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The impact of multi-location work on reaching carbon neutrality objectives: The carbon footprint of ICT equipment use at the University of Oulu

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ABSTRACT

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This thesis project aimed to quantify the impact of multi-location work on the carbon footprint of the University of Oulu by conducting a survey and monitoring the electricity consumption of ICT equipment. The work presents the concept of carbon neutrality, the Greenhouse Gas Protocol quantifying carbon emissions. In addition, global decarbonization commitments and the pledges of higher education sector are introduced. Furthermore, a benchmarking of decarbonization actions of higher education institutes was done, reviewing 29 case studies. The scopes of emissions considered in their carbon footprint were reviewed, as well as their chosen mitigation methods.

The effect of multi-location work on Higher Education Institutions and especially its impacts on the use of Information and Communication Technologies (ICT) are presented. The carbon footprint of ICT equipment, the internet, and their calculation methods are also illustrated. In addition, a survey was conducted among the staff of the University of Oulu, to collect data about the various types of ICT equipment that staff use on-campus, in their home office, and those being carried in-between these two workplaces. The survey also uncovered information about the staff's ICT equipment usage habits. In addition, electricity consumption monitoring of laptops and monitors was done to increase the accuracy of the carbon footprint calculation.

The results achieved from electricity consumption monitoring of ICT equipment demonstrate that the electricity consumption of laptops during meeting hours is approximately 2.5 times higher than the electricity consumption during regular work. Further, when leaving the laptop on and not using it, it could consume almost as much as using it on a regular basis. On the other hand, putting the laptop in sleep mode consumes only 17% electricity compared with when it is left on and not used. Furthermore, it was also found out that the laptop would consume up to 65% more when the VPN is on. The staff survey also revealed that, on average, staff would prefer working three days from home per week. This would indicate a 36% increase of the carbon footprint of the ICT equipment.

It is expected that the results of this work will help raising awareness and change habits regarding ICT equipment usage, in order to contribute to the carbon mitigation goals of the University of Oulu.

Keywords: Carbon neutrality, Carbon footprint, Multi-location work, ICT equipment, Electricity consumption

FOREWORD

This master's thesis was done as part of the University of Oulu Carbon Footprint Working Group. The aim of the group is calculation of the university's carbon footprint and prepare a roadmap for the university to reach carbon neutrality. The goal of this work was to calculate the carbon footprint of ICT equipment and internet use, and to map the staff's usage habits. The other goal was to calculate the effect of multi-location work on the carbon footprint. The working period for the thesis was from December 2021 until May 2022, supervised by Prof. Eva Pongrácz & MSc. Julia Kiehle.

This endeavor would not have been possible without my two supervisors' help and support. Thanks should also go to people who helped me measure data, which is part of this thesis project.

I could not have undertaken this journey without my family, whose belief in me has kept my spirits and motivation high during this process.

Oulu, 26.05.2022

Mohammad Amin Javid

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CF	Carbon Footprint
CFWG	Carbon Footprint Working Group
CO_2e	Carbon Dioxide Equivalent
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
HEI	Higher Educational Institution
ICT	Information and Communication Technology
IEA	International Energy Agency
ISO	International Standardization Organization
LED	Light-emitting Diode
PV	Photovoltaic
SDG	Sustainable Development Goal
SIC	Standard Industrial Classification
WRI	World Resources Institute

1 INTRODUCTION

In the past decades, the effects of climate change has been obvious. Melting ice caps and Arctic Sea ice, rising sea levels, and increasing global temperature are only a number of consequences of this matter. Due to this fact, carbon neutrality is crucial to achieve, to prevent more negative effects on earth. Several commitments between countries have been made to decrease greenhouse gas production and facilitate reaching carbon neutrality. One of the most well-known commitments is the Paris Agreement which was adopted by 192 countries plus the European Union in 2015. Specific actions taken by the committed countries will keep global warming at 2 degrees Celsius by the end of the century compared to the pre-industrial era. It is anticipated that neglecting this issue will cause global warming to increase by 3.9 degrees Celsius by the end of the century (United Nations, 2015a). Alongside this commitment, EU countries are pledged to decreasing their carbon footprint by at least 55% by 2030. For these countries, the next achievement will be reaching carbon neutrality by 2050 (EU Commission, 2021).

Achieving carbon neutrality is the goal of Finnish universities, which is planned be achieved by 2030 (UNIFI, 2021a). Moreover, the University of Oulu has targeted to halve its carbon footprint by 2025 compared to the 2019 level (University of Oulu, 2021). Some higher educational institutions around the globe have started calculating their carbon footprints to identify the sectors responsible for emission production. In this thesis project, a number of studies are investigated, and their mitigation methods based on the scopes of emissions, as presented by WRI & WBCSD (2001) are identified and categorized.

Due to the pandemic in 2020, the vast majority of staff were obliged to work from home to prevent COVID-19 spread. When the situation got better, the university's staff started to return to campus, but opted to continue working some days from home. This multi-location mode and having two workplaces resulted in requiring more equipment, especially ICT equipment, to keep the quality of work in both places the same. Increasing the number of ICT equipment clearly increases the university's carbon footprint and could damage the efforts that were made to move towards carbon neutrality. The objective of this thesis project was to calculate the carbon footprint of ICT equipment and internet used by the staff, and to measure the effect of multi-location work mode due to the pandemic. In relation to that, the following research questions will be answered:

- How much greenhouse gas emissions are produced due to the usage of ICT equiment and internet based on the habits of the university's staff?
- How much higher is the carbon footprint because of multi-location work mode?

It is hypothesized that multi-location working increases the carbon footprint of the university. As an experimental part of this thesis project, a survey is conducted to demonstrate a better overview of the type and the number of ICT equipment used by staff at the University of Oulu. Other than that, staff's habits regarding the usage of ICT equipment are investigated. The aim was to determine whether employees leave their equipment on, put it on sleep mode, or turn it off when they finish work for the day. It is suspected that the decision made by the employees affects the size of the carbon footprint.

Since the carbon footprint reports provided by the manufacturers of the ICT equipment are not specifically conducted for Finland, it is crucial to recalculate the usage phase based on Finland's electricity emission factor and the habits of the University of Oulu's staff. Therefore, in the experimental part of this thesis, the electricity consumption of laptops and monitors in various usage modes is also investigated. The aim is to find out how much electricity the laptop consumes when it is left on, and what is the impact of intense internet use, such as virtual meetings on the electricity consumption.

Furthermore, the effect of multi-location working on the carbon footprint of the University of Oulu is assessed. Finally, suggestions are to be made about the carbon footprint mitigation methods based on the staff's habits regarding ICT equipment usage.

THEORY PART

2 CARBON NEUTRALITY

“Carbon neutrality” is defined by IPCC (2018) as having a balance between the amount of produced and absorbed carbon dioxide in systems with certain boundaries. This approach is made to ease fighting climate change and global warming, which have caused so many problems around the world. This term is not specifically defined for a certain sector and could be applied to every section, including industry, education, transportation, etc. Carbon reduction plans have to be implemented to balance emission production and absorption. In the following, the decarbonization goals and commitments that countries have made are demonstrated and explained in more detail.

2.1 Decarbonization goals

Decarbonization is defined as actions to reduce carbon dioxide produced due to human activities. The main goal is to eliminate carbon dioxide emissions, and to reach that, switching to clean and renewable energy sources is crucial. (Virta Global, 2021)

Decarbonization is the solution to overcome global warming and climate change. In addition, it is no longer permissible to waste time. The damages are already obvious, and the consequences of previous negligence must be compensated. Hence, some commitments and pledges between countries are made to control these phenomena. Some of the commitments are mentioned in the following:

2.1.1 Paris Agreement

The Paris Agreement is one of the most well-known commitments regarding climate change and was adopted by 192 countries plus the European Union (EU) in 2015. The main goal is to keep global warming below 2, preferably 1.5 degrees Celsius, by the end of the century, compared to the pre-industrial era. It is anticipated that by neglecting this urgency, the temperature could rise by 3.9 degrees Celsius by 2100 (United Nations, 2015a). In the meantime, EU countries have committed to cut greenhouse gas emissions by at least 55% by 2030 and move towards carbon neutrality by 2050 (EU Commission, 2021).

The Paris Agreement works on a 5-year cycle of climate actions done by all countries. After each cycle, countries are supposed to report their progress and submit their new plans which are known as Nationally Determined Contributions (NDCs). In NDCs, countries share their information and achievements in reaching the goals of the Paris Agreement. Also, it is essential that countries get prepared for the impacts of rising temperatures. To have a better vision of the future, it is recommended that all countries have their long-term strategies. It was not mandatory, but members were supposed to submit their plans by 2020. This approach is called Long-Term Low Greenhouse Gas Emission Development Strategies (LT-LEDS). (United Nations, 2015a)

Technology plays a vital role in achieving this goal as well. By going towards carbon neutrality, countries need plans to substitute fossil fuels with renewable energies and improve their technological perspective to increase efficiency and decrease energy consumption in all sectors. Cooperation is a key factor in reaching the goals of the Paris Agreement as soon as possible. In addition, it is crucial to consider that all countries in the world should follow the pledge to gain the best results. However, most developing countries do not have sufficient funds and capacities. To deal with this issue, the Paris Agreement emphasizes climate-related capacity-building for developing countries to be done by developed countries to accelerate their actions. (United Nations, 2015a)

According to the Paris Agreement, countries have established an Enhanced Transparency Framework (ETF). Considering this clause, countries report their improvements and achievements in 2024. The report will be assessed, and recommendations for better plans will be given. So far, many sectors like energy and transportation in developed countries are planned to become carbon neutral in the near future. Since starting the Paris Agreement, companies have been more competitive in finding low-carbon solutions for their markets. This process has created many new business opportunities in various markets. (United Nations, 2015a)

2.1.2 Kyoto Protocol

The Kyoto Protocol is another important commitment to prevent climate change. This protocol was adopted in 1997 by 192 different countries as a pledge to reduce their greenhouse gas emissions. According to this commitment, the signed parties had to decrease their emission production by an average of 5 percent from 2008 to 2012 compared to the 1990 emission level. The second commitment period was defined between 2013 to 2020 when countries committed to mitigating their emission production by at least 18 percent compared to the 1990 emission level. However, the Kyoto Protocol was not forcing parties to reduce their emissions in certain sectors. In fact, countries could choose the most cost-effective sectors to start. In that case, reaching the targets become more achievable for developing countries. In addition, an adaptation fund with low interest was set for developing countries to be able to keep up with the protocol and reach the target. Furthermore, not only did the annual reporting help improving the monitoring, but it also provided the opportunity for parties to share their information and data to find the most effective solutions. (UNFCC, 2022)

According to article 10 of the protocol's manual, parties must cooperate and correlate to gain the best outcome in the areas mentioned in the following (United Nations, 2008):

- Parties are committed to helping each other to improve environmentally friendly technologies
- Raising public awareness and educating people regarding the climate change phenomenon and its consequences
- Studying and monitoring the climate system and its changes
- Upgrading greenhouse gas inventories and revising methodologies if necessary to have more accurate results

2.1.3 Sustainable development goals

The Sustainable Development Goals (SDGs) were adopted by United Nations (2015) in 17 different clauses to investigate how to end hunger, poverty, discrimination, etc., alongside reducing the carbon footprint by 2030 (Figure 1).

Figure 1. Sustainable development goals (United Nations, 2015).

Among all SDGs, the SDG 7 “affordable and clean energy” plays a vital role in reducing carbon emissions. The objectives of SDG 7 are to provide affordable, reliable, and renewable energy mix parallel to clean fuels by 2030. This target eases the path towards the carbon footprint mitigation approach around the world. It is also demonstrated in more detail in the following target (United Nations, 2015b):

1.1. Affordable and reliable types of energy will be available globally by 2030.
1.2. The fraction of renewable energy available in the energy mix will increase considerably by 2030.
1.3. The development of global energy efficiency will be doubled by 2030.

7.a Improve cooperation between countries to ease access to clean fuel, renewable energy, and implement infrastructures to increase efficiency by 2030.

7.b Improve access to sustainable energy services for least developed and developing countries by 2030.

In addition, SDG 11 is to ensure “Sustainable cities and communities” where the countries are obliged to decrease per capita environmental impacts regarding air quality and waste management (target 11.6). Furthermore, according to SDG 12 “responsible consumption and production" goal (number 12), chemicals and wastes and their release into water, air, and soil are more controlled.

One of the most effective sustainable development goals for carbon footprint reduction is established in SDG 13 "climate action" goal (number 13), which promotes climate change mitigation and adoption strategies and planning. In addition, developed countries are responsible to mobilize funding to aid less developed and developing countries in their carbon reduction efforts. Finally, SDGs 14 (Life below water) and 15 (Life on land) are also partially contributing to carbon footprint reduction.

2.2 Carbon neutrality commitments of Finnish universities

In previous decades and due to climate change, countries all over the world, especially developed countries, have tried to implement infrastructures to reduce global warming. In relation to that, making commitments between countries, organizations, or even educational institutions is an efficient way to stay on track. In addition to the well-known Paris Agreement, Finland has its own commitment to carbon reduction between its various sectors. This approach applies to Finland's universities as well. To reach this goal, working groups like UNIFI and FinnARMA were created to facilitate this path.

Finnish universities have their own commitment to carbon neutrality. According to this commitment undertaken by the University of Oulu as well, is to halve the carbon footprint by 2025 compared to the 2019 levels (University of Oulu, 2021), and becoming carbon neutral by 2030 (UNIFIb, 2021).

2.2.1 FinnARMA

This group is created of more than 500 research management experts from higher education institutions and research institutes located in Finland. The main goal is to increase cooperation and exchange information not only about carbon neutrality, but also on other subjects. The executive committee consists of representatives from Finnish universities and is responsible for managing the activities and information. University of Oulu's representative is involved in the group as a substitute member. (FinnARMA, 2021)

2.2.2 UNIFI

UNIFI is a group of 13 Finnish universities which was formed to enhance the information exchange and cooperation between its members. Due to the fact that universities play a vital role in the country's development, constant communication and cooperation are crucial for the best possible outcome. One of the main activities done by this group is the 12 theses published to create a framework for the universities on their path towards sustainability. The theses are divided into five main categories. Theses and their categorization are demonstrated as follows: (UNIFI, 2021a)

Sustainable research

1. Research is done to overcome sustainability problems
2. It is tried to reach sustainability in funding and investigation of the projects
3. Higher educational institutions use various disciplines to have a comprehensive overview of sustainability obstacles

Increase awareness regarding sustainability

4. All disciplines have sustainable development as part of the studies
5. Higher educational institutions provide an environment for safe learning and teaching

Universities' actions affect making a sustainable world

6. Universities' actions are done the way to ease reaching sustainable goals
7. Universities move towards carbon neutrality goals alongside considering biodiversity as a crucial factor
8. Universities improve fairness, equal opportunities, and well-being

University's societal role in making changes

9. Universities cooperate to affect national and global levels
10. Universities share the information and cooperate to reach the best possible outcome

Reaching sustainable development requires cooperation

11. Higher educational institutions allocate more budgets to reach sustainability
12. Sustainable development plans could be observed at the national and university levels

Regarding the ones that are more related to this thesis project, thesis number six explains the university's campus activities and their relations with the sustainable development goals. A number of measures are suggested to be taken by management, staff, students, and even the student union to reach the goals. (UNIFIb, 2021)

Thesis number seven which is called "Carbon neutral economy to advance biodiversity," is one of the main theses to investigate. It suggests campus activities to be followed by the Universities to move toward a carbon-neutral circular economy and to foster biodiversity. The objectives set by the government mandate the various sectors of the country to take action to achieve carbon neutrality by 2035. This target for higher education institutes is set for 2030. Becoming carbon-negative would be the next target (Finnish Government, 2021). The tasks taken by the organizations and universities could have a considerable effect on biodiversity as well. In that case, UNIFI has suggested measures as the following (UNIFIb, 2021):

- The universities must cooperate and share their findings in this matter. It is reported that some universities are moving faster towards carbon neutrality and have set 2025 as their goal.
- Universities are responsible for carbon emission reduction, and it is recommended to set their objectives. Although emission compensation could be considered a solution, it is not considered a priority.
- Biodiversity must not be forgotten. Universities should provide a survey to better understand students' and staff's lifestyles and habits on the campus. Some activities could harm biodiversity and nature.
- Due to the fact that procurement accounts for a considerable proportion of carbon emissions, smart procurement is a solution for moving towards carbon neutrality. Shared use and reasonable consumption are encouraged to reduce emissions.
- It is recommended to develop innovative solutions for a more sustainable future. Enhancing the utilization of the sectors that the university controls, like the campus restaurants, and diminishing the commuting emission by investing in sustainable travel are the examples that could be applied at the universities.

3 CARBON FOOTPRINT OF UNIVERSITIES

Due to climate change and global warming, the calculation of carbon footprint (CF) has become widely used to give a better understandable overview of the impacts caused by services or products during their lifetime. As the climate change situation has worsened, this concept has been taken more seriously by the public, governments, institutions, and companies.

3.1 Carbon footprint definition

The term “footprint” was developed by researchers at the University of British Columbia in 1996. At first, “ecological footprint” was defined as an approach to calculate the produced wastes and consumed resources of the human population by considering a certain land area. The term “carbon footprint” first originated and then evolved from the aforementioned “ecological footprint” term. In general, the “carbon footprint” is defined as the total amount of carbon dioxide and other greenhouse gases emitted over the lifetime of services and products. (Wiedmann & Minx, 2007) The measurement starts by calculating the emissions from material extraction and ends with the last stage of the materials, which could be recycling or waste management. The carbon footprint is expressed as total grams of Carbon Dioxide Equivalent (CO_2e) produced in the process. Compared to the ecological footprint, the carbon footprint focuses more on the consequences of human activities (East, 2008).

3.2 Greenhouse Gas Protocol and Scopes

The Greenhouse Gas Protocol is a well-known approach for quantifying the carbon emissions related to private and public sectors. This method was mainly created by the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD), two non-governmental organizations (NGOs), and in cooperation with other NGOs and firms. This cooperation resulted in the *Greenhouse Gas Protocol Corporate Accounting and Reporting Standard,* which has been extensively used in recent years regarding carbon footprint calculation (Green, 2010).

This method gives a better understanding of all the involved sections responsible for various carbon production. To make the measuring easier, the protocol is divided into three main scopes (WRI & WBCSD, 2001):

- Scope one: The produced emissions related to the assets operated or owned by the company or organization.
- Scope two: The produced emission related to the purchased electricity or other types of energy by a company or organization.
- Scope three: The produced emission is related to all other sectors except the ones mentioned in the first two scopes.

Figure 2 illustrates all the involved elements based on the scope in more detail.

