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Master’s Thesis 2021

Pradeep Mahat

Carbon Footprint of a Refurbished Smartphone Retailer and Carbon Handprint of Refurbished iPhone

Examiners:	Associate Professor, D.Sc. (Tech), Ville Uusitalo
	Junior Researcher, Anna Härri
Instructor:	Anniina Lehto
	The Company’s Development Manager

ABSTRACT

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The purpose of this thesis project was to calculate the carbon footprint of a company that offers fully functional, affordable, and eco-friendly refurbished smartphones and to find out the carbon handprint of the refurbished iPhone. For this study, two research methodologies were used: first, lifecycle assessment methodology (LCA), following ISO Standards (*ISO 14040, ISO 14044*, *ISO 14064, and ISO 14067*) and *GHG Protocol* for the calculation of carbon footprint of the company and the *Carbon Handprint Guide* developed by VTT Technical Research Centre of Finland and LUT University for the calculation of carbon handprint of a refurbished iPhone.

The functional unit of the carbon footprint study was *the company's activities in the year 2020*. The scope of the study was limited to the main activities including energy consumption in the company premises, energy consumption during the employee commute, upstream and downstream logistics, spare parts production, website use, waste management activities, and office supplies including the product packaging, and phone accessories. Likewise, the functional unit for the handprint calculation was *iPhone usage for 3 years*. The system boundary of carbon handprint calculation includes all the lifecycle stages mentioned in

Apple’s Product Environmental Report including the reverse logistics for the refurbished phones.

The total carbon footprint of the company was 1,272 tCO_2e in 2020, in which spare parts production and transportation activities (respectively) were the largest contributors. The production of the spare parts was responsible for 47% of total GHG emissions and transportation activities were responsible for 36% of the total GHG emissions. Together both spare parts production and transportation activities contributed to approximately 83% of total GHG emissions. No *scope 1* emission sources were observed in the company and only 6.9% of total emission was *scope 2* emission. The majority of the company’s emissions (93% of total greenhouse gases emitted) were *scope 3*. Similarly, the carbon handprint of the average refurbished iPhone was around 61 $kgCO_2e$. In 2020, the company’s customers were able to reduce their GHG emissions by a total of approximately 19,000 tonnes just by switching to refurbished phones instead of purchasing similar new models. Factoring both carbon footprint and carbon handprint, the company had an overall negative carbon footprint of approximately 17,728 tonnes in 2020, indicating a significant net positive impact on the environment.

A similar study was not available for the comparison of the results; hence the carbon footprint data will be utilized as the baseline for future sustainability reporting and to identify the hotspots for the emission reduction possibilities. For future research, it is recommended and encouraged to acquire more primary data whenever possible to make the study more accurate. Better collaboration between the partner companies, suppliers, manufacturers, different departments, and other various service providers and inclusion of some aspects that were left out during this study would deliver more accurate results in future studies.

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In Lahti 17 September 2021
Pradeep Mahat

Table of Contents

APPENDICES

LIST OF SYMBOLS

Abbreviations

CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon dioxide
EEA	European Economic Area
ETS	Emissions Trading System
EU	European Union
GHGs	Greenhouse Gases
GWF	Green Web Foundation
HFC	Hydrofluorocarbon
HQ	Headquarter
HSL	Helsinki Region Transport Authority
HSY	Helsinki Region Environmental Services
IC	Integrated Circuit
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LED	Light-emitting diode
LUT	Lappeenranta University of Technology
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
N_2O	Nitrous oxide
PACE	Platform for Accelerating the Circular Economy
PCB	Printed Circuit Board
PFC	Perfluorocarbon
RMA	Return Merchandise Authorization
SF_6	Sulphur hexafluoride
SYKE	Finnish Environmental Institute
UNFCCC	United Nations Convention on Climate Change
UN	United Nations

VTT	Technical Research Centre of Finland
WBCSD	World Business Council for Sustainable Development
WEEE	Waste Electrical and Electronic Equipment
WMO	World Meteorological Organization
WRI	World Resources Institute
WWF	World Wildlife Fund

Units

CO_2e	carbon dioxide equivalent
g	gram
kg	kilogram
km	kilometre
kWh	kilowatt hour
m	metre
m^2	square meter
t	tonne
℃	degree Celsius

1 INTRODUCTION

Climate change discussion is on everyone's lips nowadays as we are heading towards a critical time for our environment. The evidence of climate change due to human influence are more and more visible. Extreme weather events, polar ice and glaciers melting, and rising sea levels are commonly attributed to climate change. A report from National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) confirms that the last decade was the hottest in 140 years (since the start of the record-keeping) and it correlates with the record-high level of carbon dioxide; a key greenhouse gas (GHG) which is primarily released into the atmosphere by fossil fuel combustion (National Geographic 2020). The ever-increasing population on our planet is leading to an increase in atmospheric pollution and overconsumption of material endangering the earth's capacity to sustain humanity. Constant emission of greenhouse gases leads to warming of the earth's atmosphere and long-lasting changes in climate activities, resulting in a severe and irreversible impact on people and the ecosystem. The anthropogenic greenhouse gas emission is at its peak in human history, impacting human beings and the ecosystem. Consequently, this has led to the warming of oceans and atmosphere, melting of icecaps, and rising sea level (IPCC 2014). To maintain the existence of human life on our planet preferably by improving the livelihood of people, sustainable management of our resources is imperative and is one of the biggest challenges of the 21st century. A sustainable way of living and sustainable transition of our technology and society is crucial to hand over the planet in the same or even better condition to our future generations.

With the pressurizing environmental policies and growing public concern on ecological issues, businesses today are more and more under the spotlight for their impact on society and the environment. For a modern business, identifying, measuring, and reporting a transparent non-financial report about environmental, social, and corporate governance is equally important as traditional financial reporting. The traditional news media, research articles, and even social media are also full of news, literature reports, and posts about climate change, global warming, and environmental emissions which increase environmental awareness. It not only affects the business, policymakers, and various organizations but also the public's way of living, and consumption habits (which is evident in the increasing popularity of refurbished electronics along with the reuse and recycling practices). It is apparent that environmental issues are important agendas for any organization, and they want to reduce their environmental impact (Klemeš 2015). Generally, environmental impacts are evaluated by quantifying the negative impact of products, services, companies, or any specific system on the environment (European Commission 2006; Schaubroeck et al. 2013).

Finland is aiming to be a carbon-neutral country by 2035 and go carbon negative shortly after that (Finnish Government 2019; International Institute of Sustainable Development 2020). Companies should already start planning accordingly to be on the same bandwagon as the government and strategize to reduce their environmental impact. To reduce the environmental impact, it is essential to quantify the emissions in the first place. Without full knowledge of their footprint, companies will not be able to achieve the most effective carbon mitigation approaches.

Carbon footprint projects are utilized by organizations to evaluate themselves and their products' greenhouse gas emissions. It helps to adopt measures to cut down the emission to meet the green expectation of consumers and the government. It encourages organizations to improve efficiency, minimize resource consumption, minimize waste, promote innovation and new technologies, create new business opportunities, promote corporate social responsibility and achieve sustainable development goals. (Gao et al. 2014.)

1.1 Climate Change

IPCC (2018) defines climate change as the change in the state of the climate that persists for a prolonged period which usually lasts for decades or longer and usually occurs because of a natural phenomenon such as solar cycles and volcanic eruptions or because of anthropogenic changes in the earth's atmosphere. Whereas, the United Nations Convention on Climate Change (UNFCCC) (1992) on their usage, defined Climate Change as *'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods.'*

Climate change is a major challenge that we are facing today with the potential of affecting not only our future but also the future of other living organisms and ecosystems. IPCC (2014) stated with a high level of confidence that current climate change is liable for the altered geographical ranges, interaction, seasonal activities, and migration patterns of the species. Human actions are deemed responsible for this problem because of the historically elevated amount of greenhouse gas we are producing. We have not been able to comprehend the magnitude, seriousness, and consequences of climate change before the sea level rises, global warming, extreme weather conditions, and loss of ice and snow. Even though only some recent species extinctions have been attributed to climate change as of now, natural global climate change at slower rates than present anthropogenic climate change has caused significant ecosystem shifts and species extinctions during the past millions of years. Worldwide increases in tree mortality have been observed in many regions and some of them have been attributed to climate change. The increasing intensity and frequency of ecosystem disturbances such as droughts, windstorms, floods, fires, and pest outbreaks observed worldwide are also attributed to climate change in some cases. (IPCC 2014.)

Global attempt to stop climate change and atmospheric warming was started in the late 1980s with the establishment of the Intergovernmental Panel on Climate Change (IPCC) jointly by the United Nations and the World Meteorological Organization (WMO) (IPCC 1990; Seo 2017). The Paris Agreement, implemented at the Paris Climate Conference in December 2015, was the first legally binding international climate change agreement. It sets out a framework to limit global warming to well under 2℃ above the pre-industrial levels in the mid-1700s. It aims to limit atmospheric temperature rise to 1.5°C to reduce the risk and effect of climate change. (United Nations 2015; European Commission 2016.)

1.2 Role of Electronics Industry in Climate Change

The electronics industry has revolutionized the world and is an engine for social and economic development (Gavlovskaya 2020). Electronic devices have become a fundamental part of our everyday lives. Behind this innovative and revolutionary technology, several reports and surveys reveal various devastating environmental and social issues throughout the supply chain and manufacturing processes. Furthermore, it is well known that some of the production processes and dangerous mining practices require a huge amount of energy, water, chemicals, and unsafe human labour.(Manhart et al. 2016; Cook and Jardim 2017.)

In 2020, the total number of mobile devices (includes phones and tablets) worldwide is estimated to be around 14.02 billion (Statista 2021b) of which 6.05 billion devices were smartphones (Statista 2021c). During 2015-2020, around 1.5 billion smartphones were sold each year (Statista 2021a). Belkhir and Elmeligi (2018) estimated that the average emission of smartphone production is around 40 to 80 kgCO_2e. Considering the average use phase to be 2 years, the life cycle GHG emission will amount to 69 to 130 kgCO_2e (Belkhir and Elmeligi 2018). Billions of electronic devices manufactured, sold, and disposed of every year in the traditional linear economy (take-make-dispose) comes at the high cost of our planet and the scope extends way beyond the concern of GHG emissions and hazardous e-waste. Three major problems of the electronics sector are energy consumption (mostly fossil-based), resource consumption, and chemicals used and released into the surrounding environment. Those problems combined with other issues such as lack of transparency (especially in the supply chain), limited secondary materials use, and planned obsolescence (when a product is intentionally designed to have a short life so that consumers are forced to discard and repeat purchases (Cooper 2016)) harm the environment. Smartphones and similar electronic devices are resource-intensive products. (Cook and Jardim 2017.) According to the statistic collected by Statista (2020) regarding the most common materials used in all smartphones during 2007 to 2017, 157,478 tons of aluminium, 107,352 tons of copper, 67,663 tons of plastic, 38,198 tons of cobalt, 3,124 tons of tungsten, 2,201 tons of silver, 213 tons of gold, 355 tons of neodymium, 71 tons of indium, 71 tons of palladium and 3 tons of gallium is used during the smartphones manufacturing during those 10 years. It is estimated that miners need to dig 30 kilograms of rock to obtain around 100 grams of minerals used in smartphones. The materials and resources used during the smartphone manufacturing requires industrial mining which damages the earth permanently, producing toxic wastewater and soil (Cook and Jardim 2017).

The electronics industry has environmental impact starting from raw material extraction, manufacturing, use phase, and end of life. The production of electronics requires a large number of materials which are mostly dependent on imports resulting in supply risk and transportation emissions. (EEA 2014.) The complexity of the device leads to the high energy required to produce each device and currently, the manufacturing of electronics is mostly powered by fossil-based energy sources (Cook and Jardim 2017). As mentioned earlier mining and material processing cause high stress on the environment as well as human health. The material footprint and its impacts are not always visible and clear enough. For example, gold used in mobile phones accounts for less than 1% of total weight but is responsible for more than half of the total materials footprint. In contrast, on average 60% of a mobile phone is plastic, but this only amounts to 1% of the total materials footprint. (EEA 2014.) Life cycle assessment or carbon footprint studies provide a clearer picture of the situation. Similarly, during the use phase of the electronics devices, electricity consumption and associated environmental impacts are significant, especially with the appliances such as televisions, computers, refrigerators, washing machines, dishwashers, and driers. Likewise, at the end of life, many of the hazardous substances contained in the electronics devices might be released into the environment. Most of the processes, if not all release greenhouse gas in one form or another, directly or indirectly to the environment contributing to global warming and climate change. (EEA 2014.) The resource inputs and their main pressure outputs (its impact on the environment) for electrical and electronic equipment is shown in Figure 1.

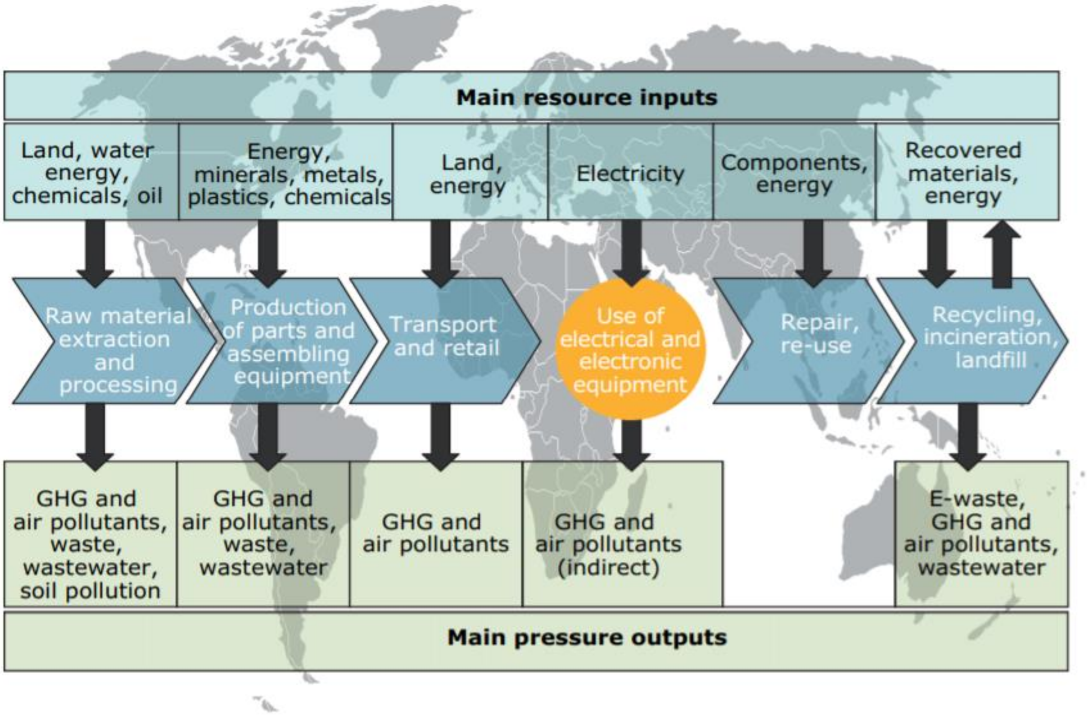


Figure 1. Overview of the value chain of the electronic goods (EEA 2014)

It is apparent that throughout the value chain, the electronics industry is contributing to greenhouse gas generation and thus to climate change. To reduce the impact, it is essential to take responsibility for the supply chain footprint and be transparent, design sustainable products that are easy to repair, standardize the parts and manufacture products with a long lifespan, provide take-back systems, eliminate hazardous chemicals, improve recyclability and use recycled and recyclable materials for manufacturing to reduce environmental emissions and unsustainable material consumption (Cook and Jardim 2017). Among all, e-waste: one of the most evident and emerging environmental challenges of the 21st century (Bhoi and Shah 2014) will be discussed in the next section.

1.3 E-waste and Sustainability

European Parliament and the Council of European Union (Council Directive 2008/98/EC 2008; Council Directive 2012/19/EU 2012) define waste electrical and electronic equipment (WEEE) as the electrical or electronic devices which the holder discards or intends or is required to discard. Similarly, a report from the Platform for Accelerating the Circular Economy (PACE) and the UN E-waste Coalition (2019) defined WEEE or e-waste as any electrical and electronic equipment with a plug, electric cord, or battery (or the components that make up these products) reaching its end of life.

E-waste is one of the most escalating problems of the 21st century (Widmer et al. 2005; Pinto 2008; Sitaramaiah and Kumari 2014; Veit and Moura Bernardes 2015; Kumar and Bharti 2017). Kumar and Bhaskar (2016) have stated that the ongoing transformation of the global economy, the exponential growth of the internet, the evolution of the technology, globalization, increase in living standards, diverse and dynamic consumer preferences, mass production and consumptions of such electronics have soared exponentially resulting in an upsurge of e-waste. Globally, e-waste represents only 2% of the total solid waste composition, while it amounts to 70% of hazardous waste in the landfill. Various precious metals such as gold, copper, and nickel, and several rare-earth materials such as indium and palladium are present in the e-waste. Most of these valuable elements can be recovered and recycled to be used as secondary raw material to manufacture new products. Complex electronics such as smartphones consist of more than 70 stable metal elements out of 83 from the periodic table (Parajuly et al. 2019), most of which can be technically recoverable. (Zhao et al. 2019.)

There is a lack of reliable studies regarding the carbon footprint of smartphones. In recent years, Apple is one of the very few companies that is providing a regular environmental report for their products. As per their reports, on average total lifecycle GHG emission of a new iPhone is around 78 kgCO_2e per phone, in which around 80% (62 kgCO_2e) is generated during the production of the phones. (Apple 2016a; Apple 2016b; Apple 2017b; Apple 2017a; Apple 2019; Apple 2020b; Compare and Recycle 2020.) The GHGs emitted during the production of iPhones are reminiscent of the average production emission estimated by Belkhir and Elmeligi (on average 60 kgCO_2e). If we consider the fact that around 1.5 billion smartphones are sold each year and each one emits around 60 kgCO_2e of GHG during the production phase, then approximately 90 million tonnes of CO_2 (equivalent) is produced each year in the world just because of the smartphone production. The escalating usage and rapid obsolescence of these devices contribute to the shorter service life (less than 2 years). This results in about 700 million of these electronic devices being discarded each year contributing to the existing colossal pile of e-waste. (Wansi et al. 2018.)

