensely expanded since their beginning in July 2018. Therefore, only the most recent data from December 2019 has been used as a baseline and an estimate for a full year with the same productivity rate as December has been developed. At the beginning of the data collection, a flowchart for the organizational processes of ASW was designed to make sure that all the data will be included (see Figure 5).

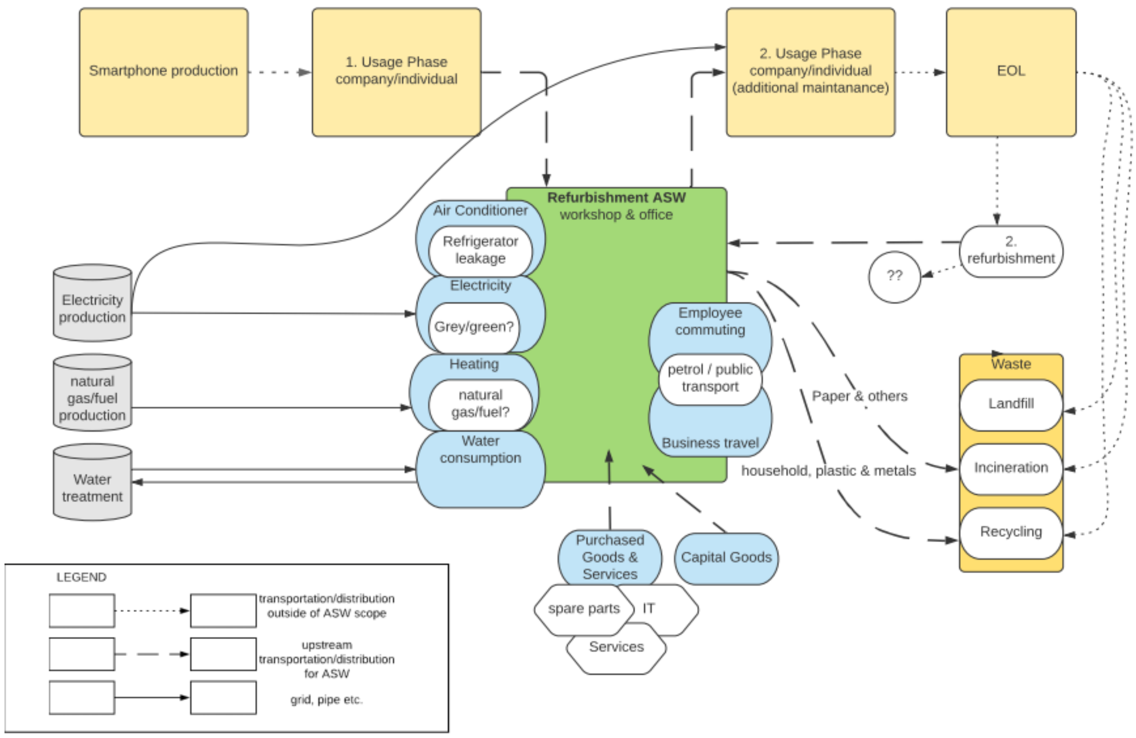

Figure 5 Flowchart ASW

The data for the other refurbishing scenarios are mostly based on assumptions or research articles because information about other refurbishing companies is not publicly available on their webpages. The data for regular phone productions is mainly based on the data from Apple because they provide a comprehensive overview of their emissions during phone production. Additionally, databases were used. For the calculations, I was supported by the Belgium consultant agency CLIMACT.

For the CF of ASW two different calculations were done. The first one is a comprehensive CF calculation following the GHG Protocol Standard. The second calculation (scenario 1) is the simplified scenario calculation including limited data. The second calculation is done for creating a better comparability between ASW and the other scenarios.

3.1 Carbon Footprint -ASW

The Carbon Footprint - ASW chapter is divided into three different sections: data collection, methodology, and calculation of the CF. The calculation is presenting the whole GHG emissions from the company ASW in December 2019. Afterwards, the CF is calculated down to the CF of one smartphone through dividing the total footprint for December through the number of smartphones refurbished in December.

3.1.1 CF Data - ASW

At the beginning of the data collection, the organizational boundaries were set. Two different approaches for this practice exist (1) equity share and (2) control approach. The equity share accounts for GHG emissions equivalent to the share the company has in the operations. This approach is useful for manufacturing companies. The equity share helps to identify the total GHG emissions from the whole production. The control approach includes 100 percent of the GHG emissions from the own operations of the company, but emissions from operations without control of the company are excluded. The control approach can be divided into financial and operational control (GHG Protocol, 2020). For this study for the case company, the equity approach is used because much of the GHG emissions occur in the supply chain, where the case company does not have control. Setting the operational boundaries means the identification of the emissions associated with the different processes. These emissions are separated into direct (scope 1) and indirect (scope 2 & 3) emissions. Direct emissions are from sources that are controlled or owned by the company. In contrast, indirect emissions occur as consequences from activities of the company, which are not managed or owned by them. The direct and indirect emissions vary depending on the chosen consolidation approach (equity or control).

The data for the CF of ASW was mostly contributed by the case company. Nevertheless, some of the data were not available, and therefore assumptions had to be made. The data was collected with a template based on the suggested scopes and categories of the GHG Protocol (see APPENDIX 1).

Scope 1

Scope 1 represents direct GHG emissions produced by the company. For the case company, emissions occur from all three sources in scope 1. The stationary combustion emission comes from the usage of heating fuel. The mobile combustion emissions occur during the pickup from bought smartphones, which are driven from the client’s office to the workshop for the refurbishment. The car is not an official company car, but the own car of the founder of ASW. The same car is also used for the commuting of the founder of ASW. The used fuel is divided into the fuel usage for commuting and for the pickup. The pickup fuel is accounted in scope 1 ´mobile combustion' and the commuting fuel is accounted in scope 3 'commuting'. The client's office is on average 24 km away one way. The pickup of smartphones happens twice per month. Therefore, the total distance traveled with the car is (24 km x2) x 2 = 96km. Another source of emissions comes from the fugitive emissions – the air conditioning in the office and workshop. At the office site are in total two air conditioners of the model 'General Inverter ASGG18LFCD- 1.5 ton'. The air conditioner is filled with a specific refrigerant for cooling. In the case of ASW, the refrigerant R410A is used. The ADEME webpage identified several numbers of the average amount of refrigerant used and of the annual leakage of these refrigerants is. For this calculation, the median of these numbers was taken. Quantity of refrigerant used: (0.5 kg +1 kg +0.6 kg +5 kg +1.5 kg)/5 = 1.72 kg. Annual leakage of refrigerant which is (2 %+ 5 % + 6 % + 2 % + 6 %)/5= 4.2 %. For the cooling, only the refrigerant leakage is account for. GHG emissions that occur during the production of the air conditioner are not accounted for (ADEME, 2020). Table 5 shows the collected data for scope 1 for ASW.

Table 5 Scope 1 data collection for ASW

Category	Specifics	Value	Source
Consumption for Heating	Heating fuel	130 l	ASW
Fuel Consumption of own fleet	Distance travelled	96 km	ASW
	Vehicle Characteristics	Dacia Duster, 110 ch. 2018	ASW
	Fuel Consumption Rate	10 L/km	ASW
	Fuel Characteristics	Diesel	ASW
	Fuel Consumption	8 L/month	ASW
Refrigerant leakage	Air conditioner model	General Inverter ASGG18LFCD - 1.5 Ton	ASW
	Number of units	2	ASW
	Refrigerant type	R410A	Esquire Electronics Ltd (2020)
	Quantity of refrigerant used	1.72 kg	ADEME, average of leakage rate (residential cooling)
	Annual leakage rate	4.2 %	ADEME, average of leakage rates

Scope 2

Scope 2 consists of indirect emissions from electricity usage and heat consumption. For ASW, emissions in scope 2 occur only from electricity usage and fuel consumption for heating. Heating fuel was accounted for in scope 1. The difference to the consumption for heating in scope 1 is that the combustion and, therefore, the emissions in scope 1 happen on-site. In contrast, in scope 2 heat consumption, the emissions occur not on the site of the company. Table 6 shows the collected data for scope 2 for ASW.

Table 6 Scope 2 data collection for ASW

Category	Specifics	Value	Source
Electricity	Type	Grey	ASW
	Amount	100 kWh	ASW

Scope 3

Scope 3 represents other indirect emissions. This scope has usually the most categories and items, which must be accounted for. For ASW, data was collected for various of the categories in scope 3. Some categories could be left out like upstream and downstream leased assets, processing of sold products, downstream transportation, franchise, and investment because they are not applicable to the case company. Table 7 shows the different categories, the values and the source of the information.

Table 7 Scope 3 data collection ASW

Category	Specifics	Value	Source
Purchased Goods and Services	Office paper consumption	2 €	ASW
	Office purchases	150 €	ASW
	Services (exclude or search for different emission factor)	5.590 €	ASW
	Plastics	0.015 ton	ASW
	Cardboard	0.02 ton	ASW
	Electronics – general	50 units	ASW
	Electronics – spare parts	60 units	ASW
Capital Goods	Furniture & repair machines	590€	ASW
Fuel and Energy related Activities	Upstream Fuel	130 litre	ASW
	Upstream Electricity	5 kWh	GHG Protocol
	Electricity - T&D losses	11.43 kWh	GHG Protocol
	Water	1400 l	ASW
Upstream transportation and distribution	Inbound	0.3 ton-km	ASW
	Outbound	6 ton-km	ASW
	Outbound (product)	42 ton-km	ASW

Waste Generated	Recycling – paper/cardboard	0.02 ton	ASW
	Recycling – metals	0.05 ton	ASW
	Incineration – household waste	0.02ton	ASW
	Incineration – plastics	0.015 ton	ASW
	Incineration – metals	0.01 ton	ASW
Business Travel	Train	120 pkm	ASW
Employee commuting	Private car	920 pkm	ASW
	Public transport	100 pkm	ASW
	Train	2520 pkm	ASW
Use of sold products	Electricity consumption	-	Apple (2020)
EOL treatment of sold products	Natural gas consumption	-	Apple (2020)
	Electricity consumption	-	
	Fuel consumption	-	
	Water consumption	-	

The section 'purchased goods and services' includes all resources which are bought to run the business. Office purchases mean paper, pens, scissors, bags for smartphones, and stickers. ASW pays for services like IT, consulting, insurances, storage & logistics. IT purchases can be excluded because all employees at ASW are using their private laptops. One printer and two additionally screens exist in the office, but they were not bought by the company. Plastics and cardboard are used for the packaging of the smartphones for the shipment. The purchase of electronics is divided into general, smartphone, and spare parts. General means chargers and headphones, which are sold together with smartphones. The spare parts consist mostly of batteries, screens, and the back cases for the phones. The CF of the production of the purchased smartphones will be excluded from the CF calculations, because including the whole CF of the smartphones would falsify the complete data. But the logistics for receiving the smartphones for the refurbishment are included in the upstream transportation and distribution section.

'Capital goods', which are final products used by the company, are in the case of ASW the existing furniture and repair machines in the office and workshop. They are indicated in the data collection in the form of their monetary value.