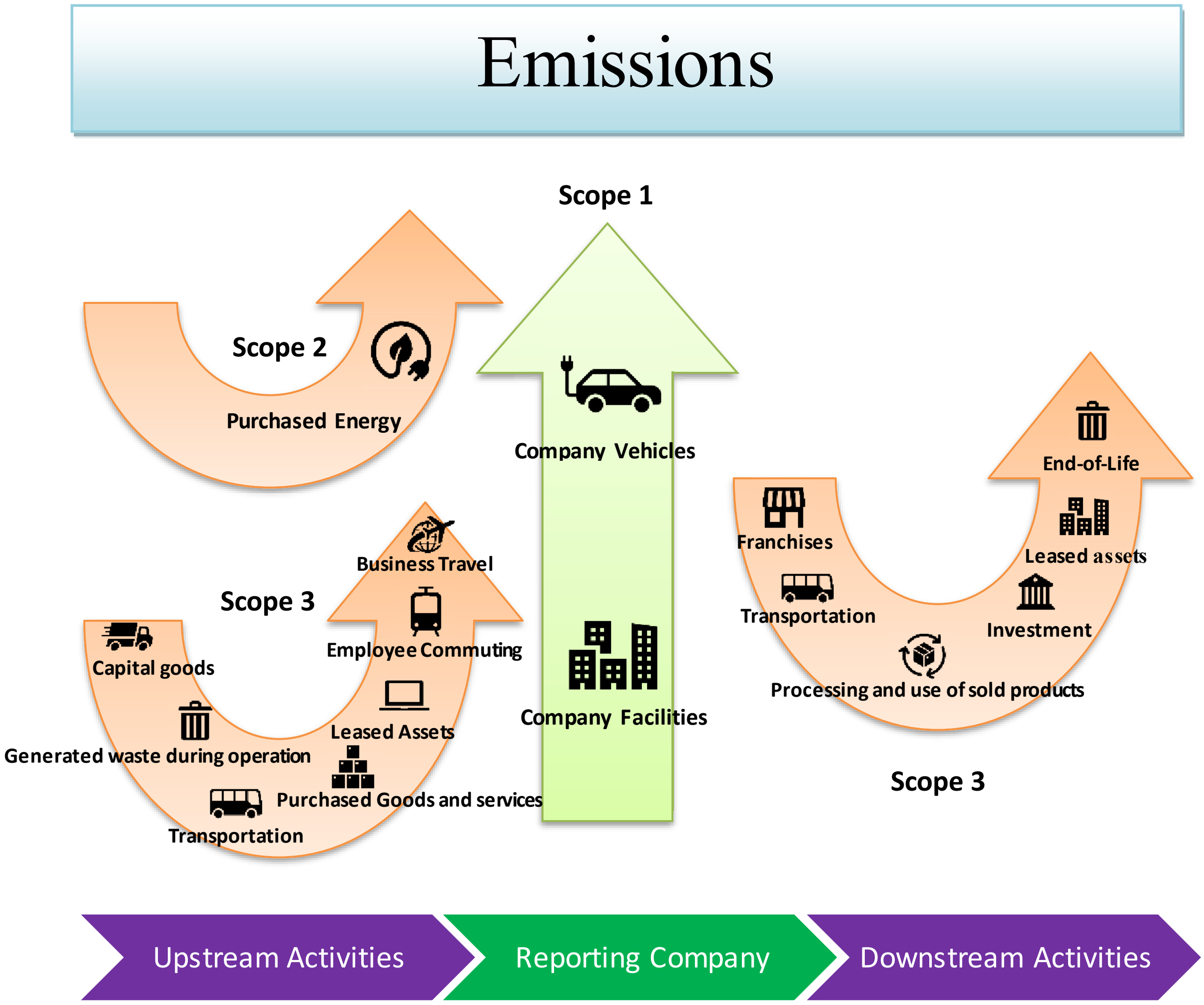

Figure 2. Greenhouse Gas Scopes (based on WRI & WBCSD, 2001).

Other than determining scopes for easier identification of emission sources in the process, the Greenhouse Gas Protocol provides a framework to help deciding which emissions to include and exclude (known as boundaries) in the measurement process. Furthermore, the protocol specifies standards, guidelines, and calculation tools as the three main criteria of the approach. The guidelines set frameworks and rules on a general basis, for the ways of collecting data, and the approaches for carbon footprint emission calculations. Finally, the protocol presents various types of calculation tools and instructions for measuring the carbon footprint for specific sectors. (Green, 2010)

3.3 Carbon footprint calculation

To achieve carbon reduction and ultimately carbon neutrality, the calculation should be applied to identify the involved sectors and their shares of the total carbon footprint production. In addition, this approach applies to all institutions and organizations and does not concern a specific sector.

The carbon footprint is defined as all the carbon emissions produced due to activities done at that specific organization or institution. The total production is calculated and reported in units of CO_2e to make it comparable with other sectors and organizations. Valls-Val and Bovea (2021) provide a formula for the carbon footprint calculation as demonstrated in Formula (1):

$$E_S = AD_S \times EF_S \tag{1}$$

Where E_S is defined as the greenhouse gas (GHG) emissions by a specific source and produced by the activities from that specific source (AD_S), considering its emission factor (EF_S). The emission factor provides the opportunity to convert the produced emissions by various activities into GHG emissions. After calculating the GHG emissions for all involved activities in the chosen boundary, total CF would be measured by adding up all CFs in units of carbon dioxide equivalent (CO_2e). (Valls-Val & Bovea, 2021)

In addition, if the GHG Protocol is used to measure the carbon footprint, the total CF would be calculated by adding all emission factors involved in the three GHG scopes as shown in Formula 2 (Gu et al., 2019):

$$CF_{Total} = CF_{Scope\ 1} + CF_{Scope\ 2} + CF_{Scope\ 3} \tag{2}$$

As East (2008) suggests, some rules should be followed in the process of carbon footprint calculation:

- The carbon footprint calculation has to be done for the emission sources that are directly controlled and owned by the intended unit. This unit could be considered as a country, an institution, a company, an organization, etc.
- All six greenhouse gases mentioned in the Kyoto Protocol should be considered to give more accurate results about the warming caused by GHG emissions.

The six main greenhouse gases covered by the Kyoto Protocol and their global warming potential (GWP) related to CO_2 are reported by the GHG Protocol (2016), which are shown in table 1:

Table 1. Kyoto Protocol's greenhouse gases and their global warming potential (GHG Protocol, 2016).

Gas	Global Warming Potential
Carbon Dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	265
Hydrofluorocarbons (HFCs)	4 to 12,400
Perfluorocarbons (PFCs)	6,630 to 11,100
Sulfur hexafluoride (SF_6)	23,500

3.4 Examples of carbon footprint assessments of universities

In recent years, higher education institutions have stepped forward to contribute to reduction of GHG emissions. In this regard, some universities started calculating their carbon footprint to act accordingly. However, contributing factors and their shares are not the same in all universities. Twenty-nine studies have been investigated to demonstrate a better understanding of the universities' approaches and the various scopes they chose to investigate.

3.4.1 North American Universities

Moerschbaecher and Day (2010) have measured the carbon footprint of Louisiana State University while considering emissions produced from the university's power plant, vehicles owned by the university, refrigerants, agriculture, and fertilizer as scope 1 of this research. Scope 2 includes produced and imported electricity utilized on campus. Last but not least, scope 3 covers air travels done by students and staff, waste management, commuting, electricity distribution losses, and wastewater treatment. Although paper and food are two main sources of emissions at the university, they were not considered in the Moerschbaecher's & Day's calculation.

Thurston and Eckelman (2011) have done the carbon footprint investigation for Yale University's procurement of goods and services. According to the used greenhouse gas method in this study, scope 1 accounts for power plant fuel, non-power plant fuel, and the university's vehicle fleet. Scope 2 contains electricity generation, and scope 3 includes staff and students' commuting and air travel. Fertilizer production, waste management, gas extraction, petroleum refineries, and coal mining factors are calculated based on the Economic Input-Output Life-Cycle Assessment (EIO-LCA) method and demonstrated as GWP stressors.

Stewart & Khare (2012) have not covered a wide range of emission sources in the study done regarding Athabasca University, Canada. The main contributors are categorized into "procurement procedures" and "paper and print waste" groups.

Mitigating the carbon footprint of higher educational institutions has been one of the main goals of some universities around the world in previous years. Texas universities joined this stream in 2015. The research was done by Bailey and LaPoint (2016) to calculate the carbon footprint of nine different universities located in Texas. This research has used the GHG protocol to categorize all emission sources into three scopes. In addition, due to uncertainties and a lack of data, scope 3 emissions are omitted from the comparative study. Transportation, refrigerants, and agriculture have formed scope 1. Scope 2 demonstrates the purchased electricity, and scope 3 accounts for commuting, air travel, solid waste, wastewater, and paper. In addition, emissions produced by university restaurants are not covered in this project.

Clabeaux et al. (2020) assessed the carbon footprint of Clemson's university campus using the lifecycle assessment approach. In this study, scope 1 includes steam generation, refrigerants, the university's own vehicles, fertilizer, and wastewater treatment. Scope 2 only consists of electricity generation. Scope 3 accounts for the largest number of categories. Electricity lifecycle, transmission and distribution losses, automotive commuting, Clemson area transit bus system, university-related travel, paper, natural gas leakage, refrigerants, waste and recycling transportation, wastewater treatment chemicals, and water treatment are all contributing factors in scope 3. Scope 1, 2 and 3 account for 19%, 41%, and 41%, respectively.

3.4.2 African Universities

According to Letete et al. (2011), in 2008, southern African universities started working groups called *Environmental Management Working Groups,* where implementing infrastructures regarding *Green Campus Action Plan* were taking place. The main goal of this working group was to legislate the policies for the universities to mitigate their carbon footprint. Since then, the University of Cape Town has joined this group to communicate and share ideas on this matter. The University of Cape Town categorizes all emission sources into goods and services, transport, and energy to set the carbon footprint calculation boundaries. The goods and services group contains all kinds of papers and wastes, including solid waste and wastewater. Commuting, vehicle fleet, and air travel are placed under the transportation category, and electricity and fuels are placed under the energy emissions group.

Ologun & Wara (2014) have grouped emission factors of the Federal University of Agriculture Abeokuta, Nigeria, containing commuting, electricity, and agricultural machinery into one category.

3.4.3 European Universities

One of the most well-known papers regarding the carbon footprint calculation is published by Larsen et al. (2011) at NTNU University, Norway. NTNU administration has represented the main categories like energy, waste, transportation, and procurement. However, the stressors are categorized into much more detailed groups. Scope 1 contributors contain fuels and the carbon footprint of heating oil directly produced on campus. Scope 2 accounts for emissions produced in the district heating and electricity consumption process.

Ozawa-Meida et al. (2013) have chosen fuel as the only element of scope 1, whereas scope 2 contains emissions regarding electricity consumption of the De Montfort University, UK. Scope 3 accounts for the most detailed group where air travel, commuting, and procurement present the main factors of this scope. In addition, purchased ICT equipment, waste management, and construction emissions are categorized under the procurement's subgroup.

Townsend & Barrett (2013) measured scope three as the only group of emission factors for the University of Leeds, UK. Procurement of goods and services, commuting, air travel, waste management, and leased assets are the measured elements of the carbon footprint production on-campus.

Employees' wages are one of the involved categories in the carbon footprint at the university mentioned by Gomez et al. (2016). It is argued that the produced emission by university staff has some relation to their income. The wage affects the amount of money they can spend on various activities. Gomez et al. (2016) have used a financial perspective to increase awareness among university workers. Alongside this vision, paper consumption, electrical equipment, electricity generation, hotels and restaurants, air travel, construction, and business activities are mentioned as the primary carbon footprint production at the University of Castilla-La Mancha in Spain.

Gu et al. (2019) have investigated emission elements at Keele University to measure the carbon footprint of the campus. By using the GHG Protocol, scope 1 contains natural gas as part of the fuel consumption and vehicle fleet. Scope 2 includes on-site generated and grid electricity, and scope three accounts for wastewater treatment, food, waste management, and water supply.

In a study regarding the difference of carbon footprints before and during the pandemic, Filimonau et al. (2021) calculated emissions for both scenarios for the Bournemouth University, UK. According to the GHG Protocol used in this study, natural gas and vehicle fleet constitute scope 1. Electricity is grouped under the scope 2 category, and scope 3 accounts for water supply and treatment, waste management, air travel, and students and staff commuting.

3.4.4 South American Universities

Mexico has set a carbon footprint reduction by 50% by 2050 as a goal. This forces higher educational institutions to join the process. Guereca et al. (2013) have published a paper to assess all the involved factors and present some tentative ways for carbon reduction at

Universidad Nacional Autonoma de Mexico. Scope 1 only concerns fuel consumption emission. Scope 2 accounts for electricity generation. Commuting, air travels, shipments, paper, and solid waste are the number of stressors categorized into scope 3. Scope 3 has the biggest carbon footprint share of 53%. Scope 1 and 2 account for 5% and 42%, respectively.

Vasquez et al. (2015) note that Latin American countries suffer from a lack of data regarding their carbon footprint. It is intended to compensate for part of these deficiencies. As the measurement method, the GHG Protocol is used to calculate and mitigate the carbon footprint of the Universidad de Talca in Chile. One of the goals is to apply sustainability to the university's campus, curricula, and students' habits and activities. In that sense, classrooms, libraries, offices, roads, parking spaces, and sports courts are considered as the main boundaries. Scope 1 represents students and staff commuting by vehicles owned by the university, fuel consumption, and refrigerant emissions. As expected, scope 2 accounts for electricity consumption, and scope 3 contains students' and staff's commuting and air travel. In addition, Yanez et al. (2019) have estimated the carbon footprint of the University of Talca using ISO 14064 and the GHG protocol as the main methodologies. All four campuses are chosen for a comprehensive calculation. Scope 1 contains LPG fuel consumption used for on-campus and off-campus transportation and campus heating. Scope 2 accounts for the electricity generation, and scope 3 includes students and staff's commute, paper, and waste process stages. The results illustrate that scopes 1,2 and 3 have shares of 5%, 35%, and 60%, respectively.

Quintero-Nunez (2015) has not categorized the emissions of the University of Baja California (UABC) in GHG scopes. Instead, all emission factors are mentioned in the same group. In that sense, energy, paper, water treatment, commuting, and construction are all the involved carbon footprint categories.

The GHG Protocol is used by Mendoza-Flores et al. (2019) to identify all the involved emission sources for Autonomous Metropolitan University (UAM), Mexico, where scope 1 covers refrigerants and mobile sources. Scope 2 accounts for electricity consumption, and scope 3 includes paper, chemical materials, water and wastewater treatment, food, gases, and staff and students' commuting sector.

Varon-Hoyos et al. (2021) have investigated the effects of carbon reduction scenarios at the University of Pereira located in Colombia. The GHG emissions are categorized into three main groups, and for this purpose, the GHG Protocols and ISO 14064-1 are used. Scope 1 includes fossil fuel consumption, fugitive emissions, and wastewater treatment. Scope 2 concerns electrical energy consumption as indirect emissions. Last but not least, scope 3 accounts for solid waste management, travel, water consumption, untreated wastewater, and paper consumption.

3.4.5 Asia-Pacific Universities

Li et al. (2015) set all active step emissions, including direct fuel consumption, electricity, and transportation, as the boundaries for Tongji University in China. Indirect emissions like embodied energy are omitted. Students' carbon dioxide emissions are categorized into daily life, academics, and transportation groups, where daily life contains dining, showering, dorms' electricity use, and computer use for entertaining applications. The academic group includes computer use (study), printing, scanning, and studying (classroom, library, and personal office). Daily commuting, hometown traveling, and vacation travel are considered as the transportation's carbon footprint producers.

Al-Mufadi and Irfan (2016) have done an investigation regarding the carbon footprint measurements and reduction plans for Qassim University located in Saudi Arabia. The GHG Protocol is utilized as the main methodology where scope 1 is categorized based on natural gas, vehicle fleet, refrigerants, and composting. Scope 2 measures electricity usage emissions and scope 3 demonstrates commuting, air travel, solid waste, and wastewater.

Kandananond (2017) only considered scopes 1 and 2 while measuring the carbon footprint for Rajabhat University in Thailand. Consumed fuel regarding commuting is considered the only scope 1's stressor. Scope 2 covers produced emissions for electricity usage. However, scope three is omitted from the research for no mentioned reason.

Sangwan et al. (2018) describe carbon footprint emission sources using the International Standardization Organization (ISO) 14064 standard regarding Birla Institute of Technology and Science Pilani (BITS Pilani) in India. According to Sangwan et al. (2018), India has committed to reducing domestic GHG emissions by 35% between 2005-2030. In that case, the education sector is involved. Scope 1 deals with direct emissions produced through burning fossil fuels for generators and vehicle fleets. Scope 2 demonstrates indirect emissions produced due to electricity consumption, and scope 3 is categorized into detailed elements. Refrigerants, waste, commuting, food, glassware, workshop procurement, capital goods, and computer and electrical components are the chosen factors.

Calculating carbon footprint for universities could be divided into academic and non-academic activities involved in the emission. Academic activities contain the type of activities related to the students' education, and any other activities are categorized under the non-academic group. Budihardjo et al. (2019) measured the non-academic activities for Diponegoro University, Indonesia. Scope 1 only includes water treatment. Scope 2 covers electricity consumption, and scope 3 illustrates waste disposal and wastewater. According to another research done by Syafrudin et al. (2020) about the carbon footprint production at Diponegoro University in Indonesia, electricity use (Scope 2) is the biggest contributor at 85.4% among all sources. Scope 1 only covers clean water. In addition, transportation, solid waste treatment, and wastewater are categorized under scope 3.

Using the GHG Protocol is not followed in all studies. An example would be the research done by Stephan et al. (2020) regarding material flows of the University of Melbourne. The scope of the study is defined based on the material inflows and outflows of the main campus. Both inflows and outflows contain procurement-related materials like furniture, stationery, electronics, lab equipment, and electricity generation. On the other hand, non-procurement-related materials include food and beverages, packaging, and gardening soil.

Providing a survey helps understanding staff and students' habits and reach more accurate results in the carbon footprint calculation process. This is the approach that Iskandar et al. (2020) used to measure the carbon footprint of Trisakti University, Indonesia. A questionnaire is conducted to help calculating the scope 3 emissions of the campus. The survey concerns daily commuting distance, transportation vehicles, food and drink, paper, and plastic goods used by students and staff. While the questionnaire covers all involved emission sources for scope 3, scope 1 contains fuel consumption, and scope 2 accounts for electricity usage and air conditioning.

Ridhosari & Rahman (2020) have categorized all emission factors into one group, including electricity, waste management, and commuting in the Universitas Pertamina, Indonesia. Data is extracted through surveys, direct sampling, and secondary data to obtain electricity consumption.

Naderipour et al. (2021) have published their research regarding the carbon footprint measurement of Universiti Teknologi Malaysia (UTM) during a four-year period. In accordance with the methodology approach of the GHG Protocol, scope 1 only concerns vehicle fleets. Scope 2 accounts for the electricity generation, and scope 3 contains waste management, paper, staff and students' commuting, air travel, and maintenance.

3.5 Summary of scopes included in the carbon footprints of universities

Table 2 sums up the investigated sectors by universities:

Table 2. Overview of the investigated studies regarding the scopes considered by various universities.

	Scope 1						Scope 2	Scope 3							
	Refrigerants	Vehicle fleet	Agricultural	Fertilizer	Fuel	Water treatment	Electricity	Air travel	Commuting	Waste management	Paper	Procurement	Food	Wastewater treatment	Electrical equipment/ ICT
W. Day Jr. (2010)	√	√	√	√	√		√	√	√	√				√	
Thurston & Eckelman (2011)		√		√	√		√	√	√				√		
Letete et al. (2011)		√			√		√	√	√	√	√			√	
Larsen et al. (2011)					√		√		√	√		√			
Stewart & Khare (2012)											√	√			
Ozawa-Meida et al. (2013)					√		√	√	√	√		√			√
Guereca et al. (2013)					√		√	√	√	√	√				
Townsend & Barrett (2013)								√	√	√		√			
Ologun & Wara (2014)			√				√		√						
Vasquez et al. (2015)	√	√			√		√	√	√						
Li et al. (2015)							√	√	√		√		√		√
Quintero-Nunez (2015)						√	√		√		√				
Gomez et al. (2016)							√	√			√		√		√
Bailey & Lapoint (2016)	√	√	√				√	√	√	√	√			√	
Al-Mufadi & A.Irfan (2016)		√		√	√		√	√	√	√				√	
Kandananond (2017)					√		√								
Sangwan et al. (2018)		√			√		√		√	√		√	√		√
Mendoza-Flores et al. (2019)	√	√					√		√		√		√	√	
Yenez et al. (2019)					√		√	√	√	√	√				
Gu et al. (2019)		√			√		√			√			√	√	
Budihardjo et al. (2019)						√	√			√				√	
Syafrudin et al. (2020)						√	√		√	√				√	
Ridhosari & Rahman (2020)							√	√	√	√					
Stephan et al. (2020)				√			√			√		√	√		√
Iskandar et al. (2020)					√		√		√		√		√		
Clebeaus et al. (2020)	√	√		√		√	√	√	√	√	√			√	
Varon-Hoyos et al. (2021)					√	√	√	√	√	√	√			√	
Naderipour et al. (2021)		√					√	√	√	√	√				
Filimonau et al. (2021)		√			√	√	√	√	√	√				√	

As demonstrated in Table 2, scope 1 contains six sectors. Scopes 2 and 3 cover one and eight sectors, respectively. The sectors are chosen in a way to illustrate the majority of investigated boundaries at the universities. 29 studies have been investigated and the coverage percentages of various sectors for scopes 1 and 3 are summarized in Tables 3 and 4, respectively demonstrated in the following:

Table 3. The coverage percentage of scope one sectors regarding the investigated studies.