Each year, an estimated 40-50 million tonnes of e-waste is generated in the world (Ongondo and Williams 2011; Perkins et al. 2014; Sitaramaiah and Kumari 2014; Blade et al. 2015; Veit and Moura Bernardes 2015; Kumar and Bharti 2017; Parajuly et al. 2019; Forti et al. 2020). That amount is equivalent to just over 6 kg per capita worldwide and the weight of almost 4500 Eiffel towers (Blade et al. 2017; Zhao et al. 2019). Out of that, approximately 17% to 20% of e-waste is formally documented as recycled waste, leaving approximately 80% or more to end up in landfills (polluting soil and groundwater, jeopardizing food supply and water resources) or informally recycled, often manually in developing countries exposing the workers to hazardous and carcinogenic elements (Kyere et al. 2018; UNEP 2019; Zhao et al. 2019; Forti et al. 2020). Even from the formally documented recycled waste, approximately 80% of collected e-waste is shipped to developing countries (Zhao et al. 2019). The environmental benefit of recycling becomes questionable when the collected waste is transported vast distances typically to another continent. Besides, there have been several reports indicating the unmanaged disposal of e-waste in developing countries, for instance, open-air combustion, releasing toxic emissions to air, soil and water systems. (Wong et al. 2007; Gaidajis et al. 2010; Zhao et al. 2019.)

E-waste creates mounting challenges to the sustainability of our planet, consisting multitude of threats to the environment and human health (Wong et al. 2007; Pinto 2008; Gaidajis et al. 2010; Bhutta et al. 2011; Ongondo and Williams 2011; Perkins et al. 2014; Sitaramaiah and Kumari 2014; Hong et al. 2015; Veit and Moura Bernardes 2015; Blade et al. 2017; Kumar and Bharti 2017; Parajuly et al. 2019; Zhao et al. 2019; Forti et al. 2020). The United Nations and all member states in September 2015, adopted a blueprint for peace and prosperity for the planet and the people: "*The 2030 Agenda for Sustainable Development*". The core of the agenda consists of 17 intertwined *Sustainable Development Goals (SDGs)* and 169 *targets*. It is a call for an action for global partnership amongst all countries to tackle the global challenges for ending poverty, inequality, and other deprivations together with the improvement in health, education, and economic growth while protecting the planet and ecosystems. (United Nations 2015b.)

Figure 2. 2015 - 2030 Sustainable Development Goals highlighted for the e-waste management relevance (Forti et al. 2020)

Out of 17 *SDGs*, e-waste management relates directly to 6 (which are highlighted on the SDG poster above in *Figure 2*): (1) *SDG 3* on good health and well-being, (2) *SDG 6* on clean water and sanitation, (3) *SDG 8* on decent work and economic growth, (4) *SDG 11* on sustainable cities and communities, (5) *SDG 12* responsible consumption and production, and (6) *SDG 14* on life below water. More importantly, e-waste management relates to *SDG 11* and *12*, in which *Target 11.6* (*SDG 11*: Make cities and human settlements inclusive, safe, and resilient, and sustainable) sets the target to reduce the harmful per capita environmental impact of cities by paying special attention to waste management and air quality. Cities are sources of most of the e-waste; therefore, it is important to properly manage the e-waste in cities. Likewise, *Target 12.4* (*SDG 12*: Ensure sustainable consumption and production patterns) which sets the target to achieve environmentally sound management of chemicals and waste throughout the whole life cycle as per the international framework to reduce emissions to air, water, and soil to minimize the adverse impact on human health and the environment. (Forti et al. 2020.)

There is an enormous untapped potential of e-waste utilization as nearly all e-waste can be technically recyclable. However, large-scale recycling has not been done effectively because of various challenges associated with e-waste recycling. Electronic devices such as smartphones are getting smaller, compact, and complex, containing up to 70 stable metals from the periodic table. Those metals are often mixed up with plastics and composites along with the presence of toxic and hazardous chemicals, making the devices challenging to recycle. There is also a lack of awareness about recycling, handling, and source separation of waste. Consumers attitude, perception, behaviour and their worries about the data security also contribute to ineffective recycling. (Chaudhary and Vrat 2018; Zhao et al. 2019.) Furthermore, that there is a lack of physical infrastructures such as recycling bins, collection centres and recycling facilities (Nivedha 2020), usually due to the high capital cost associated with it (Chaudhary and Vrat 2018). As mentioned previously, exporting e-waste to developing countries leads to informal or *'backyard'* recycling which is inefficient and unsafe. Likewise, a poor design of electronic devices also discourages reuse, repair, and recycling (Zhang and Wakkary 2011; Zhao et al. 2019). Finally, there is a lack of strict legislations, mandates, and take-back programmes that encourages the collection and recycling of e-waste (Nivedha 2020).

It is a wasted opportunity not to utilise the resources extracting from the gigantic e-waste streams. It can be an economic, less energy-intensive, and ecological solution compared to extracting the resources from the ground. As mentioned earlier, e-waste not treated properly can be toxic. It piles up in the environment contaminating soil, air, and water, affecting the health and wellbeing of humans and other living beings. Fundamentally, e-waste is the product of the traditional linear economy – “take, make and dispose of”, which does not function properly. A new vision and mindset for the entire value chain of the product is necessary rather than framing e-waste to be a post-consumer problem. (Zhao et al. 2019.) A circular economy, which *designs out* the waste and pollution keeping the product and the materials in the loop (Ellen MacArthur Foundation 2017) is required to make the system more functional and to make a transition towards the sustainable future (Blade et al. 2017; Zhao et al. 2019; Forti et al. 2020). The idea of circular economy is primarily to keep products in use as long as possible by sharing, maintaining, or prolonging the use, reusing or redistributing, refurbishing, or remanufacturing, and then finally material recovery by recycling (Ellen MacArthur Foundation 2018).

1.4 The Company

This study was conducted for a Finland-based scaleup company that offers cheaper and eco-friendly refurbished iPhones. Currently it ships refurbished iPhones to various countries in Europe from its production facility in Helsinki. The company provides affordable smartphones and helps to reduce the carbon footprint of the customers by keeping the materials in the loop, promoting a circular economy. The company was established in 2016 and during the time of this project (2020), around 500 employees from 47+ different nationalities are working in the company. The company acquires used phones from individuals or companies (mainly for suppliers in bulk). All the phones are professionally checked, repaired (if needed), tested again, and shipped to the customer with 14 days return policy and 1-year warranty (extendable up to 3 years). The company has the mission of *making refurbished electronics mainstream* and the vision of becoming the globally leading platform for the refurbished electronics market by winning customer experience and trust.

The business model of the company supports circular economy with the use of discarded phones as their product. It gives a new life to the discarded phones which otherwise would be considered as waste. It helps to keep technical material in the loop promoting circular economy. Now the company wants to go one step further by implementing concrete sustainable practices for its operations and business methods. This will substantiate the claim of being a company with sustainable values to consumers and the stakeholders. The sustainable values were always present in the company culture that can also be witnessed in their way of operating business. For instance, when the operation facility of the company in Helsinki relocated to the new premises, a location with convenient public transport (close to the metro station) was selected, reducing the commuting distance of the employees. Also, the use of a car was discouraged with the limited and expensive parking spaces. In contrast, bike parking facilities, showers, and lockers were easily accessible to the employees to encourage walking and biking. Remote working was encouraged (mostly because of COVID 19 pandemic) whenever possible reducing the commuting emission by avoiding or reducing the need to travel. Purchase of refurbished spare parts is always prioritized, and the used spare parts that were replaced during the phone repairing process are sent back to some suppliers (or to the recycling centre, in case of used batteries) for recycling or refurbishing. The devices that are not fixable are usually stripped to acquire the spare parts. Sustainable packaging materials are used for packing and delivery, such as an easily stackable paper-based packaging box (reducing logistical emissions and cost) which is easy to dismantle at its end of life for recycling. The packaging boxes coming back in the return packages (14 days return policy) are re-used when possible. On top of that the company also has a buyback plan for the scrap phones (not repairable) from its consumers for recycling and the spare parts inside the phones that are fully functional are reused during the repair.

The goal is to be a carbon-neutral and then carbon negative company and get certifications such as ISO 14000, green office, and zero waste office, and provide regular transparent sustainability reports. Determining the carbon footprint of the company has been seen as an important step towards the sustainable journey of the company. Understanding the carbon footprint will not only provide a tangible value that can be shared with its stakeholders but will also provide a much-needed baseline against which future mitigation practices will be assessed.

1.5 Objectives

The purpose of this thesis is to find out the sources of GHG emissions of the company, quantify its carbon footprint, and find out the carbon handprint of refurbished phones. Since, a similar study has not been conducted previously, the carbon footprint data will be utilized as the baseline for future sustainability reporting and to identify the hotspots for the emission mitigation opportunities. The research questions of this thesis are,

- *What is the carbon footprint of the company?*
- *What is the major contributor to the GHG emissions in the company?*
- *What is the carbon handprint of refurbished iPhones?*

Primary data will be collected from the company, literature sources will be used for the necessary values that are not easily available and some assumptions will be made to simplify the calculation process.

2 METHODOLOGY

This chapter presents the basic principles and guidelines applied for the research method used in this thesis. For the calculation of the carbon footprint, life cycle assessment methodology (LCA) is used following ISO Standards (ISO 14040, ISO 14044, ISO 14064, and ISO 14067) and GHG Protocol. ISO 14040 offers principles and the framework for LCA. ISO 14044 expands on ISO 14040 and provides the requirements and guidelines for conducting an LCA study. The ISO 14067 offers consistent principles, requirements, and guidelines for quantifying and reporting the carbon footprint of a product as per ISO 14040 and ISO 14044. Similarly, Part 1 of ISO 14064 offers specifications with guidance at the organizational level for quantification and reporting of greenhouse gas and removals. (SFS-EN ISO 14040 2006; SFS-EN ISO 14044 2006; Chomkhamsri and Pelletier 2011; SFS-EN ISO 14067 2018.)

LCA provides comprehensive knowledge about the environmental aspects and potential environmental impacts associated with the life cycle of a product, process, or organization.

Carbon footprint is LCA with only Global Warming Potential (GWP) as an impact category. Likewise, *The Carbon Handprint Guide* developed by VTT Technical Research Centre of Finland and LUT University is used for the calculation of carbon handprint.

2.1 Life Cycle Assessment

Life Cycle Assessment (LCA) is the standardized scientific method for the systematic analysis and evaluation of various aspects, typically environmental impacts, or flows, such as mass and energy of a product, technology, services, processes, or a company through all lifecycle stages. LCA is also known as *"life cycle analysis", "life cycle approach", "cradle to grave analysis"* or *"Eco-balance"*. It is one of the most common and rapidly emerging tools used in environmental management. (European Environmental Agency 1997; SFS-EN ISO 14040 2006; Finnish Environmental Institute 2013.) LCA can help in:

- identifying opportunities to improve the environmental performance of the product at various points in their life cycle,
- informing decision-makers in industry, government, or non-governmental organizations (for example, for strategic planning, priority setting, product or process design or redesign),
- the selection of relevant indicators of environmental performance, including measurement techniques, and
- marketing (for example, implementing an eco-labelling scheme, making an environmental claim, or producing an environmental product declaration). (SFS-EN ISO 14040 2006.)

There are four phases in an LCA study: the goal and scope definition phase, the inventory analysis phase, the impact assessment phase, and the interpretation phase (SFS-EN ISO 14044 2006). The phases of LCA are presented in Figure 3.

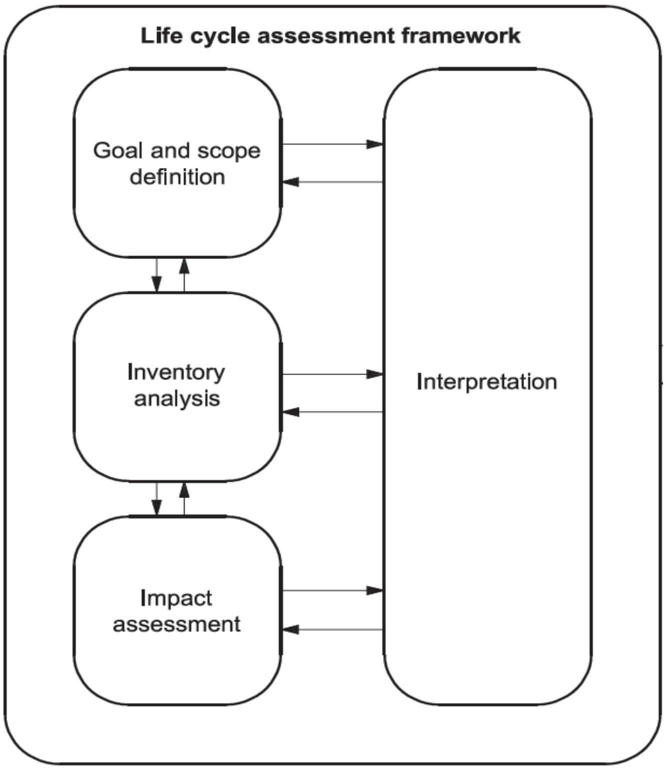


Figure 3. Four stages of an LCA process (SFS-EN ISO 14040 2006)

Goal and Scope Definition

The first phase of the LCA study is the *Goal and Scope* definition which starts with a well-defined goal of the study. The goal of the study defines the intended application, the reason for performing the study, the expected audience, and how the results are aimed to be communicated (SFS-EN ISO 14040 2006). The definition of the goal is the basis of the scope definition which sets the framework and outline for the further steps of the LCA study. The goal and scope definition mainly consists of a *functional unit* definition, deciding the scope of the study, selecting the assessment impact parameters, setting up the system boundary of the system, and identifying the necessity of critical review (if the study is intended for public disclosure). This phase is a crucial stage of the LCA study as the data collection choices, system modelling, and the assessment of the results are influenced by the choices considered during this phase. (Hauschild et al. 2018.)

Inventory Analysis

The second phase of the LCA study is *Inventory Analysis* which accounts for all the environmental exchanges such as energy and material used in the system (Pfister et al. 2017).

It involves the collection of data and calculation procedures to quantify the significant inputs and outputs (SFS-EN ISO 14040 2006). Inventory analysis gathers information about the incoming flows such as resources, materials, and products and outgoing flows such as emissions, waste, and products identified as belonging to the product systems. The flows are scaled as per the reference flow that is decided in relation to the functional unit. It is impossible to integrate and model all the aspects and impacts of the product system, hence some generalization must be established for the system boundaries. Everything outside this system boundary is regarded as a "*cut-off*" from the analysis. At times no data can be collected for some processes and flows, they are also considered as a cut-off. (Hauschild et al. 2018.)

Impact Assessment

The third phase is *Impact Assessment* which assesses the potential environmental impact of all the inventory analysis results. During this process, the specific environmental impact categories are identified and associated with the collected inventory data to be interpreted in the later phases. (SFS-EN ISO 14040 2006.) It consists of five elements of which some are voluntary (4 and 5): (1) *Selection* of impact categories, (2) Classification and allocation of the flows to the impact categories, (3) *Characterisation* of impact categories into common metrics, (4) *Normalization* of results to notify the relative magnitude of the impact by expressing them relative to a common set of references, and (5) *Grouping* or weightings of the results which helps to compare the severity of each impact category relative to others. (Hauschild et al. 2018.) As previously mentioned, data collection choices, system modelling, and the assessment of the results are influenced by the choices considered in various LCA stages which can result in bias during the impact assessment phase. Hence, the assumptions used in the various stages of the studies should be clearly described and reported to make the report as transparent as possible. (SFS-EN ISO 14040 2006.)

Interpretation

Finally, the *Interpretation* phase in which the findings from the inventory analysis and impact assessment are considered together to summarize and discuss the results to answer the questions(s) posed during the goal definition (SFS-EN ISO 14040 2006; Hauschild et al. 2018). This segment should provide results that are consistent with the goal and scope of the study and reach a conclusion explaining the limitations of the study and offer recommendations. The interpreted findings are expected to deliver easily comprehensible, complete, and coherent results that can take the form of conclusions and recommendations to the decision-makers. (SFS-EN ISO 14040 2006.) LCA is an iterative process and as data and information are collected, various aspects of the scope may require modification to meet the original goal and scope of the study. (SFS-EN ISO 14040 2006.)

2.2 Carbon Footprint

A carbon footprint refers to the amount of greenhouse gas (GHG) directly and indirectly produced by an individual, an event, an organization, a product, or a company and released into the atmosphere. The GHGs can be emitted through different human activities such as transportation, production, and consumption of food, fuels, manufactured goods, materials, wood, roads, building, and services. Some of the most recognized greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), and refrigerants (HFC’s, PFC’s, CFC’s). (Factor-X 2016.) The global warming potential (GWP) over a 100-year time horizon and the length of time each gas persists in the atmosphere is presented in Table 1.

Table 1. Greenhouse gases GWP 100-year time horizon (European Environmental Agency 1997; Forster et al. 2007; Pihkola et al. 2010; Factor-X 2016).

Greenhouse Gases	GWP 100-year time horizon	Atmospheric lifetime
Carbon Dioxide (CO_2)	1	A century
Methane (CH_4)	25	A decade
Nitrous Oxide (N_2O)	298	A century
Sulphur Hexafluoride (SF_6)	22,800	Several thousand years

Global warming potential is a comparative measure of how much heat a greenhouse gas traps in the atmosphere. The comprehensive approach to reducing GHG emissions requires a comparable quantitative value. Therefore, different greenhouse gases must be converted to a common unit for direct comparison between various gases. The most common method that has been used for this purpose is to convert all the emissions into an ‘equivalent’ reduction in carbon dioxide emission. The GWP of CO_2 is standardized to 1. It is also called carbon dioxide equivalence (expressed per kg or tonne of CO_2 equivalent, $kgCO_2eq$ or tCO_2e), which is the quantity of the given mixture and amount of greenhouse gas that would have the same global warming potential to the respective amount of CO_2 over a specific timescale, usually 100 years. (Smith and Wigley 2000; Factor-X 2016.)

As previously mentioned, LCA methodology is standardized by ISO 14040 and 14044, whereas ISO 14067 provides the guidelines and requirements for the carbon footprint of products. The international standard of Greenhouse Gas Protocol Initiative: GHG Protocol is used for the quantification and reporting of GHG emissions for a company in this report. The GHG emissions are converted into carbon dioxide equivalents using a 100-year global warming potential.

2.3 Carbon Handprint

In contrast to carbon footprint, carbon handprint refers to the positive environmental impact of the organizations presented with the help of the product and services reducing or preventing the carbon footprint of the customers (Pajula et al. 2018). Handprint can be achieved by replacing the negative impact with positive environmental benefits (Jenu et al. 2020) using the best available alternative technology, reducing, reusing, recycling, using renewable sources of energy, and being more energy efficient (Behm et al. 2016). There can be a wide range of influences that would create a carbon handprint. Individuals working for afforestation programmes, distributing recycling bins in a strategic location, substituting the traditional bulbs with efficient LED lights, and refurbishing the discarded electronics to prolong their life span all will fit as carbon handprint cases (Alvarenga et al. 2020). Appropriate guidelines are required for the correct use of carbon handprint terminology, hence the *Carbon Handprint Guide* developed by VTT Technical Research Centre of Finland and LUT University (Pajula et al. 2018) is used as a guide for evaluating the carbon handprint for this report.

