École polytechnique de Louvain

The Digital Carbon Footprint of UCLouvain

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Academic year 2020–2021
Master [120] in Physical Engineering

Université catholique de Louvain

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Master Thesis

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August 22, 2021
Version: Final Version

Abstract

For several years now, UCLouvain has adopted an environmental policy and has set itself the objective of becoming carbon neutral by 2035. It was shown in the previous global carbon footprint of the university that the most greenhouse gases (GHG) emitting sectors are the daily transport of employees and students as well as the production or purchase of heat and electricity. However, as the digital aspect was not studied in detail, this work aims to examine the impact of this sector. To do so, a carbon footprint methodology was followed. The data for the model comes from both the inventories of various UCLouvain departments and an online survey sent to the university community. To translate these data into GHG emissions, emission factors from the Base Carbone were used. This study estimates the UCLouvain digital carbon footprint to be 5446 tCO2-eq, i.e. nearly 8 % of the global university footprint. This is equivalent to drive more than 760 times the Earth's circumference by car. The most impactful sectors are students' private equipment, data transferred to and from the UCLouvain network and office equipment. Finally, different emission reduction scenarios were investigated. Three efficient reduction measures were identified. First, the limitation of the number of devices. Second, the purchase of computer models which have a lower embodied footprint. Third, the maximisation of the lifetime of the equipment. In addition, given the importance of the data transfer sector, particular attention should be paid to the evolution of this parameter.

Résumé

Depuis plusieurs années, l'UCLouvain s'est dotée d'une politique environnementale et a comme objectif de devenir neutre en carbone d'ici 2035. Il a été démontré lors d'un précédent bilan carbone global de l'université que les secteurs les plus émetteurs de gaz à effet de serre (GES) sont les transports quotidiens des employés et des étudiants ainsi que la production ou l'achat de chaleur et d'électricité. Cependant, l'aspect numérique n'ayant pas été approfondi, ce travail a comme objectif d'étudier l'impact de ce secteur. Pour ce faire, une méthodologie bilan carbone a été suivie. Les données du modèle proviennent à la fois des inventaires des différents services de l'UCLouvain et d'une

enquête en ligne envoyée à la communauté universitaire. Pour traduire ces données en GES, des facteurs d'émissions issus de la Base Carbone ont été utilisés. Cette étude estime que le secteur numérique de l'UCLouvain représente 5446 tCO2-eq, c'est-à-dire près de 8 % de l'empreinte globale de l'université. Cela équivaut à parcourir plus de 760 fois la circonférence de la Terre en voiture. Les secteurs les plus impactants sont les équipements privés des étudiants, les données transférées vers et depuis le réseau UCLouvain et les équipements de bureau. Enfin, différents scénarios de réduction des émissions ont été étudiés. Trois mesures de réduction efficaces ont été identifiées. Premièrement, la limitation du nombre d'appareils. Deuxièmement, l'achat de modèles d'ordinateurs ayant une empreinte intrinsèque plus faible. Troisièmement, la maximisation de la durée de vie de l'équipement. De plus, vu l'importance du secteur du transfert de données, une attention particulière devrait être portée sur l'évolution de ce paramètre.

Acknowledgement

Louvain-la-Neuve, August 22, 2021

During the journey that led to this thesis, many people have supported me. First and foremost, for their patience, trust, technical advices, and inspiring and insightful discussions, I would like to sincerely thank my supervisors David Bol and Hervé Jeanmart as well as Thibault Pirson. This latter has shared his knowledge and passion about this topic and always helped me the most he could throughout the realisation of this master thesis. I would like to give a special thanks to Xavier Marichal for his external view and experience during this work.
I hope that the quality of their feedback is reflected in this work.

I am thankful to Olivier Vergeynst for accepting to read this thesis as well as to be part of my jury during the thesis defence.

Next, I would like to thank all the UCLouvain employees who kindly provide me various data, spending time answering my questions.

For their help in diffusing my online survey, I would like to warmly thank Marthe Nyssens and Marc Servais.

For his seminars and excellent coaching session on how to "*Present your master thesis with impact*", a special thank is given to Francesco Contino.

Finally, for their unconditional moral support and their encouragement, I would like to warmly thank my family and my friends. In particular, I would like to warmly thank Julia Dessambre for her help, her precious advice, and her patience throughout this work.

Théo Gladsteen

« *Pour ce qui est de l'avenir, il ne s'agit pas de le prévoir, mais de le rendre possible.* »

Antoine de Saint Exupery,
Citadelle, 1948.