Sectors	**Refrigerants**	**Vehicle fleet**	**Agriculture**	**Fertilizer**	**Fuel**	**Water treatment**
Coverage %	17%	41%	10%	17%	52%	21%

Table 4. The coverage percentage of scope 3 sectors regarding the investigated studies.

Sectors	**Air travel**	**Commuting**	**Waste management**	**Paper**	**Procurement**	**Food**	**Wastewater treatment**	**ICT**
Coverage %	59%	80%	66%	45%	21%	28%	38%	17%

Scope 2 covers the electricity sector, which is included in 93% of the investigated studies. As shown in Table 4, the ICT sector has been only covered by five studies (17%) which could be considered a significant low fraction. The important question here is whether these five studies have assessed this sector in detail or not. In addition, due to the fact that this thesis concerns internet carbon footprint as a part of the ICT emissions, a further question is whether the internet sector is assessed or not. These questions will be addressed in section 4.2 of this thesis project.

3.6 The ICT sector in the investigated studies

According to Table 2 regarding the sectors investigated by the universities, five studies have considered the ICT sector as an element of the carbon footprint at higher educational institutions. However, it is important how detailed this sector has been investigated in the studies. The more detailed ones will give a better overview of the used approach for the carbon footprint calculation. In that case, this thesis project can use the opportunity to explore the ICT sector more accurately.

As part of the scope 3 emissions, the ICT sector has been considered as one of the subgroups of procurement. This subgroup demonstrates the emissions produced by monitors, desktop PCs, and printers purchased by the university during the manufacturing stage of the equipment. To calculate the emissions for this sector, emission factors extracted from standard industrial classification (SIC) codes have been utilized by Ozawa-Meida et al. (2013). SIC codes are used to classify the materials used in the equipment (SIC, 1998). SIC codes 30 for rubber and miscellaneous plastic products (SIC, 1998), 31 for leather and leather products (SIC, 1998), and 32 for stone, clay, glass, and concrete products (SIC, 1998) are the codes considered for ICT equipment and their emissions. Moreover, results illustrate that this subgroup accounts for 7% of the De Montfort University's total carbon footprint. (Ozawa-Meida et al., 2013)

Li et al. (2015) allocate the ICT section to the electricity consumption due to students' computer use (for study and entertainment) and also printing and scanning. GHG/hour factor for computer use, GHG/paper for printing, and GHG/scan factor for scanning are considered to ease the calculation process. In addition, by providing a survey, the number of hours for using computers and the number of pages for the printing process are extracted. Also, it is calculated that while computer use produces 0.079 kg CO_2e in an hour per unit, printing and scanning account for 0.0043 and 0.0013 kg CO_2e per page, respectively. As a total result, it is calculated that computer use at the Tongji University produces 0.24 t CO_2e per person annually. The number for printing and scanning would be 0.17 t CO_2e per person. (Li et al., 2015)

Electrical and optical equipment are the only components of the ICT sector considered by Gomez et al. (2016). As part of the procurement process, electrical and optical equipment's carbon footprint is reported based on the university's expenditures. However, only "own calculation" is reported as the source of the figure and measurement in this matter.

ICT equipment is categorized as one of the subgroups of procurement by Sangwan et al. (2018), who have used the university's central purchasing unit (CPU) inventory to collect data for electric and electronic components. Also, Ecoinvent and WEEE databases are utilized to extract emission factors regarding carbon footprint production. No further details are explained about the calculation methodology for this sector.

Stephan et al. (2020) have considered the ICT components as part of the procurement sector with the components and their carbon footprint calculated based on their mass and material flows. Computers, electronics, and lab equipment account for the involved elements of the ICT sector. First, material inflows and their emissions and embodied energies are identified. Then, the same approach is used to identify material outflows and their emissions. Finally, the total produced emissions during this process is calculated.

By investigating the studies that contain the ICT sector as part of their carbon footprint scopes, it is concluded that previous studies have almost exclusively (4 out of 5 studies) focused on the ICT sector as part of the procurement process. Although Li et al. (2015) have used a different approach for calculating the carbon footprint for this sector, the calculation method cannot be followed clearly. In addition, no prior studies have considered the ICT sector as a separate factor of emission. Also, the internet section has not been covered by any of these aforementioned studies as part of the ICT sector's carbon footprint.

3.7 Carbon footprint mitigation methods

Other than identifying emission sources, it is crucial to reduce the carbon footprint to move towards carbon neutrality goals. Thus, a number of studies were investigated to demonstrate a better understanding of their mitigation methods and the sectors they have chosen for their actions.

Changes in supply-chain processes of the sectors involved in carbon footprint production are illustrated by Baboulet and Lenzen (2010) as effective ways of carbon mitigation in university. The study is done at the University of Sydney, and Input-Output Analysis (IOA), Structural Path Analysis (SPA), and Path Exchange (PXC) are the methods used in the project to investigate the steps in the supply chain. As an example, the printing process starts with softwoods converting to the pulp, and then making paper and paperboard using pulps. After that, printing papers would be possible. Although the exact changes to the steps are not specified, it is demonstrated that alternative steps could make significant differences in the final carbon footprint production. The differences might increase or decrease the ultimate emission. Baboulet and Lenzen (2010) go through the transportation, food, paper, waste management, electricity supply, and glass product sectors in their investigations.

Larsen et al. (2011) suggest some carbon mitigation methods for NTNU University. Applying GHG methods to new buildings regarding their construction, maintenance, etc. would reduce emissions. For older buildings, some actions could be effective. For example, a solution is to control heating and ventilation when the buildings are not used by students and staff (during the night on the 24 h campuses). Moreover, it is noted that air traveling produces significant amounts of emissions; thus, using video conference for the meetings that don't have to be face-to-face is recommended for carbon reduction. A green purchasing method regarding electronic devices, papers, foods, etc., is explicitly suggested for the faculties with the most share of procurement. Small changes could wind up in considerable positive results.

After calculating GHG emissions for the procurement sector of Yale University, Thurston and Eckelman (2011) suggest improving the sustainable procurement standards to reduce the emissions in this section. Although current mitigation methods are selected based on the expense point of view and not the environmental aspect, it is recommended that the university should focus on green supply chain management for this section to decrease the carbon footprint production.

For the universities that consider the procurement process the main emission factor, sustainable and effective procurement procedures would be considerably practical. Ozawa-Meida et al. (2013) note this fact and also suggest replacing new and efficient campus buildings with the older and inefficient ones for the De Montfort University. It is believed that this action will decrease the carbon footprint considerably in the longer term. Also, due to the fact that procurement accounts for a considerable fraction of emissions, purchasing energy-efficient equipment is suggested. Moreover, designing a decision-making tool to improve the decisions for purchasing ICT devices by considering various equipment and suppliers is recommended as a carbon footprint reduction measure.

To reduce the carbon footprint at the Federal University of Agriculture Abeokuta, Nigeria, Ologun & Wara (2014) suggest increasing the number of buses for staff. Also, it would be effective to implement the infrastructures for renewable energies. Other than decreasing the use of energy and increasing energy efficiency on campus, planting trees could ease the process of carbon footprint reduction.

Vasquez et al. (2015) propose four scenarios for carbon reduction at the Universidad de Talca. The first scenario suggests that students living less than 3 km away from campus, use bicycles instead of motor vehicles for two-thirds of the academic year. Applying this scenario declines carbon reduction by 7%. The second scenario considers using trains for 50% of the students and staff who live in the city. In the case of following this scenario, 5% of emissions will be reduced. The third scenario suggests using public transport for half of the car riders. 3% carbon reduction will be achieved if the scenario is followed. Last but not least, the fourth scenario recommends using energy-efficient components for lighting purposes to reduce lighting electricity consumption by 40%. Applying this scenario decreases the carbon footprint by 5%. In addition, the paper published by Yanez et al. (2019) suggests encouragement for students and staff for public transportation usage and implementing the infrastructures according to ISO 50001 as carbon footprint reduction methods for the University of Talca. Moreover, because commuting is one of the main emission contributors, increasing the fully residential campus for students is advised. In that sense, controlling common activities like studying at the library, dining, etc. could be done according to carbon reduction plans. Moreover, using public transportation, bikes, and carpooling would accelerate the reduction because commuting is one of the biggest stressors in the calculation. Furthermore, Yanez et al. (2019) believe that substituting fossil fuels with renewable energies would lead to 17% to 23% of carbon footprint reduction at the university.

By looking at Table 2 and the results, it is obvious that increasing awareness should be one of the main goals of consumption reduction. In that sense, Li et al. (2015) used the results of the survey they conducted for the carbon footprint reduction to increase students' consciousness about their behavior and its effect on the production of GHG emissions. Furthermore, data extracted from the survey helped the Shanghai university to make better decisions and find an optimum path toward sustainable development. In addition, suggesting students eat on campus and encouraging the university to centralize amenities like shopping and exercise facilities near the campus would be helpful. The goal is to conduct and monitor the carbon footprint related to the students' daily routines. In that case, the university would be able to make adjustments and control the production of emissions.

Carbon reduction methods for Qassim University are not explained in detail by Al-Mufadi and Irfan (2016). Implementing infrastructures for solar and wind energy, planting trees, and raising awareness among students and staff are mentioned as future methods to be considered.

While no carbon footprint mitigation scenario is mentioned for Rajabhat University (Kandananond, 2017), energy saving is the only suggested recommendation by Budihardjo et al. (2019) regarding carbon footprint mitigation at Diponegoro University.

To collect data and reach more accurate results alongside reliable sources, Sangwan et al. (2018) have provided a survey to better understand students' and staff's commuting, travel, and food habits at Birla Institute of Technology and Science Pilani. As a result of the survey, raising awareness and increasing teleconferencing meetings to avoid unnecessary commuting are recommended to reduce carbon production.

Mendoza-Flores et al. (2019), calculating the carbon footprint of the Autonomous Metropolitan University (UAM) located in Mexico City, demonstrate uncertainties, and suggest a number of carbon reduction approaches for the campus. A survey to achieve more accurate data for the commuting part, which is one of the main stressors, is recommended to decrease the emission. To mitigate emissions allocated to scope 2, installing solar panels and utilizing LED lights are recommended. In addition, chemical materials are widely used in research laboratories at this university which considerably affects waste disposal. It is suggested that by implementing infrastructures to reduce waste, and monitoring the disposal sector to control chemicals, the emissions will be mitigated.

To reduce the carbon footprint of the Keele University, UK, Gu et al. (2019) recommend implementing infrastructures for photovoltaic and wind energy technologies. Moreover, increasing vegetable-based food types would be effective alongside collecting food wastes for the composting process. Furthermore, installing energy monitoring systems to prevent utilizing unnecessary energy would help reducing carbon emissions.

Syafrudin et al. (2020) represent some recommendations for carbon footprint reduction at Diponegoro University. By applying energy consumption reduction plans and increasing energy efficiency, up to 30% of the carbon footprint related to this sector could be reduced. Furthermore, encouraging staff and students to use buses is suggested to decrease emissions in the transportation sector, which is the second biggest stressor. Furthermore, it is believed that expanding green areas near campuses provides the opportunity for carbon absorption, and thus, the carbon reduction approach would be more achievable.

Installing photovoltaic panels and wind turbines is a common way to reduce the carbon footprint of generated electricity at universities located in geographical areas with the potential to use renewable energy. In that sense, Ridhosari & Rahman (2020) suggest using this opportunity for the University of Pertamina, Indonesia, and recommend using electrical buses, as well as constructing dormitories near the campus area to prevent unnecessary transportation for students. The well-known Reduce, Reuse, and Recycle concept is advised to raise awareness and mitigate the carbon footprint from a waste management perspective.

Iskandar et al. (2020) have suggested utilizing Light-emitting Diode (LED) lights in all campus areas at Trisatki University instead of less efficient ones. In addition, installing window films could help reducing electricity usage for air conditioning considerably. Moreover, installing photovoltaic panels on roofs would decrease the electricity consumption from the grid and help producing clean energy.

Varon-Hoyos et al. (2021) have mentioned two different scenarios for carbon reduction at the University of Pereira. The first one is a conservative scenario. It is defined as applying water consumption reduction by 10% per year, installing photovoltaic infrastructure, and considering that students and teachers participate in virtual classes 18 times a year. The other scenario is called the optimistic scenario and contains water consumption reduction by 20%, decreasing electricity consumption by 2% each month, installing the photovoltaic generation system, and virtual class participation for students and staff 36 times in an academic year.

Naderipour et al. (2021) have some ideas regarding carbon footprint mitigation at Universiti Teknologi Malaysia (UTM). It is suggested that implementing infrastructures for installing photovoltaic technology at parking lots, encouraging staff and students to use the bike and electric scooters, installing wind turbine-based lighting, and constructing green buildings on campus would decrease the carbon footprint production considerably. Also, it is recommended to follow a comprehensive waste management procedure to reduce emissions in this section (see Lee et al., 2017).

The Bournemoth University set the target of carbon footprint reduction by 40% untill 2020-2021 compared to the 2005-2006 baseline. The target was achieved two year early (BU University, 2021). Using the bicycle and public transportation is encouraged for staff and students to reach the goal. In addition, traditional and energy inefficient lighting systems have been substituted with LED lights. Furthermore, the infrastructures for installing Ground Source Heat Pumps (GSHP) and photovoltaic technologies are implemented. (Filimonau et al., 2021)

The most common carbon footprint mitigation methods presented by the aforementioned studies are demonstrated in Table 5. Out of 29 investigated studies, 19 have recommended carbon footprint reduction methods.

Table 5. The carbon footprint reduction methods presented by the investigated studies.

The carbon footprint mitigation methods	**Percentage**
• Increasing energy efficiency by installing energy-efficient equipment like LED lights	58%
• Implementing infrastructures for installing renewable energy sources like photovoltaic, wind turbines, and ground source heat pumps	53%
• Encouraging students and staff to use public transportation and bikes	53%
• Decreasing water and energy usage on-campus	37%
• Centralizing amenities and students near the campus area to decrease commuting	21%
• Reduce waste and disposal alongside implementing infrastructures for waste management	21%
• Increasing video conferencing possibility to prevent unnecessary commuting	21%
• Expanding green areas by planting trees	21%
• Sustainable and green procurement	16%
• Raising awareness among students and staff	16%
• Using a survey to have a better understanding of students' and staff's habits	16%
• Installing an energy monitoring system to control the consumption	16%

3.8 Obstacles to carbon footprint measurements of universities

Many countries around the globe have started to move towards low-carbon structures in various sectors. However, there is still a noticeable distinction between developed and developing countries in the case of improvement and development (Drori et al., 2014). Identifying the emission sources and calculating their carbon footprint are one of the first steps of this process. To be able to reach this goal, defining boundaries helps making an inventory and categorize the involved emission sources. This is the main reason for using the GHG Protocol to distinguish emission sources into three scopes. This approach applies to higher educational institutions (HEI) as well. However, there are a number of obstacles to selecting the sources, which end up in different results for HEIs research. To identify these obstacles, Robinson et al. (2018) have provided a survey of 31 individual institutes to better understand the limitations of calculating the carbon footprint of universities.

According to the survey done by Robinson et al. (2018), fuel combustion, electricity, and waste were the most calculated emission sources using reliable data. Scope 3, on the other hand, contains the most data uncertainties compared to the other two scopes. However, staff commuting, waste, and business travel were found to demonstrate more reliable data. Furthermore, respondents had reported that getting data from the supplier is difficult. Furthermore, measuring the procurements' carbon footprint was chosen as one of the most challenging parts due to insufficient knowledge about the manufacturing process. In addition, some universities tend not to calculate most of the scope three emissions due to difficulties and negative publicity they could receive.

Robinson et al. (2018) suggest providing a universal carbon footprint methodology for all institutions to follow. In that case, the results would be comparable. Current methodologies have some flaws, and universities tend to choose various approaches. For example, it is not specified which sources and activities should be included, and double counting would be inevitable in many cases. In addition, there is no clear methodology for data collection, which makes the universities choose their own path. As a result, the lack of reported scope 3 emission sources by universities demonstrates the difficulties that many HEIs are facing in this process, although this category accounts for the majority share of produced emissions by the universities.

In addition, Clabeaux et al. (2020) point out the fact that due to various GHG emission sources, it is difficult to compare the universities' carbon footprints. In addition, according to Mendoza-Flores et al. (2019), uncertainties in the data and information section are crucial obstacles in carbon footprint investigation. Improvement in this area would lead to more accurate results.

Furthermore, Kiehle (2021) states that although scope 3 accounts for the highest share of all three scopes, it is not prioritized in calculations due to its complexity and cost-consuming process. In addition, the system boundaries should be accurately defined to prevent carbon leakage. This term demonstrates the fact that while a sector is chosen for the carbon footprint reduction, defining inaccurate boundaries could end up with an increase in carbon footprint in another sector that is not selected for the carbon footprint mitigation process (see Barker & Crawford, 2015).

4 MULTI-LOCATION WORK MODE

Multi-location working has been mostly used during the pandemic when employees started working in various places instead of working only at the office. The term workplace refers to the location where the employees perform tasks for the employer (Indeed, 2022). Thus, multi workplace indicates that there are several places where the job is done. Blended and hybrid workplaces are multi-location workplaces where both are used interchangeably, mainly after the Covid pandemic (PenkethGroup, 2022). These two terms are defined as the combination of face-to-face and online working types (Tredinnick & Laybats, 2021). In other words, in hybrid and blended working modes, workers spend some days in a week working from home and the remaining working days at their company or university. Figure 3 gives a better overview of the relation between hybrid, remote, and in-person working modes.

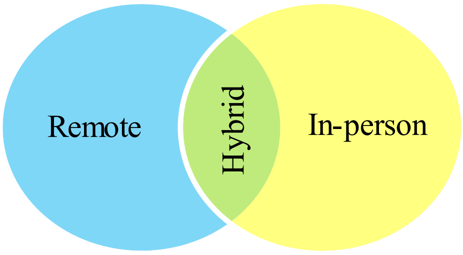

Figure 3. A demonstration of hybrid work as a combination of remote and in-person working modes. (SAP, 2021)

Regarding the thesis project, the question that then arises is what the best combination is to achieve a balance between workplaces from the perspective of the carbon footprint? In addition to that, do blended and hybrid working modes produce more carbon footprint compared to online or face-to-face working modes? If yes, from the emissions point of view, does it make sense to consider blended working even after the pandemic? A more systematic and theoretical analysis and calculation are required to answer these questions which will be addressed in the following chapters.

4.1 The effect of the pandemic on the workplace

According to the European Commission (2020), almost 30% of Finns used to work remotely before the pandemic started in spring 2020, in Europe. After the pandemic, due to the fact that COVID-19 forced the change of workplace from office to home (Yang et al., 2021), this number increased significantly, and according to research done at Aalto University, over 86% of Finnish workers are willing to continue working from home (Aalto University, 2020). Another research demonstrates that employees are not willing to work full-time at the office; instead, they prefer working some days from home during the week (Colley & Williamson, 2020).

While workers changed their workplace from home to office, they had to make changes to other aspects as well. Online meetings and communication with colleagues are two examples to mention (Yang et al., 2021). From the universities' point of view, the changes also include online teaching, providing required resources for students, evaluating, etc. On the other hand, working from home has given more flexibility to workers in case of working hours and schedule. Note that working flexibility is defined as the possibility for workers to choose their working time and workplace during the day (Yang et al., 2021). In that case, balancing between work and routine life is more possible.

To work from home, required equipment should be provided. Otherwise, the quality of work is compromised. Now that many workers work from home, the expenses for utilities and spaces in traditional offices are reduced. In that case, the decreased cost could be spent on required equipment for working from home. (Yang, et al., 2021) According to the survey done by Yang et al. (2021), laptop, desktop PC, smartphone, tablet, monitor, headset, and webcam are the main required equipment for this purpose. This result could be applied to the university workers as well, where teachers need various ICT equipment at home to be able to provide the same teaching quality as before the pandemic.