According to Pajula et al. (2018), the idea of carbon footprint is to achieve a footprint close to zero; whereas there is no barrier on how much positive impact could be achieved with carbon handprint. The objective is to assess the positive greenhouse gas impact of a product or service for a customer or future customer. The carbon footprint of a baseline solution is compared to the proposed carbon handprint solution to achieve the carbon handprint of a product. Carbon handprint can be achieved in two ways: (1) providing a lower carbon footprint solution compared to baseline or (2) by improving the footprint of their existing processes, or both. (Pajula et al. 2018.) The following figure illustrates the ways to contribute to the carbon handprint.

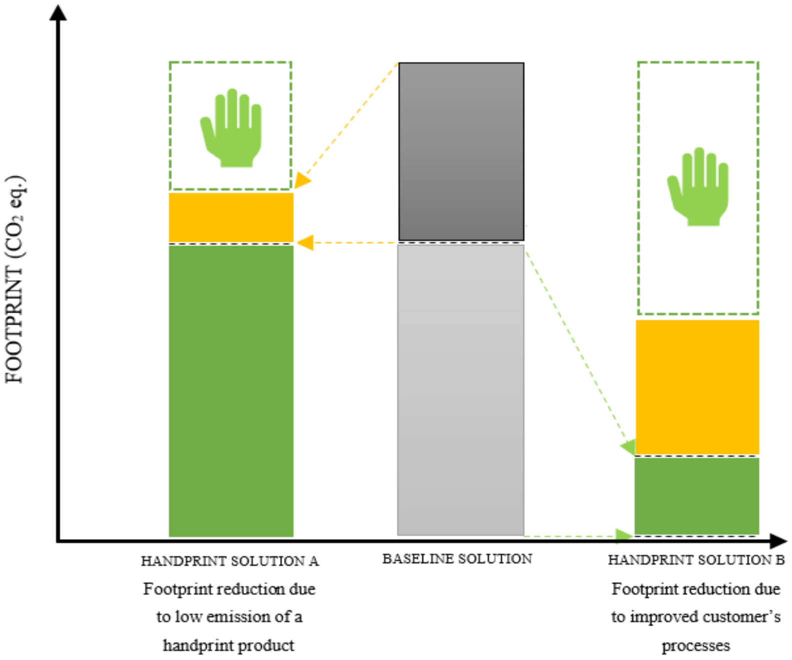


Figure 4. Carbon handprint creation due to improved customer's process and low emission of handprint compared with baseline solution (Pajula et al. 2018).

Four stage process (including 10 steps) based on the LCA method is required to calculate the carbon handprint. The initial stage is exclusive to handprint calculation, which is recognition of the operating environment to set the baseline for the proposed solution. This stage includes the following steps: finding the potential uses for the solution, finding the potential advantages of the product, and deciding the baseline condition. The baseline definition should be well justified and clear as it has a significant influence on the handprint results. The next stage is based on standard LCA and carbon footprint practices according to ISO 14040, 14044, and 14067 which requires the definition of functional unit, system boundary, data requirements, and data sources. The third stage is the standard footprint quantification procedure which computes the carbon handprint, followed by the final stage, where the findings are communicated to the intended audience with the critical review of the carbon handprint. Similar to LCA and carbon footprint, carbon handprint is also an iterative process, where the discovery in the future step might necessitate the revision of previous steps. The carbon handprint is expressed by the following equation:

$$\text{Carbon Handprint}_{\text{Product}} = \text{carbon footprint}_{\text{Baseline solution}} - \text{carbon footprint}_{\text{Handprint solution}}$$

In which,

$\text{Carbon Handprint}_{\text{Product}}$ = Carbon handprint of the existing product used by the customer

$\text{Carbon footprint}_{\text{Baseline solution}}$ = Carbon footprint of the customer's product system using the baseline product

$\text{Carbon footprint}_{\text{Handprint solution}}$ = Carbon footprint of the customer's product system applying the handprint product (Pajula et al. 2018)

2.4 GHG Protocol

The Greenhouse Gas Protocol Initiative is a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI), a U.S. based environmental NGO, and the World Business Council for Sustainable Development (WBCSD), a Geneva-based coalition of 170 international companies. The mission of the initiative is to develop internationally accepted GHG accounting and reporting standards for businesses and to promote their broad adoption. The GHG Protocol Initiative comprises of two separate but linked standards:

- *GHG Protocol Corporate Accounting and Reporting Standard (*which provides a step-by-step guide for companies to use in quantifying and reporting their GHG emissions)
- *GHG Protocol Project Quantification Standard* (forthcoming document; a guide for quantifying reductions from the GHG mitigation projects)

The protocol considers the six most important GHGs that are listed in the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The objective of the GHG protocol is to provide a cost-effective, simple, accurate, and honest way of performing GHG inventory analysis. It supports organizations to improve consistency, transparency, and understandability of GHG accounting and reporting, making it easier to track and compare progress over time. To help distinguish direct and indirect sources of emission, improve transparency, and offer utility for different types of organization and different types of climate policies and business goals, three '*Scopes'* are defined for the GHG accounting and reporting purposes: *Scope 1, Scope 2 and Scope 3*.

Scope 1: Direct GHG emissions

Scope 1 accounts for the direct GHG emissions from the sources that are owned or controlled by the company. For example, emissions from company-owned or controlled boilers, furnaces, vehicles, and chemical production or controlled process equipment. Direct CO_2 emissions from the combustion of biomass and the emission not covered by the Kyoto Protocol (CFCs, NOx, etc.) shall not be included in scope 1 but may be reported separately.

Scope 2: Indirect GHG emissions: purchased electricity, heating, and cooling

The GHG emissions from the generation of purchased electricity, heating, and cooling consumed by the company fall under the *scope 2* emissions. Purchased electricity is defined as electricity that is purchased or brought into the organizational boundary of the company. For most of the companies, purchased electricity represents one of the largest sources of GHG emissions and has the most significant opportunities associated with changing the electricity and GHG emissions costs.

Scope 3: Other indirect GHG emissions

Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions that are a consequence of the activities of the company but occur from sources not owned or controlled by the company. This provides a broad overview of business linkages and possible opportunities for significant GHG emission reductions that may exist upstream or downstream of a company's operations. Some examples are extraction and purchase of materials, transport of materials, waste disposal, leased assets, franchises, and outsourced activities. (GHG Protocol 2004.) The above-mentioned scopes are represented in Figure 5.

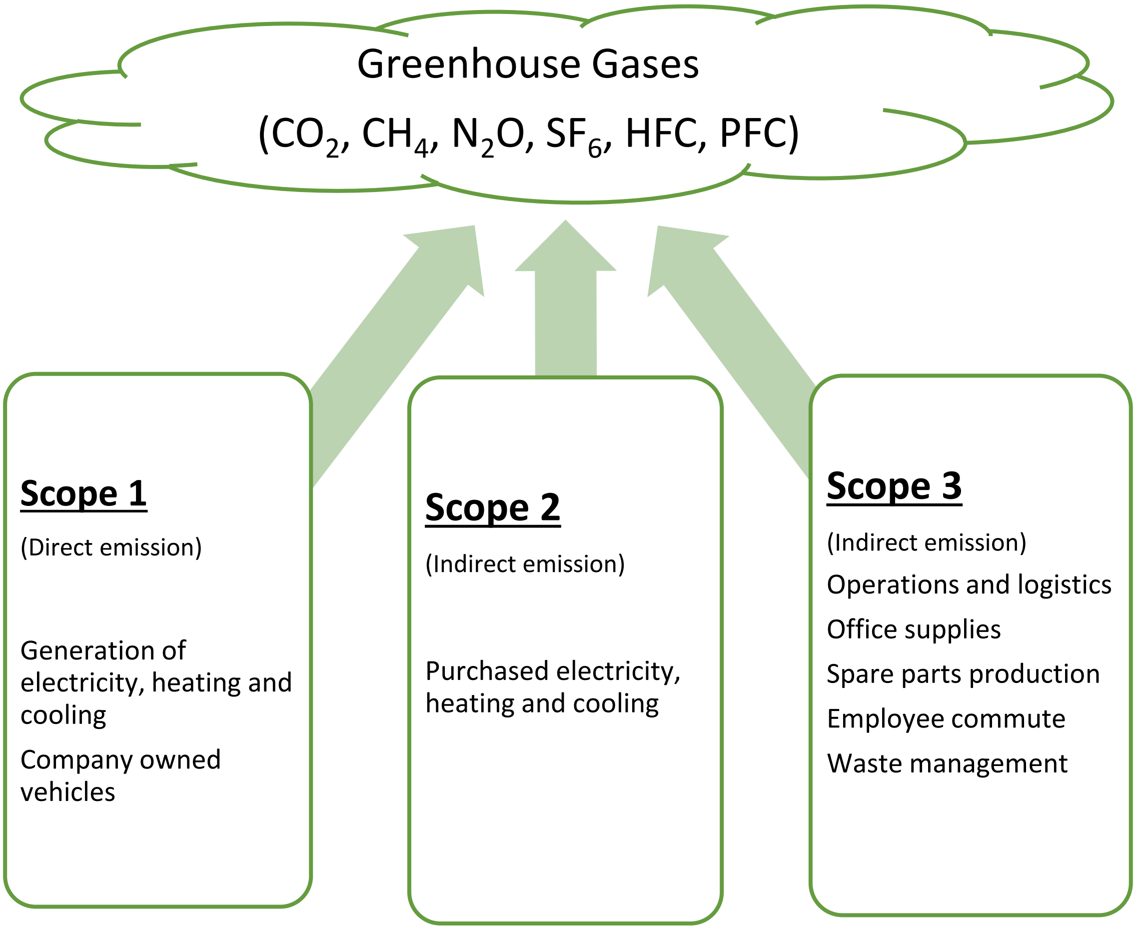


Figure 5. Overview of scopes and emissions across a value chain (Adeyemi 2018)

3 CARBON FOOTPRINT OF THE COMPANY

In the following chapter, carbon footprint was calculated by using LCA methodology (as the guidelines and requirements) and GHG Protocol for the quantification and reporting of the company’s emissions. First, the goal and scope of the study were defined by setting up the system boundary of the studies, followed by inventory analysis, impact assessment and quantification, visualization, and analysis of results. The carbon footprint study was carried out for the year 2020.

3.1 Goal and Scope

The main goal of the study is to calculate the carbon footprint of the company and to find out major hotspots of GHG emissions in its operations. The result of the carbon footprint will not be compared to any previous work because no carbon footprint studies have been done before in the company. This study will act as the baseline for future carbon footprint calculations and carbon mitigation approaches. The carbon footprint calculations can also be improved and complemented in the future if new data will be available. The carbon footprint is calculated for the year 2020, hence the functional unit of the study is considered as the ***company's activities in the year 2020***. The carbon footprint only includes emissions from the operational activities and the stored carbon emissions (emissions stored in the equipment, furniture, and pieces of machinery) are eliminated from the scope of the study.

3.1.1 System Boundary

The system boundary of this study is presented in Figure 6. The scope of this study is limited to the energy consumption in the company premises and energy consumption during the employee commute, upstream and downstream logistics, spare parts production, website use, waste management activities, office supplies including the product packaging, and phone accessories. The data for the spare parts production is challenging to collect as there are multiple parties involved during the production and supply phase. Therefore, only major spare parts like battery and display (which has the biggest influence by weight and volume during delivery and represents almost 70% of the whole spare parts used during the refurbishment of the phones) were allocated specific emissions, and the average emission factor was used for other spare parts. The delivery emission of spare parts and the delivery of used spare parts to the recycling facilities (if recycled) is also included in this study.

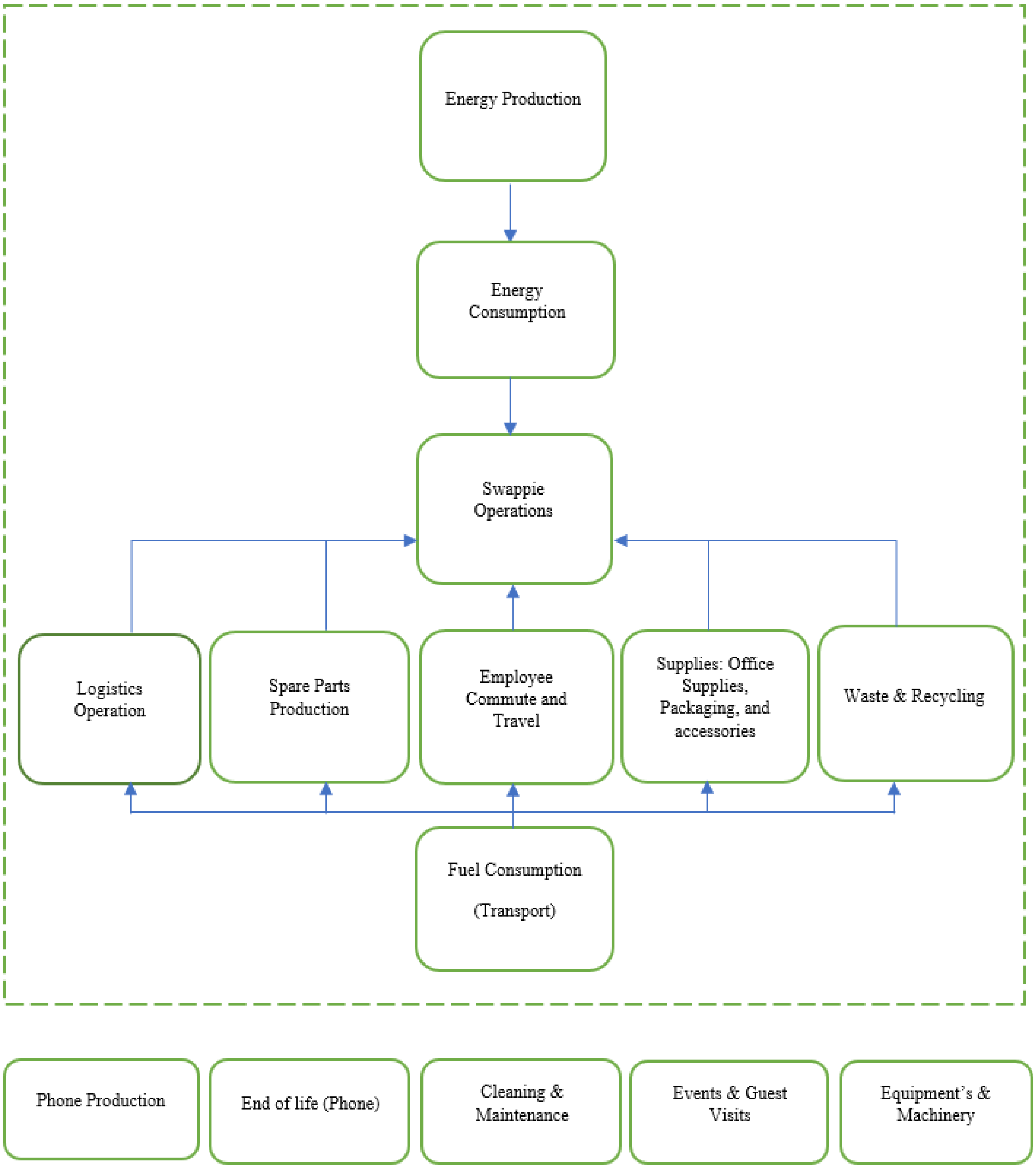


Figure 6. System boundary for carbon footprint of the company's activities

The emission from the material extraction and phone production is excluded from the study as the company is using waste electronics as its product. According to the European Parliament and the Council of European Union (Council Directive 2006/12/EC 2006), waste is defined by the Waste Framework Directive as "any substance or object in the categories set out in *Annex I* which the holder discards or intends or is required to discard". Thus, the used phones that the holder discards or intend to discard and/or, sometimes no longer performs satisfactorily and the holder has no use of the product is categorised as waste. Not all phones are used long enough to be simply categorised as waste. Some phones are used only a few times, and some phones are used multiple times. Therefore, in the future, it could be considered whether also a share of phone manufacturing emissions should be allocated for the company. The use phase can be considered as a part of carbon handprint and life cycle greenhouse gas emission of a particular phone. However, for the carbon footprint of the company, the use phase is not relevant as it is the part of consumers' carbon footprint. The end of life of the phone is also excluded from the scope of this study, as the company has proper in-house repair and micro soldering (expert repair) processes which allow them to fix most of the issues with the phones and make them functional again. Those repaired phones are fully functional and could be sold again, keeping the materials in the loop. Some phones that are not repairable are recycled and the spare parts inside the phones that are completely functional are reused during the repair processes. Other non-functional scrap spare parts are sent back to the recycling facilities for recycling or purchase credits. The transportation emission for the delivery of those used spare parts was included in this study.

The emission from the cleaning, repair, and maintenance, guest visits, and the carbon footprint of the equipment and machinery are excluded from the scope of the study. Since no side product or side streams were observed during the data collection phase, allocation procedures were not needed for this study.

3.1.2 Data Collection

Primary data was collected for the upstream and downstream logistical operations. The electricity consumption data for the carbon footprint calculation was also taken as primary data from the utility bills. Data for the employees' commuting habits (mobility) was collected primarily from electronic surveys. A companywide survey was conducted for the estimation of transport distances, commuting habits, and means of transport used during the commute. Primary waste data was collected physically from the direct measurement at the source. As remote work was encouraged (when possible) in all the departments. Most people from the headquarters (HQ) and customer service were working remotely. Similarly, some individuals who were considered as a high-risk group for the COVID-19 virus contamination were offered the remote working opportunity even in the operations during the pandemic period which had an impact on commuting emissions in 2020.

In real-life scenarios, it is not always practical or possible (in many cases) to directly measure the greenhouse gas emissions from all the sources. Therefore, the GHG calculation process also involves various assumptions and estimates. Secondary sources of data from literature and databases were also used for some estimation, for instance, values of emission factors for the footprint calculations. To calculate the carbon footprint, first, the emission sources were identified, and then estimated or collected activity data was multiplied by the emission factor. Emission factors were identified for all the emission sources from various literature and databases specifically from the *Technical Research Centre of Finland (VTT), WWF Climate Calculator, Helsinki Region Environmental Service (HSY), Helsinki Region Transport Authority (HSL),* Energy Providers (*Helen and Fortum*).

3.2 Inventory Analysis

The inventory analysis for the carbon footprint calculation was performed following the ISO 14040, ISO14044, and GHG Protocol, examining the inputs and outputs of the unit process. Material and energy flows were taken as input and the GHG emissions as output. The emissions categorized per scopes according to the GHG protocol are listed in Table 2.