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Nomenclature

Acronyms

ADEME	Agence De l'Environnement et de la Maîtrise de l'Energie[1]
CAGR	Compound Annual Growth Rate
CO2-eq	Carbon dioxide equivalent
DC	Data center
EF	Emission Factor[2]
GHG	Greenhouse Gases
GWP	Global Warming Potential
ICT	Information and Communication Technologies
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LLN	Louvain-La-Neuve
M2M	Machine to Machine
POE	Power Over Ethernet
PUE	Power Usage Effectiveness
UCLouvain	Université catholique de Louvain
UNFCCC	United Nations Framework Convention on Climate Change

[1] In English: Environment and Energy Management Agency)

[2] The term *Emission Intensity* is sometimes preferred. However, for clearness reason compare to french, *Emission Factor* is used in this work.

Introduction

Context and Motivation

The United Nations (UN) wrote: « *Climate change is the defining issue of our time and we are at a defining moment* » [102] and recently its secretary-general Mr. António Guterres, defined the climate emergency as « *the defining issue of our time* » adding, « *2021 is a make it or break it year* » [103]. These statements tell it all.
Similarly, the Intergovernmental Panel on Climate Change (IPCC) wrote in its latest Assessment Report (AR6) dating from 2021: « *It is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes [...] have occurred*» [97]. IPCC evaluates that emissions must reach net zero by 2050 in order to comply with the Paris Agreement (which aims to keep average warming well below 2°C while pursuing our efforts to limit this warming to 1.5°C [110, Article 2]) [77, p. 12]. To reach this goal, greenhouse gases (GHG) emissions must decrease by 6 % each year. As a comparative indicator, a study estimated a GHG emission reduction of 7 % between 2019 and 2020 due to the COVID-19 crisis [60]. Global agreements as the Paris agreement [89] or the more recent European Green Deal [28] give directions to follow. More locally, the Wallonia government approved in 2014 the « Décret Climat » [90] which aims to reduce by 95 % the GHG emissions in 2050 compared to 1990. Knowing all this, it seems clear that huge changes in our daily habits must be made.

In this context of large transformation of our societies, The Université catholique de Louvain (UCLouvain), as a leading academic player, must change its habits and practices in order to respect the Paris Agreement. To do so, UCLouvain has the ambition to transform itself into a sustainable institution. Different policies have recently been established as it is discussed in this study. The main objective which can be highlighted here is UCLouvain's ambition to become carbon neutral by 2035.

Given the global and local context of this environmental crisis, it becomes urgent to look for solutions. A first step towards addressing the climate issue is to depict a portrait of the current situation. This can be done by conducting a carbon footprint, which aims to evaluate and identify the different sources of GHG emissions and their relative importance and subsequently quantify the reduction impact of specific actions. It is with these goals in mind that UCLouvain conducted its first global carbon footprint in 2019. From this study, it emerged that the university's main sources of emissions are employees' and students' transportation as well as energy consumption (gas and electricity) [95]. However, one aspect which was overlooked when conducting this carbon footprint was the emissions associated with digital. From this observation, there was a need acknowledged by UCLouvain itself to investigate this digital aspect further in order to get a better understanding of the impacts of this sector. Indeed, UCLouvain wrote in a recent report: « *Determining good institutional and individual practices to reduce our data consumption and maximise its use by the community as a whole is therefore essential to avoid an explosion of this digital sector in the years to come* » [131, p. 22]. The present study aims at addressing this concern.

Problem Statement, Methodology and Inputs

In this study, the approach which is chosen to quantify the environmental impacts is the carbon footprint. The method is detailed in Section 1.2. The key idea is to quantify in terms of GHG emissions the environmental « cost » of a good or service. This carbon footprint is conducted following the Bilan Carbone® methodology [1].
In this study, the ICT impacts are considered regarding their impacts over global warming, i.e. considering GHG emissions. It is however essential to note that GHG emissions represent only a fraction of the general climate issue. A more detailed analysis could extend this work further to analyse other aspects of the climate issue such as water and resources depletion or even social and human impacts.
The idea behind a carbon footprint is to associate to each good or service a corresponding *weight* (called an emission factor, this is detailed in Section 1.2). Despite certain imperfections, most of the emission factors used in this work come from the Base Carbone from ADEME [9]. In addition, a sensitivity analysis using other emission factors was carried out to determine the importance of these parameters.
A large part of this work consisted of the collection of data. Two main sources were used. First, UCLouvain data collected from different UCLouvain departments (all the sources can be found in Appendix A). Second, an online survey was sent to the entire university community (both employees and students). The results extracted are presented in detail in Section 2.4.1.