Even during the pandemic, some institutions have provided the possibility for their teaching staff to teach on-campus for attending students and teach online for non-attending students simultaneously, which are the aforementioned hybrid and blended teaching modes. Considering the study done by Filimonau et al. (2021) regarding the carbon footprint difference before and during the pandemic, it is illustrated that blended teaching produces more carbon emissions compared to online teaching or face-to-face teaching. Moreover, it is suggested to consider at-home study/work carbon footprint within scope 3 of the GHG Protocol.

4.2 Positive and negative consequences of working from home

Aczel et al. (2021) emphasize the researchers' willingness to work from home. By analyzing their survey, it is reported that 66% of researchers want to work more from home than they had been doing before the pandemic. On the other hand, almost 16% want to work less from home, and 18% ask for the same amount of work from home in the future as they worked before. This transition has its benefits and drawbacks.

Less commuting is one of the most effective factors regarding carbon emissions when working from home. A project done by the University of Oulu's carbon footprint working group demonstrates that approximately 8% of the total amount of produced GHG emissions at the University of Oulu is related to the commuting sector (University of Oulu, 2022a). Thus, reducing commuting could considerably affect the total carbon footprint.

In addition, work time control could be much easier when working from home. This is a good opportunity to optimize time management and maintain a balance between work and home life (Kaushik & Guleria, 2020). Furthermore, Aczel et al. (2021) state that working from home provides a more comfortable environment, more flexibility, and fewer office-related distractions. On the other hand, less interaction with colleagues and a difficult communication process are the potential drawbacks.

Moreover, adopting a multi-location workplace requires specific infrastructures. It is evident that providing equipment when working on campus is the university's responsibility. The question is, who is responsible when researchers work from home? Because employees should be well-equipped to handle remote working. This applies to all needed ICT equipment like laptops, monitors, headphones, webcams, etc., chairs, desks, and high-speed internet. Internet with appropriate speed is essential. Internet interruption ends up in delays and waste of time. Some companies offer an allowance to employees to purchase the equipment, and others take complete responsibility for the purchase. However, companies and institutes with less budget, leave this problem to employees, which in many cases results in inefficient working from there. Other than providing equipment, working space is another issue to consider. Not all employees have private and free spaces in their homes to continue working. In these cases, companies could provide some facilities as an alternative option. (Kaushik & Guleria, 2020)

Companies and universities deal with some confidential information. Securing the information would be more accessible when all employees work at the company or on campus. When working remotely, monitoring the employees' equipment and securing their data is a challenge to face. The first stage could be installing security software and enabling auto-update on all equipment containing confidential information. Device encryption is another action to take. It would reduce the possibility of losing important information. Proper training for employees could be another solution. It provides the opportunity for employees to spot suspicious activities and cyber-attacks (Kaushik & Guleria, 2020). Companies and educational institutes should look for the most efficient and optimized way to balance working from home and the office for the best results.

5 CARBON FOOTPRINT OF ICT AND INTERNET

Due to climate change and global warming, the carbon footprint has become widely used to give a better understandable overview of the impacts caused by services or products during their lifetime. As the climate change situation has worsened, this concept has been taken more seriously between by public, governments, institutions, and companies.

The manufacturing company usually reports the carbon footprint of ICT equipment. The total carbon footprint is divided into four main categories:

- Production, which contains the carbon footprint of the material extraction and manufacturing phases.
- Transport stage, which contains all the GHG emissions during the transportation and distribution step.
- Use phase, which is the carbon footprint based on the electricity used to run the equipment.
- End-of-life processing, which is the last stage includes the carbon footprint for waste management, recycling, or disposal.

Some manufacturers include subgroups like packaging, power supply unit, mainboard etc., as part of the production process. However, for easier comparison, the main groups are compared together. Furthermore, the considered lifetime for ICT equipment varies between the equipment and manufacturer. The reports published by companies show lifetimes of 3 to 6 years for ICT equipment. The ICT equipment’s carbon footprint depends on the stages explained earlier, but even the manufacturers' methodologies for carbon footprint calculation can affect the final result. For simplification, all reported numbers by manufacturers are considered reliable, and their methodologies are not scrutinized.

In addition, the reported carbon footprint for the use phase is usually calculated according to the USA’s electricity data, and it must be measured separately for other countries. So, to calculate the CF production for the use phase, an accurate way would be to measure the electricity consumption of ICT equipment during a certain period of time and then apply country-specific electricity emission factors to calculate the intended CF production. Another rough estimation would be to use the ICT’s power consumption (instead of measuring the consumption) and then apply the electricity emission factors to reach the CF production for use phase. According to Fingrid (2020), emission factors for electricity consumed in Finland for 2019 and 2020 are 101 and 72 (gCO_2/kWh), respectively. By using this factor and adding the equipment's working hour time, an approximate estimation would be achieved.

5.1 Information and Communication Technology sector

ICT is a shortened term for Information and Communication Technology (or technologies), and although there are various definitions provided for this term, ICT is basically defined as all components, devices, and network systems that connect people and organizations together and provide an opportunity for them to communicate digitally (TechTarget, 2019).

According to the proposed hierarchy boundaries by Zuppo (2012), four main areas are covered by the ICT sector. The economic sector, education sector, business sector, and socioeconomic development sector are the classified areas categorized as the main groups. The ICT sector is related to the socio-economic sector by implementing infrastructures for mobile devices and their signals to cover more areas and tracking opportunities, which is known as Global Positioning System (GPS) technology. For the economic sector, ICT eases goods' manufacturing and providing services. These days, online shops and service providers are tangled with our daily life. In addition, ICT offers technologies and applications like engineering software for the business section. Various ICT devices like computers and tablets are used in this matter. Last but not least is the connection between ICT and the education sector, which is the primary objective of this thesis project. Equipment like laptops, desktop computers, routers, monitors, keyboards, etc. are only a number of ICT devices involved in the education sector. Wireless and cable-connected equipment both play a crucial role in making this correlation happen.

In general, software, hardware, communication technology, data, internet, cloud computing, and transaction could be considered the main components of ICT in all sectors (TechTarget, 2019).

5.1.1 ICT in the higher education sector and research

Since the pandemic, ICT technology significantly helped the higher education sector to continue operating while contact teaching was not an option. Moreover, online studying has provided an opportunity for millions of people around the world to have access to up-to-date information and science.

The role of ICT in the research sector has been considerably clear in the past years. ICT plays a crucial role in four areas (Sarkar, 2012):

- Power computers and supercomputers provide the opportunity for complex calculations and simulations
- Research teams in various higher educational institutions communicate with each other, so the research is spread easier
- The availability of online libraries and article inventories helps institutions to have equal access to resources
- By linking countries around the globe, ICT has been using the full advantage of dynamic research development by sharing information between HEIs

Data processing could be mentioned as one of the most crucial roles of ICT in the higher education sector, where ICT processes a significant number of data, accurately. Moreover, online libraries and databases provide the opportunity for researchers to have access to updated articles, books, etc. Also, due to ICT, the collaboration between the universities and industries is now clear, which helps improving science and provides the opportunity for students to find jobs. (Sarkar, 2012)

Das (2019) has noted some benefits of ICT in the higher education sector as follows:

- ICT increases the quality of teaching, learning, and interaction between students and teachers
- ICT provides new tools to the education sector to enhance skills of teaching and learning
- ICT eases the access to various materials at any time and at any place
- ICT provides opportunities for a variety of services
- Increases the cooperation and collaboration between students and teachers
- New sources of science would be available faster than the traditional approach
- Distance-learning would be possible for learners all around the world
- Helps teachers to motivate students by using a variety of applications and tools
- Helps teachers and students to communicate properly throughout the semesters

- Provides a more flexible learning atmosphere

5.1.2 Carbon footprint reduction in University's ICT use

Since the pandemic, the path towards carbon neutrality should undergo some changes. For instance, from a higher education point of view, all modifications used to be applied according to campus activities. However, the pandemic and hybrid workplace mode have changed the approach. Carbon reduction for campus activities should be considered, and working from home and its carbon emission share should not be forgotten. The main difference is regarding the fact that the university's policies could draw stricter lines for on-campus workers. Raising awareness and handling carbon reduction would be easier to manage. When working from home, the personal choices for producing less carbon are more involved. This thesis project concerns mostly the choices that include ICT equipment and the internet. In the following, some of the decisions that researchers could make are demonstrated (Uddin et al., 2017):

- Using equipment with eco-labels and the ones made with renewable energy and containing the eco-energy label.
- Utilizing equipment with low consumption and acceptable efficiency according to the energy label.
- Using product services like peer-to-peer or sharing and rental.
- Using client computers instead of desktop PCs.
- Managing windows startup applications and avoiding using screen savers.

Also, some other aspects worth considering are illustrated as follows (Javid, 2021):

- Internet usage habit (duration and time of the day)
- Choosing an internet provider with a carbon reduction commitment
- Number of equipment used

The thesis study addresses several further questions in this matter. An important question associated with personal choices is whether the internet transfer rate affects the internet's carbon footprint or not? Furthermore, is data usage an influential factor in this regard? Moreover, is it important to turn off the ICT equipment after finishing work, or is it enough to put them on sleep mode? It is planned to answer these questions in further sections.

Stewart & Khare (2012) evaluate the possibility of carbon footprint reduction of ICT usage at Athabasca University. First, the university's ICT sector and its contributing factors must be identified. Applying the Electronic Product Environmental Assessment Tool (EPEAT) and decreasing print waste using a series of steps are examples of carbon footprint reduction methods. Moreover, the following actions applied by AU have been helpful in reducing carbon footprint in the ICT sector:

- Increasing the data center's ambient temperature from 18 to 22 degrees Celsius.
- Implementing a central storage Array network to decrease the server's power consumption.
- Utilizing hardware for at least 12 months.
- Using laptops instead of PC towers.
- Applying power settings on computers to prevent unnecessary power consumption after working hours.
- Considering environmentally friendly process for end-of-life stage.

Li et al. (2015) administered an online survey to gain information about the carbon footprint of student behavior for a sustainable university campus at Shanghai University in China. The survey is created to give a better overview regarding students' energy consumption patterns and the effect of their behavior on the carbon footprint. Another study about energy saving suggested that approximately 10 to 20% of energy could be saved by changing some of the student's routine behavior (see Langevin et al., 2013). Furthermore, an insight gained from the questionnaire conducted by Nisiforou et al. (2012) about employee's energy-saving attitudes and behaviors questionnaire note that almost 28% of the employees do not turn their computers off when they are done working for the day (see Nisiforou et al., 2012).

The Li et al. (2015) survey concerns students' computer and lighting using habits. In this matter, a couple of various questions are asked, and the results are demonstrated in Table 6:

Table 6. Students' responses regarding their computer and lighting usage habits. (Li et al., 2015)

Question	**Answer**	**Percentage**
	Yes	22%
	No	43%

Do you turn off your computer, lights, and other electrical	Sometimes	35%
Do you turn off your computer, lights, and other electrical equipment when you are away for less than 10 minutes?	Yes	37%
	No	38%
	Sometimes	25%
Do you turn off your computer, lights, and other electrical equipment when you are away for more than one hour?	Yes	53%
	No	17%
	Sometimes	30%

By considering students' and staff's habits regarding ICT usage, Larsen et al. (2011) believe that turning the lights off when they are not needed or putting computers on standby mode instead leaving them on could have a considerable effect on the final carbon at NTNU University. Increasing equipment's lifetime and reducing waste should be encouraged as well.

5.2 Examples of carbon footprint reports regarding ICT equipment

Reducing the carbon footprint production in the ICT sector requires collecting information and data regarding the utilized equipment. In that case, some companies publish environmental reports about the CF production of their equipment. As an example of the carbon footprint of ICT equipment, Lenovo (2021) has published the CF report regarding the laptop ThinkPad T14 Gen 2 (2021) as follows:

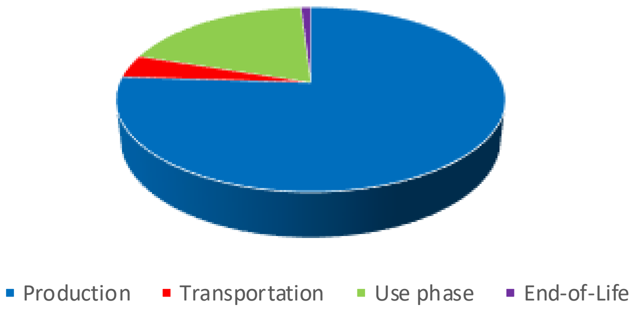

Figure 4. Share of main carbon footprint groups regarding laptop ThinkPad T14 Gen 2 (Lenovo, 2021).

- Total lifetime carbon footprint: 313 kg
- Production phase carbon footprint share: 76%

- Transportation carbon footprint share: 4%
- Use phase carbon footprint share: 19%
- End-of-life carbon footprint share: <1%
- Lifetime period: 5 years

As demonstrated in the example (Figure 4), the total carbon footprint is given for a lifetime of five years for this specific product. Thus, CF production accounts for 62.6 kg of CO2 as a yearly emission. In addition, and Lenovo has considered the 95th percentile of the carbon footprint as an estimation for this uncertainty (Lenovo, 2021).

As previously explained, the usage share is not calculated according to Finland's electricity production factors. To calculate the CF production for Finland's electricity usage, the measurement should be based on the factors given by Finnish sources. In this example, for instance, a rough estimation for electricity usage would be using the ICT's power consumption, which in this case it is 65 W. Then, by adding Finland's emission factor for consumed electricity and equipment's working time, the estimation for the carbon footprint usage phase could be calculated according to the following Equation (3):

Note that, according to the general collective agreement for universities, the annual working time for the university's teaching and research staff is 1,612 hours. (Tieteentekijat, 2020)

$$\text{Use Phase CF} = 65\ \text{W} \times 1{,}612\ \text{h} \times 72\ \left(\frac{\text{g CO}_2}{\text{kWh}}\right) = 7.55\ \text{kg CO}_2\text{e per year} \qquad (3)$$

As another example of electrical equipment, Apple's (2020) carbon footprint report regarding a 13 inches MacBook air (2020) is demonstrated as follows:

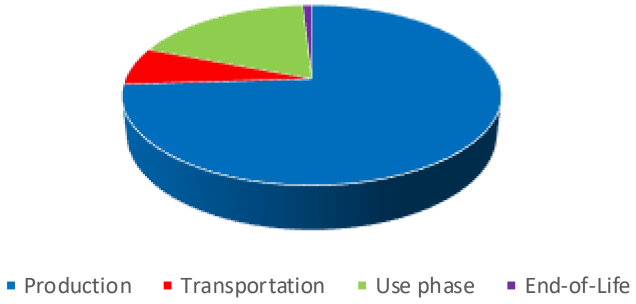

Figure 5. Share of main carbon footprint groups regarding laptop MacBook air (Apple, 2020).

- Total lifetime carbon footprint: 174 kg
- Production phase carbon footprint share: 77%
- Transportation carbon footprint share: 7%
- Use phase carbon footprint share: 15%
- End-of-life carbon footprint share: <1%
- Lifetime period: 4 years

As seen in the example (Figure 5), the total carbon footprint is reported for the whole lifetime. To compare different equipment with various lifetimes, the yearly carbon footprint is calculated. Moreover, as mentioned earlier, the use phase share is not calculated based on Finland's electricity. Considering this thesis project, the carbon footprint of the use stage should be calculated again according to Finland's electricity emission factor. Other types of ICT equipment follow the same method, but not all manufacturers publish carbon footprint reports for their equipment. Laptops and monitors account for the most published reports, but the lack of reports regarding headsets, keyboards, mouses, etc., affects the accuracy of the result.

To calculate the carbon footprint of the use phase, the same used method from the previous example is utilized. In this case, Apple has reported the 30 W of power consumption for a 13 inches MacBook air (2020). Thus, the calculation considering 1,612 hours of working time and 72 (g CO_2/kWh) for Finland's electricity emission factor (2020), would be as follows according to Equation (4):

$$\text{Use Phase CF} = 30\ \text{W} \times 1{,}612\ \text{h} \times 72\ \left(\frac{\text{g}\,CO_2}{\text{kWh}}\right) = 3.48\ \text{kg}\ CO_2\text{e per year} \qquad (4)$$

It is crucial to know that the estimation in both cases is done based on the equipment working at its full capacity all the time. That is why this method would not be accurate compared to measuring consumption with an energy metering device.

5.3 The Carbon footprint of the internet

Our daily routine activities cause environmental impacts. Now that internet has become part of our everyday life, do we consider its negative impacts on the environment? Every time we search for an article or send an email to a colleague, a certain amount of carbon dioxide is emitted, which might be negligible on a small scale, but considering almost 5 billion active internet users (Statista, 2021), this number would be significant. According to Climateimpact (2021), the carbon footprint of the internet and equipment we use for this purpose account for 3.7% of global emissions, which is similar to share of the airline industry. In addition, ESCP (2021) notes 1.6 billion tons of carbon dioxide is emitted, annually. This shows that, controlling and reducing emissions in this sector is critical. However, first, it is vital to better understand the components and sections responsible for the internet's carbon footprint.

The electricity consumption which is part of the ICT sector’s carbon footprint is divided in four main components (Climateimpact, 2021):

- Device usage
- Lifecycle of equipment
- Data centers
- Network

The device usage factor covers the carbon footprint regarding the utilized electricity for operating the device. On the other hand, the lifecycle of equipment includes the produced emissions starting from manufacturing and ending in the end-of-life stage. The methodology for calculating the carbon footprint for the electricity usage and lifecycle sectors was explained in chapter 6.3. Data centers and network components and their contribution to the carbon emissions are explained as following:

5.3.1 Data centers

There are three main elements contributing to the carbon footprint of data centers (Bouley, 2011):

Geographical location

Humidity and ambient temperature are the most crucial elements of this sector contributing to the electricity consumption of the data centers. A place that experiences high temperatures and humidity levels would consume more energy to cool down the components. In addition, energy sources and renewable energy contributions affect emission production considerably. Due to the fact that data centers consume a noticeable amount of electricity, renewable energies play a crucial role in reducing the carbon footprint. Moreover, based on the geographical location, peak hours vary between countries and data centers' operations during peak hours end up increasing the carbon footprint production.

IT components

IT components and their architecture represent the required energy for the operation process in a data center. Telecommunication devices, servers, computers, routers, monitoring and security systems, and storage equipment could be considered the main components in data centers. Due to the fact that more components consume more electricity, a higher carbon footprint is inevitable.

Efficiency

The old generation of data centers was compensating for inefficiency by oversizing the infrastructures and adding more components to the system. This resulted in more energy consumption and thus a higher carbon footprint. However, newer data centers use optimized software and infrastructures to overcome the lack of efficiency instead of adding more components to the system. Optimization is done by using better cooling, power, servers, and components technologies.

With a rising number of internet users, demands for data storage have been increasing. Thus, more data centers are required to cover the needs. Data centers consume a significant amount of energy, while servers, access switches, aggregation switches, and core switches account for 70%, 15%, 10%, and 5% of consumed energies by data centers, respectively. Using green energy would reduce consumption by 20 to 50%. (Batmunkh, 2022)

5.3.2 Network

The network carbon footprint consists of the produced emission due to data transmission. The energy is consumed by sending a request from the user where data is transmitted to data centers. The answer where data is transmitted from the data center to the user to complete the request also consumes energy. This process could be done through wires or even a wireless network. Furthermore, the number of transmitted data within a specific time period is called the data transfer rate (CDNetworks, 2021). This term demonstrates the internet's download and upload speed.

Each of the four mentioned components has a different share in total emissions based on the country being investigated. It is mostly due to the fact that countries have different infrastructures regarding their electricity production and the share of involved renewable energy. Batmunkh (2022) concludes that using technology has more negative effects on the environment than manufacturing the devices. This is because of the fossil fuels being used for producing electricity and the number of technology users increasing every day.