Table 2. Emission types per scope

Scope 1	No *scope 1* emission was observed in the company (no company-owned vehicles, no electricity and heat generation inside the company)
Scope 2	Electricity production Heat production and cooling

Scope 3	Fuel combustion (employee commute) Spare parts production Waste management Website use Upstream and downstream logistics Office supplies (snacks, refreshments, phone accessories, and outbound product packaging supplies)

3.2.1 Energy Consumption

In 2020, the operation of the company involved two physical stores, a headquarter, and a production site in the Uusimaa region, Finland. At the beginning of 2021, the company launched another production site in Tallinn, Estonia, and a new store (Kamppi, Helsinki Finland) in March. Those facilities are out of the scope of this study, as the study is conducted for the year 2020. The operation facilities were rental spaces shared with other companies and the utility bills were already included in the rent, hence the energy consumption data was not allocated to the individual companies in some instances. Therefore, the energy consumption data was not reported for the facilities which are already using renewable sources of electricity, and the emission factor was considered 0 g/kWh (data also verified from the service providers' website). The emission factor does not consider the emission emitted during the production of the solar panel, wind turbine, and the construction of the production facilities. Whereas the company headquarter (HQ) does not yet use 100% renewable electricity, therefore the electricity consumption units were reported for it. The HQ Helsinki electricity consumption consists of 39% Nuclear Energy (NE), 37% Renewable Energy (RE), and 24% Fossil Fuel Energy (FE), hence the respective emission factor was taken from the Helen, which is 139 g/kWh (Helen 2020b). Table 3 presents the total emission from the electricity consumption in the company premises.

Table 3. Electricity consumption emission (*Scope 2*) in the company premises in 2020

Location	**Service Provider**	**Electricity Type**	**Emission Factor (gCO$_2$e/kWh)**	**Units consumed (kWh/year)**	**Total Emission (tCO$_2$e)**
OPS Helsinki	Helen	RE + Rooftop Solar	0	-	0
Iso-Omena Store	Fortum	RE + Rooftop solar	0	-	0
Ruoholahti Store	Helen	Wind Energy	0	-	0
HQ Helsinki	Helen	NE 39% + RE 37% + FE 24%	139	9465.15	1.32
Total				9465.15	1.32

In 2020, the total greenhouse gases emitted from electricity consumption in the company was **1.32 tCO$_2$e**.

In the case of heat consumption, no first-hand data was obtained from the property manager, therefore estimates were based on the average heat consumption requirement of the corporate buildings in the Helsinki region as per its surface area. The average heat consumption required for the Helsinki region corporate buildings is assumed to be 119 kWh/m^2 (Energiateollisuus 2019). The emission factor for district heating and cooling was also taken from Helen, which are 182 g/kWh and 0 g/kWh, respectively (Helen 2020b). The district cooling provided by Helen is carbon neutral because of renewable energy use and waste heat utilization (Helen 2020a). Similarly, the emission factor for district heating in the Iso Omena building is also considered 0 g/kWh as the building uses Fortum's Ekoplus heat which uses 100% renewable energy and waste heat (Citycon 2020). Table 3 presents the total emission from the heat consumption and cooling in the company premises.

Table 4. Heat consumption emission (*Scope 2*) in the company premises in 2020

Location	**Office Space (m^2)**	**Average Heat consumption (kWh/m^2)**	**Heat Type**	**Units Consumed (kWh/year)**	**Emission Factor (gCO$_2$e/kWh)**	**Total Emission (tCO$_2$e)**
OPS Helsinki	1500	119.40	District Heating/Cooling	179100	182	32.60
HQ Helsinki	2464	119.40	District Heating	294201	182	53.54
Iso Omena Store	25	119.40	District Heating	2985	0	0
Ruoholahti Store	19	119.40	District Heating	2268	182	0.41
Total				478555.20		86.55

In 2020, the total greenhouse gases emitted from heat consumption and cooling in the company was **86.55 tCO_2e**.

In 2020, the total greenhouse gas from energy consumption (*scope 2*) was **87.87 tCO_2e**. The greenhouse gas emission for energy consumption is dependent on some estimation, especially for the heat consumption data. None of the company facilities produce direct GHG emissions from the combustion of the fuel for heat or electricity. The company does not have any company-owned vehicles to have direct *scope 1* emissions as of now. In the future, it would be ideal if exact heat consumption amounts would be available.

3.2.2 Employee Commute

An electronic survey was organized to collect information regarding the commuting habits of the company employees. It was not possible to collect the information from all the employees, hence the survey was used to map the average daily commute. In 2020, the operation of the company was relocated from Ruoholahti to Kalasatama, and HQ was relocated within Ruoholahti, Helsinki. Since HQ was relocated within walking distance of the old premise, the relocation is assumed to have no significant effect on commuting. Whereas the operation department relocation had a significant effect on commute. Approximately 8 minutes of commute distance was reduced on average by moving to the new location. In addition, the new facility has a more convenient public transport facility mainly because of its proximity to the metro station. As mentioned earlier, the use of a car was discouraged with the limited and expensive parking spaces. In contrast, bike parking facilities, showers, and lockers were easily accessible to the employees to encourage walking and biking. Remote work was encouraged (mostly because of COVID 19 pandemic) whenever possible reducing the commuting emission by avoiding or reducing the need to travel. Since no previous studies were conducted on commuting habits to old premises, commute to the new premises was considered for this study. The survey also consists of some questions to quantify the effect of the COVID-19 pandemic on employee commuting habits. However, it was challenging to allocate the effect between the effect due to the COVID-19 pandemic and the effect due to the relocation of the office. Hence, only the current commuting patterns were considered for this study and the effect of the COVID-19 pandemic and relocation was excluded from the scope of this study.

On average the respondents travelled 14 km to work, of which 78% commute regularly to work (1 day or more per week). Out of estimated 22,572 round trips for the year 2020, 32% of the journey was completed by walking, biking, or riding an e-scooter to work, 30% by metro, 15% by bus, 12% by car, 7% by train, 3% by tram, and 1% by other means such as rideshare and taxi. Most of the journey was completed by walking, biking, riding an e-scooter, and using public transport. The means of transportation used by the respondents are presented in Figure 7. Out of 12% commuting by car, 61% of the respondents used petrol cars, 26% used diesel cars, 9% used hybrid cars, and only 3% used electric cars for their journey.

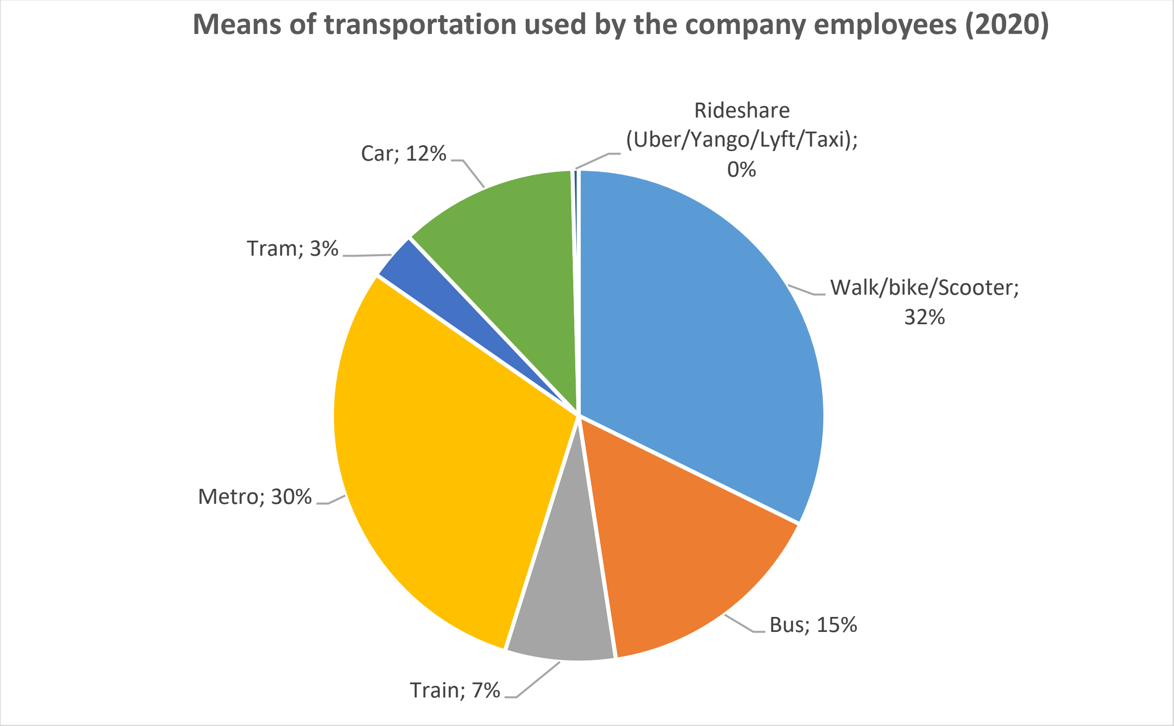


Figure 7. Means of transportation used by the company employees for commuting

Total workdays were estimated to be 231 days, assuming 52 weeks with 5 working days per week, 4.5 weeks of vacation and around 5-7 days of public holidays. Out of 427 employees, 78% regularly commuted to work, which is 330 employees. The emission factors used for the calculation of GHG emissions are presented in Table 5.

Table 5. Emission factors of different types of vehicles (VTT 2019; HSL 2020; WWF 2020)

Type of Vehicles	Emission Factor (gCO2e/km)	References
Petrol Car	159.80	VTT, WWF
Diesel Car	141.10	VTT, WWF
Electric Car	0	VTT, WWF
Hybrid	100	VTT, WWF
Tram	0	HSL, WWF
Train	0	HSL, WWF
Metro	0	HSL, WWF
Bus	53	VTT, WWF
Taxi	152	VTT, WWF

The emission factor for a bus is averaged for 18 passengers per trip and it is estimated that the average car driver drives alone unless it was used for ridesharing or carpooling. The emission factor of the respective type of cars used by the respondent was used to calculate the overall emission of car commute which was on average approximately 144 gCO_2e/km. Only tank-to-wheel emissions were considered for this study; hence the emission of an electric car, tram, and train is zero. Irrespective of the estimation, HSL claims that all of its trains, trams, and metro runs on hydropower which makes the real emission close to zero on those services (HSL 2020). Table 6 presents the company commute emissions in 2020.

Table 6. Commute emissions of the company for the year 2020

Means of Transport	Total Distance (km/year)	Emission factor (gCO_2e/km)	Total Emissions ($gCO_2e/year$)	Total Emission (tCO_2e)
Walk/bike/Scooter	318173.91	0	0	0
Bus	21868.06	53	1159007.28	1.16
Train	91500.57	0	0	0
Metro	188115.18	0	0	0
Tram	53.28	0	0	0
Car	216954.19	144	31269397.79	31.27
Rideshare (Uber/Yango/Lyft/Taxi)	191.83	40	7673	0.01
Total				32.44

Figure 8 reveals the GHG emissions from commuting as per the means of transportation used during 2020 in the company.

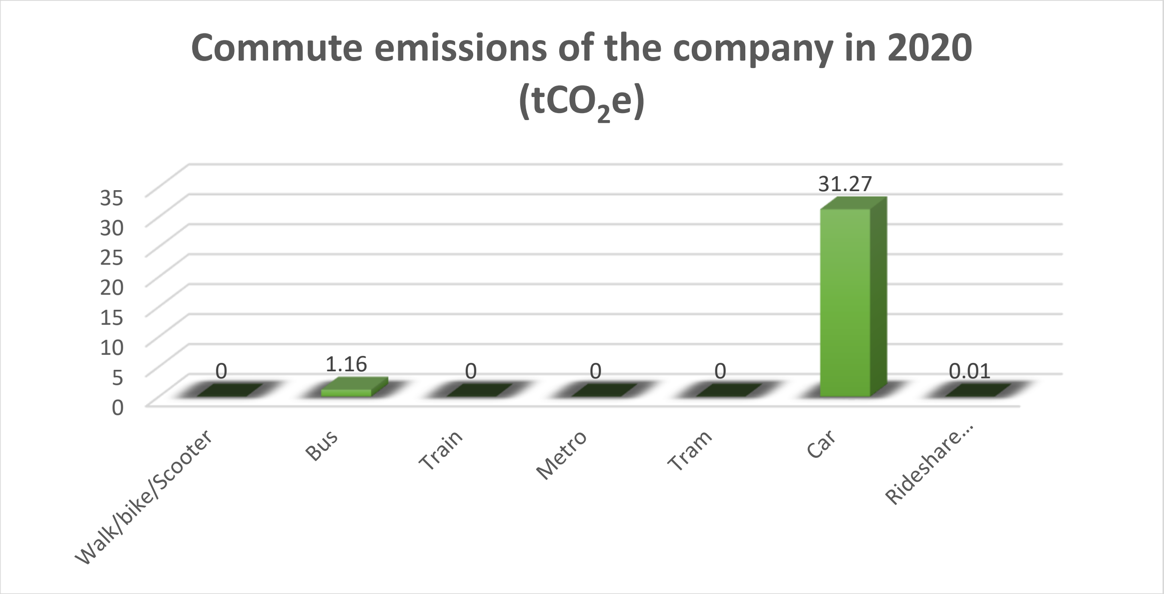


Figure 8. Total commute emissions of the company for the year 2020

In 2020, the total greenhouse gases produced from commuting activities (*scope 3*) in the company was **32.44 tCO_2e**, in which commuting by car contributed the most. Even though only 12% of the commuter used cars, it represents 96% of total commuting emissions. The result has the influence of COVID-19 pandemic mostly because of remote work and the commuting patterns after the relocation of the office premises was considered as no previous commuting data available for old premises.

3.2.3 Waste Management

There was no previous record of waste data collection, even though sound waste management practices are evident in the company. Waste was categorized into mixed, biological (organic), plastic, cardboard, e-waste, and recycled cans. The e-waste includes the regular electronics mixed waste such as non-functional cables, and some small used spare parts that were not sent back to the suppliers or recycling centres directly for recycling or purchase credits, batteries (excluding cell phone batteries), old electronic appliances, and discarded chargers. To collect the waste data, each department was requested to fill out the waste spreadsheet (amount per above-mentioned waste categories). The data was collected for a month and was estimated for the whole year based on monthly data. The emission factors for waste handling were taken from *WWF Climate Calculator*. They collected data on waste management for the Helsinki metropolitan area (which is where all the company premises were located as of 2020) using references from the *Finnish Environmental Institute* (SYKE) and *Helsinki Region Environmental Services* (HSY) (WWF 2020). The emission factors for waste management used in the studies are listed in Table 7.

Table 7. Emission factor for waste management in Helsinki metropolitan area

Waste	Emission Factors (gCO2e/kg)	References
Mixed Waste	410	(WWF 2020)
Biowaste	65	(WWF 2020)
Cardboard	60	(WWF 2020)
E-waste	720	(WWF 2020)
Aluminium Cans	6.80	(Damgaard et al. 2009)
Wooden Pallets	0.02	(Deviatkin and Horttanainen 2020)

Some of the waste collected in insignificant amounts (such as metal, glass, paper, and plastic waste) were excluded from this study. The data includes the waste generated in all the company premises (Operations, HQ, and Stores) in 2020. The total emissions from waste management activities in the company are presented in Table 8.

Table 8. Total emission from waste management in the company premises in 2020

Waste Categories	Total Waste (kg)/year	Emission Factor (gCO2e/kg)	Total Emission (tCO2e)
Mixed Waste	67584.86	410	27.71
Cardboard	111113.10	60	6.67
Wooden Pallets	16217.14	0.02	0.003
Aluminium cans	6840.15	6.80	0.05
E-waste	2163.20	720	1.56
Bio waste	34992.57	65	2.27
Total			38.26

In 2020, the total greenhouse gases emitted from waste management activities in the company was **38.26 tCO_2e**. This value is an estimation based on the data collected for a month. The exact waste quantities may vary over the year and there might also be irregularities during the data collection as there were multiple individuals involved. As previously mentioned, some of the insignificant amounts of waste collected were excluded from this study, which can be adjusted in future studies. Additionally, waste-related emissions factors include some uncertainty because waste is usually operated by various companies in different locations and these emissions factors are typical estimations.

3.2.4 Office Supplies

The office supplies include snacks, refreshments, and packaging materials supplies for the outbound deliveries. The equipment and machinery used in the company along with the products used for cleaning and maintenance were excluded from the scope of this study. For shipping, average distance and mass related emission factors (62 gCO_2/t-km for road, 10 gCO_2/t-km for Sea, and 600 gCO_2/t-km for Air) were used (Jofred and Öster 2011; Canfora et al. 2018). The yearly amount of office snacks and refreshments was estimated based on the weekly purchase invoices and some of the items such as soft drinks, carbonated water, milk, coffee, tea, and snacks were allocated average emissions for simplicity even though the emission difference within the categories itself might be significant enough in some cases. Table 9 provides the emission associated with office snacks and refreshments.

Table 9. Office snacks and refreshments emissions in the company in 2020

Items	**Amount (kg/year)**	**Emission Factor (kgCO2e/kg)**	**Total Emission (tCO_2e)**	**References Used for Emission Factors**
Coffee	200.20	8.26	1.65	(Usva et al. 2020)
Tea	40.87	0.30	0.08	(Hartikainen and Pulkkinen 2016)
Oat Milk	1716	0.44	1.29	(Oatly 2021)
Milk	3229.20	1.30	4.20	(Clune et al. 2017)
Apple	416	0.39	0.16	(Clune et al. 2017)
Oranges	514.80	0.33	0.17	(Clune et al. 2017)
Banana	808.08	0.72	0.58	(Clune et al. 2017)
Kiwi	156	0.36	0.06	(Clune et al. 2017)
Pear	156	0.31	0.05	(Clune et al. 2017)
Plum	260	0.45	0.12	(Clune et al. 2017)
Soft Drinks	926.64	0.30	0.51	(Hartikainen and Pulkkinen 2016)
Ketchup	156	2.25	0.35	(Wohner et al. 2020)
Yogurt	377	1.31	0.49	(Clune et al. 2017)
Carbonated Water	276.64	0.30	0.15	(Hartikainen and Pulkkinen 2016)
Muesli	78	0.50	0.04	(Clune et al. 2017)
Snacks (energy bars, biscuits etc)	851.29	2.00	1.70	(Raisio Oyj 2014)
Total			10.70	

In 2020, the total greenhouse gases emitted from office snacks and refreshments supplies in the company was **10.70 tCO_2e**.

Outbound Supply

The outbound supply consists of phone accessories and the items required for product packaging. The weight of items was measured physically as first-hand data and the corresponding production emission factors were taken from the respective literature mentioned in the references section. In some cases, primary data was challenging to collect, hence the data was estimated based on the number of phones sold during that year. The number of charger cables, paper inserts (paper leaflets), packaging box (paper-based box for phone packaging), and envelopes (bubble envelope mailers) was assumed to be equal to the number of phones sold in 2020. The emission factor was unavailable for the tempered glass screen protector, silicone case, packaging box, and paper inserts, hence the emission factor for regular tempered glass, regular silicone rubber, regular cardboard box, and regular office paper were used for the corresponding products respectively. The outbound supply emissions were calculated in Table 10.