'Fuel-and-energy-related activities' is divided into four different aspects. For upstream emissions from fuel, the same amount of fuel like in scope 2 was taken. This looks like a double-counting now, but later when the CF is calculated different emission factors are taken for the fuel combustion (scope 2) and the upstream emissions (scope 3). Upstream electricity and T&D losses were calculated with a percentage of the total amount of electricity (scope 2) consumed. The percentage is based on the *Corporate Value Chain (Scope 3) Accounting and Reporting Standard – Supplement to the GHG Protocol Corporate Accounting and

Reporting Standard' from the GHG Protocol (GHG Protocol, 2020c) Additionally, this section includes the water used at the office for sanitary.

'Upstream transportation and distribution' can be divided into inbound, outbound in the company, and outbound of the product. Inbound means the transportation, storage of the goods to the company. ASW gets smartphones in two different ways. The majority of smartphones are former working phones from companies. In the CF we calculated that ASW bought 200 smartphones in December. 180 of them were from companies, 20 from individuals. ASW picks up the working phones directly from the company. When ASW purchases former working phones, they pick up a bigger quantity of them. The picking up happens with the diesel car of the founder of the company. The emission from the pickup is accounted for in scope 1 in the category: fuel consumption of own vehicles. The second way of how ASW gets the smartphones are when individuals sent them via post to them. The post services in Belgium is called Bpost. In general, the packages are sent 50km and it is assumed that one package weights 0.3 kg. 20 packages were sent in December which calculates to 0.0003 t x 20 x 50km = 0.3 ton-km The emission factor for Bpost transportation used is based on the emissions from a 19 t GVW Carrier. Outbound transportation inside the company means transportation from the office and workshop to the storage (BME). The ready refurbished smartphones are sent with Bpost to BME frequently. The storage is located in Genk which is 100 km away from the office. It can be calculated that 0.0003 ton x 100 km x 200 = 6 ton-km. The outbound transportation of the product means when the phone gets sold and BME sent the refurbished smartphone to the customer. On average the package is sent 700 km. The calculation is 0.0003 ton x 700 km x 200 = 42 ton-km. Downstream transportation and distribution mean all logistics after the point of sale. This would be for products which are sold for example to another retail shop, which sells the product afterward. This does not apply for the products of ASW, because they sell the smartphones straight away to the end-user. Therefore, the subcategory downstream transportation and distribution can be left aside.

The 'waste treatment' can be differentiated into landfills, recycling, and incineration. Landfilling is overall forbidden in Belgium and therefore not performed by ASW. The data from the recycling and incineration are from the ASW office and workshop.

Data from 'business travel' does not include pick up from smartphones, because that is accounted for in upstream transportation. In December 2019, two employees from ASW had a business trip with the train to Brussels, which is a distance of 15 km per way: 2 people * 2 times * 2 * 15km = 120 passenger-km (pkm).

'Employee commuting is split up in the different ways of transportation Two employees are coming with a car 8 distance of 3 and 20 km one way to the office), one with the public transport (meaning bus, tram or metro) (2.5 km distance one way) and 3 employees are coming via train (15 km, 15 km and 42 km distance one way). The emissions of the different modes are multiplied with the kilometers traveled and the number of days in the office. Some of the employees are every day in the office, others like the ones working on the refurbishment only work a few days per week. (In the calculation days stands for workdays in that month)

Car: (2 * 3km * 20 days) + (2 * 20km * 20 days) = 920 pkm

Public transportation: 2 * 2.5km * 20 workdays = 100 pkm

Train: (2 * 15 km * 20days) + (2 * 15km * 8days) + (2 * 42km * 20days) = 2520 pkm

'Use of sold products' describes the usage behavior of the consumer. Overall, it is very challenging to get data for this category. The power consumed for charging the phone contributes around ¼ of the total CF of a smartphone, states LoveFone, which is a smartphone refurbishing company based in England. Next to the impacts of the charging of the phone, the infrastructure for the usage of a phone can be included as well. The servers, air-conditioning, and power are working non-stop to provide working mobile phone connections 24/7. The study estimates that a two-minute phone call every day for a year contributes to 1250 kgCO2e (LoveFone, 2018). Needless to say, that the infrastructure is not taken into account in the common CF for a smartphone, because otherwise, the CF would be significantly higher. The research of Belkhir & & Elmeligi (2018) analyzed that the energy usage of a smartphone contributes 4.50 – 5.25 kgCO2e per year. They assume that the phone is used for two years, which would add to a CF of the usage phase of 9 – 10.5 kgCO2e. Another study suggests that the average user consumes 3.87 kWh/year and uses the phone for three years (Ercan et al., 2016). For this research, the data from the Apple environmental reports will be used, to keep the footprints better comparable. Apple does not describe the energy used in the consumer phase but provides a kgCO2e amount for the usage, which will be seen in the chapter 3.2 Carbon Footprint - Producer.

Data about the 'EOL treatment of sold products' was also difficult to find, hence the data from Apple was taken again, which will be seen in more detail in the chapter 3.1.2 Carbon Fotprint – Methodology in the paragraph EOL treatment.

3.1.2 Carbon Footprint Methodology

After gathering all the required information from the company and databases the data needed some treatment. The first step was to reorganize the data. They were not ordered into scopes anymore but into categories. The categories are based on the most crucial steps of the refurbishment process: Energy, Cooling, Electricity, Mobility, Logistics, Materials, Water, Waste, Consumer use, and EOL. One category can include data from different scopes. The scopes were changed to categories, because the scopes vary so much depending on the organizational boundaries set and which approach is chosen. Additionally, in the authors opinion, the importance should not be on the fact if the emissions are direct or indirect, but rather on the GHG emission hotspots.

In the next step, emission factors were selected. Most of the emission factors used are from Base Carbon ®, which is a public database of emission factors. Base Carbon ® is run by ADEME (Agence de l'environment et de la maîtrise de l'énergie). ADEME has the project Bilans ges (gaz á effet de serre) which is a resource center for greenhouse gas accounting (ADEME, 2020). ADEME is a French database and most of their emission factors are also based on the data of France. As France and Belgium are geographically and infrastructure wise quite similar, the French emission factors can be also used for the case company located in Belgium. Table 8 shows the list of emission factors used for the CF calculations. The emission factors are listed in their respective categories and subcategories. Next to it the associated scope can be seen. The units of the emission factors vary depending on the subcategory. Additionally, if the information was available the specific zone for the emission factor is mentioned, if that field is empty no information were available. In the last column, the source of the emission facor can be seen.

Table 8 Emission factors for CF calculations

Category	**Subcategory**	**Scope**	**Unit**	**Emission Factor**	**Zone**	**Source**
Energy	Heating fuel	1	tCO2e/l	0.00262	Europe	Bilan GES Ademe, October 2014
	Heating fuel upstream	3	tCO2e/l	0.000571	Europe	Bilan GES Ademe, October 2014
Electricity	Electricity consumption	2	tCO2e/kWh	0.00022	Belgium	bilan GES Ademe, November 2014
	Upstream emissions	3	tCO2e/kWh	0.00003		CLIMACT (EDF Nuclear, Ademe v7.5 for Gas and Coal)
	T&D losses	3	tCO2e/kWh	0.00001		Climact (IEA)

Cooling	R410A	1	tCO2e/kg	1.924	World	CLIMACT (Bilans GES ADEME; December 2019)
Mobility	Fuel consumption own fleet	1	tCO2e/l	0.000316	France	bilan GES Ademe, December 2016
	Employee commuting – car	3	tCO2e/km	0.000251	France	Bilan GES Ademe, March 2015
	Employee commuting – public transport	3	tCO2e/km.passenger	0.000167		Climact (Ademe v 7.5, intermediate category)
	Employee commuting – train	3	tCO2e/km.passenger	0.000484	Belgium	Bilan GES Ademe, November 2014
	Business Travel – train	3	tCO2e/km.passenger	0.000484	Belgium	Bilan GES Ademe, November 2014
Logistics	Inbound – road	3	tCO2e/ton-km	0.000946	France	bilan GES Ademe, (OEET) November 2014
	Outbound (company) – road	3	tCO2e/ton-km	0.000251	France	Bilan GES Ademe, March 2015

	Outbound (product) – road	3	tCO2e/ton-km	0.000379	France	bilan GES Ademe, (OEET) November 2014
Materials	Office paper	3	tCO2e/kg	0.000919	France	bilan GES Ademe (Copacel) March 2015
	Office purchases	3	tCO2e/€	0.000367		Bilan GES Ademe, November 2014
	Services	3	tCO2e/k€	/		
	Capital Goods	3	tCO2e/k€	/		
	Aluminum	3	tCO2e/ton	7.803	France	Bilan GES Ademe, FEDEREC, September 2018
	Other metals	3	tCO2e/ton	3.5692	France	Bilan GES Ademe, FEDEREC, September 2018
	Plastics	3	tCO2e/ton	2.383	France	Bilan GES Ademe, November 2014
	Cardboard	3	tCO2e/ton	0.39	France	Bilan GES Ademe, FEDEREC, September 2018
	Electronics - general	3	tCO2e/unit	0.0000742	World	Bilan GES Ademe (Base Impact) Nov. 2014

	Electronics – spare parts:	3	tCO2e/unit	0.009106643		Own calculation
	- Battery	3	tCO2e/unit	0.015891		Apple (2020)
	- Backside	3	tCO2e/unit	0.0000357		Bilan GES, Ademe, November 2014
	- Screen	3	tCO2e/unit	0.0000734		Bilan GES, Ademe, November 2014
Water	Water	3	tCO2e/l	0.000000168	France	bilan GES Ademe (FOOD GES) Nov. 2019
Waste	Recycling – paper & cardboard	3	tCO2e/ton	0.033	France	Bilan GES Ademe, Nov. 2014
	Recycling – metals	3	tCO2e/ton	0.014	France	Bilan GES Ademe, Nov. 2014
	Incineration – paper & cardboard	3	tCO2e/ton	0.0466	France	Bilan GES Ademe, Nov. 2014
	Incineration – plastics	3	tCO2e/ton	2.68	France	Bilan GES Ademe, Nov. 2014
	Incineration – metals	3	tCO2e/ton	0.04	France	Bilan GES Ademe, Nov. 2014

Energy

The energy category combines the heating fuel consumption from scope 1 with the upstream emissions of heating fuel from scope 3.

Electricity
This section combines the electricity usage accounted for in scope 2, as well as upstream electricity emissions and T&D losses, which was accounted for in scope 3. The emission of electricity production varies in every country depending on the energy mix. The electricity can be divided into grey and green electricity.

Cooling
This category includes the leakage of the refrigerant of the two air conditioner which is accounted in scope 1.

Mobility
The category mobility consists of emissions from employee commuting and from business travel.

Logistics
The category logistics combines upstream transportation and distribution from scope 3 with the fuel consumption of own fleet from scope 1 because the fuel is used during the pickup from the smartphones from the clients.