5.4 Calculating the internet's carbon footprint

Batmunkh (2022) proposes four different methods for measuring carbon footprints during internet activities. The methods are used to calculate the carbon footprint of watching one hour of online video. It is demonstrated that the results would be different based on the chosen calculation method. In the following, a short explanation for these methods is provided:

The shift project is one of the most well-known methods for measuring the carbon footprint of internet activities. This method considers the impacts of devices, networks, and data centers as the main involved factors. In addition, to calculate the environmental impact of watching online videos, viewing time has to be involved in this method (see The shift project, 2019). Furthermore, IEA (2021) has also published the required assumptions for the shift project. However, IEA (2020) notes that the figures reported by the shift project are significantly higher than they should be. IEA (2020) claims that the assumptions taken by the shift project are exaggerated based on the calculations done for the carbon footprint of streaming video.

Anders and Andrae (2015) have calculated the electricity consumption of ICT and networks based on the consumption of manufacturing, devices, networks, and data centers for two various scenarios. The scenarios include using 1 GB/hour and 3 GB/hour of data traffic.

Obringer et al. (2021) have mainly focused on the carbon footprint of online meetings regarding different available applications and the comparison with watching online videos. Also, water and land footrpint by gigabyte of internet use are considered in the calculation.

Hintemann & Hinterholze (2019) demonstrate that the carbon footprint production of online videos depends on the type of equipment used and the screen's resolution. In this method, first, the accumulated consumed energy is measured, and then the carbon footprint is calculated according to the utilized data traffic in GB.

As another method, Burtscher et al. (2020) propose using simple mathematics to calculate the carbon footprint of a 5-day meeting during the pandemic. The equation could be used for both measuring the emission of data transmission (5) and data centers (6). This method is also used for the calculation of internet carbon footprint regarding the University of Oulu's staff and students' emissions (see Javid, 2021). The Equations are as following:

$$CF_{DT} = t \times n \times EI_{DT} \times CI_{G} \times {}^{1\,\mathrm{kg}}/_{1000\,\mathrm{g}} \tag{5}$$

Where CF_{DT} refers to the carbon footprint of data transmission [kg CO_2e], t refers to network usage time [h], n is the number of users, EI_{DT} is data transmission network energy intensity [kWh/h], and CI_G refers to global carbon intensity [g CO_2e/kWh].

$$CF_{DC} = t \times n \times DTR \times {}^{1\,\mathrm{GB}}/_{1024\,\mathrm{MB}} \times {}^{1\,\mathrm{Byte}}/_{8\,\mathrm{bit}} \times CI_{G} \times {}^{1\,\mathrm{kg}}/_{1000\,\mathrm{g}} \tag{6}$$

Where CF_{DC} refers to the carbon footprint of data centers [kg CO_2], t refers to network usage time [h], n is the number of users, DTR is data transfer rate [Mbps], EI_{DC} is data centers energy intensity [kWh/GB], and CI_G refers to global carbon intensity [g CO_2e/kWh].

In the equations above, the information regarding data transmission network energy intensity, global carbon intensity, and energy intensity of data centers are published by

IEA (2021). The shift project has also reported the data regarding the aforementioned factors, but as mentioned earlier, IEA (2020) believes that this data is not accurate enough to be used in the calculations.

EXPERIMENTAL PART

6 STAFF SURVEY AND ELECTRICITY CONSUMPTION MEASUREMENTS

The Carbon Footprint Working Group (CFWG) was mandated to calculate the Carbon Footprint (CF) of the University of Oulu when the university decided to reduce its CF by 50% by 2025 compared to the level of 2019. The goal was to get a better understanding of the sectors responsible for the emissions produced and be able to propose solutions to mitigate the carbon footprint. The calculations on district heat, business travel, procurement, research and laboratory equipment, restaurant services, commuting, district fuel combustion, and property management sectors are done. As part of a summer internship, The CF of internet and ICT equipment for both staff and students on-campus was calculated in 2021 (Javid, 2021).

To achieve more accurate data in the carbon footprint calculation process, a survey was conducted to give a better perspective about staff's habits in case of ICT equipment usage during and after working hours. Fifty-four respondents answered the questions, and the results were used in the calculation process. In addition, a three-week of electricity consumption monitoring was done by employees considering laptops and monitors and their consumption during various modes. In that sense, instead of considering the full power capacity of ICT equipment, the average consumption of different usage modes was used for a more accurate CF calculation. The results demonstrate that staff is responsible for producing 82 tonnes of CO_2e due to internet usage. In addition, the yearly usage of ICT equipment accounts for 745.8 tonnes of CO_2e production if the staff works three days from home and the other two days on-campus during a week. It demonstrates that hybrid working increases the carbon footprint by roughly 36%.

According to the data calculated by the CFWG, 1.13 tonnes of CO_2e per person (not including the internet usage) is produced by the University of Oulu's staff and students during a year (University of Oulu, 2022a). Based on the calculation in this thesis project, approximately 148 kg CO_2e per capita is produced due to internet and ICT equipment used by staff during only on-campus working, which makes the total carbon footprint of 1.278 tonnes CO_2e per capita, annually. The summer internship research results illustrate that roughly 132 kg CO_2e is produced per capita. Produced emissions after working hours and during weekends were not considered as part of the calculation during the summer research. Moreover, the staff's habits were not part of the project. Thus, the results achieved in this thesis project are considerably more accurate.

In the multiple workplace mode, the university's staff procure the required extra equipment in their other workplaces. This will result in using more equipment than before the pandemic. Thus, the carbon footprint due to ICT equipment has increased. Furthermore, due to distance working, online meetings are held more often. As a result, electricity consumption and internet usage have increased significantly. In addition, when working from home, the university's control over carbon footprint production would be more challenging. For example, the electricity used at home might not be carbon neutral, so the overall emissions will increase.

6.1 Survey among staff

In order to calculate the carbon footprint of various types of ICT equipment used by staff for work purposes, the staff's habit regarding the ICT equipment usage is a crucial factor to investigate. Whether the CF emissions produced at home due to ICT equipment when remote working is the university's responsibility or not, measuring the carbon footprint facilitates finding methods to reduce emissions. To calculate the carbon footprint more accurately, it is important to map the ICT equipment and have a better understanding of the way they are used by the university's staff. To this effect, a survey was conducted through Webropol (2022) to assess the staff's habits regarding ICT equipment usage.

6.2 Hybrid working mode habits

The habit of using ICT equipment could be different from one person to another. Usually, people have various approaches while dealing with ICT equipment. For example, turning the laptop off, leaving it on, or putting it on sleep mode are different decisions that could be made after working time is done. This debate applies to some other ICT equipment like monitors or PC towers as well. Even if the emissions are not considerably large individually, choosing each of these options affects the final carbon footprint. The question was whether the differences are negligible or not. Moreover, ICT equipment consumption varies according to its type, brand, and model. It demonstrates that it is crucial what kind of equipment is used by staff. Usually, older equipment accounts for a higher carbon footprint, while the newer versions are mostly manufactured according to certain environmental standards.

Furthermore, the number of carried equipment between campus and home matters as well. In that case, the carbon footprint of that specific equipment accounts for both places, which should be considered differently compared to a situation where all equipment is installed stationary at the workplace.

The habit contains working hours and internet usage as well, because it matters how much the equipment is used every day. This approach applies to the internet too. The Internet has its own carbon footprint, and the results could differ between users and from one provider to another. This is because internet providers could use different shares of renewable energy. In addition, some of them might have their own plan for carbon footprint mitigation.

6.3 Survey results

The survey included 24 questions containing open-ended and multiple-choice (Appendix 1), with ten being mandatory and 14 optional. Fifty-four respondents have participated in the survey. The survey was conducted in Winter 2022 and therefore the remote work recommendation was still in place. The most important results of the survey are presented in the following:

6.3.1 Working time and preference

According to the respondents, the university's staff works for an average of 39 hours a week. Also, according to Figure 6, the majority of staff work from home five days a week, and only 8% work from campus every day.

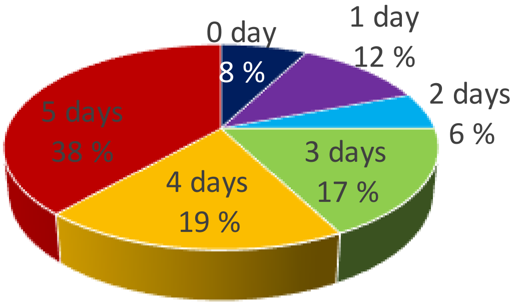

Figure 6. Share of the number of days the university staff work from home.

Moreover, Figure 7 illustrates that most employees prefer working from home between 4 to 5 days a week.

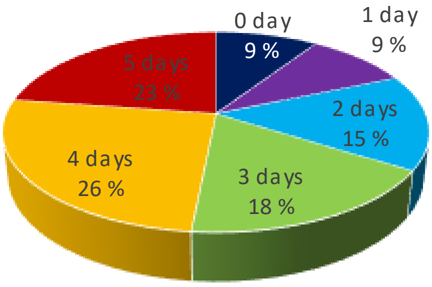

Figure 7. Share of the number of days the university staff prefer to work from home.

6.3.2 ICT equipment used at home and work

As one of the most important parts of the survey, participants were asked about various types of ICT equipment they use on-campus, at home, and carry between these two workplaces. Figures 11 and 12 demonstrate the types of ICT equipment and the numbers which staff use on-campus for work purposes, respectively.

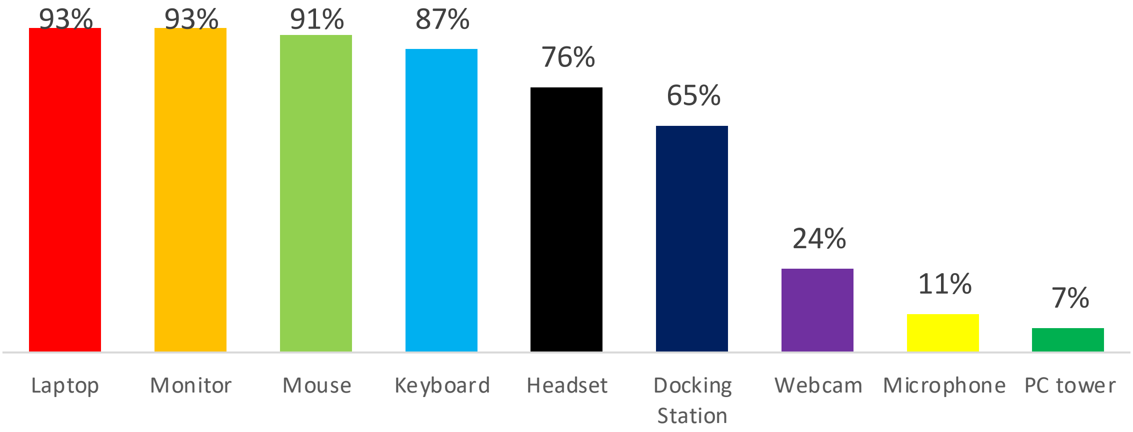

Figure 8. Types of ICT equipment being used by staff on-campus for work purposes.

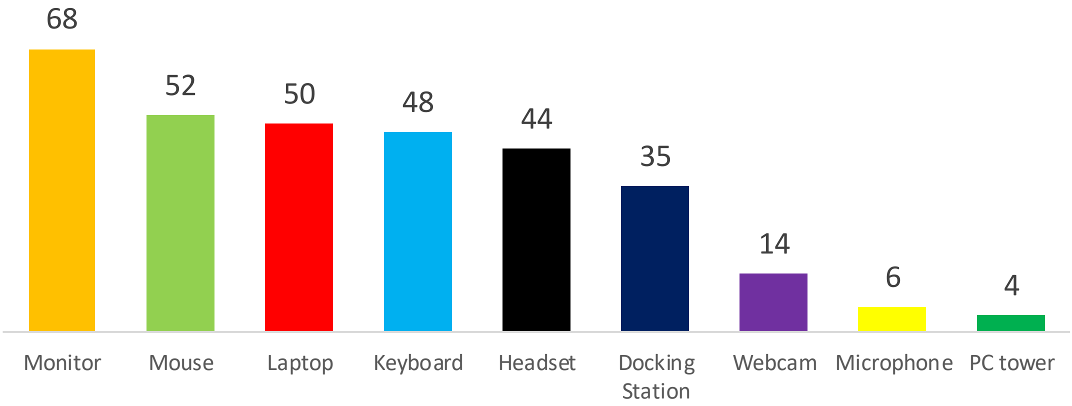

Figure 9. The number of ICT equipment being used by staff on-campus for work purposes.

According to Figure 8, laptops and monitors are used by 93% of staff, where PC towers with a 7% fraction are not widely used anymore. Mouse and keyboard are chosen by 91 and 87 percent of staff, respectively, which demonstrates their wide usage among the university's staff. In addition, Figure 9 shows that employees own on average more than one monitor. This average number for mouse, laptop, and keyboard is roughly one piece of equipment for each person.

Moreover, the types of ICT equipment and their numbers being carried by staff between campus and home are illustrated in Figures 10 and 11, respectively. Fifty-four respondents answered these two questions.

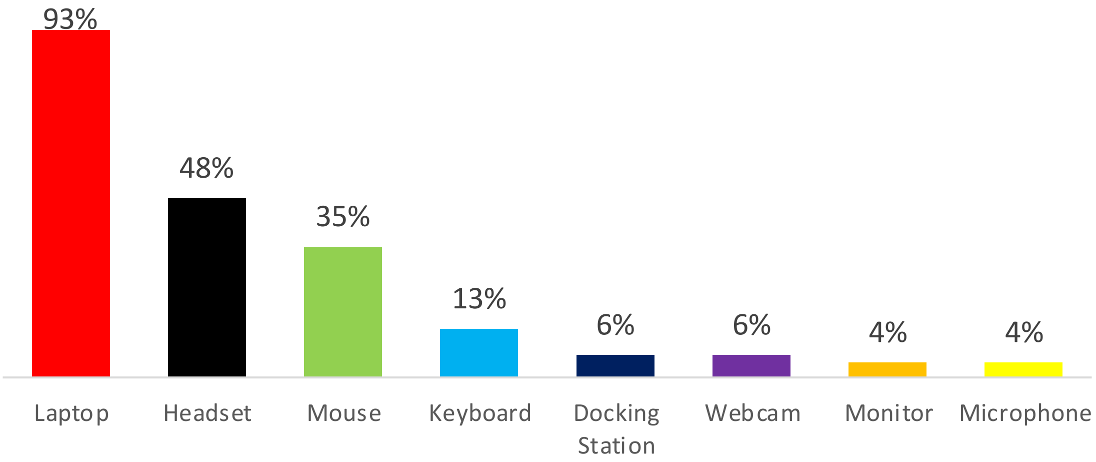

Figure 10. Types of ICT equipment being carried by staff between campus and home.

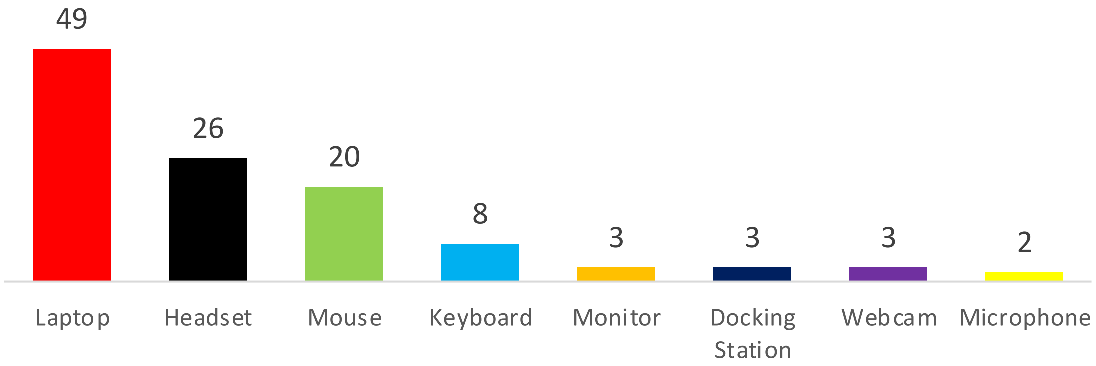

Figure 11. The number of ICT equipment being carried by staff between campus and home.

As demonstrated in Figure 10, almost all laptops are being carried between home and campus. Headset and mouse account for the next most carried equipment category, but with a considerable difference to the share of laptops. Figure 11 shows that 54 respondents carry 49 laptops between the two workplaces.

Figures 12 and 13 illustrate data about the additional ICT equipment being used by staff at home for work purposes. Fifty-four respondents answered these two questions, and approximately half of the employees use an additional mouse at home. Monitor, keyboard, headset, and laptop account for the largest fractions.

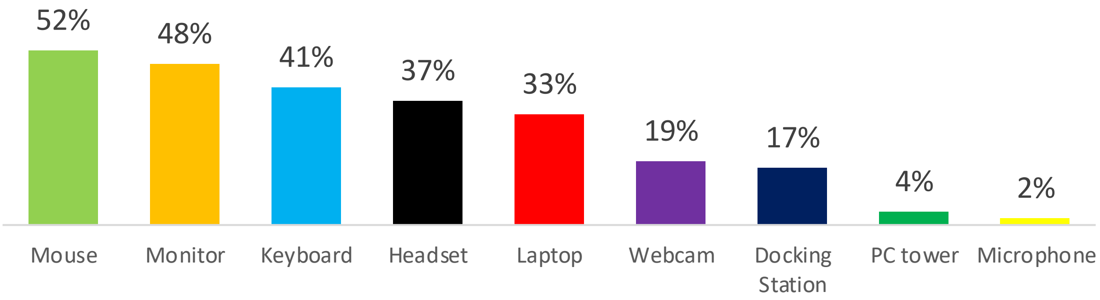

Figure 12. Additional types of ICT equipment being used by staff at home for work purposes.

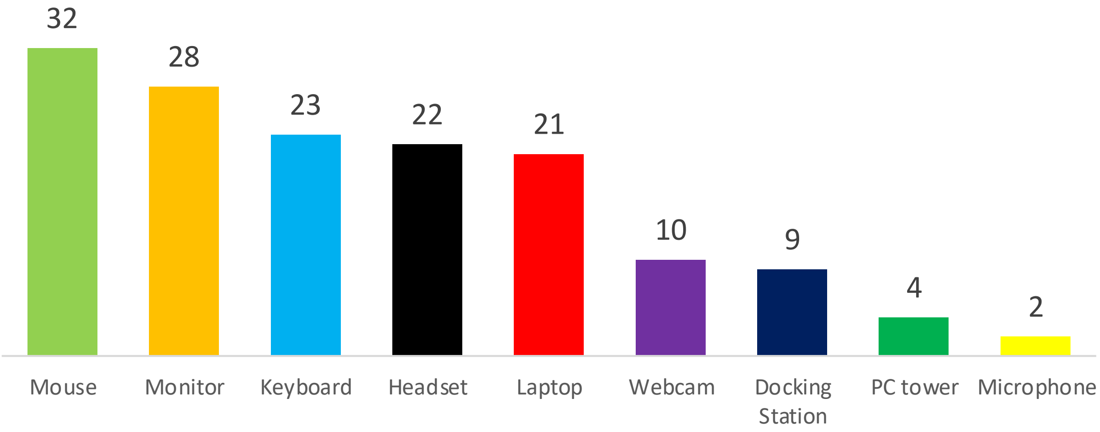

Figure 13. The additional number of ICT equipment being used by staff at home for work purposes.

In addition, participants were asked about the production year of their laptops and monitors used both on campus and at home. By analyzing the results given by the 20 respondents who answered this question, it seems that the ICT equipment being used at home is on average older compared to the one being used on-campus. Table 7 demonstrates the numbers in more detail.

Table 7. Average age of monitors and laptops used at home and at the university.

Equipment	Home	On-campus
Laptop	3-4 years	2-3 years
Monitor	3-4 years	2-3 years

6.3.3 Habits of using ICT equipment

In this part of the questions, participants were asked about their habits regarding laptops, monitors, and PC towers after they are done working for the weekdays and weekends.