Table 10. Outbound supply emissions in 2020

Items	**Amount (pcs)**	**Weight per Item (kg)**	**Total Weight (kg)**	**Emission Factor (kgCO_2t/kg)**	**Total Emission (tCO_2e)**	**References used for Emissions Factors**
Silicone Case	142050	0.023	3267.15	2.67	8.72	(Winnipeg 2012)
Tempered Glass	309050	0.011	4017.65	1.20	4.06	(Kua and Lu 2016)
Packaging Boxes	312770	0.110	34404.70	0.32	11.01	(Pihola et al. 2010)
Paper Inserts	312770	0.005	1563.85	1.25	1.95	(Pihola et al. 2010
Envelops	312770	0.013	4066.01	4.13	16.79	(Pilfold 2013)
Earbuds	4400	0.034	149.60	20	2.99	(Malmodin and Lundén 2018)
Charger Cables	312770	0.018	5629.86	0.01	0.07	(European Commission 2020)
Charger Adapters	13860	0.027	374.22	0.04	0.01	(European Commission 2020)
Total					45.62	

In 2020, the total greenhouse gas emitted from outbound supplies production in the company was **45.62 tCO_2e.** In total, the GHG emissions from office supplies including both outbound supply and snacks and refreshments was **56.32 tCO_2e.** The office supplies emissions do not cover the transportation emissions, which will be calculated in the upcoming section (Transportation) separately.

3.2.5 Spare Parts Production

Most of the phones supplied to the company are fully functional hence they can be resold without any repair. In 2020, 35% of all the phones were repaired during the refurbishment process in the company. During repair, 50% of the total spare parts used was battery and 19% of the total spare parts used was display. Altogether, battery and display represent almost 70% of all spare parts used during the repair process in the company. As spare parts production data was not available as primary data, a secondary data source was used for the calculation. Proske et al. (2020) collected emission data from several life cycle assessments of smartphones and categorized the emission into various factors, presented in Figure 9. According to that report, display production accounts for 5% of total production emissions, and battery production accounts for 12% of total production emissions. The remaining spare parts were allocated an average emission of 6% of total production emission, which is the average of phone external housing and frame, internal structural elements, and miscellaneous parts (from Figure 9).

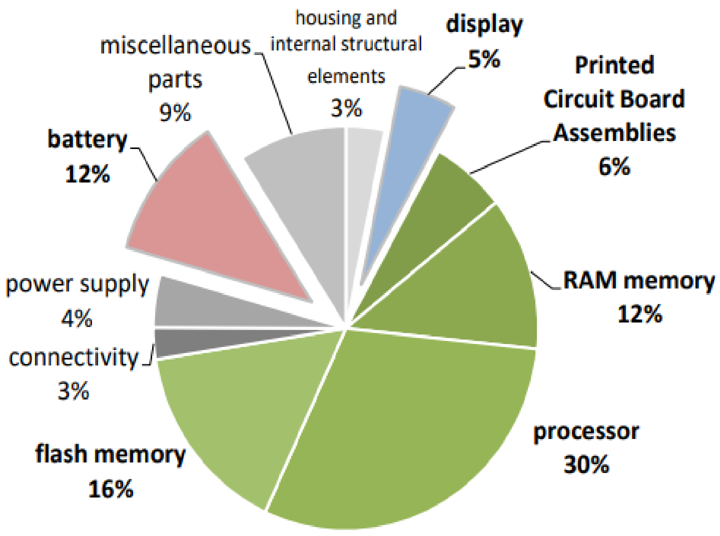


Figure 9. Share of GHG emission during smartphone manufacturing (Proske et al. 2020)

Printed circuit board (PCB) and the main Integrated Circuits (ICs) processor, memory, and storage can cause more than half of the whole manufacturing GHG emissions. Those units were not often used in repair processes, and such issues were usually fixed with the help of expert micro-soldering personnel. Since the process requires human labour and technique and does not require a significant amount of material resources and energy, the emission of the micro-soldering process is excluded from the scope of the study. Likewise, some of the minor spare parts and displays are purchased as refurbished parts or used from scrap phones. These parts will have negative emissions compared to the regular spare parts. Whereas the allocation percentage or quantity of the refurbished and reused parts are not properly identified during the data collection phase, hence all the spare parts were allocated the emission factor of newly produced parts.

A total of 312,770 phones were sold in 2020 of which 109,470 were repaired (35% of all the phones sold in 2020 were repaired during the refurbishment process) in the company. Out of all repair activities, 50% was battery replacement and 19% was display replacement. It can be assumed that only one display and/or battery was used per phone that required display and/or battery replacement (ignoring human error and failed attempts). The spare parts used in 2020 are presented in Table 11.

Table 11. Spare parts used in 2020

Spare parts	Units
Battery used	54735
Display used	20799
Other spare parts used	33936

Average GHG emission of a new iPhone is around 78 kgCO2e in which,

80% is production emissions = 62.40 kgCO_2e

16% is use phase emissions = 12.48 kgCO_2e

3% is transportation emissions = 2.34 kgCO_2e

1% is end of life emissions = 0.78 kgCO_2e (Apple 2016a; Apple 2016b; Apple 2017a; Apple 2017b; Apple 2019; Apple 2020b; Compare and Recycle 2020)

As mentioned earlier, display accounts for 5% of total production emissions and battery accounts for 12% of total production emissions. The remaining spare parts were allocated an average emission of 6% of total production emission. Hence the emission factors are:

Display (5% of 62.40 $kgCO_2e$) = 3.12 $kgCO_2e$
Battery (12% of 62.40 $kgCO_2e$) = 7.49 $kgCO_2e$
Other Parts (6% of 62.40 $kgCO_2e$) = 3.74 $kgCO_2e$

The GHG emission from the spare parts production is calculated in Table 12.

Table 12. Spare parts production emissions in 2020

Spare Parts	Units	Emission Factor ($kgCO_2e$)	Total Emission ($kgCO_2e$)
Display	20799	3.12	64892.88
Battery	54735	7.49	409965.20
Other Parts	33936	3.74	126920.60
Total			601778.70

In 2020, the total GHG emitted from spare parts production was **601.78 tCO_2e.** This result is heavily based on the estimation of emission factors during spare parts production based on Figure 9 and the use of refurbished spare parts and parts reused from scrap phones were not considered for the calculation as those data could not be properly identified during the data collection phase. These assumptions have an impact on the results and should be considered in future projects.

3.2.6 Transportation

The greenhouse gases emissions during the transportation of goods from suppliers to the company premises (upstream) and the transportation of the products from operations to and from the customer (downstream) is covered in this section. As it would be complex to collect data for the complete journey from the raw material extraction to the final product manufacturing of all the suppliers involved, the scope of this study only covers the last journey from the vendors’ shipping location to the company premises. Similarly, for the outbound logistics (product delivery from the company to the customers), only the average delivery distance from the company’s operations to the capital city of the respective country is considered for this study. Countries with less than 1000 phones supplied (supplier phones) and less than 50 phones sold to the company (customer sales) were combined and categorised as *Others* and were allocated average delivery distance. To make the study consistent, only tank-to-wheel emissions were considered for the transportation throughout the calculations.

Along with the sales, customer sales, the packages returned for a 14-days refund (one-way shipping), warranty processing (two-way shipping), return merchandise authorization (RMA), and customer sales return were also included in the calculations. For the incoming shipping, average distance emission factors (62 gCO_2/t-km for road, 10 gCO_2/t-km for Sea, and 600 gCO_2/t-km for Air) were used (Jofred and Öster 2011; Canfora et al. 2018). The transportation emissions were broken down into seven categories:

- Phone Supply (Upstream)
- Spare Parts Supply (Upstream)
- Outbound Supply: Phone Accessories and Packaging Products
- Office Supplies: Snacks and Refreshments
- Product Delivery to the Customer: Sales, Warranty and Returns
- Customer Sales and Returns
- Store Phone Transportation

The emissions associated with the transportation of the above-mentioned categories are analysed and presented in the following sections.

Phone Supply (Upstream)

The transportation emissions associated with the phone supplied to the company are assessed in this section. The phone supply emissions also include transportation emissions related to return merchandise authorization (RMA). Some phones from suppliers that do not fulfil the promise as per the agreement and are not up to the promised standard are returned to the suppliers during the RMA process. Around 10.36% of the phone returned during the RMA process in 2020. The average weight of the phone represents the average weight of all the iPhone models sold in the company in 2020. The total distance from supplier location and operation facility of the company was measured using Google maps. Table 13 presents the transportation emissions for the phone supplied to the company in 2020.

Table 13. Phone supply emissions in 2020

Supplier's Location	Number of phones	Average weight (kg)	Total Weight (t)	Total distance (km)	Emission Factor (gCO_2e/t-km)	Phone Supply Emission (tCO_2e)	RMA Emission (tCO_2e)
Location 1	132151	0.19	24.45	2122	600	31.13	3.11
Location 2	78418	0.19	14.51	7959	600	69.28	6.93
Location 3	47804	0.19	8.84	2606	600	13.83	1.38
Location 4	46649	0.19	8.63	2441	600	12.64	1.26
Location 5	37056	0.19	6.86	3435	600	14.13	1.41
Location 6	26714	0.19	4.94	1253	600	3.72	0.37
Location 7	25423	0.19	4.70	1453	600	4.10	0.41
Location 8	11153	0.19	2.06	552	62	0.07	0.01
Location 9	10851	0.19	2.01	1779	600	2.14	0.21
Location 10	2699	0.19	0.50	1735	600	0.52	0.05
Location 11	2543	0.19	0.47	2520	600	0.71	0.07
Location 12	2155	0.19	0.40	10133	600	2.42	0.24
Location 13	1781	0.19	0.33	1704	600	0.34	0.03
Others	4156	0.19	0.77	3053.23	600	1.41	0.14
Total						156.43	15.64

Total phone supply emissions (including RMA) = 156.43 + 15.64 = 172.07 tCO_2e. In 2020, total GHG emissions associated to the phone supply including RMA freights was **172.07 tCO_2e.**

Spare Parts Supply

Transportation emissions for the spare parts supply were allocated according to the average weight of the spare parts. The average weight of the spare parts was estimated based on Ercan et al. (2016) LCA study. The number of spare parts was estimated based on spare parts used in 2020 for in-house repair in the company. It is assumed that number of spare parts supplied is equal to the number of spare parts used during the repair processes. Minor spare parts with less significant volume and weight (compared to major parts such as batteries, displays, frames, and back glasses) were categorized together as *Others* and allocated an average weight of 11 grams/units (Ercan et al. 2016). Almost all the spare parts we supplied from Hongkong, except for some backup suppliers. Therefore, the distance from the port of Hong Kong to the operation facility of the company was used for the calculation and instead of calculating the individual distance of all the spare parts suppliers. The emission factor of 600 gCO_2e/t-km (aviation transport) was used as spare parts were supplied by air. Table 14 presents the calculation of emissions associated with the transportation of spare parts supplied to the company in 2020.

Table 14. Spare parts supply transportation emissions in 2020

Spare Parts	Number of Spare parts	Average weight (g)	Total Weight (kg)	Total distance (km)	Emission Factor (gCO$_2$e/t-km)	Total Emission (tCO$_2$e)
Battery	84733	48	4067.18	7800	600	19.03
Display	31397	21	659.34	7800	600	3.09
Frame	4031	27	108.84	7800	600	0.51
Normal Display	708	21	14.87	7800	600	0.07
Back Glass	314	27	8.48	7800	600	0.04
Others	46884	11	515.72	7800	600	2.41
Total						25.15

In 2020, the total greenhouse gases emitted for the transportation of spare parts supplied to the company was **25.15 tCO$_2$e.**

Outbound Supply: Phone Accessories and Packaging Products

The outbound supply consists of phone accessories and packaging products used for product delivery. Transportation emissions of the outbound supply were also allocated according to the average weight of the products. In some cases, primary data was challenging to collect, hence the data was estimated based on the number of phones sold during that year. The number of charger cables, paper inserts, packaging boxes, and envelopes was assumed to be equal to the number of phones sold during that year. Table 15 presents the emissions associated with the transportation of outbound supply.

Table 15.Outbound supply transportation emissions in 2020

Suppliers	Items	Amount (pcs)	Weight per item (kg)	Total Weight (kg)	Distance (km)	Emission Factor (gCO$_2$/t-km)	Total emission (tCO$_2$e)
Supplier 1	Tempered Glass	309050	0.011	3399.55	7795	600	15.90
Supplier 2	Silicone Case	142050	0.023	3267.15	7822	600	15.33
Supplier 2	Charger Cables	312770	0.018	5629.86	7822	600	26.42
Supplier 3	Paper Inserts	312770	0.005	1563.85	950	600	0.89
Supplier 3	Packaging Boxes	312770	0.110	34404.7	950	600	19.61
Supplier 4	Envelopes	312770	0.013	4066.01	313	62	0.08
Supplier 2	Earbuds	3400	0.034	115.6	313	600	0.02
Supplier 6	Charger Adapters	13860	0.027	374.22	313	600	0.07
Supplier 5	Earbuds	1000	0.034	34	80	62	0.0002
Total							78.32

In 2020, the total greenhouse gasses emitted from the outbound supply (transportation emissions) were **78.32 tCO_2e**

Office Supplies: Snacks and Refreshments

To calculate the delivery emission of snacks and refreshments, the distance of the nearest grocery store was estimated to be around 5 km. Since the supply is delivered weekly, the total distance travelled to deliver to two major offices will be 520 km per year. Using the delivery emission factor of 62 gCO_2e/t-km and the total weight of goods delivered (10.16 tonnes in 2020, from Table 9), the delivery emission of snacks and refreshments in 2020 becomes **0.33 tCO_2e.**

Product Delivery to the Customer: Sales, Warranty and Returns

The product delivery emissions include the emissions associated with the transportation of phones sold to customers and phones returned for a 14-days refund (one-way shipping), warranty processing (two-way shipping). All the packages were estimated to be equal weight (average weight of 500 grams including the packaging). As mentioned previously, only the average delivery distance from the company's operations to the capital city of the respective country is considered for this study. In the case of Finland, the average distance from the company's operation to the Jyväskylä (around 85% of the Finland population is located south of the Kokkola-Joensuu line (Tilastokeskus 2016)) is used to estimate the average distance for the parcel delivery.

Primary data regarding the service providers, exact routes, and means of transportation used for supply was available for the shipping routes, especially for the downstream transportation. The information about the route of the shipping product was extracted from the company's internal databases for the outbound downstream logistics. Therefore, DHL's carbon calculator tool was used to calculate the exact emission factors for the specific routes. The routes data was used in the DHL's carbon calculator, where various scenarios can be entered to get the emission estimation (DHL [no date]). DHL claims that the emissions calculations are based on the GHG protocol and are prepared following the requirements of the European Emissions Trading System (EU-ETS) and the EN16258 and ISO 14064 standards. The packages were estimated to be delivered with other shipments. It was estimated that a 3.5 cubic meter container will hold 1 tonne of packages (estimated by the average weight and volume of the delivery parcels). The product delivery to the customer emissions (including 14 days return and warranty services) is presented in Table 16.

Table 16. Emissions from product delivery to the customer (including 14 days return and warranty) in 2020

Country	Total Sales (units)	14 Days Return (1-way shipping)	Warranty (2-way shipping)	Total Trips Required	Weight per package (kg)	Total Weight for delivery (kg)	Emission factor ($kgCO_2e/kg$)	Total Emission (tCO_2e)
Country 1	116737	5893	8954	140538	0.5	70269	1.12	78.70
Country 2	93116	6650	6644	113054	0.5	56527	1.08	61.05
Country 3	72848	3088	6816	89568	0.5	44784	0.02	0.90
Country 4	19937	832	1248	23265	0.5	11632.5	0.85	9.89
Country 5	10797	1244	418	12877	0.5	6438.5	0.67	4.31
Country 6	7248	274	304	8130	0.5	4065	1.21	4.92
Country 7	4836	270	296	5698	0.5	2849	1.8	5.13
Country 8	4157	326	179	4841	0.5	2420.5	0.88	2.13
Country 9	1330	111	79	1599	0.5	799.5	1.13	0.90
Others	882	89	49	1069	0.5	534.5	0.98	0.52
Total								168.45

In 2020, the total greenhouse gas emitted from product delivery (including the 14 days return and warranty services) was **168.45 tCO_2e.**

Customer Sales and Returns

The emission associated with the transportation of the phones sold by the individual customers to the company and the return to the customers (when no agreement could be made because of the price or the condition of the phone). Similar conditions regarding the location, distance, weight, and emission factors (using DHL's carbon calculator tool) as mentioned previously in the *Product Delivery to the Customer* section. The emissions associated with the transportation of customer sales and returns packages are calculated in Table 17.

Table 17. Emission from the transportation of customer sales and return in 2020

Country	Customer Sales (units)	Customer Sales – Return (units)	Total Trips Required	Weight per package (kg)	Total weight for delivery(kg)	Emission factor ($kgCO_2e/kg$)	Total Emission (tCO_2e)
Country 1	2385	604	2989	0.5	1494.5	1.12	1.67
Country 2	8516	1262	9778	0.5	4889	1.08	5.28
Country 3	9732	766	10498	0.5	5249	0.02	0.10
Country 4	715	94	809	0.5	404.5	0.85	0.34
Country 5	766	99	865	0.5	432.5	0.67	0.29
Country 6	142	46	188	0.5	94	1.21	0.11
Country 7	54	15	69	0.5	34.5	1.8	0.06
Country 8	502	76	578	0.5	289	0.88	0.25
Country 9	0	0	0	0.5	0	1.13	0
Others	23	3	26	0.5	13	0.98	0.01
Total							8.14

In 2020, the total greenhouse gases emitted from customer sales and return transportation was **8.14 tCO_2e.**

Store Phones Transportation

A rented diesel van is used to transfer the phone between the stores and the company’s production facility. The daily route was recorded to be around 34 km. Considering 5 workdays per week, the total distance travelled by the van would be around 8,160 km. According to the VTT (2019) database, the average diesel van used for urban driving emits 232 gCO_2e/km while driving empty and 276 gCO_2e/km while driving fully loaded (25t load). Assuming the van is filled with only 25% of full capacity, the emission factor of diesel van driving in an urban setting would be around 242 gCO_2e/km.