Materials
The material section equals the 'purchased of goods and services' section. There were no emission factors available for the electronics general and spare parts. Therefore, some assumptions had to be made. For "general", which includes chargers and headphones, the emission factor of an inner electric cable used for power supply with copper conductor and PE insulation was taken. The functional unit is 1 m. The charger or headphones are usually short, but they include more complex additional elements like the plug, microphone, or speaker. The emission factors for the "spare parts" were divided into battery, backside, and screen. For the battery, no factor could be found and therefore the total CF (83.83kgCO2e/unit) of a smartphone with the weight of 187.5g was transformed proportionately to the weight of the battery (45g). This calculation leads to an emission factor of 0.015891 tCO2e/unit. For the backside, the emission factor of plastic was taken (2.383 tCO2e/ton) and calculated down proportionally for one backside which weights on average 15g. The emission factor for plastic is 0.0000357 tCO2e/unit. The screen was equaled to glass in the calculation. The emission factor for glass is 3.67 kgCO2e/kg. Calculated down to one smartphone screen with a weight of 20 g, the factor is 0.0000734. In the next step, these three different emission factors were calculated to one according to the frequency of usage. ASW stated that they change for smartphones in average 40% of batteries, 10% of backsides, and 20% of screens. In December they bought 60 spare parts. The average emission factors for these is: ((4* 0.015891) + (1*0.0000357) + (2*0.0000734))/7 = 0.009106643 tCO2e/unit. The emissions of the services will be excluded, because it only accounts for insurances and consulting. Other used services like transportation with Bpost is accounted for in other categories. Also, the

emissions from capital goods are excluded from the calculations because no fitting emission factors could be found and because the usage over a long period of time of these goods is expected to have a minimal impact on the companies CF.

Water

In the water category is only the water accounted that is used at the office for sanitary, which is the blue water. A more detailed calculation of the amount of water used is in the water footprint section. Nevertheless, the blue water should not be excluded from the CF calculation, because water usage in the office also emits GHG emissions.

Waste

The waste section equals all the information from the 'waste treatment' from scope 3. For the different types of waste are separate emission factors calculated from ADEME. For recycling, the emission factor can vary from negative to positive emissions. Negative emissions occur when the avoided emissions are included as well. Avoided emissions represent the emission that would occur if the metal would not be recycled and therefore new metal would have to be produced. But for the CF calculation, only the emission factor for the treatment is included. Positive emissions from the collection and negative emissions from the avoided emissions are excluded.

Consumer use

This section equals scope 3 'use of sold products'. For this category no emission factor was used. The data was taken from the Apple environmental reports, which state that the usage phase accounts on average for 17% of the total CF of the LC of a smartphone. 17% of the total CF (83.83 kgCO2e) are 14.2511kgCO2e. This number represents the consumer use for one phone. The calculations for ASW account for the whole company. In December 2019, ASW refurbished 200 smartphones. Therefore, this number has to be multiplied by 200.

EOL treatment

This section represents the data from the section 'End-of-Life Treatment of the Sold Products' from scope 3. For this category no emission factor was used. The data for the EOL treatment is taken from the environmental reports of Apple. Apple states that on average 1% of the total CF comes from the EOL treatment. A total of 83.83 kgCO2e for a smartphone is estimated. Hence, the 1% of the EOL treatment equal 0.8383 kgCO2e. It should be noted that Apple did not specify which EOL option they are analyzing. Many manufacturers choose to include recycling as an EOL option in their reports. The recycling process can be the best controlled by the manufactures in contrast to reuse, landfilling, or refurbishment. Therefore, the manufacturers have the most accurate data about this process (Suckling & Lee, 2015). Same as for the consumer use, the data is only for one smartphone and has to be adjusted to the number of smartphones refurbished by ASW.

3.1.3 Carbon Footprint Calculations

The CF calculations were done for the case company including all their organizational activities. To make the data comparable, the information had to be adjusted to the refurbishment of only one smartphone. Therefore, Table 9 provides an estimation about the productivity of the company and hypotheses about the average weight of a smartphone and a package.

Table 9 Assumptions about general smartphone data and productivity of the case company

Item	Value	Source
Smartphone (average weight)	187.5 grams	ASW
Smartphone shipment (weight)	300 grams	ASW
Package size	0.2 x 0.1 x0.05 m = 0.001 m3	ASW
Smartphones refurbished	200 devices/month	ASW
Spare parts bought	60 parts/month	ASW

The CF was calculated "number of smartphones" x Emission Factor = Carbon Footprint.

Additionally, the CF for ASW was estimated for a whole year by multiplying the CF result for December times 12. This number can only be used as a rough estimation.

Next the CF for one smartphone refurbishment by ASW was calculated. In December, 200 devices were refurbished and therefore the total CF of ASW was divided by 200 to get the CF for one device.

3.2 Carbon Footprint - Producer

The data for the carbon footprint of the producer is collected from the website of Apple, which has released environmental reports for the different phone models. Apple is using the ISO 14040 and 14044 standards for its reports (Apple, 2020). In contrast to the data of ASE, the Apple data shows the CF of the production of one smartphone, whereas the calculation above from ASW shows the CF of the whole company. Table 10 shows the CF for iPhone models released between 2017-2019 including data about the CF for different configurations. The complete list with the data for all iPhone models can be found in the Appendix 2.

Table 10 Carbon Footprint iPhone production (Apple, 2020)

Apple	Configuration	Unit	CF	Year
iPhone 11 Pro max	64 GB	kgCO2/unit	86	2019
iPhone 11 Pro max	256 GB	kgCO2/unit	102	2019

iPhone 11 Pro max	512 GB	kgCO2/unit	117	2019
iPhone 11 Pro	64 GB	kgCO2/unit	80	2019
iPhone 11 Pro	256 GB	kgCO2/unit	96	2019
iPhone 11 Pro	512 GB	kgCO2/unit	110	2019
iPhone 11	64 GB	kgCO2/unit	72	2019
iPhone 11	128 GB	kgCO2/unit	77	2019
iPhone 11	256 GB	kgCO2/unit	89	2019
iPhone Xr	64 GB	kgCO2/unit	62	2018
iPhone Xr	128 GB	kgCO2/unit	67	2018
iPhone Xr	256 GB	kgCO2/unit	76	2018
iPhone Xs max	64 GB	kgCO2/unit	77	2018
iPhone Xs max	256 GB	kgCO2/unit	91	2018
iPhone Xs max	512 GB	kgCO2/unit	106	2018
iPhone Xs	64 GB	kgCO2/unit	70	2018
iPhone Xs	256 GB	kgCO2/unit	85	2018
iPhone Xs	512 GB	kgCO2/unit	99	2018
iPhone 8	64 GB	kgCO2/unit	57	2017
iPhone 8	256 GB	kgCO2/unit	71	2017
iPhone 8 plus	64 GB	kgCO2/unit	68	2017
iPhone 8 plus	256 GB	kgCO2/unit	82	2017
iPhone x	64 GB	kgCO2/unit	79	2017
iPhone x	256 GB	kgCO2/unit	93	2017

3.3 Carbon Footprint – Smartphone refurbishment

The CF for the smartphone is calculated for five different scenarios. These scenarios are made up of assumptions. The scenarios are all describing the refurbishment process of a smartphone originating from Belgium. The scenarios were chosen because studies suggest that frequently smartphones are not refurbished in a local process but are rather exported to another, often developing country (Zink & Geyer, 2017).

Scenario 1: The first scenario represents the current situation of the case company. The phones are picked up with the company car from a client within a range of 50 km to the office. The replacement rate is low because ASW only replaces the spare parts which are necessary for the functionality of the smartphone. Even though the more comprehensive CF for smartphone refurbishment from ASW was calculated before, this simpler CF had to be calculated to guarantee better comparability to the competition, because the CFs for the different scenarios are all calculated the same.

Scenario 2: In the second scenario, the phone is transported to China. The refurbishment process in China includes a high number of spare part usage. It can be more compared to a remanufacturing, because the goal is to have a phone which is in an as good or even better condition than before. A reason for that is the cheap production of the spare parts.

Scenario 3: The third scenario assumes a transportation to East Europe. The replacement rate is quite high because of cheap labor and cheap spare parts.

Scenario 4: In the fourth scenario, the phones are flown to the United State for the refurbishment. We assume, that the replacement rate is the second lowest in this scenario after the ASW scenario.

Scenario 5: The fifth scenario describes a refurbishment process in Africa. The phones are flown to the African continent. The refurbishment process is inefficient. Many spare parts are used and often the WEEE is treated very poorly.

The CF of the scenarios is not calculated for the whole company and also not for the whole smartphone refurbishment process. Instead the CF is only accounted for the transportation and the spare parts. The reasons for this decision are the limited available information about the refurbishment processes at other sites. To make these CF's more comparable a second CF for ASW was calculated which also only includes these two aspects.

The calculated scenarios are representing scenarios with higher environmental impacts through longer transportation ways and less optimized replacement rates. The goal of the scenarios is to understand the range of reduction of the environmental impacts and to possibly see the point where refurbishment is not environmentally preferable anymore.

3.3.1 Data collection

The data collection is based on the data and observations from ASW. An important aspect for the CF of the smartphone refurbishment is the replacement rate, which indicates how often (in percentage) parts of the smartphone are replaced. The analyzed spare parts in this study are the battery, the backside, and the screen of the phone. For ASW the rate is that 40% of the batteries, 10% of the backside, and 20% of the screens are replaced. In the following, these rates are labeled as "optimized replacement rate". The not optimized replacement rate is 100% battery, 100% backside, and 100% screen. Table 11 shows the different replacement rates.

Table 11 Optimized and not optimized replacement rate for spare parts (source ASW)

Spare part	Optimized	Not optimized
Battery	40%	100%

Backside	10%	100%
Screen	20%	100%

An optimized replacement rate means that only the very necessary parts are replaced, which are needed to keep the phone functional. A not optimized replacement rate indicates that also unnecessary replacements are taking part, which is not for functionality but for the optic of the phone. There is literally no information available from other smartphone producers about their replacement rates. Therefore, the replacement rate for the scenarios in the different countries is based on assumptions of the CEO of ASW. Table 12 shows the optimization rates in different locations.

Table 12 Optimization of replacement rate in different locations (source ASW)

Location	**Replacement - battery**	**Replacement - backside**	**Replacement - screen**	**Total replacement rate**	**Optimized replacement rate**
ASW	40%	10%	20%	77%	100%
China	100%	100%	100%	0%	0%
East Europe	82%	73%	76%	23%	30%
USA	70%	55%	60%	38%	50%
Africa	100%	100%	100%	0%	0%

The rates above indicate how optimized the replacement rates are in the different locations. The total replacement rates were calculatde first. On the example of ASW: 1 – (40% +10% + 20%) / 3 = 77%. It is assumed that this rate is the lowest replacement rate a refurbishing company can have. Hence, 77% are equaled as 100% optimization rate. Afterward, the total replacement rates of the other scenarios were converted to the optimization rates. An optimized replacement rate of 100% like for ASW indicates that only the necessary parts are being replaced. This means for ASW that for 100 smartphones 40 batteries, 10 backsides, and 20 screens are being replaced. The 0% optimized replacement rate in China and Africa means that every battery, backside, and screen is replaced in every refurbishment process. For battery, plastic, and screen the same emission factors were taken as in the business CF calculation for ASW.

For transportation only the inbound transportation from the previous owner to the refurbishment place is calculated. ASW is using mainly its own car for transportation. In December, they bought 200 smartphones, 20 were sent by parcel with Bpost to them. The other 180 were bought and directly picked up by ASW with the own car. ASW had two pickups in December á 90 smartphones each time. In the following calculation, only the transportation with the own car, which is the majority, is accounted for. For the other refurbishment companies, we assume that it is with a cargo airplane. The location where the refurbishment is taken place in different countries is chosen more or less randomly. Mostly a city in the center of the country/continent was chosen. The travel distance is calculated from Brussels to the chosen place because the WF is comparing the additional usage of water compared to the water usage of ASW refurbishment. Therefore, the origin of the smartphone is in Belgium in this study. Tabel 13 shows the collected data for the CF calculation for the different scenarios.