For laptops and PC towers, leaving it on, putting on sleep or hibernate mode, or turning it off are considered as the only options. On the other hand, for the monitor, “on”, “standby”, and “off” are the options to be selected. Figure 17 demonstrates the results for staff’s habits in case of using laptops based on 53 respondents.

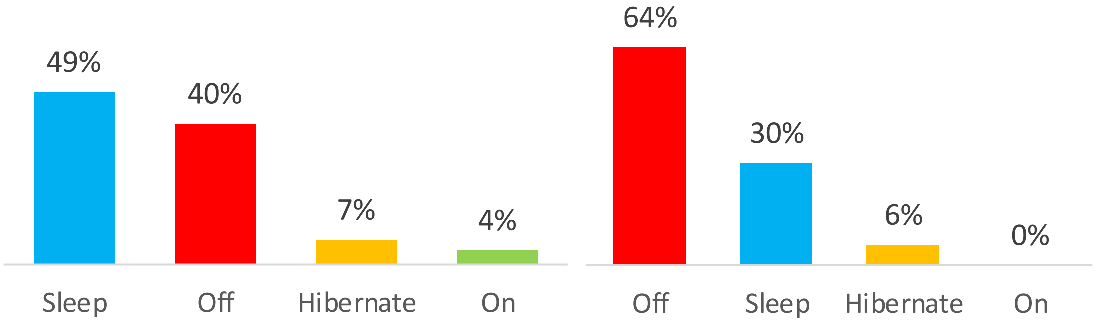

Figure 14. Left: Staff’s habits regarding the usage of laptop when they are done working for the day on weekdays. Right: Staff’s habits regarding the usage of laptop when they are done working for the day before weekends or holidays.

As illustrated in Figure 14, the results show that the majority of staff put their laptops on sleep mode after they are done working for the day on weekdays. On the other hand, turning the laptop off is the most popular choice taken by staff after they are done working for the day before weekends.

The same questions were asked about staff’s habits regarding monitors. Figure 16 demonstrates the results in more detail.

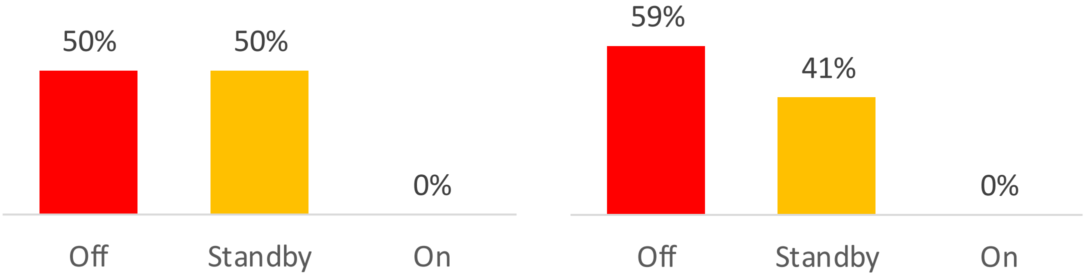

Figure 15. Left: Staff’s habits regarding the usage of monitor when they are done working for the day on weekdays. Right: Staff’s habits regarding the usage of monitor when they are done working for the day before weekends or holidays.

Based on the results illustrated in Figure 15, while half the people turn their monitors “off” when they are done working for the day on weekdays, the other half put them on "standby" mode. On the other hand, approximately 60% of staff turn their monitors "off" before starting the weekends. The other 40% put their monitors on "standby" mode. In both cases, no one leaves the monitor "on."

The same questions were asked about PC towers, and only 17 respondents answered the questions. It is mostly due to the fact that PC towers are no longer used as often as they used to be. Figure 16 shows the results of staff's habits regarding the usage of PC towers in more detail.

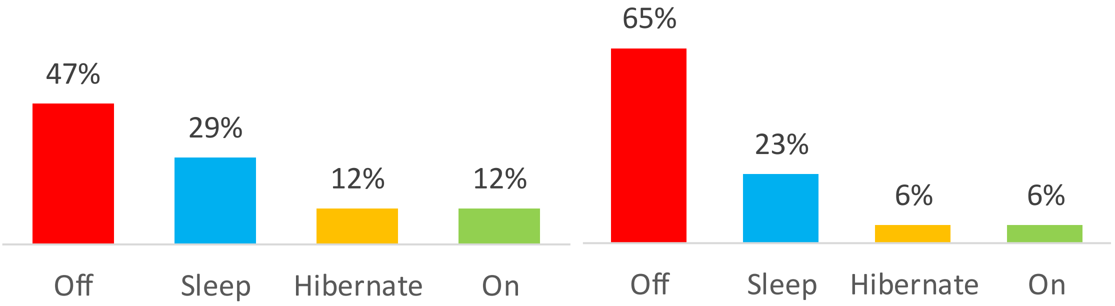

Figure 16. Left: Staff's habits regarding the usage of PC tower when they are done working for the day on weekdays. Right: Staff's habits regarding the usage of PC tower when they are done working for the day before weekends or holidays.

Figure 16 demonstrates that the majority of staff turns their PC towers "off" when they are done working for the day.

6.3.4 General information about the internet

As a part of the questions, participants were asked about some general information regarding the internet they use at home. Figure 17 illustrates the share of internet providers being used by staff. Figure The vast majority of staff seems to use DNA as their home internet provider. Elisa and Telia provide internet for 30% of staff in total. The remaining fraction (6%) accounts for other internet providers.

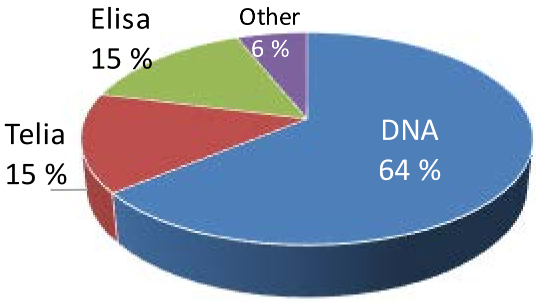

Figure 17. Share of internet providers being used by staff at home.

Moreover, Table 8 demonstrates the average internet usage and data transfer rate of the internet being used at home. Forty-nine respondents answered these questions on average.

Table 8. The average data transfer rate and internet usage per day

Average downloading data transfer rate	Average internet usage
210 Mbps	7 hours per day

6.4 Electricity consumption measurements

A crucial part of the carbon footprint of ICT equipment is its electricity consumption. As an empirical research of this thesis project, electricity consumption measurements for laptops and monitors were collected by five people. The monitoring was done during a periods of 2 to 3 weeks including working and after work hours. The measurements were done in various modes for these two equipment as follows:

- Laptop in-use and connected to the docking station
- Laptop not in-use but left on, and connected to the docking station
- Laptop in sleep mode and connected to the docking station
- Laptop in use, not connected to the docking station
- Laptop not in-use but left on, and not connected to the docking station
- Laptop on sleep mode, and not connected to the docking station
- Monitor in-use
- Monitor on sleep mode

The following equipment was used for measuring the electricity consumption:

Laptop: Lenovo ThinkPad T14 Intel (2020) (65W)

Docking station: Lenovo TP Hybrid USB-C Dock (2018) (135W)

Monitor: Lenovo ThinkVision T27h-20 flat panel monitor (2019)

Energy meter: Conecto home smart plug 16 A PM

Electricity consumption monitoring was done during two weeks and three weekends for laptops and a monitor during and after working hours. VPN connection is taken into consideration when the laptop is in-use while not connected to the docking station, as well as when the laptop is not in-use but left on and not connected to the docking station. Table 9 shows the results for the electricity consumption measurements.

Table 9. The electricity consumption measurements results.

Equipment	Mode	VPN	Average consumption per hour
Laptop	In-use (regular work), and connected to docking station	N/A	0.014 kWh
Laptop	In-use (meeting), and connected to docking station	N/A	0.035 kWh
Laptop	Not in use but left on, and connected to the docking station	N/A	0.012 kWh
Laptop	Sleep and connected to the docking station	N/A	0.01 kWh
Laptop	In-use and not connected to the docking station	On	0.033 kWh
Laptop	In-use and not connected to the docking station	Off	0.02 kWh
Laptop	Not in use but left on, and not connected to the docking station	On	0.0175 kWh
Laptop	Sleep and not connected to the docking station	Off	0 kWh
Monitor	In-use	-	0.02 kWh
Monitor	Sleep	-	0 kWh

The results demonstrate that laptops when left on but not used, consume almost the same amount of electricity as when they are in use. In contrast, when in sleep mode, their consumption is minimal. Therefore, staff will have to be instructed to engage the sleep mode while not in use, instead of just leave the laptops on. Furthermore, while monitors not used, go to sleep mode and do not consume any electricity.

7 RESULTS

This chapter summarizes the results of calculating the carbon footprint of university employees ICT use. This includes the emissions of both internet and ICT equipment use. For the latter, the data from the electricity consumption measurements are utilized.

7.1 Calculation of the internet's carbon footprint of the university's staff

As explained in chapter 5.3, the carbon footprint of the internet is divided into the emissions produced due to networks and data centers. The calculation process for the network's carbon footprint is shown in formula (7).

$$CF_{DT} = t \times n \times EI_{DT} \times CI_G \times {}^{1\,kg}/_{1000\,gr} \tag{7}$$

Where CF_{DT} refers to the carbon footprint of data transmission [kg CO_2e], t refers to network usage time [h], n is the number of users, EI_{DT} is data transmission network energy intensity [kWh/h], and CI_G refers to global carbon intensity [g CO_2e/kWh].

Based on the average working hours per week (36.25 hours) and the survey's results illustrated in section 9.2.4 regarding average internet usage per day, 1740 hours of working hours and internet usage are considered for staff annually. The University of Oulu (2022b) reports that 3700 employees are currently working at the university. Furthermore, IEA (2021) has published data transmission network energy intensity equal to 0.018 kWh/hours. In addition, the factor regarding global carbon intensity has been reported by Our world in data (2021) equal to 442 g CO_2e/kWh. The carbon footprint of data transmission for the University of Oulu's staff is demonstrated in Equation (8):

$$CF_{DT} = 1740 \times 3700 \times 0.018 \times 442 \times {}^{1\,kg}/_{1000\,gr} \times {}^{1\,t}/_{1000\,kg} = 51.22\ t\ CO_2e \tag{8}$$

Some elements in calculating the carbon footprint for data centers are the same as the ones that are involved in calculating the CF for networks as demonstrated in formula (7). Other than those factors, data transfer rate and data center energy intensity are involved. The data transfer rate (Mbps) is extracted by monitoring data traffic consumption in a week by using the "DU meter" software. Both, meetings and regular work, have been considered in this measurement (Table 9 in chapter 10). In addition, IEA (2021) has reported data center energy intensity in kWh/GB during the data transfer process. Data centers' carbon footprint is calculated using formula (9):

$$CF_{DC} = t \times n \times DTR \times EI_{DC} \times {}^{1\,GB}/_{1024\,MB} \times {}^{1\,Byte}/_{8\,bit} \times CI_G \times {}^{1\,kg}/_{1000\,g} \tag{9}$$

Where CF_{DC} refers to the carbon footprint of data centers [kg CO_2e], t refers to network usage time [h], n is the number of users, DTR is data transfer rate [Mbps], EI_{DC} is data centers energy intensity [kWh/GB], and CI_G refers to global carbon intensity [g CO_2e/kWh].

Network usage time, the number of staff, and global carbon intensity factors were explained earlier. The numbers for these elements are considered equal to 1740 (hours), 3700, and 442 g CO_2e/kWh, respectively. Furthermore, according to IEA (2021), data centers energy intensity is equal to 0.002 kWh/GB. Moreover, the result of data monitoring regarding the data transfer rate demonstrates that, on average, 1 Mbps of data transfer rate is utilized. The result for data centers' carbon footprint based on the explained factors is illustrated in Equation (10):

$$CF_{DC} = 1740 \times 3700 \times 1 \times 442 \times 0.002 \times \frac{1\ GB}{1024\ g} \times \frac{1\ Byte}{8\ bit} \times \frac{1\ kg}{1000\ g} \times \frac{1\ t}{1000\ kg} = 2.5\ t\ CO_2 e \tag{10}$$

Based on reported data by the University of Oulu's ICT service, the University of Oulu does not own data centers; thus, Oulu data center racks are used, which consume approximately 350,000 kWh per year. The cooling process for the racks is estimated to consume 350,000 kWh of electricity as well. Furthermore, telecommunication rooms, switches, and wireless base stations have a considerable share of electricity consumption, with 250,000 kWh and 920,000 kWh per year, respectively (Javid, 2021). The carbon footprint calculation regarding Oulu data center racks, cooling, telecommunication rooms, switches and stations are demonstrated in Equations (11), (12), (13), and (14), respectively.

$$\text{Oulu data center racks CF: } 350{,}000\ kWh \times 72\ {}^{g\,CO_2}/_{kWh} = 25.2\ t\ CO_2e \tag{11}$$

$$\text{Cooling CF: } 350{,}000\ kWh \times 72\ {}^{g\,CO_2}/_{kWh} = 25.2\ t\ CO_2e \tag{12}$$

$$\text{Telecommunication rooms CF: } 250{,}000\ kWh \times 72\ {}^{g\,CO_2}/_{kWh} = 18\ t\ CO_2e \tag{13}$$

Switches and stations CF: $920{,}000\ \text{kWh} \times 72\ {}^{\text{g}\,\text{CO}_2}/_{\text{kWh}} = 66.24\ \text{t}\ \text{CO}_2\text{e}$ (14)

The University of Oulu's students and staff together are responsible for all the consumption mentioned above. Due to the fact that 13800 students and 3700 staff members account for the consumption, the staff is responsible for approximately 21% of total consumption. As a result, 28.27 tonnes of CO_2e are produced per employee. So, data centers' carbon footprint was calculated by summing up 28.27 tonnes of CO_2e and 2.5 tonnes of CO_2e, which equals to 30.77 tonnes of CO_2e. Thus, the internet's carbon footprint was calculated by summing up the results obtained from the data centers' and networks' carbon footprints (see Equation (15)).

Data center CF+ Network CF= $(30.77+51.22)$ tonnes CO_2e= 82 t CO_2e (15)

Table 10 also demonstrates the results in the following:

Table 10. The annual carbon footprint of the internet's main contributors produced by the university's staff.

Network CF	Data centers CF	Total Internet CF
51.22 tonnes CO_2	30.77 tonnes CO_2	82 tonnes CO_2

7.2 Calculation of ICT equipment's carbon footprint of the university's staff

Calculating the carbon footprint of ICT equipment is done by summing up the produced emissions during manufacturing, transportation, usage, and end-of-life phases. Manufacturing, transportation, and end-of-life carbon footprint data are extracted from the reports published by the manufacturers. On the other hand, the information regarding the use phase is extracted from the data measured in chapter 10.

As investigated by the survey regarding the staff's habit of using the ICT equipment, the share of equipment used on-campus, at home, and the ones being carried between these two workplaces are summarized in Figure 18:

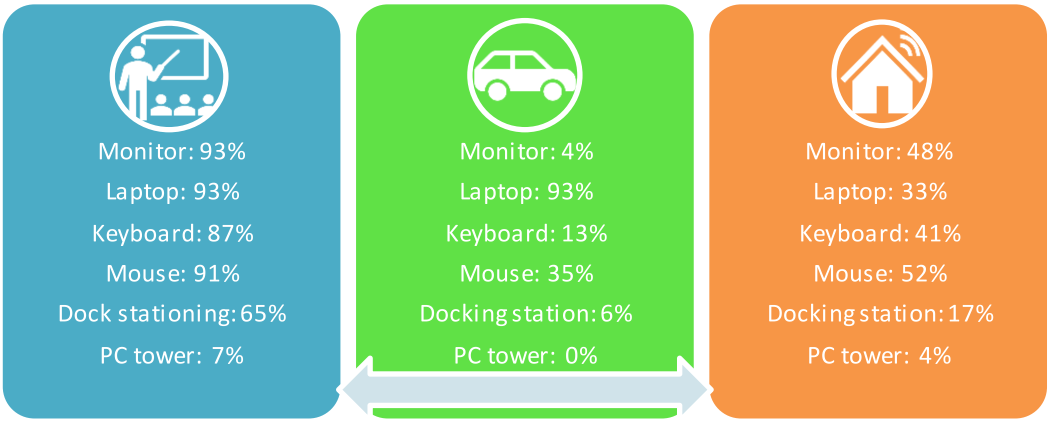

Figure 18. Share of ICT equipment used on-campus, at home, and being carried by staff between these two workplaces.

Thus, the carbon footprint calculation for ICT equipment regarding hybrid working is based on the share of equipment used by staff in both workplaces. In the following, the CF of ICT equipment used for the electricity measurement is explained in more detail. This equipment is used as a sample model for calculating the carbon footprint of the ICT sector.

7.2.1 Laptops' carbon footprint

Due to the fact that the vast majority of staff uses the Lenovo ThinkPad T14 Intel, this equipment is considered the main device for calculating the carbon footprint of laptops. However, due to the lack of data published by Lenovo for this specific model, the data for Lenovo ThinkPad T14 Gen 2 is utilized. The information regarding this device as published by Lenovo is demonstrated in Figure 19 (Lenovo, 2021):

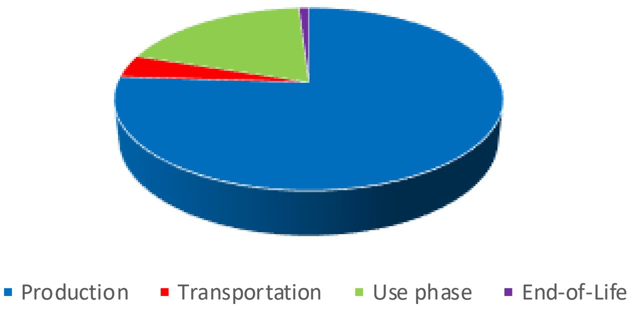

Figure 19. Share of main carbon footprint groups regarding laptop ThinkPad T14 Gen 2 (Lenovo, 2021).

- Total lifetime carbon footprint: 313 kg
- Production phase carbon footprint share: 76%
- Transportation carbon footprint share: 4%

- Use phase carbon footprint share: 19%
- End-of-life carbon footprint share: <1%
- Lifetime period: 5 years

According to the data presented in Figure 19, 313 kg of GHG emissions are produced during the five years of the laptop's estimated lifetime. For easier comparison, annual emissions are calculated. Thus, the annual carbon footprint for this device would be approximately 62.6 kg of CO_2e. Based on this number, the shares of the main factors involved in the carbon footprint are as following:

- Annual carbon footprint: 62.6 kg
- Production phase carbon footprint share: 47.6 kg
- Transportation carbon footprint share: 2.5 kg
- Use phase carbon footprint share: 11.9 kg
- End-of-life carbon footprint share: 0.62 kg

Revising each of these elements according to Finland's data would make the results more accurate. However, finding data in this regard is not the goal of this thesis project. So, only the use-phase carbon footprint share is calculated based on Finland's and the University of Oulu's data. Other factors are used exactly according to the data published by the manufacturers.

Table 11 demonstrates the approximate number of hours ICT equipment is used during weekdays, after working hours, and on weekends. The numbers are based on the fact that the university's staff work 36.25 hours a week. Also, Reclaim.ai (2021) claims that workers spent 21.5 hours of online meetings per week after the pandemic occurred. Considering this number and 40 hours of working time per week mentioned by Reclaimai (2021), staff spend 53.75% of their working time in meetings. As a result, during 7.25 hours of work time during a day for the university's staff, 4 hours are allocated to meetings, and the remaining 3.25 hours are allocated to regular work.

Table 11. Approximate number of hours ICT equipment are used during weekdays, after working hours, and weekends.