Hence, total greenhouse gases emitted during the transportation of phones between the stores and the company’s operation facility = 8160 km * 242 gCO_2e/km

= 1,974,720 gCO_2e

= 1.97 tCO_2e

In 2020, the total greenhouse gases emitted during transportation of phones between the stores and operation facility was **1.97 tCO_2e.** Altogether, in 2020, the total greenhouse gases emitted from all the transportation activities in the company was **454.42 tCO_2e.**

3.2.7 Website Use

The emissions associated with the website use were calculated with the help of a website called website carbon [websitecarbon.com]. It calculates the carbon footprint of websites based on energy used at the data centre, telecoms network, and the energy use by the end user's computer or mobile devices. The *Website Carbon Calculator* assumes the energy use by the telecom network and end-user to be standard grid electricity. The energy used by the data centre is checked with the Green Web Foundation (GWF) database to check whether the data centre is using green energy or not. In case of this company, the data centre was found to be running on sustainable energy (Website Carbon Calculator 2021).

As per *Website Carbon Calculator* results, 1.50 g CO_2 is produced every time someone visits the company website. Assuming the website visits were equal to the total sales in 2020, a total of approximately 312,770 website visits was estimated. This results in the emission of 0.47 tCO_2e because of website use.

Therefore, in 2020, the total emission from website use was estimated to be around **0.47 tCO_2e.**

3.3 Impact Assessment

The impact assessment phase of the life cycle assessment is used to understand and evaluate the magnitude and significance of the potential environmental impact of the product or services (SFS-EN ISO 14044 2006). The purpose of this phase is to provide additional information for assessing the results of a product system to understand its environmental significance (SFS-EN ISO 14040 2006). As the LCA study is an iterative process, the goal and scope of the study can be reviewed during the impact assessment phase and modified if required to meet the objectives of the study. (SFS-EN ISO 14040 2006.) The annual carbon footprint activities of the company in 2020 are presented in this chapter.

3.3.1 Carbon Footprint Results

The final phase of the LCA study is the interpretation of the results. During this phase, the result of the study is assessed with the help of inventory analysis and impact assessment. The findings are used to draw some conclusions and provide recommendations. The total carbon footprint of the company in 2020 was approximately ***1,272 tCO$_2$e*** as per the set system boundary, assumptions, and inventory analysis. The results were presented under the instructions of the GHG Protocol. This amount is equivalent to the electricity used by 231 homes for 1 year, or 277 cars driven for 1 year, or the carbon sequestered by 21,033 tree seedlings grown for 10 years (EPA 2021). The categorized greenhouse gas emission according to the respective activities are presented in Figure 10.

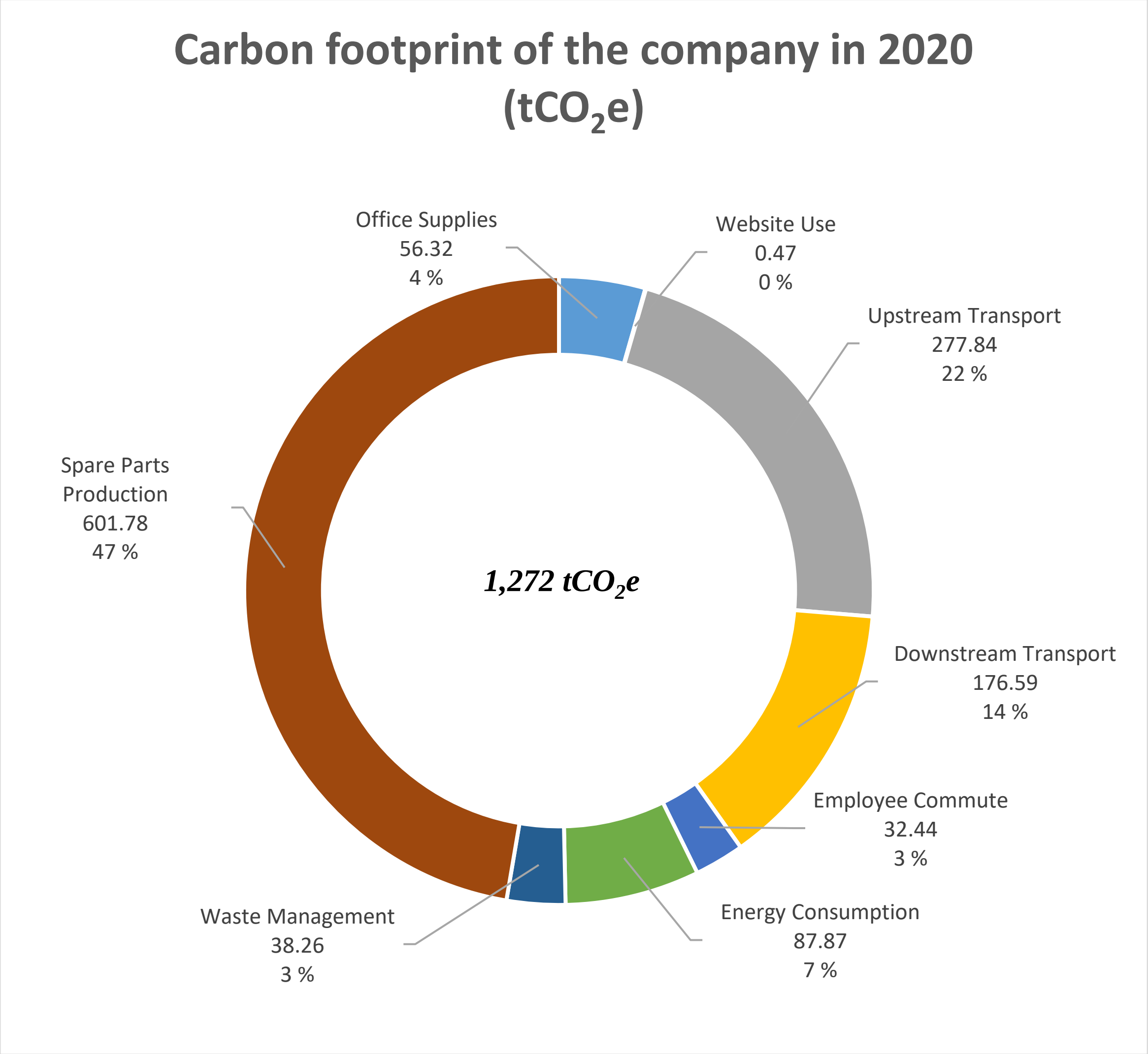


Figure 10. The carbon footprint of the company in 2020 (tCO$_2$e)

Spare parts production has the biggest impact on the carbon footprint of the company, followed by upstream transportation, downstream transportation, energy consumption, office supplies, waste management activities, employee commute, and website use. Spare parts production was responsible for almost half (47%) of the total GHG emissions in the company, which can be explained by the need for raw materials (including some rare earth metals) and the energy used during the manufacturing process. Transportation was another major contributor (36%) of GHG emissions in the company that can be attributed mainly to the use of aviation transportation in the supply chain. Most of the electricity consumption in the company's facilities was produced from renewable sources. In contrast, heat consumption was responsible for the majority (~ 98.5%) of GHG emissions associated with energy consumption in the company. Commuting emissions were also comparatively lower contributing only 3% of total GHG emission, which can be attributed to the good location with proper public transportation infrastructures (particularly due to most of the locations being near to the metro, which runs on renewable energy) and remote working arrangements because of COVID-19 pandemic. Commuting by car was responsible for majority of the commuting emissions. Even though only 12% of the commuters used cars, it represents 96% of total commuting emissions.

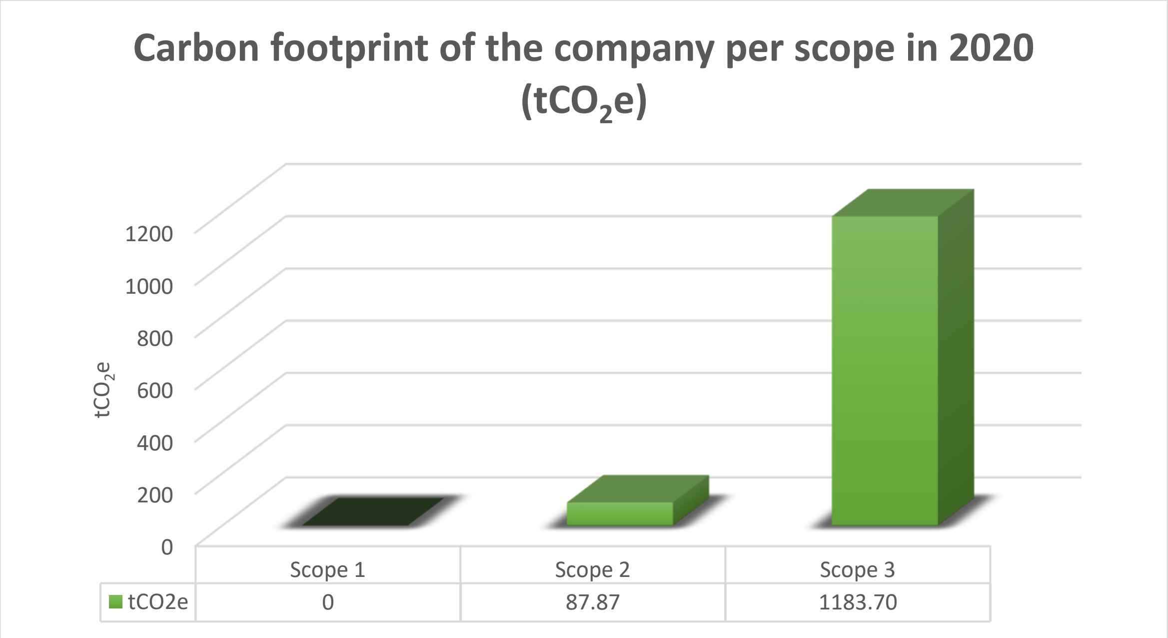


Figure 11. The carbon footprint of the company per scope in 2020 (tCO_2e)

Figure 11 categorizes the emission to its corresponding scope as per GHG Protocol. There were no *scope 1* emissions (direct emissions) sources in the company and very small (87.87 tCO_2e) *scope 2* emissions, which is 6.9% of total emissions. The *scope 2* emissions are associated with the purchased electricity, heating, and cooling. Finally, around 93% of total greenhouse gas emissions were (indirect emissions) scope *3* emissions. *Scope 3* emissions reporting are optional, and it mainly occurs from sources that are not owned or controlled by the company and are usually related to suppliers and third parties. However, understanding the role of *scope 3* emission is important for the company because most of the emissions are related to this scope.

4 CARBON HANDPRINT OF REFURBISHED IPHONE

Prior to carbon handprint calculation, it is important to discuss the *operating environment* of the refurbished iPhone. Manufacturing a new phone requires numerous raw materials including rare earth metals. Mining and production of these materials emit a significant amount of GHG emissions contributing to global warming. On average total lifecycle, GHG emission of a new phone is around 78 $kgCO_2e$ per phone, in which around 80% (62 $kgCO_2e$) is produced during the production of the phones.(Apple 2016a; Apple 2016b; Apple 2017b; Apple 2017a; Apple 2019; Apple 2020b; Compare and Recycle 2020) This number is calculated by taking the average emission of all iPhones. Since the refurbishment of the phones eliminates most of the emissions that occurred during the production phase of the phone's life cycle (as the phone is reused during the refurbishment process eliminating the need for virgin raw materials extraction and the energy used during the manufacturing process), using refurbished phones has the potential carbon handprint contribution to the customer. The goal of this handprint study is to investigate the positive environmental impact of refurbished iPhones compared to the new ones.

The *baseline condition* for this study is the use of the new iPhone. A refurbished iPhone is presented as a handprint solution. The *functional unit* is defined as *iPhone usage for 3 years*.

4.1 System Boundaries

All the life cycle stages and processes included in Apple's Product Environmental Reports are included in this study. The GHG emission of a new smartphone is not calculated and is taken directly from the same reports. The use phase and end of life of both new and refurbished phones were assumed to have an identical impact on the environment. Primary phone production is excluded from the scope of the study for the refurbished phones, as refurbishing reuses the discarded phones. The primary phone production and use phase falls under the previous life cycle of the phone and since mostly discarded phones are used during the refurbishment process, the need for production and material extraction is eliminated. The emissions from the production and delivery of the spare parts used during the refurbishment are included in the scope of the study. The used spare parts (battery and display) are sent back to the recycling facilities. The transportation emission for the delivery of those used spare parts was also included in this study. The life cycle of refurbished phones also includes reverse logistics from initial use to the refurbishing company and distribution back to the final customer. A detailed overview of the process is represented in Figure 12.

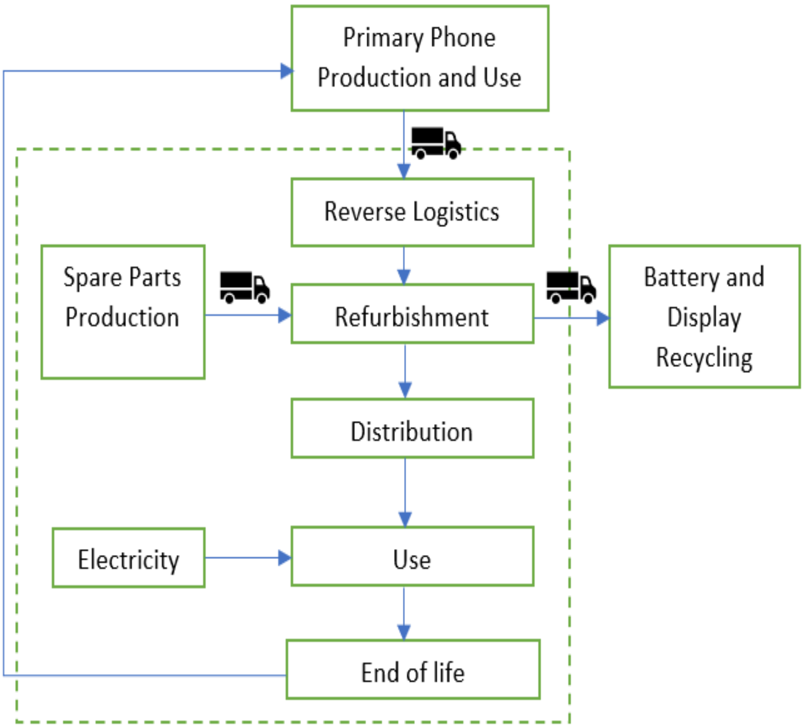


Figure 12. The system boundary for the carbon footprint calculation of refurbished iPhones

4.2 Carbon Footprint Calculation

Average GHG emission of a new iPhone is around 78 kgCO_2e in which,
80% is production emissions = 62.40 kgCO_2e
16% is use phase emissions = 12.48 kgCO_2e
3% is transportation emissions = 2.34 kgCO_2e
1% is end of life emissions = 0.78 kgCO_2e (Apple 2016a; Apple 2016b; Apple 2017a; Apple 2017b; Apple 2019; Apple 2020b; Compare and Recycle 2020)

As mentioned earlier, spare parts production data was not available as primary data, and a secondary data source was used for the calculation. The emission data categorized into various factors by Proske et al. (2020) collected from several life cycle assessments of smartphones (Figure 9) were used for this study. As battery and display were the most significant repairs as per the weight, volume, and percentage of repair performed, individual emission factors were allocated for the battery and display production emission. While other spare parts were allocated with a combined average emission value of housing, internal structural elements, and miscellaneous parts.

As discussed during the spare parts production emission calculations, 5% of total production emissions were allocated to display production and 12% to battery production. The remaining spare parts used during the repair were allocated an average emission of 6% of total production emission, which is the average of housing, internal structural elements, and miscellaneous parts from Figure 9. Similar conditions and values declared during the carbon footprint calculation were used for the spare parts handprint calculations. That is, out of 35% of all the phones that were repaired in the company during the refurbishment process in 2020, 50% was battery replacement and 19% was display replacement.

Printed circuit board (PCB) and the main integrated circuits (ICs) processor, memory, and storage can cause more than half of the whole manufacturing GHG emissions. Those units were not often used in the company’s repair processes, and such issues were usually fixed with the help of expert micro-soldering personnel. Since the process requires human labour and technique and does not require a significant amount of material resources, the emission of the micro-soldering process is excluded from the scope of the study. Likewise, some of the minor spare parts and displays are purchased as refurbished parts or used from scrap phones. These parts will have negative emissions compared to the regular spare parts. Whereas the allocation percentage or quantity of the refurbished and reused parts are not properly identified during the data collection phase, hence all the spare parts were allocated the emission factor of newly produced parts.

Refurbished iPhones

A total of 312,770 phones were sold in 2020 in which 109,470 were repaired (35% of all the phones sold in 2020 were repaired during the refurbishment process in the company). Out of all repair activities, 50% was battery replacement and 19% was display replacement. It can be assumed that only one display and/or battery was used per phone that required display and/or battery replacement (ignoring human error and failed attempts). The spare parts used in 2020 are presented in Table 18.

Table 18. Spare parts used in 2020

Spare parts	Units
Battery used	54735
Display used	20799
Other spare parts used	33936

Spare parts production emissions

As already discussed earlier, the major spare parts such as, display production emits 5% of total production emissions and battery accounts for 12% of total production emissions. The remaining spare parts were allocated an average emission of 6% of total production emission.

Hence, the emission factors are:

Display (5% of 62.40 kgCO_2e) = 3.12 kgCO_2e
Battery (12% of 62.40 kgCO_2e) = 7.49 kgCO_2e
Other Parts (6% of 62.40 kgCO_2e) = 3.74 kgCO_2e

The greenhouse gas emission of the spare parts production is calculated in Table 19.

Table 19. Spare parts production emissions

Spare Parts	Units	Emission Factor ($kgCO_2e$)	Total Emission ($kgCO_2e$)
Display	20799	3.12	64892.88
Battery	54735	7.49	409965.20
Other Parts	33936	3.74	126920.60
Total			601778.70

The total greenhouse gas emissions during the spare parts production is 601778.70 $kgCO_2e$. Therefore, spare parts production emission allocation per phone (601778.70 $kgCO_2e$/ 312,770 units) = 1.92 $kgCO_2e$

Hence, spare parts production emissions per phone = **1.92 $kgCO_2e$**

Transport emissions

Reverse logistics (phone supply) = 0.36 $kgCO_2e$

Spare parts supply = 0.59 $kgCO_2e$

Used spare parts delivery (recycling) = 0.52 $kgCO_2e$

Phone delivery to customer (average)= 0.45 $kgCO_2e$

Total transportation emission per phone = **1.92 $kgCO_2e$**

Use phase and end-of-life emissions were estimated to be equal for both new and refurbished phones.