Table 13 Data collection of smartphone refurbishment for ASW and competitors

Category	**Subcategory**	**unit**	**Value**	**Source**
ASW (Belgium)				
Spare part	Battery		0.4	ASW
	Backside		0.1	ASW
	Screen		0.2	ASW
Transportation - car	Client – office ASW	km	50	ASW
China				
Spare part	Battery		1	ASW
	Backside		1	ASW
	Screen		1	ASW
Transportation – airplane	Brussels – Beijing	km	7963	Luftlinie (2020)
East Europe				
Spare part	Battery		0.82	ASW
	Backside		0.73	ASW
	Screen		0.76	ASW
Transportation – airplane	Brussels - Sofia	km	1699	Luftlinie (2020)
USA				
Spare part	Battery		0.7	ASW
	Backside		0.55	ASW
	Screen		0.6	ASW
Transportation – airplane	Brussels – Kansas	km	7305	Luftlinie (2020)
Africa				
Spare part	Battery		1	ASW
	Backside		1	ASW
	Screen		1	ASW
Transportation – airplane	Brussels – Kinshasa	km	6226	Luftlinie (2020)

3.3.2 Methodology & Calculation

The emission factors are the same ones used in the calculation for the business CF of ASW. Only the emission factor for aviation fuel was added, which is 3.01 kgCO2e/L. This factor is retrieved from ADEME bilans again and is accountable for the region of Europe.

3.4 Water Footprint - Producer

As mentioned in the introduction for the WF data section, no original smartphone manufacturer is publishing data about water usage in the production. Some information could be found on other webpages about the water amount used. GRACE Communications Foundation (in the following called GRACE) launched a water footprint calculator in 2015. Hanlon (2015) the director at that time of GRACE wrote a blog about the new calculator and stated that the manufacturing of a smartphone uses 908.5 L of water. In 2017, GRACE published the article 'the hidden water in everyday products' which measured the WF of a smartphone production with 12.000 L. Both calculations use the same calculator (GRACE). Nevertheless, the newer number is significantly higher. The reason could be an updated and more detailed version of the calculator. In the article GRACE (2017) mentions the significant impact of the grey water footprint in the production. An assumption could be that the first version of the GRACE calculator did not take the grey footprint appropriately into account. Sandahl (2020) published on her webpage concerning the WF of a smartphone which stated a WF of 910 L for the manufacturing. But she does not state the source of this number. These three WF are calculating the manufacturing of a phone, meaning they include raw material procurement, processing, and transportation. Not included are the usage and EOL phase. The research of Ercan et al. (2016) is comparing the life cycle assessment of a smartphone in two different scenarios. The first scenario is a Sony Z5 smartphone with an assumed 50/50 recycling approach including 19% of recycled gold. The second scenario with Sony Z5 smartphone which a 50/50 recycling approach including 83% of recycled gold. In the first scenario where the Ecoinvent database was used a total amount of 50.000 L water over the whole LC was calculated (7% raw material, 86% production, and 7% EOL). In the second scenario where the GaBi database was used a total WF of 3.000 L over the whole LC was calculated (72% raw material and 28 % production). For this research, the WF calculated by GRACE (2017) will be used, which states that the smartphone production uses on average 12075.46 L for the manufacturing. Tabel 14 shows the different WF for smartphone production.

Table 14 Water Footprint smartphone production

Liters	Source	Comment

12075, 46 L	**GRACE (2017)**	Comprehensive manufacturing process
910 L	Sandahl (2020)	Manufacturing
908,5 L	Hanlon (2015)	Manufacturing
50000 L	Ercan et al. (2016)	Whole LC, 19% recycling
3000 L	Ercan et al. (2016)	Whole LC, 83 % recycling

3.5 Water Footprint – Smartphone refurbishment

The chapter is divided in two different section: data collection and methodology and calculation of the WF.

3.5.1 Data collection - WF of smartphone refurbishment

For this research, only a product WF for ASW and its competitors will be conducted. Contrary to the CF calculation for the WF, not a complete business WF is calculated. There are two reasons for this decision. The first one is, that overall, too little data about water usage in the ICT sector is available. For the business WF data about the own operations as well as the supply chain are needed. The second is, that the WF is only used for awareness-raising. Therefore, it is enough to highlight the hotspots (replacement rate and transportation). Usually, transportation does not significantly influence the product WF in many cases and therefore can often be excluded. Nevertheless, in this study, the transport will be added, because it is assumed that transportation in the case company differentiates ASW from their competitors. Hence the data is needed for a comprehensive comparison. Contrary to the calculation of a business WF, for a product WF, the distinction between the operational and supply chain WF is not important. The data for the WF calculation comes from the case company, from webpages and research articles. Most of the data is the same as for the CF calculations (see Chapter 3.3.1 Data Collection – Smartphone refurbishment).

3.5.2 Water Footprint Methodology and Calculation

After gathering all the information, the data had to be treated and the water usage factors had to be collected and adjusted. There was no platform available that collects different factors like Base Carbon ®. Zygmunt (2007) wrote a briefing for Waterwise, a UK based organization, with the focus on hidden waters. On the example of a car, he pointed out the water footprint of the used materials including glass and plastic. As I was not able to find another source for the WF of glass and plastic, I took the WF of the materials of the car from Zygmunt (2017). For the calculation, the screen was equaled with glass and the backside with plastic. For the battery, no information could be found. Therefore, the total WF for smartphone production was taken and divided by the percentage of the weight from the whole smartphone. This percentage was equaled to the production of a new battery. For the calculation, it was assumed that a smartphone weights 187.5g total, the battery 45g, the backside 15g, and the screen 20g. The different factors used for the WF calculation can be seen in Table 15.

Table 15 WF factors for smartphone refurbishment

Category	Unit	Value	Scope	Source
Battery	L/unit	2897.88	Percentage of total smartphone WF	GRACE (2017)
Backside	L/kg	187	Plastic	Zygmunt (2007)
	L/unit	2.805		
Screen	L/kg	7	Glass	Zygmunt (2007)
	L/unit	0.14		
Fuel/crude oil	L/GL (giga-joule)	1060		Gerbens-Leens, Hestra & Van der Meer (2008)
Diesel	M3/l	0.03258		

For the spare parts, the water factor could easily be calculated down from kg to one unit with the usage of the weight percentages (see table 9 – assumptions about general smartphone data). For the transportation, the distance is measured in km, but the water factor in L/GJ. Some converting had to be done to use these data. The following shows the calculation of the WF for the diesel car for transportation from ASW.

The car can drive 10 km/L and the distance is 50 km one way (data from ASW). Diesel has 9.8 kWh/L (Nektalova, 2008). 1 kWh equals 0.0036 GJ. This can be converted 9.8 x 0.0036 GJ = 0.03528 GJ/L has diesel. For one distance ASW uses 5 L of diesel: distance (50km) / fuel consumption (10 km/L) = 5 L. The total amount of diesel used in GJ is diesel usage (5 L) x Diesel in GJ (0.03528 GJ) = 0.1764 GL of Diesel used. Now, the diesel usage in GJ (0.1764GJ) can be multiplied with the water factor of crude oil (1060 L/GJ) = 186.984 L. Now this must be calculated down for one smartphone. ASW picks up on average 90 smartphones at the same time. Hence, the water footprint for one smartphone is 186.984 L / 90 = **2.0776 L**.

The calculation for the transportation to the other countries is similar, except that the transportation mode is with the cargo airplane. For the calculation, the Boeing 747, which uses 12 L/km of fuel was chosen (Howstuffworks, 2020). The fuel type used is jet a or jet A-1, which are both known as kerosene. One barrel of oil (boe) equals 42 gallons which equal 159 L, From one boe of crude oil four gallons of kerosene can be produced (EIA, 2020), which equals 15.14 L. One boe in GJ is 5.86125 GJ. The distance travelled in the example of China is 7963km. Therefore, the kerosene usage is distance (7963 km) x kerosene usage (12 L/km) = 95,556 L of kerosene. We know that 15.14 L of kerosene can be produced from one boe. So, kerosene usage (95,559 L) / 15.14 L =6311.49 barrel of crude oil needed. In the next step, boe must be converted to GJ. One boe equals 5.86125 GJ (Unitjuggler, 2020). Kerosene usage (6311.49 L) x 5.86125 = 36993.2208 GJ used on the flight. The WF is calculated: GJ used (36,993.2208 GJ) x water factor (1060 L/GJ) = 39,212,816 L for the whole cargo plane. Now the WF must be scaled down to one smartphone package. The Boeing 747-8F Freighter has a cargo capacity of 854.5 Cubic Metres (330,177 Cubic feet) (Modern Airliners, 2020). It is assumed that a package weighs 300g and has the measures 0,20 x 0,10 x 0.05 m = 0.001 m3. The cargo has 854.5 m3. So, the package takes 0.0000017 of the space. As the whole flight has the WF of 39 212 814 L, the proportion of the package than would be **45.89 L.**

For the other scenarios (3-5) the calculations were done the same way and only the distances traveled where adjusted.

To calculate the WF of the refurbished product the different WF for the spare parts and transportation are added together.

4 RESULTS

In this chapter, the results of the CF and WF calculation are shown. The results are presented in the same order as the data collection. First, the results of the business CF of the case company is shown. Then the CF of the regular smartphone producers on the example of Apple. Afterward, the second, simpler CF for smartphone refurbishment of ASW in comparison to the four different refurbishment scenarios is shown. Then the WF calculation results are presented. First for the smartphone refurbishment and afterward for the regular producer.

4.1 Carbon Footprint ASW

For ASW for December 2019 a total CF of 4.844258381 tCO2e was calculated. Tabel 16 shows a detailed list of the Carbon Footprint from ASW for the whole company, the different categories and for one device. The CF exists only for December 2019. An estimated annual CF for 2019 was calculated by multiplying the data from December times 12. This is a very rough estimation because it does not take seasonal changes in the energy consumption or any other changes like investments in former months into account.

Table 16 Carbon Footprint ASW

Category	December 2019	Estimated 2019
Energy	0.4148	4.9779
Electricity	0.0223	0.2671
Cooling	0.3006	3.6072
Mobility	0.3779	4.5351
Logistics	0.0177	0.2125
Materials	0.6498	7.7982
Water	0.0002	0.0028
Waste	0.0428	0.5143
Consumer Use	2.8502	34.2026
EOL treatment	0.1676	2.0119
Total ASW	**4.8442 tCO2e**	**58.1299 tCO2e**
	4844,2 kgCO2e	**58129.9 kgCO2e**
One device	**24.22 kgCO2e**	

Figure 6 shows the percentage share between the different categories: energy (9%), electricity (0%), cooling (6%), mobility (8%), logistics (0%), materials (13%), waste (1%) , consumer use (59%) and EOL treatment (4%).