	Weekdays (During working hours)		**Weekdays (after working hours)**	**Weekends**
	Meetings	Regular work		
Monday	4	3.25	8.35	8
Tuesday	4	3.25	16.35	-
Wednesday	4	3.25	16.35	-
Thursday	4	3.25	16.35	-
Friday	4	3.25	8	8.35
Saturday	-	-	-	24
Sunday	-	-	-	24

The electricity consumption measurements for laptops as presented in chapter 10. The carbon footprint calculations regarding laptop's various usage modes are done based on these two approaches:

- Laptop connected to the docking station
- Laptop not connected to the docking station

In the following, the calculations of electricity consumption and the carbon footprint of laptops when connected and not connected to the docking stations are presented:

A laptop's average annual consumption when connected to the docking station

Weekdays (during working hours):

Considering Tables 11 and 12, the weekly electricity usage of the laptop when connected to the docking station during working hours, for both meeting hours and regular work, is shown in Equations (16) and (17), respectively.

Meeting hours: $20\ {}^{\text{hours}}/_{\text{week}} \times 0.035\ {}^{\text{kWh}}/_{\text{hour}} = 0.7\ \text{kWh}$ (16)

Regular work: $16.25\ {}^{\text{hours}}/_{\text{week}} \times 0.014\ {}^{\text{kWh}}/_{\text{hour}} = 0.2275\ \text{kWh}$ (17)

Weekdays (after working hours):

The calculation for a laptop's avearge weekly electricity consumption when it is put on sleep mode and left on after working hours is demonstrated in Equations (18) and (19), respectively. Based on the survey conducted in chapter 9, 56% of the staff put their laptops on sleep mode, and 4% leave them on after they are done working for the day during weekdays.

$$\text{Sleep mode: } 65.4\ {}^{\text{hours}}/_{\text{week}} \times 56\% \times 0.01\ {}^{\text{kWh}}/_{\text{hour}} = 0.3662 \text{ kWh} \tag{18}$$

$$\text{Left on: } 65.4\ {}^{\text{hours}}/_{\text{week}} \times 4\% \times 0.012\ {}^{\text{kWh}}/_{\text{hour}} = 0.0314 \text{ kWh} \tag{19}$$

Weekends:

The survey also shows that 36% of staff members put their laptops on sleep mode when they are done working before weekends and holidays. Others turn their laptops off. Based on these results, the laptop's average weekend consumption is calculated according to Equation (20). Equations (21), (22), and (23) illustrate total weekly consumption, weekly usage CF, and daily usage carbon footprint, respectively.

$$\text{Sleep mode: } 64.35\ {}^{\text{hours}}/_{\text{week}} \times 36\% \times 0.01\ {}^{\text{kWh}}/_{\text{hour}} = 0.2316 \text{ kWh} \tag{20}$$

$$\text{Weekly consumption when connected to docking station} = 1.5567 \text{ kWh} \tag{21}$$

$$\text{Weekly use-phase CF: } 1.5567 \text{ kWh} \times 72\ {}^{\text{g } CO_2}/_{\text{kWh}} = 112.08 \text{ g } CO_2e \tag{22}$$

Based on the calculations, the average carbon footprint of the laptop's daily usage would be equal to 16.01 g CO_2e. So, by calculating the daily CF of a laptop demonstrated in Figure 19 for three phases (production, transportation, and end-of-life) and add them to 16.01 g CO_2e of the laptop's daily usage CF, the total daily carbon footprint of 154.91 g CO_2 is obtained.

Laptop annual consumption when not connected to the docking station

Weekdays (during working hours):

Weekly laptop consumption when it is not connected to the docking station is not separately measured during regular work and meeting hours. Thus, average hourly consumption is considered. Equation (23) represents the weekly consumption of laptop during working hours.

$$36.25\ {}^{\text{hours}}/_{\text{week}} \times 0.0265\ {}^{\text{kWh}}/_{\text{hour}} = 0.9606\ \text{kWh} \tag{23}$$

Weekdays (after working hours):

Based on the survey, 4% of staff leave their laptops on when they are done working after working hours during weekdays. 56% put them on sleep mode, but Table 12 shows zero consumption when the laptop is on sleep mode and not connected to the docking station. As a result, Equation (24) demonstrates the weekly consumption only when the laptop is left on.

$$\text{Left on: } 65.4\ {}^{\text{hours}}/_{\text{week}} \times 4\% \times 0.0175\ {}^{\text{kWh}}/_{\text{hour}} = 0.0457\ \text{kWh} \tag{24}$$

Total weekly consumption, weekly use-phase CF, and daily usage carbon footprint regarding laptops not connected to the docking station are demonstrated in Equations (25), (26), and (27), respectively.

$$\text{Weekly consumption when not connected to docking station} = 1.0063\ \text{kWh} \tag{25}$$

$$\text{Weekly use-phase CF: } 1.0063\ \text{kWh} \times 72\ {}^{\text{g}\,\text{CO}_2}/_{\text{kWh}} = 72.45\ \text{g}\,\text{CO}_2e \tag{26}$$

Based on the calculations, the daily usage carbon footprint would be equal to 10.35 g CO_2e. So, by calculating the daily CF of a laptop demonstrated in Figure 19 for three phases (production, transportation, and end-of-life) and add them to 10.35 g CO_2e of the laptop's daily usage CF, the total daily carbon footprint of 149.25 g CO_2 is obtained.

Table 12 sums up the results achieved for laptops when connected and not connected to the docking station due to the calculations above.

Table 12. The laptop's daily carbon footprint when connected and not connected to the docking station.

CF, when connected to the docking station	CF, when not connected to the docking station
154.91 g CO_2e	149.25 g CO_2e

7.2.2 Monitors' carbon footprint

The measuring of the monitor's electricity consumption was done based on extracted data from Lenovo ThinkVision T27h-20. Lenovo (2019) has published the carbon footprint data for this device regarding four main carbon footprint phases. Figure 20 shows the share of these phases as following:

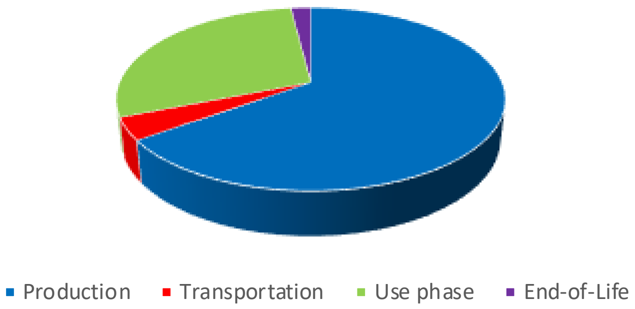

Figure 20. Share of main carbon footprint groups regarding Monitor Lenovo ThinkVision T27h-20.

- Total lifetime carbon footprint: 273 kg
- Production phase carbon footprint share: 65%
- Transportation carbon footprint share: 4%
- Use phase carbon footprint share: 29%
- End-of-life carbon footprint share: 2%
- Lifetime period: 2 years

- Annual carbon footprint: 136.5 kg
- Production phase carbon footprint share: 88.72 kg
- Transportation carbon footprint share: 5.46 kg
- Use phase carbon footprint share: 39.59 kg
- End-of-life carbon footprint share: 2.73 kg

The results from electricity monitoring demonstrate that the monitor does not consume electricity in sleep mode and when it is turned off. On the other hand, an average of 0.02 kWh per hour was measured with the energy meter during the monitoring. Table 13 illustrates the results:

Table 12. A monitor's hourly electricity consumption in different modes.

Equipment	Mode	Average consumption per hour
Monitor	In-use	0.02 kWh
Monitor	Sleep	0 kWh
Monitor	Off	0 kWh

Weekdays (during working hours):

Due to the fact that survey's participants (results shown in chapter 9) claimed that they either turn their monitors off or put them on sleep mode after working hours, electricity consumption is only calculated during working hours on weekdays. Equations (27) and (28) show the results regarding the monitor's weekly usage and use-phase carbon footprint, produced during working hours, respectively.

$$36.25\ {}^{\text{hours}}/_{\text{week}} \times 0.02\ {}^{\text{kWh}}/_{\text{hour}} = 0.725\ \text{kWh} \tag{27}$$

$$\text{Weekly use-phase CF: } 0.725\ \text{kWh} \times 72\ {}^{\text{g CO}_2}/_{\text{kWh}} = 52.2\ \text{g CO}_2 e \tag{28}$$

Based on the calculations, daily usage carbon footprint would be equal to 7.46 g CO_2e. So, by calculating the daily CF of a monitor demonstrated in Figure 20 for three phases (production, transportation, and end-of-life) and add them to 7.46 g CO_2e of the monitor's daily usage CF, the total daily carbon footprint of 272.96 g CO_2 is obtained.

7.2.3 PC towers' carbon footprint

PC towers are not as widely used as before; however, based on the survey results conducted in chapter 9, 7% of staff still use this device. Therefore, the carbon footprint of this equipment should be considered in the calculation. Based on the information given by the University of Oulu's ICT service, Dell Optiplex 3050 pc tower is utilized by a considerable number of people on-campus. Thus, the information regarding this equipment as published by Dell (2018) is considered as the model of the calculation and illustrated in Figure 21.

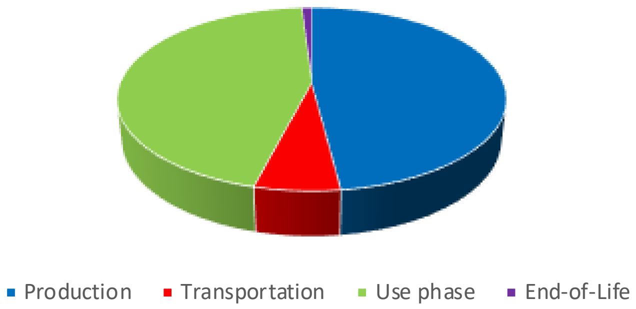

Figure 21. Share of main carbon footprint groups regarding PC tower Dell Optiplex 3050.

- Total lifetime carbon footprint: 432 kg
- Production phase carbon footprint share: 48%
- Transportation carbon footprint share: 6%
- Use phase carbon footprint share: 45%
- End-of-life carbon footprint share: 1%
- Lifetime period: 4 years

- Annual carbon footprint: 108 kg
- Production phase carbon footprint share: 51.84 kg
- Transportation carbon footprint share: 6.48 kg
- Use phase carbon footprint share: 48.6 kg
- End-of-life carbon footprint share: 1.08 kg
- Power: 240 W

Power usage of 240 W is reported by the manufacturer as the full power capacity of this specific equipment. Thus, this number is used for the calculation of electricity usage and carbon footprint production. Equations (29) and (30) illustrate the results of the weekly electricity consumption and use-phase carbon footprint of this equipment, respectively.

$$\text{Weekly consumption: } 240\text{W} \times 36.25\ {}^{\text{hours}}/_{\text{week}} = 8.7\text{ kWh} \tag{29}$$

$$\text{Weekly use-phase CF: } 8.7\text{ kWh} \times 72\ {}^{\text{g}\,\text{CO}_2}/_{\text{kWh}} = 626.4\text{ g}\,\text{CO}_2 e \tag{30}$$

Based on the calculations, the daily usage carbon footprint would be equal to 89.48 gr CO_2. So, by calculating the daily CF of a PC tower demonstrated in Figure 21 for three phases (production, transportation, and end-of-life) and add them to 89.48 g CO_2e of the PC tower's daily usage CF, the total daily carbon footprint of 252.22 g CO_2e is obtained.

7.2.4 Docking stations' carbon footprint

According to the survey conducted in chapter 9, the docking station is used by 65% of staff while working on-campus. In addition, 17% of staff claimed that they use an additional docking station at home. So, this equipment is important to be included in the calculation. However, no manufacturer has published a carbon footprint report specifically regarding docking stations. The only report that could be found is regarding Lenovo Thinkedge SE30, which is the closest device to the docking station. The carbon footprint share for this device and its main carbon footprint elements are demonstrated in Figure 22:

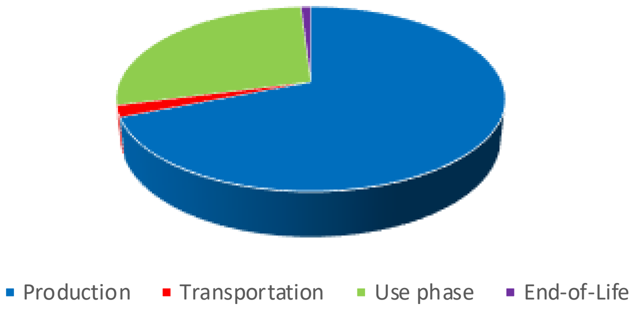

Figure 22. Share of main carbon footprint groups regarding Lenovo Thinkedge SE30.

- Total lifetime carbon footprint: 541 kg
- Production phase carbon footprint share: 69%
- Transportation carbon footprint share: 2%
- Use phase carbon footprint share: 28%
- End-of-life carbon footprint share: <1%
- Lifetime period: 5 years
- Power: 65 W

- Annual carbon footprint: 108.2 kg
- Production phase carbon footprint share: 74.66 kg
- Transportation carbon footprint share: 2.16 kg

- Use phase carbon footprint share: 30.3 kg
- End-of-life carbon footprint share: 1.08 kg

A reported power of 65 W is used for the calculation of electricity consumption and carbon footprint. Equations (31) and (32) demonstrate the results regarding weekly electricity consumption and use-phase CF, respectively.

$$\text{Weekly consumption: } 65\text{W} \times 36.25\ {}^{\text{hours}}/_{\text{week}} = 2.35\ \text{kWh} \tag{31}$$

$$\text{Weekly use-phase CF: } 2.35\ \text{kWh} \times 72\ {}^{\text{g}\,\text{CO}_2}/_{\text{kWh}} = 169.2\ \text{g}\,\text{CO}_2 e \tag{32}$$

Based on the calculations, the daily usage carbon footprint would be equal to 24.17 g CO_2e. So, by calculating the daily CF of a docking station demonstrated in Figure 22 for three phases (production, transportation, and end-of-life) and add them to 24.17 g CO_2e of the docking station's daily usage CF, the total daily carbon footprint of 255.6 g CO_2 is obtained.

7.2.5 Keyboards' carbon footprint

The survey demonstrates that keyboards are used by 87% of staff when working on-campus and 41% of staff when working from home. Thus, to calculate the carbon footprint of this equipment, the report published by Logitech (2020) based on the carbon footprint production of the G213 gaming keyboard is utilized. This carbon footprint report is the only report found regarding a keyboard's carbon footprint. Therefore, this model is considered the sample model for the calculation. Detailed information is demonstrated in Figure 23:

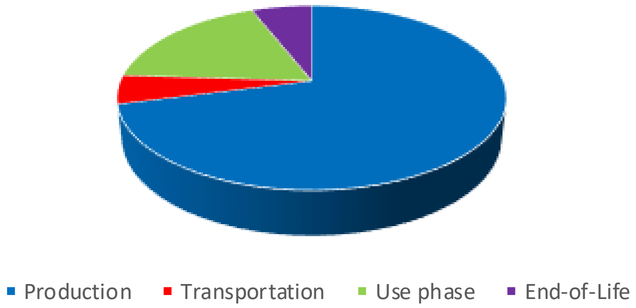

Figure 23. Share of main carbon footprint groups regarding Keyboard Logitech G213.

- Total lifetime carbon footprint: 22 kg

- Production phase carbon footprint share: 71%
- Transportation carbon footprint share: 5%
- Use phase carbon footprint share: 18%
- End-of-life carbon footprint share: 6%
- Lifetime period: 2 years

- Annual carbon footprint: 11 kg
- Production phase carbon footprint share: 7.81 kg
- Transportation carbon footprint share: 0.55 kg
- Use phase carbon footprint share: 1.98 kg
- End-of-life carbon footprint share: 0.66 kg

So, by calculating the daily total CF of a keyboard based on the total annual carbon footprint (11 kg) demonstrated in Figure 23, 30.13 g CO_2e is obtained. In addition, daily use-phase CF would be equal to 5.42 g CO_2e. These two numbers are used for further calculations.

7.2.6 Mouses' carbon footprint

Same as for the keyboard, Logitech is the only manufacturer who has published carbon footprint reports for several mouses. As a sample model for the calculation, Logitech G Pro wireless was chosen. Furthermore, the survey results show that in addition to 91% of the staff using a mouse when working on-campus, 52% utilize an additional mouse when working from home. The carbon footprint data regarding this equipment published by Logitech (2020) is illustrated in Figure 24:

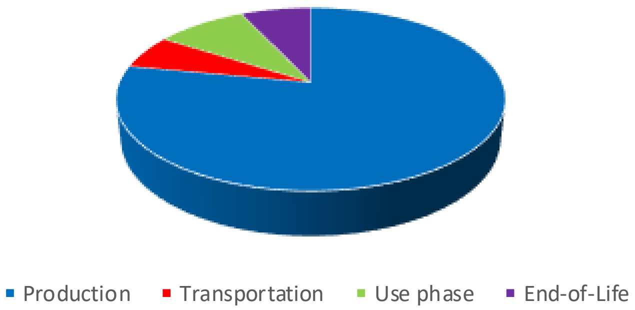

Figure 24. Share of main carbon footprint groups regarding Mouse Logitech G Pro wireless.

- Total lifetime carbon footprint: 7.84 kg

- Production phase carbon footprint share: 78%
- Transportation carbon footprint share: 6%
- Use phase carbon footprint share: 9%
- End-of-life carbon footprint share: 7%
- Lifetime period: 2 years

- Annual carbon footprint: 3.92 kg
- Production phase carbon footprint share: 3.06 kg
- Transportation carbon footprint share: 0.26 kg
- Use phase carbon footprint share: 0.35 kg
- End-of-life carbon footprint share: 0.28 kg

So, by calculating the daily total CF of a mouse based on the total annual carbon footprint (3.92 kg) demonstrated in Figure 24, 10.74 g CO_2e is obtained. In addition, daily use-phase CF would be equal to 0.96 g CO_2e. These two numbers are used for further calculations.

7.3 The carbon footprint of ICT equipment when working on-campus

The carbon footprint of ICT equipment used by staff is calculated based on the results extracted from the survey and electricity consumption measurements. In addition, reports published by the manufacturers have been used. According to the carbon footprint of each equipment as demonstrated in the previous chapters, the total annual CF for the staff working on-campus is calculated.

Equations (33) and (34) calculate the total daily carbon footprint of laptops used by staff on-campus when connected and not connected to the docking stations, respectively.

$$3700\ (\text{staff}) \times 93\%\ (\text{own laptop}) \times 65\%\ (\text{connected to the docking station}) \times 154.91\ \text{g}\,CO_2 = 346.48\ \text{kg}\,CO_2e \tag{33}$$

$$3700\ (\text{staff}) \times 93\%\ (\text{own laptop}) \times 35\%\ (\text{not connected to the docking station}) \times 149.25\ \text{g}\,CO_2 = 179.75\ \text{kg}\,CO_2e \tag{34}$$

Equation (35) demonstrates the total carbon footprint of monitors used by staff on-campus.

$$3700\text{ (staff)} \times 93\%\text{ (own monitor)} \times 272.96\text{ g }CO_2e = 939.25\text{ kg }CO_2e \tag{35}$$

Equation (36) illustrates the total carbon footprint of mouses used by staff on-campus.

$$3700\text{ (staff)} \times 91\%\text{ (Own Mouse)} \times 10.74\text{ g }CO_2e = 36.16\text{ kg }CO_2e \tag{36}$$

Equation (37) shows the total carbon footprint of keyboards used by staff on-campus.

$$3700\text{ (staff)} \times 87\%\text{ (Own keyboard)} \times 30.13\text{ g }CO_2e = 96.99\text{ kg }CO_2e \tag{37}$$

Equation (38) demonstrates the total carbon footprint of docking stations used by staff on-campus.

$$3700\text{ (staff)} \times 65\%\text{ (Own docking station)} \times 255.6\text{ g }CO_2e = 614.72\text{ kg }CO_2e \tag{38}$$

Equation (39) illustrates the total carbon footprint of PC towers used by staff on-campus.

$$3700\text{ (staff)} \times 7\%\text{ (Own PC tower)} \times 252.22\text{ g }CO_2e = 65.32\text{ kg }CO_2e \tag{39}$$

The daily total carbon footprint of all equipment used by staff on-campus would be equal to 2.28 tonnes of CO_2e. The results are also demonstrated in Table 14 as following:

Table 13. The daily carbon footprint of ICT equipment used by staff when working on-campus.