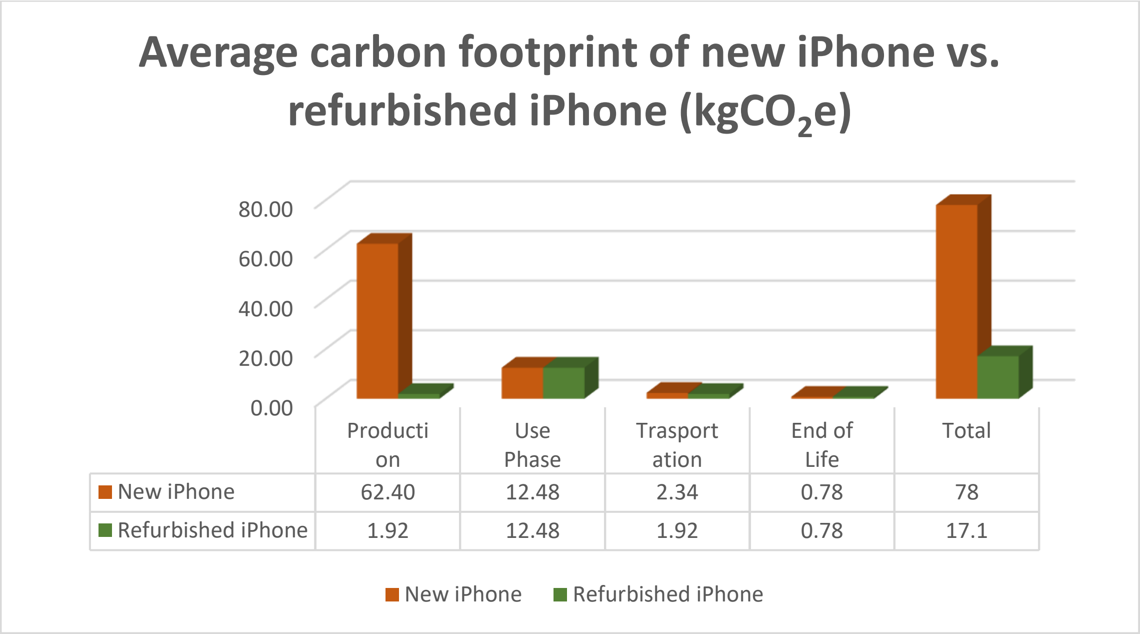
Use phase emission per phone = 12.48 $kgCO_2e$

End of life emission per phone = 0.78 $kgCO_2e$

Carbon Footprint of refurbished iPhone (average) = **17.10 $kgCO_2e$**

Carbon Footprint of new iPhone (average) = 78 $kgCO_2e$

Figure 13 compares the differences between the average carbon footprint of the new iPhone to the average carbon footprint of the refurbished iPhone.



	Producti on	Use Phase	Trasport ation	End of Life	Total
🟧 New iPhone	62.40	12.48	2.34	0.78	78
🟩 Refurbished iPhone	1.92	12.48	1.92	0.78	17.1

Figure 13. The carbon footprint of new iPhone vs. refurbished iPhone

It is worth noting that the *use phase* and *end of life* were assumed to have a similar impact in both cases. The phone production emissions were eliminated during the refurbishment process as the phone is reused avoiding the need of manufacturing a new phone, whereas spare parts production emissions were considered for the refurbished iPhones.

4.3 Carbon Handprint Calculation

As acknowledged earlier, carbon handprint refers to the positive environmental impact of the company created with the help of the product and services, reducing or preventing the carbon footprint of the customers.

$$\text{Carbon Handprint}_{\text{Product}} = \text{carbon footprint}_{\text{Baseline solution}} - \text{carbon footprint}_{\text{Handprint solution}}$$

Carbon Handprint of refurbished iPhone (average)= 78 $kgCO_2e$ - 17.10 $kgCO_2e$

= **60.90 $kgCO_2e$**

4.4 Carbon Handprints Results

The final stage of the handprint calculation is the communication stage, where the results are communicated to the intended audience. The carbon handprint of average refurbished iPhone was around 61 kgCO$_2$e. In 2020, the company's customers were able to reduce the GHG emissions by a total of approximately ***19,000 tonnes*** just by switching to the refurbished phones instead of buying a similar new model. The estimation was based on the number of phones sold during the year 2020. This amount of carbon is equivalent to the electricity used by 3,451 homes for 1 year, or 4,132 cars driven for 1 year, or the carbon sequestered by 314,169 tree seedlings grown for 10 years (EPA 2021).

It is evident that refurbished phones have a positive carbon footprint on the environment compared to a new phone, whereas quantifying the exact impact is challenging and not always straightforward. It can also be argued that new phones can be used longer compared to refurbished phones specifically because of design obsolescence: the planned service life of the product and non-availability of software updates after a specific period. In contrast, the company claims that in some cases, a factory refurbished phone can have even enhanced condition than a brand new one, especially with some models with common motherboard issues which can be reinforced during the repair process. If the service life of the new phone is longer than the life span of refurbished, it will reduce the total handprint and vice versa. Proper comparative studies should be performed regarding the service life of new phones and refurbished phones to have a better understanding of its true impact environmental impact.

5 SENSITIVITY ANALYSIS

Sensitivity analysis is the systematic process for assessing the impacts of selections regarding the data and methods used on the outcome of the study (SFS-EN ISO 14040 2006). The idea is to alter the variables used during the inventory analysis to observe their influence on the results to emphasize the uncertainties in the data.

One of the obvious factors is phone use duration. What if the phone is used only for 1 year before refurbishment, or two years, or more? With the ever-increasing popularity, usage, and rapid obsolescence of the smartphones, use phase of smartphones is getting shorter despite the phone's functionality. Even though the EU directive defines the items the user discards or intends to discard as waste, it seems unfair to categorize all the used phones simply as waste. Some of the phones are used only once for a short interval even if the lifespan of the devices is much higher. Similarly, the carbon footprint of refurbished iPhone is also dependent on the components used during the repair process. The effects of these scenarios are analysed in the forthcoming paragraphs.

Phone use duration scenarios

Using lifespan assessment models, Apple determines the service life of their products. Apple states the 'years of use' for iPhones to be 3 years (Apple 2020a). Considering the service life of 3 years, all phones that are used only for 1 year could be allocated 2/3rd of manufacturing emissions. Similarly, 1/3rd of the manufacturing emission can be allocated for the devices that are used for 2 years. Using this assumption, we can allocate 41.60 kgCO_2e/phone (2/3rd of 62.40 kgCO_2e) for the devices that were used only for 1 year, and 20.80 kgCO_2e/phone (1/3rd of 62.40 kgCO_2e) for the devices that were used for 2 years. Considering these scenarios, the true carbon footprint per refurbished phone becomes ***58.70 kgCO_2e/phone*** (17.10 kgCO_2e +41.60 kgCO_2e) for the phones used for 1 year, and ***37.90 kgCO_2e/phone*** (17.10 kgCO_2e +20.80 kgCO_2e) for the phones used for 2 years. This is still impressive considering the average carbon footprint of the new iPhone is around 78 kgCO_2e.

These variations will also have a significant impact on the overall carbon footprint of the company as well. Estimating 25% of the phones were used only for 1 year, it will increase the carbon footprint of the company by 3250 tCO_2e/year and the same percentage of phones used for 2 years will increase the carbon footprint of the company by 1620 tCO_2e/year. These numbers themselves are significantly higher than the total carbon footprint of the whole company operations in 2020.

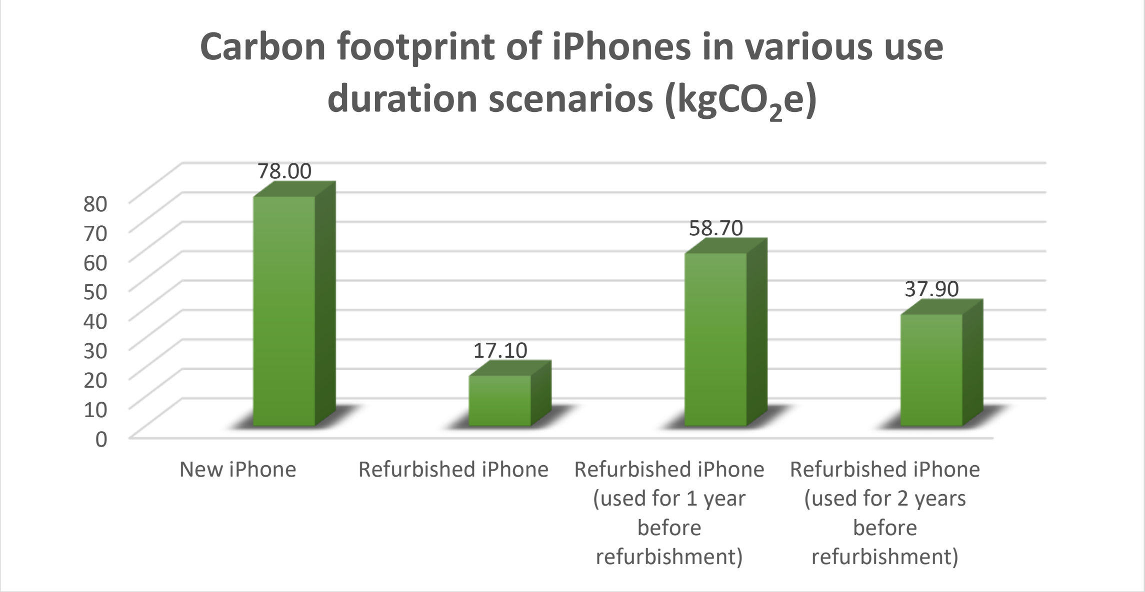


Figure 14. Effect of use allocation on the carbon footprint of refurbished iPhones

Figure 14 compares the average emissions of the new iPhone with the average emission of the refurbished iPhone, the average emission of the refurbished iPhone that was used only for 1 year before the second use, and the average emission of refurbished iPhone that was used for 2 years before the second use. Part of manufacturing emissions was allocated for the second use depending on the duration of phone use before the refurbishment (second use) of the phones. It is also worth mentioning that the devices that have been used for less than 1 year or even 2 years might not need any repair services. Hence the emission from the spare parts production and delivery probably needs to be deducted from the total emissions in that case.

Components Use Scenarios

The carbon footprint of refurbished iPhone is also reliant on the components used during the repair process. Considering the example of most used components: battery and display, the influence of the spare parts used during the repair on the overall carbon footprint could be assessed. The average carbon footprint of the new iPhone is around 78 kgCO$_2$e. To get the emissions as per the components used, the average spare parts production emission (allocated to the refurbished phone) is deducted from the carbon footprint of the refurbished iPhone in which emission of the components used is added. The equation used for the calculation is presented below.

Carbon footprint considering the components used = Carbon footprint of refurbished iPhone – Average spare parts production emissions + Carbon footprint of the used component

In case of no components used, both average spare parts emissions and emission during the transportation of spare parts are deducted from the equation. Assuming only the display is replaced during the repair, the final carbon footprint of the refurbished iPhone becomes ***18.30 kgCO$_2$e*** (17.10 kgCO2e – 1.92 kgCO$_2$e + 3.12 kgCO$_2$e = 18.30 kgCO$_2$e). Likewise, considering only the battery is replaced during the repair, the final carbon footprint of the refurbished iPhone becomes ***22.67 kgCO$_2$e*** (17.10 kgCO$_2$e – 1.92 kgCO$_2$e + 7.49 kgCO$_2$e = 22.67 kgCO$_2$e). Assuming both display and battery are replaced during the repair, the final carbon footprint of the refurbished iPhone becomes ***25.79 kgCO$_2$e*** (17.10 kgCO$_2$e – 1.92 kgCO$_2$e + 7.49 kgCO$_2$e+3.12 kgCO$_2$e = 25.79 kgCO$_2$e). Finally, some of the phones do not need any repair as they are in perfect condition. Selling the phones without any repair, the final carbon footprint of the iPhone comes down to ***14.49 kgCO$_2$e*** (17.10 kgCO$_2$e – 1.92 kgCO$_2$e - 0.59 kgCO$_2$e = 14.49 kgCO$_2$e). All these effects due to components used are presented in Figure 15.

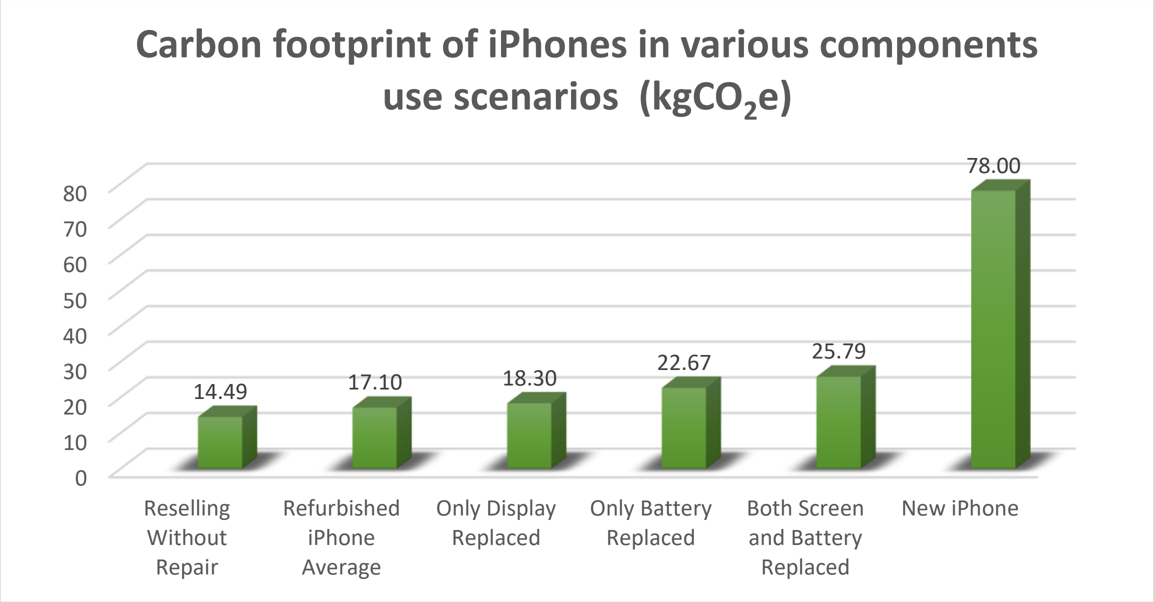


Figure 15. Effect of components used on the carbon footprint of refurbished iPhones.

These variations will also have a significant impact on the overall carbon footprint of the company as well. The spare parts required for the refurbishment determine the number of spare parts purchased and delivered to the company. As seen in the results, spare parts production has the most significant impact on the carbon footprint of the company. The number of spare parts used, and the type of components used (see Figure 9) will have a significant impact on the overall carbon footprint of the company.

6 CONCLUSION AND DISCUSSION

The purpose of this thesis study was to discover the sources of GHG emissions in the company, quantify its carbon footprint and carbon handprint of its products (refurbished iPhones). As this footprint study was the first of its kind in the company, the results will be utilized as the baseline for future sustainability reporting and to identify the hotspots for the emission mitigation opportunities. The results will help to set targets and goals for the future carbon reduction and carbon offset possibilities. There are three steps in achieving the carbon reduction and carbon offset. The first step is to quantify the carbon footprint, which has been the main purpose of this study. The second step is to analyse the results and explore potential reduction opportunities inside the company, which can be achieved by reducing consumption, switching to renewable energy, and supply chain optimization. The last step is to offset the emissions, which can also encourage management to consider the environmental impact of the company's activities as the offsetting price is proportional to their carbon emissions.

Three research questions were proposed during the introduction phase of this report to achieve the set objectives of this thesis work. Those research questions are responded in the following paragraphs.

- *What is the carbon footprint of the company?*

The carbon footprint of the company's activities during the assessment period (2020) is 1,272 tCO_2e as per the set system boundary, assumptions, and inventory analysis. This amount is equivalent to the electricity used by 231 homes for 1 year, or 277 cars driven for

1 year, or the carbon sequestered by 21,033 tree seedlings grown for 10 years (EPA 2021). The footprint result is not absolute as various assumptions and estimations were made resulting in potential uncertainties. To provide a clearer picture, the annual carbon footprint of an average Finn is 10.30 tCO_2e (Sitra 2018). The carbon footprint of the whole company's activities in 2020 is equivalent to the annual carbon footprint of approximately 123 Finns.

- *What is the major contributor to the GHG emissions in the company?*

In 2020, spare parts production and transportation activities (respectively) were the major contributors to the GHG emissions in the company. Spare parts production contributed 47% of total emissions, whereas transportation activities were responsible for almost 38% of total emissions especially due to aviation transportation. Together, spare parts production and transportation activities contributed to 85% of total greenhouse gas emissions in the company in 2020. It is worth noting that the company does not have any *scope 1* emissions and a very small footprint (6.9% of total emissions) for the *scope 2* emissions. About 93% of total greenhouse gases emitted is *scope 3,* which occurs from sources that are not owned or controlled by the company and are usually related to suppliers and third parties.

According to GHG Protocol, *scope 3* reporting is optional, and companies might only focus on accounting for and reporting those activities that are relevant to their business, goals, and which they have reliable information. Usually, *scope 3* emissions are not comparative across the companies as companies have the discretion to choose the categories to report. However, understanding the role of *scope 3* emissions is important for the company because most emissions are related to the processes.

- *What is the carbon handprint of refurbished iPhones?*

The carbon handprint of average refurbished iPhones was around 61 $kgCO_2e$. In 2020, they company's customers were able to reduce the GHG emissions by a total of approximately ***19,000 tonnes*** just by switching to the refurbished phones instead of buying a similar new model. This amount of carbon is equivalent to the electricity used by 3,451 homes for 1 year, or 4,132 cars driven for 1 year, or the carbon sequestered by 314,169 tree seedlings grown for 10 years (EPA 2021). Similarly, taking the average footprint of 10.30 tCO_2e/Finn, in

2020, they company’s customers were able to reduce the GHG emissions equivalent to the annual carbon footprint of 1,845 Finns. Refurbishment and carbon handprint is possible if a user sells the extra phone (which is usually forgotten in the drawer) for refurbishment. The phone will get a new life and manufacturing emissions of the new phone will be eliminated as the phone is sold back to another user. Therefore, selling the extra phones for refurbishment and/or buying refurbished phones will reduce the need of manufacturing new phones globally reducing GHG emissions.

The carbon handprint of the company’s refurbished phones seems to be significantly higher than the carbon footprint of the company. It can be concluded that the company has an overall net positive impact on the environment. Quantifying the impact: The company was able to save approximately 17,728 tonnes of greenhouse gas from releasing into the atmosphere in 2020, which is equivalent to the electricity used by 3,220 homes for 1 year, or 3,855 cars driven for 1 year, the carbon sequestered by 293,136 tree seedlings grown for 10 years (EPA 2021), or the annual carbon footprint of 1,721 Finns.