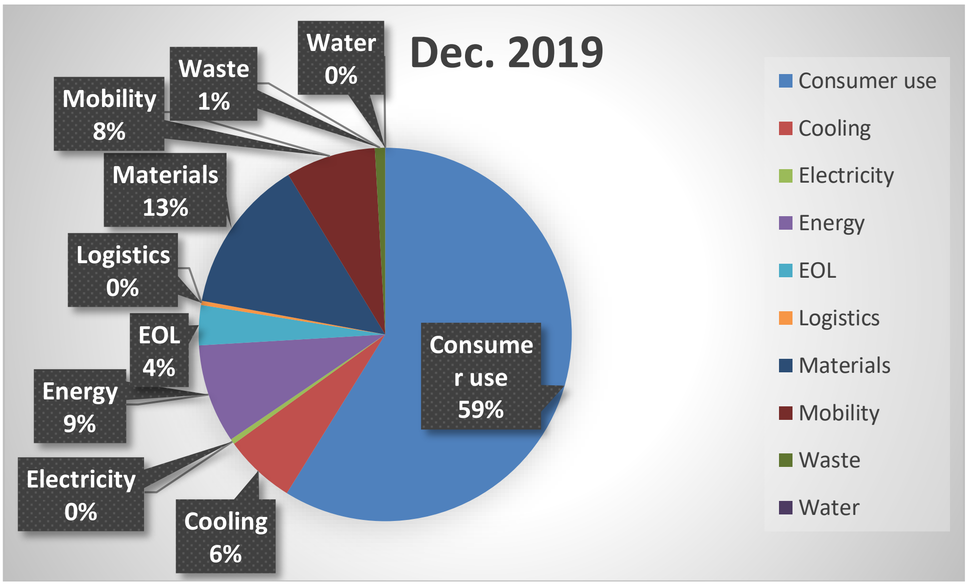

Figure 6 The share of emissions between the different categories including for ASW consumer use and EOL treatment

Consumer use is the most significant category and at the same time the one where the company has the least control over. Also the EOL treatment is a contributor to the CF, which the company can only control minimal. Therefore, Figure 7 presents the share of the different categories excluding consumer use and EOL treatment.

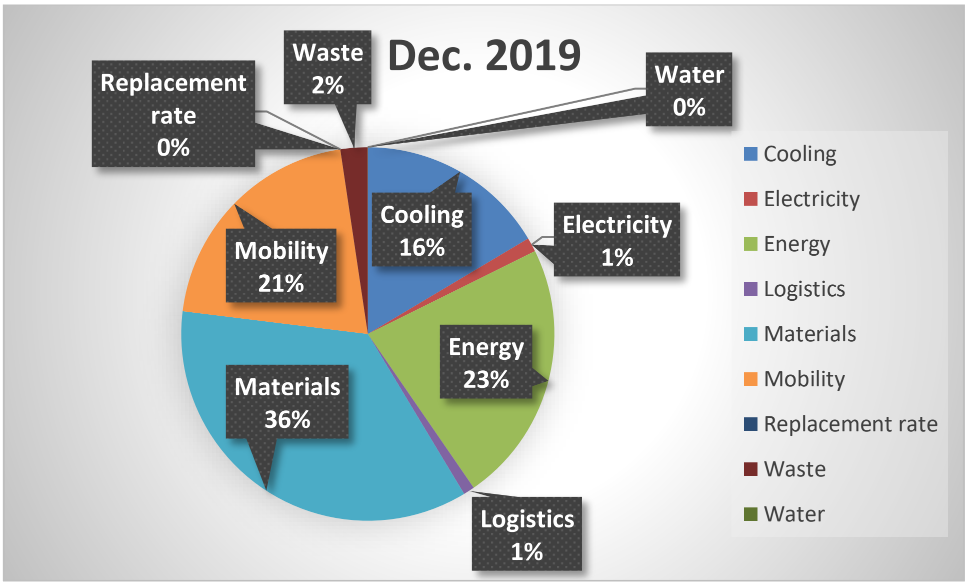

Figure 7 The share of emissions between the different categories for ASW in dec. 2019 excluding consumer use and EOL treatment

Figure 7 shows that material usage represents the most significant part of the CF (if consumer use and EOl are excluded). Figure 8 shows the share of emissions in the material category. The spare parts contribute with 84% the most to the CF.

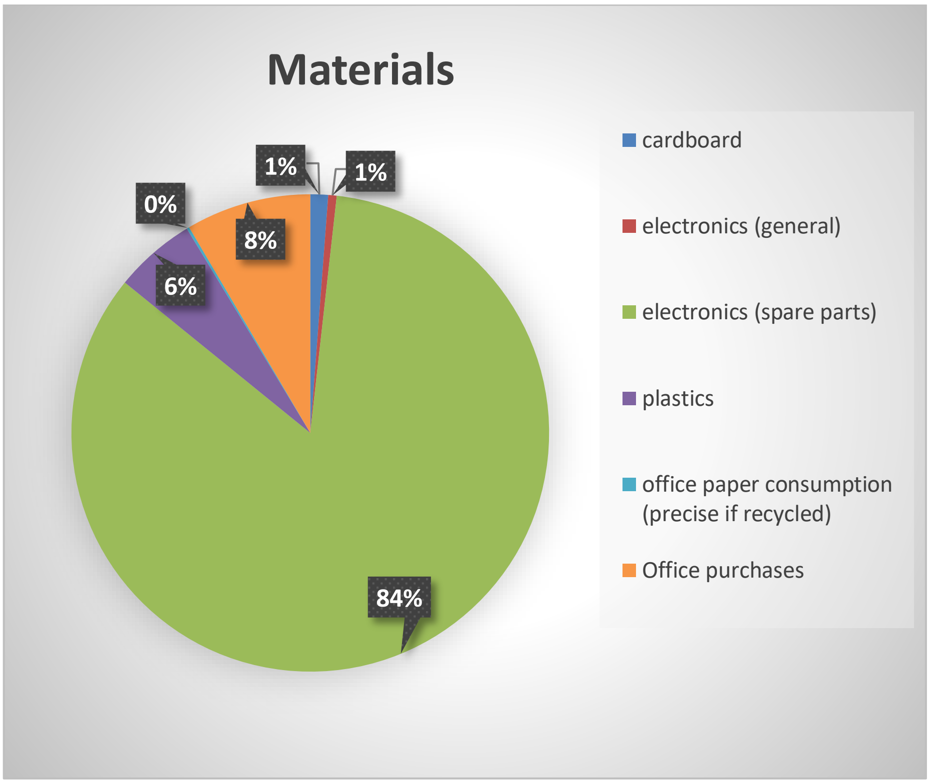

Figure 8 The share of emissions of the category materials

Figure 9 shows the share of emissions for the different scopes for ASW. Scope 3 has by far the most significant impact on the CF.

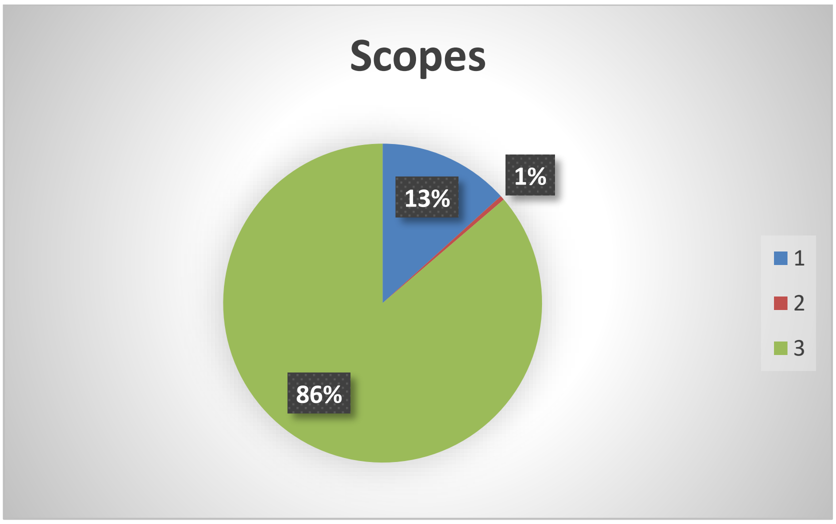

Figure 9 the share of scopes for the CF of ASW (dec. 2019)

The CF for the refurbishemt of one smartphone by ASW is **24.22 kgCO2e**.

4.2 Carbon Footprint producer

The average carbon footprint for a new manufactured iPhone is **83.83 kgCO2e** for one device. This number includes all the models released from 2017-2019, and it includes all the various configuration versions (64-512 GB). Apple also indicates where the CF emissions occur through differentiating production, transportation, use, and EOL. The average percentage separation for the analysed Apple models is production 79%, transportation 3%, use 17%, and EOL 1 %. If these percentages are transferred to the CF, the CF is split up as follows:

- Production: 66.2257 kgCO2e
- Transportation: 2.5149 kgCO2e
- Use: 14.2511 kgCO2e
- EOL treatment: 0.8383 kgCO2e

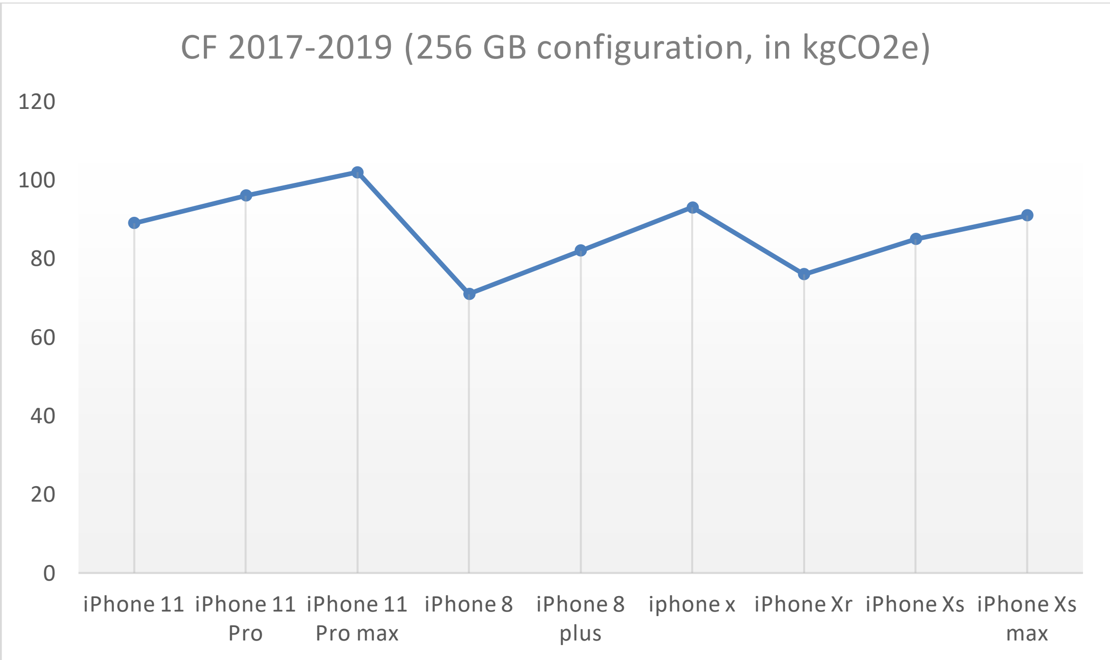

Figure 10 Development of CF of different iPhone models in kgCO2e (Apple)

Comparing the CF of the different iPhone Models from Appel, the impact is increasing with the development of new models. Figure 10 shows this development on the models released in 2017-2019. To make the results better comparable, all the models in this analysis have the same configuration (256 GB). In total the CF of the Apple models varies from 45 kgCO2e (iPhone 4s, 64 GB) to 117 kgCO2e (iPhone 11 Pro max, 512 GB).