Equipment	**Daily carbon footprint**
Laptop connected to the docking station	346.48 kg CO_2e
Laptop not connected to the docking station	179.75 kg CO_2e
Monitor	939.25 kg CO_2e
Mouse	36.16 kg CO_2e
Keyboard	96.99 kg CO_2e
Docking station	614.72 kg CO_2e
PC tower	65.32 kg CO_2e
Total carbon footprint	**2.28 tonnes CO_2e**

7.4 The carbon footprint of additional ICT equipment used while remote working

The calculation in this section is done based on the results extracted from the survey and the electricity consumption measurement. In addition, the data regarding the carbon footprint of equipment published by the manufacturers are utilized. In the following, the calculation process is shown.

Equations (40) and (41) calculate the total carbon footprint of laptops used by staff at home when connected and not connected to the docking stations, respectively.

$$3700\text{ (staff)} \times 33\%\text{ (own laptop)} \times 17\%\text{ (connected to the docking station)} \times 154.91\text{ g }CO_2e = 32.15\text{ kg }CO_2e \quad (40)$$

$$3700\text{ (staff)} \times 33\%\text{ (own laptop)} \times 83\%\text{ (not connected to the docking station)} \times 149.25\text{ g }CO_2e = 151.25\text{ kg }CO_2e \quad (41)$$

Equation (42) demonstrates the total carbon footprint of additional monitors used by staff at home.

$$3700\text{ (staff)} \times 48\%\text{ (own monitor)} \times 272.96\text{ g }CO_2e = 484.77\text{ kg }CO_2e \quad (42)$$

Equation (43) illustrates the total carbon footprint of additional mouses used by staff at home.

$$3700\text{ (staff)} \times 52\%\text{ (Own Mouse)} \times 10.74\text{ g }CO_2e = 20.66\text{ kg }CO_2e \quad (43)$$

Equation (44) shows the total carbon footprint of additional keyboards used by staff at home.

$$3700\text{ (staff)} \times 41\%\text{ (Own keyboard)} \times 30.13\text{ g }CO_2e = 45.7\text{ kg }CO_2e \quad (44)$$

Equation (45) demonstrates the total carbon footprint of additional docking stations used by staff at home.

$$3700\text{ (staff)} \times 17\%\text{ (Own docking station)} \times 255.6\text{ g }CO_2e = 160.77\text{ kg }CO_2e \quad (45)$$

Equation (46) illustrates the total carbon footprint of additional PC towers used by staff at home.

$$3700 \text{ (staff)} \times 4\% \text{ (Own PC tower)} \times 252.22 \text{ g } CO_2e = 37.32 \text{ kg } CO_2e \tag{46}$$

The daily total carbon footprint of all additional equipment used by staff at home would be equal to 932.62 kg CO_2e. The results are also illustrated in Table 15:

Table 15. The daily carbon footprint of ICT equipment used by staff when working at home.

Equipment	Daily carbon footprint
Laptop connected to the docking station	32.15 kg CO_2e
Laptop not connected to the docking station	151.25 kg CO_2e
Monitor	484.77 kg CO_2e
Mouse	20.66 kg CO_2e
Keyboard	45.7 kg CO_2e
Docking station	160.77 kg CO_2e
PC tower	37.32 kg CO_2e
Total carbon footprint	**932.62 kg CO_2e**

7.5 The carbon footprint of equipment being carried between campus and home

This section is allocated to the equipment being carried by staff between campus and home. To prevent duplicate calculations, only the carbon footprint of the use phase is considered, and other equipment phases involved in the emissions production are omitted. In the following, the calculation process is shown.

Equations (47) and (48) calculate the daily carbon footprint of laptops being carried by staff when connected and not connected to the docking stations, respectively.

$$3700 \text{ (staff)} \times 93\% \text{ (carry laptop)} \times 6\% \text{ (connected to the docking station)} \times 16.01 \text{ g } CO_2e = 3.3 \text{ kg } CO_2e \tag{47}$$

$$3700 \text{ (staff)} \times 93\% \text{ (carry laptop)} \times 94\% \text{ (not connected to the docking station)} \times 10.35 \text{ g } CO_2e = 33.48 \text{ kg } CO_2e \tag{48}$$

Equation (49) illustrates the daily carbon footprint of mouses being carried by staff between two workplaces.

$$3700\ (\text{staff}) \times 35\%\ (\text{carry mouse}) \times 0.96\ \text{g}\ CO_2e = 1.24\ \text{kg}\ CO_2e \qquad (49)$$

Equation (50) shows the daily carbon footprint of keyboards being carried by staff between campus and home.

$$3700\ (\text{staff}) \times 13\%\ (\text{carry keyboard}) \times 5.42\ \text{g}\ CO_2e = 2.6\ \text{kg}\ CO_2e \qquad (50)$$

Equation (51) demonstrates the daily carbon footprint of docking stations being carried by staff.

$$3700\ (\text{staff}) \times 6\%(\text{carry docking station}) \times 24.17\ \text{g}\ CO_2e = 5.36\ \text{kg}\ CO_2e \qquad (51)$$

The results are also illustrated in Table 16:

Table 14. The daily carbon footprint of ICT equipment being carried by staff between campus and home.

Equipment	**Daily carbon footprint**
Laptop connected to the docking station	3.3 kg CO_2e
Laptop not connected to the docking station	33.48 kg CO_2e
Mouse	1.24 kg CO_2e
Keyboard	2.6 kg CO_2e
Docking station	5.36 kg CO_2e
Total carbon footprint	**45.98 kg CO_2e**

8 DISCUSSION OF THE RESULTS

The University of Oulu is taking action to reduce its carbon footprint by 50% by 2025 compared to the level of 2019 (University of Oulu, 2022a). In accordance with the carbon reduction methods and commitments, the next step would be achieving carbon neutrality by 2030. Accomplishing this goal requires investigating the sources of carbon footprint and making plans to mitigate the emissions. In this regard, district heat, business travel, procurements, research and laboratory equipment, restaurant services, commuting, direct fuel combustion, and property management sectors have already been investigated by the CFWG. The carbon footprint of these sectors was also calculated. This thesis project focuses more on the carbon footprint of ICT equipment and internet produced based on the habits of the University of Oulu's staff members. A survey was conducted to gain a better understanding of staff's habits regarding the usage of ICT equipment and the internet. In addition, measurements of electricity consumption were done for laptops and monitors following various working modes.

Electricity consumption measurements were conducted by five people during a monitoring period of 2 to 3 weeks. The consumptions of laptops were monitored via an energy meter device when the laptop is in use, left on but not in use, and during sleep mode. The effect of VPN and docking stations on consumption was investigated as well. In addition, the different consumption during meetings and regular work was investigated when the laptop is connected to the docking station. Table 9 in chapter 6.4 illustrates the results in more detail.

By looking at the results, it could be concluded that laptops consume approximately 2.5 times more during meetings compared to regular work. Also, the results show that when the laptop is connected to the docking station, the consumption increases by 0.01 kWh per hour. Moreover, the consumption for the situation when the laptop is in use and not connected to the docking station and the VPN is on, is equal to 0.033 kWh per hour. In same situation, but with the VPN off, the laptop consumes 0.02 kWh per hour. It is concluded that the laptop consumes roughly 65% more when the VPN is on. Furthermore, comparing the results illustrated in Table 9 show that the consumption difference between the laptop which is left on and the one which is used on a regular basis, is numerically insignificant, and could be negligible. It could be concluded that leaving the laptop on and not using it could consume almost as much as using it on a regular basis.

Monitoring the consumption of the docking station shows that this device does not consume electricity when it is not connected to other equipment. Furthermore, the consumption results for the monitor demonstrate that the electricity consumption of this device is constant when operating. In addition, the monitor does not consume electricity when it is in sleep mode.

8.1 How much carbon footprint is produced based on staff's habits due to ICT equipment and internet usage?

The University of Oulu's ICT service has reported the consumption of ODC racks, cooling, telecommunication rooms, switches, and stations according to the share of staff and students. The carbon footprint of these contributors is equal to 134.64 tonnes of CO_2e. However, because the employees only account for 21% of the University of Oulu's population, the carbon footprint share would be equal to 28.27 tonnes of CO_2e. Besides these numbers, as calculated in section 11.1, global data centers and data transmission's carbon footprint account for 2.5 and 51.22 tonnes of CO_2e. To measure the data transmission rate which is one of the main factors of calculating the internet's carbon footprint, DU meter software was used during a 2-week monitoring. It was also monitored that an average of almost 500-600 MB of data traffic is consumed per hour during online meetings. Regular work accounts for roughly 100 MB of data traffic per hour. An average of 1 Mbps data transfer rate is needed to satisfy these consumptions. As a result, approximately 82 tonnes of CO_2e are produced annually by the staff's internet usage.

Results shown in chapters 7.3, 7.4, and 7.5 illustrate that, due to ICT equipment, working on-campus produces 2.28 tonnes of CO_2e every day. By considering only additional ICT equipment that staff use at home for work purposes, the emissions production would be equal to 932.62 kg per day. Moreover, some equipment is being carried by staff members between these two workplaces. Only considering the usage emissions of this equipment, the carbon footprint would be equal to 45.98 kg CO_2e. Calculating the annual carbon footprint of the aforementioned factors results in 547.2 tonnes of CO_2e due to staff only working on-campus. Additional ICT equipment used at home accounts for producing 223.83 tonnes of CO_2e per year if staff only use their additional equipment. The carbon footprint of carried equipment shows 11.03 tonnes of CO_2e production per year. However, adding up the annual carbon footprint of the aforementioned factors will cause calculation duplication in the usage phase. The annual carbon footprint should be calculated by using daily CF production, which is explained in the following.

8.2 How much more carbon footprint is produced due to hybrid working?

Based on the survey, staff members are willing to spend an average of three days working from home and the other two days working on-campus. Considering this assumption as the balance between two workplaces, 521.67 tonnes of CO_2e is produced annually when the staff work on-campus for two days per week. In addition, 224.16 tonnes of CO_2e are produced annually due to the additional ICT equipment used at home and the equipment being carried from campus to home for three days per week. As a result, 745.83 tonnes of carbon footprint are emitted annually. By considering 547.2 tonnes of CO_2e CF emissions if the staff work fully on-campus, it could be concluded that in this specific case of the study, hybrid working increases the carbon footprint production of ICT equipment by roughly 36%.

The calculations are done based on the assumption that the University of Oulu does not use 100% renewable energy as the main source of electricity. However, this assumption is not true, and the University of Oulu uses 100% renewable energy as source of electricity. Due to this fact, the carbon footprint of the consumed electricity by ICT equipment would be omitted. In that case, working on-campus accounts for producing 491.25 kg CO_2e annually. By assuming the fact that staff members do not use renewable energy in their homes, the carbon footprint due to additional and carried ICT equipment would remain the same. However, compared to the situation where the university does not use 100% renewable energy, the carbon footprint is 8% smaller.

8.3 Limitations

There are some limitations identified during the project. The problem with the accuracy of the results is that not all the measurement variables are monitored exclusively during all laptop modes. For instance, during meetings and regular work, consumption is only monitored when the laptop is connected to the docking station. On the other hand, only one number is reported for the consumption when the laptop is in-use and not-connected to the docking station. Thus, the consumption of a laptop when it is not connected to the docking station would not be significantly accurate, and it is only reported as an average of both meeting hours and regular work. Moreover, VPN's effect is only monitored when the laptop is not connected to the docking station. Because two different persons monitored the effect of VPN on electricity consumption, 65% of more consumption when VPN is connected might not be considerably accurate. This is because it is not reported whether the monitoring is done during meeting hours or regular work. Furthermore, although only Lenovo laptops are used for monitoring, different models used during measurements affect the accuracy of the results. This is because different models may consume different amounts of electricity. Also, for simplification of the calculation, only one model of each type of ICT equipment is considered. Thus, the possibility of inaccuracy rises. In addition, since the monitoring is only done for laptops and monitors, the full capacity of usage is considered for other ICT equipment. So, ICT equipment's use phase carbon footprint (except laptops and monitors) is partially inaccurate.

As part of the thesis project, a survey was conducted to provide information about various types of ICT equipment used by the staff. Their habits regarding ICT equipment usage were also considered. The survey included 24 questions and answered by only 54 staff members. The low number of respondents decreases the accuracy of the results considerably.

9 CONCLUSIONS AND RECOMMENDATIONS

Decreasing the carbon footprint and moving towards carbon neutrality are crucial ways to face and combat climate change. Many international and national commitments are made to achieve these concepts. The Paris Agreement is one of the most well-known commitments regarding decarbonization. On a smaller scale, higher educational institutions play crucial roles in facilitating reaching the targets. UNIFI, for instance, created by Finnish universities, ensures maximum contribution alongside rising awareness between students and staff regarding battling climate change.

Achieving carbon neutrality requires calculating the carbon footprint of the involved sectors and categorizing the emissions based on the scopes provided by GHG Protocols. The categorization gives a better overview of emission contributors and facilitates making decisions regarding decreasing the carbon footprint of sectors. This approach applies to universities as well. In the case of the University of Oulu, the CFWG is responsible for identifying and calculating the carbon footprint produced by the sectors. In this thesis project, 29 different studies about the carbon footprint of various universities around the globe were investigated. The sectors identified by the universities were summarized and presented. The most popular mitigation methods in the investigated studies are increasing energy efficiency, implementing the infrastructures for renewable energies, and motivating and raising awareness of staff and students to use public transportation. Calculating the carbon footprint of the ICT sector, which was one of the main goals of this thesis project, was only investigated by 5 of these studies. However, the calculation's approach is not mentioned in any of those studies.

Due to the pandemic, hybrid working has become a reality. The survey conducted in this thesis project demonstrates that the staff of the University prefers working three days a week from home and the other days on-campus. Thus, the number of ICT equipment they need to keep the quality of work the same as before, compared to working only on-campus, increases. As a result, the carbon footprint production of the ICT sector increases. The results demonstrate that hybrid working will raise the carbon footprint of the University of Oulu by roughly 36%. Therefore, using multi-location workplaces seems not to help reducing the carbon footprint.

In addition, the habits that staff members use affect the total emission. Leaving their ICT equipment on, putting it on sleep mode, or turning it off will change the share of the carbon footprint due to equipment usage and electricity consumption. For instance, putting the laptop in sleep mode instead of leaving it on and not using it would reduce the electricity consumption by almost 83%. Therefore, changing habits when using ICT equipment would affect the final consumption significantly. Moreover, the electricity consumption results demonstrate that the electricity consumption could increase up to 65% when VPN is on. Thus, it is recommended to turn the VPN off when it is not necessary. Furthermore, it is observed that the amount of consumption when the laptop is in-use (regular work) is almost as same as the times when the laptop is not in use but left on. For that reason, not using the laptop but leaving it on will not affect electricity consumption. When done working, it is suggested to put the laptop on sleep mode.

As the main motivation of this thesis project was to help making better decisions for reducing the carbon footprint of the University of Oulu, raising awareness between staff and students regarding their ICT equipment usage habits seems crucial. Although the usage phase of the ICT equipment does not account for a big fraction of the carbon footprint production, it is necessary to take small but effective steps to reach carbon neutrality.

Conducting a survey with higher participants will help gaining more accurate data. In addition, 13800 students study at the University of Oulu; therefore, calculating the carbon footprint of students' ICT equipment usage based on their habits would also be necessary to advance of carbon footprint reduction efforts. Moreover, one of the main focuses of this thesis project was to calculate the use-phase carbon footprint of ICT equipment. For further projects, it is recommended calculating the carbon footprint of transportation and end-of-life phases based on Finnish data, to get more accurate data compared to those published by the manufacturers.

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APPENDIX 1: Questions of the staff survey

To have a better understanding about the staff's habit for using ICT equipment, a survey is provided. The questionnaire is demonstrated as following:

Finnish universities have committed to become carbon neutral by 2030. This work is part of the University of Oulu's carbon footprint working group, which aims at determining our carbon footprint and also provide recommendation on how and where to reduce it. Due to the pandemic, remote working has become the reality for the majority of the university's staff. In this research, which is part of a master's thesis work, we are trying to have a better understanding of the different ICT equipment that the university's workers use during their working hours both on-campus and at home.
This survey should take between 5 to 10 minutes to answer, and your responses are completely anonymous. Also, the survey contains both necessary and voluntary questions. The ones we need you to answer are marked with an asterisk (*).

We appreciate your time and support.

1- **What group do you represent?**
Doctoral student
Teaching and research personnel
Service staff
Other? Please specify

2- **Which department/faculty are you primarily belonging to?**
Faculty of Humanities
Faculty of Education
Faculty of Science
Faculty of Medicine
Oulu Business School
Faculty of Technology
Faculty of Information Technology and Electrical Engineering
Sodankylä Geophysical Observatory
Kerttu Saalasti Institute
Kvantum Institute
Kajaani University Consortium

Thule Institute

Biocentre

Eudaimonia institute

Communication, Marketing and Public relations

Research infrastructures

Human resources

Rector's Office

Education services

UIC Innovation Center

Library

Financial services

Centre for Continuing Studies

Management and Services

ICT services

Research and project services

Unit for Strategy and Science Policy

Infotech

Service Operations Unit

Other? please specify

3- Which campus is your primary work or study place?

Linnanmaa

Kontinkangas

Other? Please specify

4- How many hours do you work per week on average?

5- How many days per week are you working from home on average?

1 day per week

2 days per week

3 days per week

4 days per week

5 days per week

Other? Please specify

6- What type of ICT equipment do you use on campus for work purposes? (Please specify the number of each equipment you use)

Laptop

Monitor

PC Tower

Keyboard

Mouse

Docking station

Headset

Webcam

Other? Please specify

7- **Which equipment do you carry with you between home and the university? (Please specify the number of each equipment you carry)**

Laptop

Monitor

Keyboard

Mouse

Docking station

Headset

Webcam

Other? Please specify

8- **What additional type of ICT equipment do you use at home for work purposes? (Please specify the number of each equipment you use)**

Laptop

Monitor

PC Tower

Keyboard

Mouse

Docking station

Headset

Webcam

Other? Please specify

9- **Please specify the name, model, and production year of the laptop you use on-campus. (Please only answer if you use laptop)**

10- **Please specify the name, model, and production year of the laptop you use at home for work purposes. (Please only answer if you use laptop)**

11- **Please specify the name, model, and production year of the monitor you use on-campus. (Please only answer if you use monitor)**

12- Please specify the name, model, and production year of the monitor you use at home for work purposes. (Please only answer if you use monitor)

13- Do you use shared spaces like meeting rooms, group-work places, laboratories, etc. during your working hours on campus? If yes, please specify the location, the ICT equipment that you use, and an approximate average time (hours) you spend in those areas in a week.

14- Which internet provider do you use at home?

DNA
Telia
Elisa
Moi
Other? Please specify

15- Please specify your internet's data transfer rate (Mbps) if you are aware of:

16- How many hours as an average you use internet in a day for your work purposes?

17- On what mode do you usually leave your laptop when you are done working for the day on weekdays? (Please do not answer the question if you do not use laptop)

On
Sleep
Hibernate
Off

18- On what mode do you usually leave your laptop when you are done working for the day before starting the weekends or holidays? (Please do not answer the question if you do not use laptop)

On
Sleep
Hibernate
Off

19- On what mode do you usually leave your PC tower when you are done working for the day on weekdays? (Please do not answer the question if you do not use PC tower)

On
Sleep
Hibernate

Off

20- **On what mode do you usually leave your PC tower when you are done working for the day before starting the weekends or holidays? (Please do not answer the question if you do not use PC tower)**

On
Sleep
Hibernate
Off

21- **On what mode do you usually leave your monitor when you are done working for the day on weekdays? (Please do not answer the question if you do not use monitor)**

On
Standby
Off

22- **On what mode do you usually leave your monitor when you are done working for the day before starting the weekends or holidays? (Please do not answer the question if you do not use monitor)**

On
Standby
Off

23- **How many days per week do you prefer working from home on average?**

0 day per week
1 day per week
2 days per week
3 days per week
4 days per week
5 days per week
Other? Please specify

24- **Any suggestion regarding the subject of the survey?**