Limitations and Future Research

The carbon footprint and handprint calculation processes required several assumptions and estimations regarding data collection choices, system modelling, and determining the system boundary of the study. The assessment of the results is influenced by the choices considered in various stages which can impact the final output of this report. The assumptions used during the different stages of the studies are clearly described and reported to make the report as transparent as possible. This report was heavily dependent on the materials and data collected from various literary sources and databases (such as *Technical Research Centre of Finland (VTT), Helsinki Region Environmental Service (HSY), Helsinki Region Transport Authority (HSL),* Energy Providers (*Helen and Fortum*), *WWF Climate Calculator*). It was equally dependent on multiple individuals from several departments for the internal data collection mainly because of the COVID 19 pandemic (social distancing) restrictions. Both internal data collection and literary sources and databases were assumed to be reliable. Since most of the properties were in the shared office space and some had a shared energy metering system, average energy units were allocated especially for heat consumption. This might affect the accuracy of the results. For future research, the use of separate energy meters is recommended to get more precise data.

The production emission of the spare parts, office supplies, and outbound packaging supplies was collected from various literary sources and required some estimations and assumptions as no first-hand data was available. For example, in the case of spare parts production emissions, some minor spare parts with less significant volume, weight, and percentage of total parts used during the refurbishment processes (compared to major parts such as batteries, displays, frames, and back glasses) were categorized together and allocated average emissions. For future research, it is recommended to get first-hand data (if possible) from the suppliers or producers and allocate individual emissions to each of the separate parts to get accurate data. As of now, most of the company’s suppliers do not monitor their environmental footprint and precise technical information about the products. Same with the emission factors of the delivery partners, it would be convenient and more accurate to obtain the transportation emission data from the delivery company instead of using average emissions.

Furthermore, this study was performed during the COVID-19 pandemic, which has altered the working and commuting patterns of the employees due to travel restrictions and health concerns. Remote working was encouraged when possible, eliminating the need for commuting and some employees have shifted their commute from public services to private means of transportation. The commuting data were collected with the help of an internet survey and were dependent upon the designed questionnaires. The data is reliant on the comprehensibility of the questions, the truthfulness of the respondent, and the total number of responses received. Nevertheless, a higher response rate would have produced more accurate data.

Even though the supplied phones were considered as waste, not all the phones are used equally before discarding them. It would be ideal to allocate emissions proportionate to the phone use duration, instead of categorizing all the used phones simply as waste, regardless of EU directives definitions. Also, the true social, environmental, and economic impact of phones received from suppliers (which are already on the way to being rescued) and the phone recycled directly from the customer might be different. These factors could be considered in future studies.

It was challenging to collect information for the phones, spare parts, accessories, and other life cycle aspects and supply chain. All the information used in this report was presented with a transparent description of the available information and assumptions made with the critical analysis of the results, consulting with university supervisors and field experts from the company. Better collaboration between the partner companies, suppliers, manufacturers, different departments, and other various service providers would deliver more relevant and accurate information.

7 SUMMARY

In this report, the carbon footprint of the company and the carbon handprint of the refurbished iPhone is calculated. The carbon footprint was calculated using LCA methodology and GHG Protocol, whereas carbon handprint was calculated using the *Carbon Handprint Guide* developed by VTT Technical Research Centre of Finland and LUT University. Primary data were collected whenever possible for upstream and downstream logistical operations, electricity consumption, waste collection, and office supplies. Some secondary sources of data from literature and databases were also used to estimate unavailable data. A companywide survey was conducted for the estimation of transport distances, commuting habits, and means of transport used for commuting. Literary sources were also used for determining the emission factors, as no LCA software was used for this study. It is worth mentioning that the GHG calculation process involved various assumptions and estimates which could influence the results.

The carbon footprint of the company for the studied year (2020) was 1,270 tCO_2e, in which spare parts production and transportation activities were major contributors to greenhouse gas emission respectively. The spare parts production was responsible for 47% of total GHG emissions and transportation activities were responsible for 36% of the total GHG emissions. Together both spare parts production and transportation activities contributed to approximately 83% of total GHG emissions. Hence, the bulk of emission reduction opportunity lies in spare parts production and transportation activities. Correspondingly, the carbon handprint of the average refurbished iPhone was around 61 $kgCO_2e$, which indicates that just by switching to the refurbished iPhones instead of buying a similar new model, the company's customers were able to reduce their GHG emissions by a total of approximately 19,000 tonnes. It also indicates that the company had an overall negative carbon footprint of approximately 17,730 tonnes in 2020, indicating a significant net positive impact on the environment.

The carbon footprint data from this report is not comparable to any previous work as a similar study has not been performed previously. This carbon footprint data will be utilized as the baseline for future sustainability reporting and to identify the hotspots for the emission reduction possibilities.

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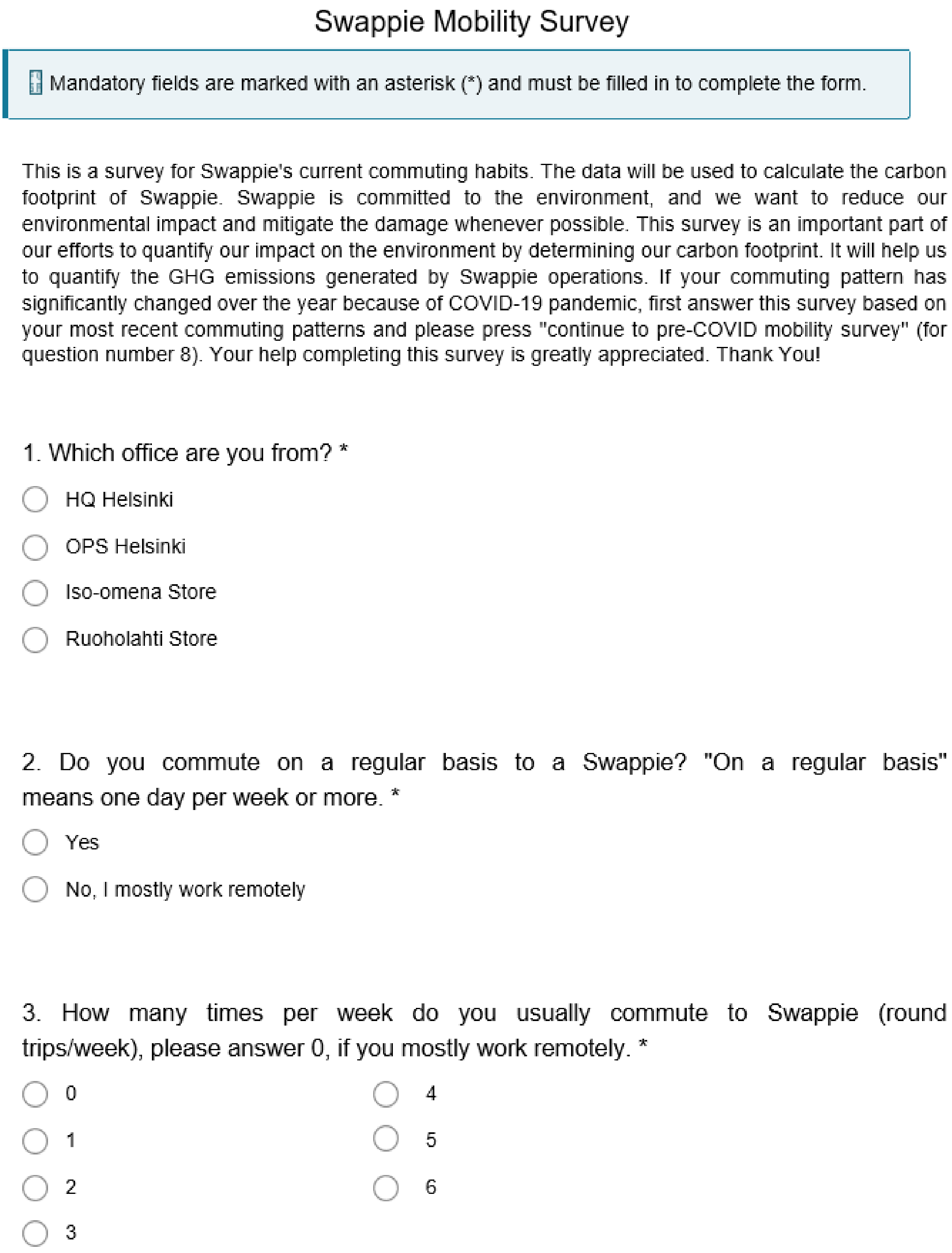
APPENDIX 1: Survey Questions



Swappie Mobility Survey

Mandatory fields are marked with an asterisk (*) and must be filled in to complete the form.

This is a survey for Swappie's current commuting habits. The data will be used to calculate the carbon footprint of Swappie. Swappie is committed to the environment, and we want to reduce our environmental impact and mitigate the damage whenever possible. This survey is an important part of our efforts to quantify our impact on the environment by determining our carbon footprint. It will help us to quantify the GHG emissions generated by Swappie operations. If your commuting pattern has significantly changed over the year because of COVID-19 pandemic, first answer this survey based on your most recent commuting patterns and please press "continue to pre-COVID mobility survey" (for question number 8). Your help completing this survey is greatly appreciated. Thank You!

1. Which office are you from? *

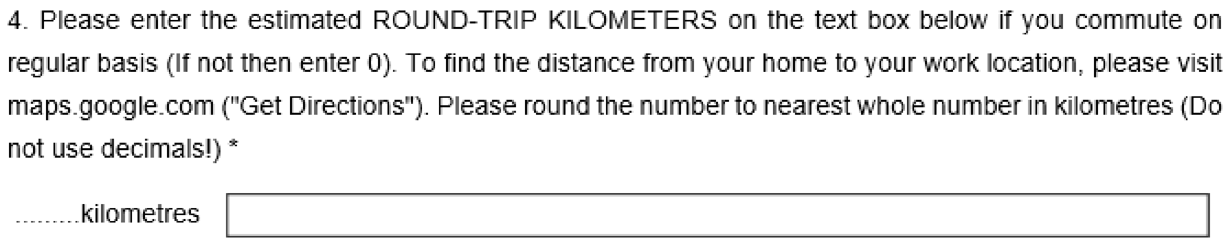
○ HQ Helsinki
○ OPS Helsinki
○ Iso-omena Store
○ Ruoholahti Store

2. Do you commute on a regular basis to a Swappie? "On a regular basis" means one day per week or more. *

○ Yes
○ No, I mostly work remotely

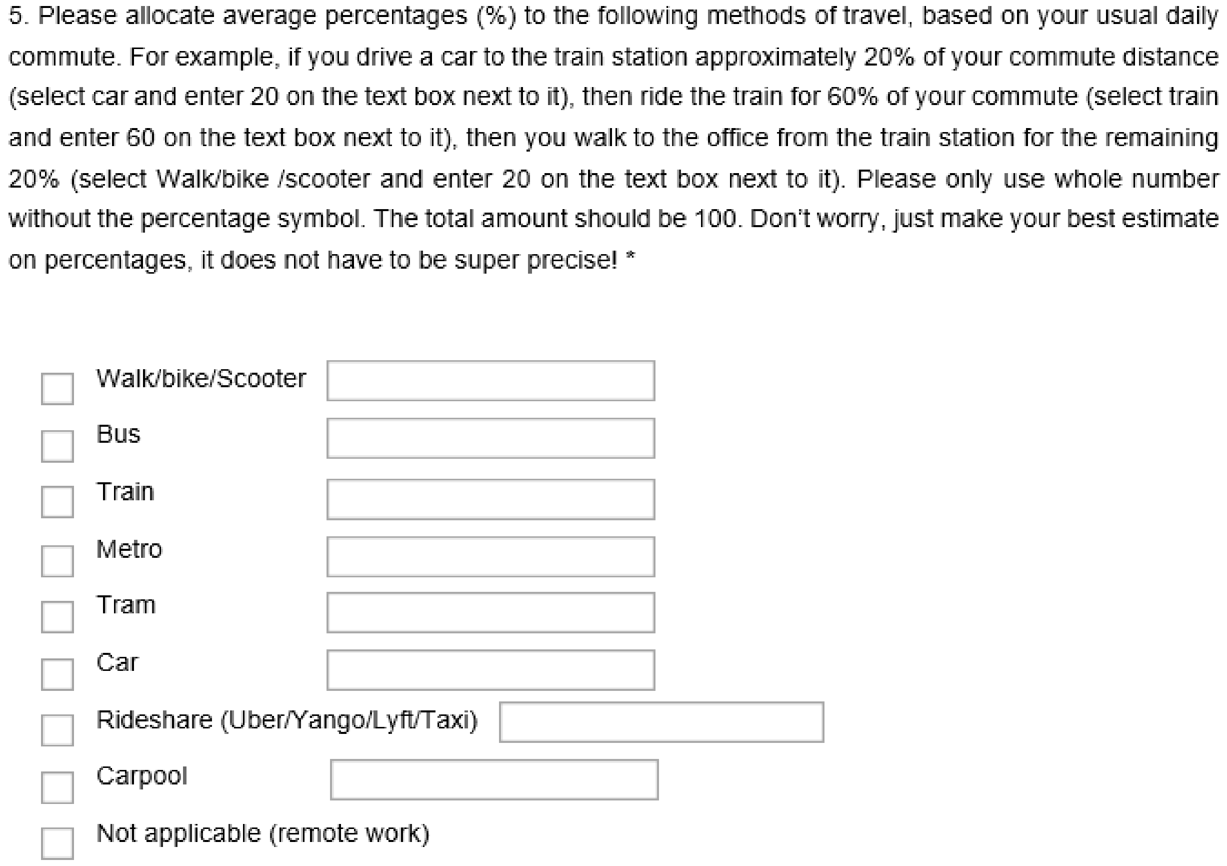
3. How many times per week do you usually commute to Swappie (round trips/week), please answer 0, if you mostly work remotely. *

○ 0
○ 1
○ 2
○ 3
○ 4
○ 5
○ 6



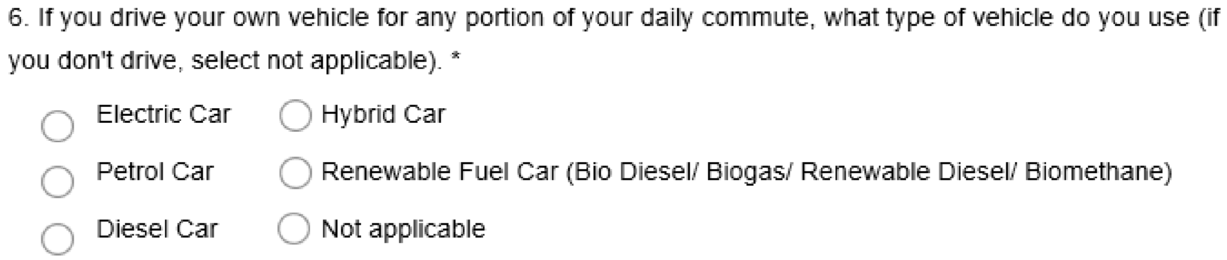
4. Please enter the estimated ROUND-TRIP KILOMETERS on the text box below if you commute on regular basis (If not then enter 0). To find the distance from your home to your work location, please visit maps.google.com ("Get Directions"). Please round the number to nearest whole number in kilometres (Do not use decimals!) *

.........kilometres



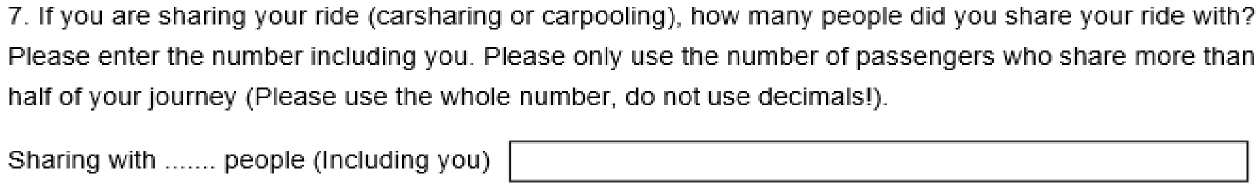
5. Please allocate average percentages (%) to the following methods of travel, based on your usual daily commute. For example, if you drive a car to the train station approximately 20% of your commute distance (select car and enter 20 on the text box next to it), then ride the train for 60% of your commute (select train and enter 60 on the text box next to it), then you walk to the office from the train station for the remaining 20% (select Walk/bike /scooter and enter 20 on the text box next to it). Please only use whole number without the percentage symbol. The total amount should be 100. Don't worry, just make your best estimate on percentages, it does not have to be super precise! *

☐ Walk/bike/Scooter
☐ Bus
☐ Train
☐ Metro
☐ Tram
☐ Car
☐ Rideshare (Uber/Yango/Lyft/Taxi)
☐ Carpool
☐ Not applicable (remote work)



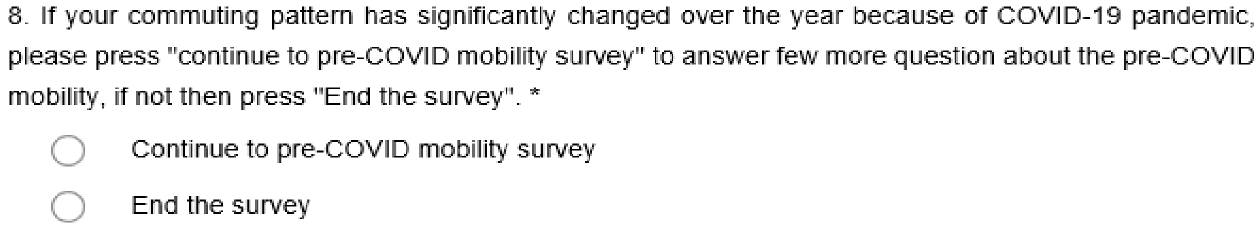
6. If you drive your own vehicle for any portion of your daily commute, what type of vehicle do you use (if you don't drive, select not applicable). *

○ Electric Car ○ Hybrid Car
○ Petrol Car ○ Renewable Fuel Car (Bio Diesel/ Biogas/ Renewable Diesel/ Biomethane)
○ Diesel Car ○ Not applicable



7. If you are sharing your ride (carsharing or carpooling), how many people did you share your ride with? Please enter the number including you. Please only use the number of passengers who share more than half of your journey (Please use the whole number, do not use decimals!).

Sharing with .... people (Including you) ☐



8. If your commuting pattern has significantly changed over the year because of COVID-19 pandemic, please press "continue to pre-COVID mobility survey" to answer few more question about the pre-COVID mobility, if not then press "End the survey". *

○ Continue to pre-COVID mobility survey

○ End the survey

**Note: The pre-COVID mobility survey had identical questions which were to be filled by the respondents whose commuting pattern was significantly changed over the year because of the COVID-19 pandemic. It was challenging to allocate the impact between the effect due to the COVID-19 pandemic and the effect due to the relocation of the office. Hence, only the current commuting patterns were considered for this study, and the effect of the COVID-19 pandemic and relocation was excluded from the scope of this study.*