4.3 Carbon Footprint smartphone refurbishment

The CF for smartphone refurbishment is shown in different scenarios. The first scenario is a local, optimized refurbishment process from ASW, which has the lowest CF. Other scenarios include transportation from Belgium to a different country for the refurbishment. Therefore, the differences in these calculations are based on the transportation ways and on the different optimization rates in the refurbishment process. Scenario 2 in China and scenario 5 in Africa have the highest CF. Table 17 shows the CF for the 5 different scenarios. Scenario 1 is the CF of ASW but with a limited amount of data used and therefor different to the total CF for ASW calculated in Chapter 4.1.

Table 17 CF of smartphone refurbishment for different scenarios (in kgCO2e/unit)

Category	Sub-category	Scenario 1: ASW	Scenario 2: China	Scenario 3: East Europe	Scenario 4: USA	Scenario 5: Africa
Material usage	Battery	6.3564	15.891	13.0306	7.9455	15.891
	Plastic	0.0036	0.0357	0.0261	0.0196	0.0357
	Glass	0.0147	0.0734	0.0514	0.044	0.0734
Logistics	Transportation	0.0176	0.3366	0.0718	0.3088	0.2632
	total	**6.3922**	**16.3367**	**13.1799**	**11.4962**	**16.2633**

4.4 Water Footprint smartphone refurbishment

Next, the results of the WF calculation for smartphone refurbishment are presented. The results can be sen in detail in table 18. ASW has a significantly lower WF compared to the competition in the four different scenarios. The battery replacement contributes the most to the WF. The second most impacting aspect is transportation to the different countries from Belgium with the cargo plane.

Table 18 WF of smartphone refurbishment in litre

Category	Sub-category	Scenario 1: ASW	Scenario 2: China	Scenario 3: East Europe	Scenario 4: USA	Scenario 5: Africa
Material usage	Battery	1159.15	2897.88	2376.26	2028.52	2897.88
	Plastic	0.28	2.81	2.05	1.54	2.81
	Glass	0.03	0.14	0.11	0.08	0.14

Logis-tics	Transpor-tation	2.08	45.89	9.79	42.1	35.88
	total	**1161.54**	**2946.71**	**2388.21**	**2072.24**	**2936.7**

4.5 Water Footprint producer

The data for the WF of a manufactured smartphone is varying significantly, because of the different scopes and scenarios. The different WFs can be seen I figure 11. The GRACE (2017) WF with 12075,46 L per phone was taken as a reference number. For the data of Sandahl (2020) no valid reference could be found on her webpage, which makes the source less trustworthy. The information of Hanlon (2015) are compared to GRACE (2017) outdated and less comprehensive. Therefore, the WF of GRACE (2017) was chosen, because it was the most updated and comprehensive number.

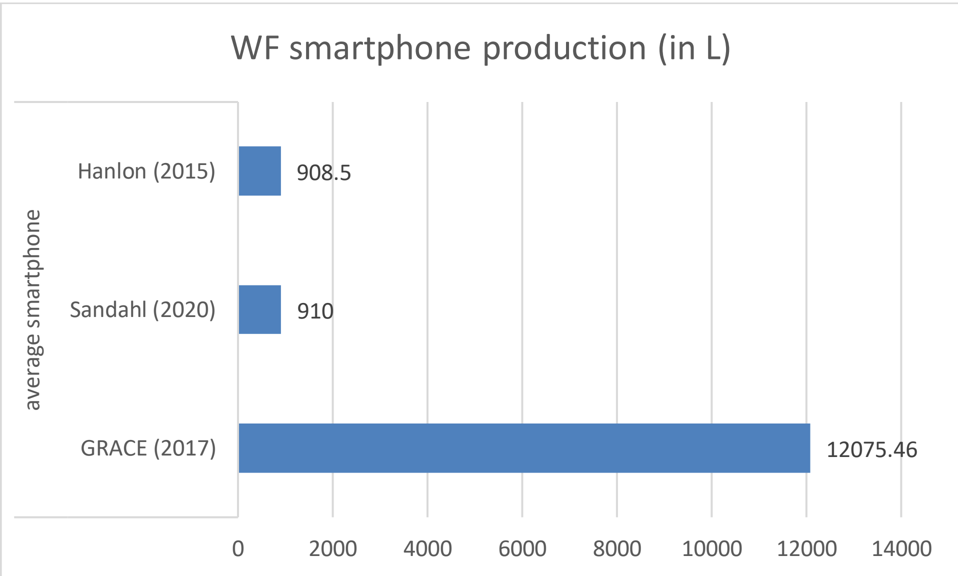

Figure 11 WF smartphone production in L/unit

5 DISCUSSION AND CONCLUSION

In this chapter, the results presented above are analyzed and compared with existing literature. The research questions will be answered followed by implications. The chapter concludes with the limitations of this research project and suggestions for future studies in this field.

5.1 Answering the research questions

The primary objective of this thesis was to understand whether a refurbishement of smartphones is beneficial in terms of sustainability in comparison to a newly produced product and which areas of the refurbishment process have the highest impact on overall sustainability. To answer the research question, first, the two subquestions will be answered.

5.1.1 SQ 1: Does smartphone refurbishment have a lower CF than smartphone production?

The CF of a smartphone can vary depending on the chosen scopes and boundaries. A CF can, e.g. either only include the production, or the product usage and EOL or the whole LC of the smartphone including the needed infrastructure for smartphone usage which includes the data centers and telecommunication networks (Belkhir & Elmeligi, 2018). Most of the studies concerning the CF of smartphone production are conducted by the producer themselves. Scopes and boundaries of the calculations are often not clearly mentioned and make the studies difficult to compare (Suckling and Lee, 2015).

Figure 12 shows the results for the CF calculations. The CF of the refurbished smartphone by ASW (24.22 kgCO2e/device) is significantly lower than the CF of a newly produced smartphone (83.83 kgCo2e/device). The CF scenario calculation for ASW (which uses only limited data) is even lower (6.3922 kgCO2e/device). As explained in chapter 2.3.4 Smartphone components the phones are composed of a variety of different pieces that are produced in several steps all over the globe. Each of these steps has an impact and produces some a certain amount of GHG emission. 79% of the CF for the manufacturing of a smartphone comes from the production process including the extraction of raw material, which is a high energy and resource intensive step (Apple, 2020). These findings are aligned with the study of Ercan et al. (2016) on the LCA of smartphones, stating that around 85% of the total CF come from the production stage. Therefore, the CF of a refurbished smartphone is significantly lower, because most of the production process can be skipped. Nevertheless, a few spare parts are needed for the refurbishment process.

It is difficult to say how high the GHG emission reductions through smartphone refurbishment exactly are because the CF is influenced by so many aspects. The results also show that the CF for smartphone production is increasing with the development of the models (Apple, 2020). The same result can be seen in the studies of the Nokia phone which shows that a simpler phone model has a lower overall impact as a complex model (Suckling & Lee, 2015). Looking at manufacturing the numbers are already changing significantly. The CF of the Apple models varies greatly (45-117 kgCO2e) depending on the model and the configuration.

Also, the CF for the refurbishment process can vary depending on the different models and steps in the refurbishment process. The calculations of the five scenarios show significant differences depending on the transportation and replacement rate which can be seen in Figure 12. The CF of the first scenario from ASW is significantly lower compared to the other refurbishment scenarios, because of the local factor and the optimized replacement rate. The calculations show that the optimized replacement rate is a crucial factor for a low CF, because of the great impacts of the production and transportation of the spare parts. A study based on energy usage for PC refurbishment estimates that for the production of the spare parts 30% of the total energy of producing a new computer is needed (Williams and Sasaki, 2003).

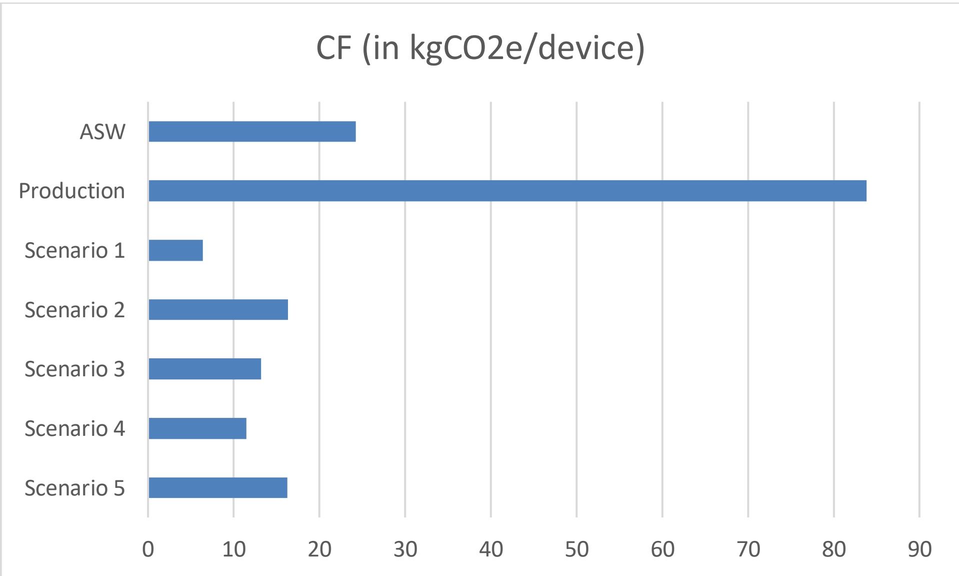

Figure 12 CF of the different options (in kgCO2e/device)

The CF of all scenarios is greatly lower compared to the production of a new smartphone. Attention has to be paid to different boundaries. The CF of the newly produced smartphones includes the whole LC, while the refurbishment only includes two aspects of the refurbishment process: the spare parts and the transportation to the workshop. The CF for transportation is significant lower for the refurbishment (0.0176 – 0.3366 kgCO2e/unit) compared to the production

(2.5149 kgCO2e/unit). Nevertheless, it has to be remembered that the transportation for the refurbishment only includes transportation to the refurbishment workshop. The transportation to the customer is not included in the calculations. Transportation for manufacturing includes the transportation of raw materials, other components, and the product itself.

The CF calculations clearly indicate that the CF for smartphone refurbishment is lower than for smartphone production. Even the scenarios which include a 0% optimized replacement rate and long transportation (scenario 2 & 5) have a significantly lower CF than the smartphone production. These findings fit the calculations of other smartphone refurbishment companies who state a reduction from up to 70% of GHG emissions through refurbishment processes (Asgoodasnew.com, 2020; refurbed.de, 2020) as well as to the study from the EEB (2019) which stated high reductions from 4.3 megaton CO2e through smartphone refubrishments. It can be assumed that the CF of smartphone refurbishment would decrease even more, the more phones were being refurbished because the infrastructure and operational processes would consequently be optimized (Riisgaard et al., 2016).

5.1.2 SQ 2: Does the smartphone refurbishment process have a lower WF than smartphone production?

Concerning the WF, as mentioned before, the available data are very limited in the ICT sector. For the smartphone production, no data from the OEMs could be found concerning the WF of the production. The water footprint calculator indicated a number of 12075,46 L GRACE, 2017). Unfortunately, no more specific data about the WF of the different process stages could be identified.

In an attempt to understand the details behind this number, the procurement, and manufacturing of some resources was analyzed. Lithium is one of the crucial elements in a smartphone. Literature in the field of lithium-ion batteries for electric mobility pointed out the great amounts of water used for the lithium-ion battery production. Two million L of water are used for the extraction of merely a ton of lithium (Katwala, 2018). Plastic, which makes up around 23% of the material used into a smartphone (Statista, 2020), has a WF for procurement of 187 L/kg (Zygmunt, 2007). Lithium and plastic are only two of the many elements integrated in a smartphone. Therefore, it can be assumed that similar to the CF, the extraction and production stage contribute significantly to the total WF. GRACE (2017) states that the major part of the WF comes from cleaning and diluting the wastewaters at the production site and therefore would be represented by the grey WF. Unfortunately, because of the limited data, the WF in this study could not be separated into blue and grey.

The supply chain for the various resources and materials used for the production of smartphones spreads all over the globe. Therefore, another important contributor to the WF is the energy used for transportation. The kind of energy used plays a role in the development of the footprint. Production and refining of crude oil to natural gas, fuel, or biofuel requires a huge amount of water. Studies of the Lawrence Berkeley National Laboratory state that only in the United States around one to two billion gallons of water are used to produce 800 million gallons of petrol – on a daily basis (GRACE, 2017). Therefore, the transportation of the different (spare) parts is a crucial contributor to the WF.

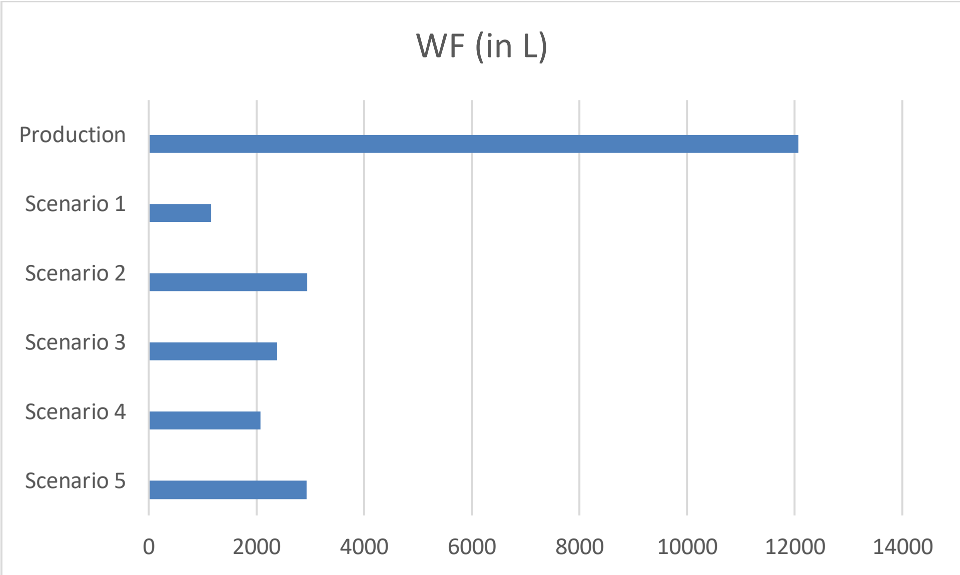

Figure 13 WF of the different options (in L)

The WF of the all refurbishment scenarios (**1161.54 – 2946.71 L/device**) is significantly lower than the WF for smartphone production (**12075.46 L/device**). This could be seen in all of the five different refurbishment scenarios – even the ones with a 100% not optimized replacement rate (see figure 13). Even though the calculations are conservative due to the missing factors, it can be clearly stated that smartphone refurbishment has a lower WF than smartphone production.

5.1.3 RQ: Does smartphone refurbishment have a lower environmental impact compared to smartphone production?

The findings point out that the carbon and water footprints of a refurbished phone are significantly lower compared to a newly produced smartphone. The footprints were lower in every calculated scenario – even the ones with long transportation and bad optimization rates. These findings go along with the results of the studies of Zink et al. (2014) and Sarath et al., (2015) which stated that smartphone refurbishment is the most preferable EOL option concerning the environemntalimpacts. In the ICT sector often only the GHG emissions or the GWP are analyzed. The combination of a WF and CF analysis has the advantage of the inclusion of another important factor in the form of water usage for the actions of the company and hence, a more complex picture of the actions and its impacts is created. It can be noted that some actions can reduce the CF and increase the WF and vice versa. One example of that is energy. A study on future energy production showed that the 'greenest' energy scenario, so the ones based on more renewable energy like wind, solar, or hydropower have the highest WF (Mekonnen, Gerbens-Leens & Hoekstra, 2016). Therefore, a more comprehensive analysis is recommended. The acknowledgment of the complete footprint family would, therefore, be recommendable. But at the same time, this requires a lot more time, effort, and data and therefore was not feasible for this research.

Following, some other factors which influence the environmental impacts of smartphone production are mentioned.

Studies suggest that a long first usage phase is environmentally preferable over CE strategies like repair, reuse, or refurbishment because long usage saves the most resources and energy (Andrae, 2018; Bakker et al., 2016). On the other hand, the study of Osibanjo and Nnorom (2008) stated that the smartphones in Nigeria are being used up to 7 years, which is significantly longer compared to other countries (Riisgaard et al., 2016). But for keeping the phones so long, the batteries and chargers are being replaced frequently. Estimations say that replacement of these spare parts happens usually twice a year, which adds up to a huge quantity of waste (approximately 3000 tons or respectively up to 9500 tons of e-waste in the period of 2001-2006) (Osibanjo & Nnorom, 2008). Hence, it is crucial to analyze the efficiency of the chosen strategy and the environmental impacts that come along with it.

For reaching the long usage period the crucial aspect is the consumer behavior. Consumers should be encouraged to keep their new or refurbished smartphones for a long period of time while not buying refurbished smartphones more frequently than is considered "normal" for new ones. It should be kept in mind that smartphones are fragile and must be treated with care so they don't break. Studies show that one out of ten smartphone users break the screen or describe some other form of damage within the first year of usage. These frequent damages and the quick update of phone models on the market encourages the consumers to replace their phones more often than necessary (Riisgaard et al, 2016). In this study, no calculations were conducted on consumer behavior. The data for the CF of consumption and EOL treatment were taken from the smartphone producer Apple. In the footprint calculations from Apple, it is not mentioned how long they assume that the consumer keeps the phone and what the user's habits are. Nevertheless, it could be assumed that users of a refurbished smartphone are generally more aware of the impacts of their actions and consumption and therefore keep their phones longer or repair it instead of discharge it when it has a small dysfunction. The long usage of the refurbished smartphone would decrease environmental impacts even more.

The quality of the collected phones for refurbishment can vary a lot and some phones might not be suitable for refurbishment (Ijomah, 1999). Even if the phones are not suitable for refurbishment, the phones are collected and the value can be retained. So even if the phone is too outdated or broken to be refurbished, the discarded phones are collected and can be recycled. Regardless, a study analyzing different EOL options for computer stated that reselling and refurbishment are significantly more effective in reducing environmental impacts than recycling. The reason is that the production is a very energy intensive step due to the complexity of the product (Williams & Sasaki, 2003). An additional environmental impact is the resource savings through the refurbishment and reuse of parts of the phone. We assume that the old phone is either being brought to a landfill or will be lying in a drawer somewhere without being used.

The further development of the smartphone refurbishment sector is able to lower the impacts even more through better networks and infrastructure. The local aspect can be crucial, because of the job creation and the involvement of the community, which can play an important role in a successful business model (Streicher-Porte et al., 2009). Another beneficial development would be to produce spare parts from recycled materials(Valero Navazo et al., 2014). Currently, a major barrier to the development of the refurbishment sector is the willingness of the customers to hand out their phones. The main reasons are unawareness of the environmental impact and concerns about the data security of old phones (Hobson, Lynch, Lilley & Smalley, 2018). The willingness of the customers to buy a refurbished smartphone is also important to keep the businesses profitable. The study of Van Weelden et al. (2016) showed that the environmental benefits are only a minor reason for buying a refurbished smartphone. The major reason is usually the lower price. Nevertheless, the study is already four years old and the awareness of climate change has increased among the public. Refurbishment companies should communicate the environmental benefits to attract conscious consumers. Other benefits that should be included in marketing campaigns are the high quality of a refurbished phone compared to a second-hand phone, the opportunity to add extra product features into the refurbishment process, as well as the possibility to avoid undesirable product features on the models.

Technology development was not considered in this study. Advanced technology can lead to a significant decrease in energy usage in the consumption phase through the usage of newer models (Ardente et al., 2018). This fact plays a crucial part in the smartphone refurbishment. It is arguable how efficient refurbishment is for a smartphone which is a product with a very quick innovation rate seem in the regular release of new models. Even if the consumer behavior does not change with a refurbished smartphone, the energy consumption can increase for a refurbished smartphone due to inefficiency from the technology, for example, the battery (Quariguasi & Bloemhof, 2012).

Overall, the research question can be answered by stating that the refurbishment of smartphones has a lesser environmental impact than the production of a new one. The findings of this study fit the research of Rashid et al. (2013) pointing out that CE strategies are environmentally preferable and adapt well to the uncertainties of the future. The results of this research clearly indicate the advantages of a circular economy by keeping the resources in the loop. Even if the energy usage of a refurbished smartphone is possibly higher, the overall environmental impacts are decreasing significantly through resource savings of the CE.

5.2 Implications

The thesis contributes to the research on a corporate and a scientific level. For the case company, the footprints identify the hotspots of emissions and water consumption in the organizational processes. This information can be used to develop and adopt changes in the working ways of the company to decrease the CF and the WF. This change can additionally lead to cost cuttings. Furthermore, the information about the footprints can be used to communicate the competitive advantage to clients and customers and therefore to expand the business.

On a scientific level, the research contributes to the overall understanding of the far-reaching impacts of the ICT sector. The study shows that the refurbishment process has significantly lower impacts in the form of GHG emissions and water consumption and pollution than the production and therefore supports the positive studies on CE. Additionally, the study expands the knowledge of the water footprint assessments in the ICT sector. Even though the WF calculations only cover a minor part of the refurbishment process.

Following, the implications are discussed in more depth to highlight the importance of the study.

5.2.1 Decrease of the environmental impacts of refurbishment

Smartphone refurbishment saves resources which is increasingly important because of the rising demand on the resources and the increasing exploition of the non-renewable resources. The highest contributor to the CF and WF is the selection and extraction of the raw materials. Hence, a careful consideration of which materials to use and how the production and the whole supply chain behind the product impact the environment should be considered. It is recommendable to either use sustainabily sourced or recycled materials in addition. Also, a local aspect in the supply chain of the spare parts can contribute significantly to decreasing the impacts. So far, the energy and electricity do not contribute much to the CF and WF of ASW, but if ASW expands its operations in the future, the impact will increase. Therefore, changes could be done by using more renewable energy sources and green electricity.

5.2.2 Marketing for ASW

ASW has a significantly lower CF and WF as other refurbishment competitors and smartphone manufacturers. This should be used as a competitive advantage and should be clearly pointed out in their marketing actions.

Even though the studies of Van Weelden et al. (2016) and Mugge et al. (2017) point out that the environmental benefits of the smartphone refurbishment only play a minor role in the decision process of the customer to purchase a certain phone, the decreased environmental impacts should be used in the communication.

ASW has two different groups of customers: the ones selling their discarded phones and the ones buying the refurbished phones. The decreased environmental impacts of ASW can be used positively in the CSR reports of the client companies who sell their discarded phones to ASW because consequently it lowers the environmental impacts of the client company. Regarding the customers of the refurbished phones the majority of consumers do not take smartphone refurbishment into account, because of missing awareness, but also missing trust and misunderstanding of the concept (Van Weelden et al., 2016). The perceived risks and benefits should be well-balanced and explained to attract more customers. An opportunity to gain the trust and create transparency, and increase the consumer willingness to pay is the usage of eco-labels (Harms and Linton, 2015)

5.2.3 OEM

OEMs should consider including a refurbishment department in their organizations. Implementing refurbishment offers can lower the impacts of the company significantly. Also, it will lead to economic benefits, because the refurbishment process is financially beneficial. OEMs have the advantage over refurbishment companies that they have the knowledge about the phones and are at the source for spare parts. Using parts of the discarded phones will decrease the cost of production. Additionally, they do not need to fear cannibalization from outside competition, if they offer the refurbishment process.

5.2.4 Discarded phones

A lot more effort should be put on raising awareness, that phones should not be stored in drawers (for individuals or companies), because the stored or landfilled phones are lost and toxic resources. More effort should be put into achieving the European WEEE Directive goal to recycle 50% of the waste generated from small electronic devices. The more phones are getting recycled or refurbished the better optimized the infrastructure and process behind it will become and therefore the CF and WF can be lowered even more.

5.3 Limitations

This research was conducted with the effort to make it as reliable as possible. Nevertheless, some limitations occurred mainly during the data collection. The main limitation of this study is the unavailability of detailed data about the competition.

5.3.1 Limitations Carbon Footprint

Producer
Apple as a smartphone producer indicates the amount of CO2e produced for one smartphone. They even distinguish between the different models. But in their reports, the exact scope and boundaries of the CF calculations are not mentioned. It is not possible to understand which information were included and which were excluded. Therefore, it is difficult to create a study on refurbished smartphones which is 100% comparable.

ASW
For the case company, there are also several limitations in the data collection. The first one is that the data was only used from December 2019 and then calculated times 12 to calculate the CF for the whole year 2019. The reason behind that is that ASW is a quick-growing start-up and the numbers are changing quickly. Another limitation is that parts of the data are based on hypotheses like the usual shipment distance for a smartphone from an individual to a company and from the BME storage to the customer.

Competition
For the competition, there was no available data. Hence, the calculations are only based on assumptions. It is not possible to estimate how realistic the chosen scenarios are.

Emission factors
The emission factors were mostly collected on Base Carbon ® which is a French platform. Hence, most of the information is based on French data and not on Belgian ones. The effect should not be significant as France and Belgium are geographically and culturally quite close, but it should still be mentioned in this section. Additionally, for some data like the general electronics in the form of chargers and headphones no exact emission factors could be found. In this case, the emission factor for inner electric cable was used because it was the closes that could be found in the database. Overall, all of the emission factors must be used with uncertainty, because they are general emission factors for e.g. paper and are not focused on the exact information of the paper product of the specific company producing the paper the company purchases.

5.3.2 Limitations Water Footprint

Overall, the data for the WF is limited compared to the CF calculations. The WF has gotten recently more awareness, but mostly in the agricultural sector because that sector also consumes the highest amounts of water (McMahon & Price, 2011). Therefore, the data and emission factors were limited.

Producer
For the WF of one newly produced smartphone, three different sources could be found. Two of them had calculated nearly the same footprint (908 L and 910 L) the third one was significantly higher (12075.46 L). None of the sources pointed out the scope more detailed then mentioning that it included the manufacturing process. Therefore, it was difficult to understand the exact boundaries and what was included in the calculation. Hence, creating a comparable WF for the refurbished smartphones is difficult.

Refurbished Smartphones
The WF for the refurbished smartphones for the case company as well as for the competition is only based on limited factors: transportation and replacement rate of spare parts. Both are based on hypotheses because there is no available information. For the case company, the information on the replacement rate is based on the available data about how many spare parts were bought. Nevertheless, the company still does not explicitly track their replacement rate. The rate for the competition is based on pure assumptions. There is no information available on if and how other refurbishing companies are trying to optimize their replacement rate.

Additionally, the WF calculation does not include the different scopes of blue, green, and grey water footprints, because there was just no information available. The only available information is the blue water footprint of the case company which is indicating the water used in the everyday life at the office and workshop.

Emission factors
As seen in the methodology section there is no platform or other sources available with factors indicating the WF of different products except some studies about agriculture. Therefore, the emission factors must be used carefully as the battery factor is only a percentage factor of the WF of a complete smartphone and the complex screen production is equaled to simple glass production.

5.4 Future research

Overall, it is evident, that the environmental impacts from smartphone refurbishment are significantly lower. Nevertheless, research should be done on the aspect in which cases the refurbishment process gets counterbalanced through tradeoff of other environmental impacts. The tradeoff can be seen between resource saving and higher energy consumption from the outdated products as well as for the refurbishment process. Possible rebound effects of smartphone refurbishment through inefficient usage and more frequent purchases of the 'cheaper' products should be researched to be able to prevent them. The study does not include consumer behavior and EOL treatment. For the usage it would be interesting, if the users of refurbished phones have different consumption patterns as the users of a newly manufactured phone in terms of the amount of time spent on the phone, charging cycles, and the length of the period of time they keep the phone overall. Concerning the EOL treatment, it would be particularly interesting, if users of a refurbished smartphone are more aware of the value of their old phones and if they discard them more appropriate.

The WF calculations of smartphone refurbishment in this study are very limited but they are representing a starting point for this research area. As the ICT sector is rapidly growing the WF of mining the essential resource like lithium-ion and its manufacturing should be studied.

As this research only focuses on the WF and CF of the smartphone refurbishment, it would be interesting to extend the study on the ecological footprint to complete the footprint family. Another extended research could be an LCA of smartphone refurbishment.

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APPENDIX 1 Sources of GHG emission (GHG Protocol)

Scope	Category	Category description
Scope 1	Stationary Combustion Emission Sources	• Boiler • Combustion turbines • Process heaters • Incinerators
	Fugitive Emission Sources	• Refrigerated transport • Industrial process refrigeration • Cold storage warehouses • Mobile air conditioning
	Mobile Combustion Emission Sources	• Vehicles owned/controlled by the company • Transport by road, rail, air and water • Mobile machinery (agricultural and construction)
Scope 2	Electricity	• Lightning • Electric vehicles • Machine operating
	Steam	• Steam usage for industrial processes
	Heat	• For heating • Sources can be electricity, or non-electrical processes like solar thermal heat or thermal combustion
	Cooling	• The cooling may come from electricity or cooled water or air
Scope 3	Purchased Goods and Services	• Extraction, production and transportation of goods and services purchased or acquired
	Capital Goods	• Extraction, production and transportation of capital goods purchased or acquired
	Fuel-and-Energy-Related Activities (not included in scope 1 or 2)	• Upstream emissions of fuels • Upstream emissions of electricity • Transmission & Distribution (T&D) losses • Water

	Upstream Transportation and Distribution	• inbound logistics • outbound logistics (company) • outbound logistics (product)
	Waste Generated in Operations	• landfill • recycling • incineration
	Business Travel	• Business related travel (in vehicles not owned or controlled by the company)
	Employee Commuting	• Transportation of employees (in vehicles not owned or controlled by the company)
	Upstream Leased Assets	• Operation of leased assets
	Downstream Transportation and Distribution	• Transportation and distribution of products sold by the company to the end consumer (including retail and storage)
	Processing of Sold Products	• Processing of intermediate products sold downstream (to manufacturers)
	Use of Sold Products	• End use of the sold goods and services
	End-of-Life Treatment of Sold Products	• Waste disposal and treatment of the products sold by the company
	Downstream Leased Assets	• Operation of assets owned by the company leased to others
	Franchises	• Operation of franchises
	Investments	• Operation of investments

APPENDIX 2 CF of different iPhone models (in kgCO2e/unit)

Model	Configu-ration	Value	Year	Pro-duc-tion	Trans-porta-tion	Use	EOL
iPhone 11 Pro max	64 GB	86	2019	78%	3%	18%	1%
iPhone 11 Pro max	256 GB	102	2019	78%	3%	18%	1%
iPhone 11 Pro max	512 GB	117	2019	78%	3%	18%	1%
iPhone 11 Pro	64 GB	80	2019	83%	3%	13%	1%
iPhone 11 Pro	256 GB	96	2019	83%	3%	13%	1%
iPhone 11 Pro	512 GB	110	2019	83%	3%	13%	1%
iPhone 11	64 GB	72	2019	79%	3%	17%	1%
iPhone 11	128 GB	77	2019	79%	3%	17%	1%
iPhone 11	256 GB	89	2019	79%	3%	17%	1%
iPhone Xr	64 GB	62	2018	76%	4%	19%	1%
iPhone Xr	128 GB	67	2018	76%	4%	19%	1%
iPhone Xr	256 GB	76	2018	76%	4%	19%	1%
iPhone Xs max	64 GB	77	2018	79%	3%	17%	1%
iPhone Xs max	256 GB	91	2018	79%	3%	17%	1%
iPhone Xs max	512 GB	106	2018	79%	3%	17%	1%
iPhone Xs	64 GB	70	2018	81%	3%	15%	1%
iPhone Xs	256 GB	85	2018	81%	3%	15%	1%
iPhone Xs	512 GB	99	2018	81%	3%	15%	1%
iPhone 8	64 GB	57	2017	80%	3%	16%	1%
iPhone 8	256 GB	71	2017	80%	3%	16%	1%
iPhone 8 plus	64 GB	68	2017	79%	3%	17%	1%
iPhone 8 plus	256 GB	82	2017	79%	3%	17%	1%
iPhone x	64 GB	79	2017	80%	2%	17%	1%
iPhone x	256 GB	93	2017	80%	2%	17%	1%
iPhone 7	64 GB	56	2016	78%	3%	18%	1%
iPhone 7	128 GB	63	2016	78%	3%	18%	1%
iPhone 7 plus	64 GB	67	2016	78%	3%	18%	1%
iPhone 7 plus	128 GB	74	2016	78%	3%	18%	1%
iPhone SE	64 GB	45	2016	80%	4%	12%	1%
iPhone SE	128 GB	53	2016	83%	4%	12%	1%
iPhone 6s plus	64 GB	63	2015	78%	3%	18%	1%
iPhone 6s plus	128 GB	70	2015	78%	3%	18%	1%
iPhone 6s	32 GB	54	2015	80%	3%	16%	1%
iPhone 6s	128 GB	61	2015	80%	3%	16%	1%
iPhone 5s	64 GB	65	2013	80%	5%	14%	1%

iPhone 4s	64 GB	45	2011	57%	8%	34%	1%
iPhone 4	32 GB	55	2010	60%	7%	31%	1%
iPhone 3Gs	32 GB	55	2009	45%	5%	49%	1%
iPhone 3G	32 GB	55	2008	45%	5%	49%	1%
	Average	**74.18**		**77%**	**3%**	**19%**	**1%**
	Max.	**117**		**83%**	**8%**	**49%**	**1%**
	Min.	**45**		**45%**	**2%**	**12%**	**1%**