Key Results

This study estimates the UCLouvain digital carbon footprint to be 5446 tCO2-eq, i.e. nearly 8 % of the global UCLouvain footprint. As a comparative indicator, this is equivalent to drive more than 760 times the Earth's circumference by car. The most impactful sectors are students' private equipment, data transferred to and from the UCLouvain network, and office equipment. However, several arguments suggest that this result is probably underestimated.

Different emission reduction scenarios were investigated. It was found that the most efficient reduction measures are those that aim either to limit the number of equipment, or to purchase computer models which have a lower embodied footprint, or to maximise the lifetime of the equipment.

Thesis Structure

The outline of this work is as follows:

Chapter 1: Background and related works

Chapter 1 defines the main concepts used for this work. Next, the increasing importance of the Information and Communication Technologies (ICT) sector in our society is illustrated and quantified based on previous studies. Results of the impacts of ICT extracted from previous studies are presented and finally, similar works are analysed and their results exposed.

Chapter 2: Data and Methodology

Chapter 2 details the complete methodology. It exposes the scope and the data as well as the calculations made and then details the assumptions.

Chapter 3: Results and Discussion

Chapter 3 presents the main results and discusses them. Next, a sensitivity analysis is carried out to point out the key parameters involved in results variation. In addition, improvement scenarios are quantified in order to identify high impact reduction actions. Finally, a section addresses the question of the COVID-19 crisis from a digital footprint perspective.

1 Background and related works

This chapter begins by presenting UCLouvain and its environmental policy. Second, the key concepts of this study are developed and defined. Third, details about the increasing use of ICT in our society are introduced and several key numbers regarding the current carbon footprint of ICT are given. Finally, the results of similar works carried out in other universities are outlined and discussed.

1.1 UCLouvain organisation and environmental policy

With almost 32000 students and more than 6000 employees, UCLouvain is the largest university in Wallonia and the fourth in Belgium [129]. The university is spread out among six different campuses, namely, listed by number of students, Louvain-La-Neuve (71 % of the students), Bruxelles Woluwe (22 %), Mons (4 %), Bruxelles St-Gilles (1.5 %), Tournai (1.4 %), and Charleroi (<1 %). The main authorities of the university are located in Louvain-La-Neuve and most of the administrative services, as well as the data centers are centralised on this campus.

As mentioned, both international and local agreements exist in order to decrease the global carbon footprint [36, 110, 111]. To cope with sustainability and transition challenges, UCLouvain created in 2014 the sustainable development council (le Conseil du Développement Durable, CoDD) which aims « *to produce opinions, recommendations, and analyses* » [130]. It is composed of scientific experts and both administrative and student representatives. In 2019, it was supported by the « Transition and Society » pro-rector in order to coordinate the environmental policy at UCLouvain. The same year, a first report was conducted on the current situation of the university in terms of environmental policy [128].
Recently, UCLouvain published a roadmap named « Plan Transition » which gives the key objectives over the next 5 years in order to support the transition of UCLouvain towards a more sustainable future [131]. One of the main objective of UCLouvain that can be

highlighted from this report is the willingness to reach carbon neutrality[1] by 2035, ahead of national and international targets. However, this Plan Transition gathers not only guidelines related to the organisation of campuses but also changes to be done within research and teaching such as this thesis.
Finally, UCLouvain decided in 2020 to join annually the Times Higher Education (THE) Impact Ranking [51] which aims to classify universities depending on their impacts over the 17 Sustainable Development Goals (SDG) [104]. This choice was made in order « *to anchor the university in the transition in a sustainable and internationally visible way and to enhance the efforts undertaken by the institution and its community* » [131, p. 43]. Despite the good intentions behind this choice, several counterarguments could be given against the THE ranking. For example, while this ranking boasts of taking into account the 17 SDG, they actually take only four of them (the 17th and the three with the highest score among all others) for the final ranking. This ranking should therefore not represent an exhaustive objective for the university, only an additional measuring tool. In 2021, the UCLouvain was ranked between the top 101 and 200 of the world, leading to first place in Belgian universities.

Regarding sustainability concerns associated with the use of digital technologies (sometimes called Green IT), UCLouvain is not starting from scratch. In 2014, an Advisor of the Rector in charge of the Digital University was appointed. The latter conducted a study entitled: *Towards a sustainable digital at UCLouvain* [23] which details five digital issues at UCLouvain. However, no quantification of the impacts is made. Moreover, in the last «Plan Transition» report, a brief section is addressed to the digital aspect. However, this part is relatively small and it mainly consists of determining what would be interesting to investigate, i.e. the impacts of the data transfer and the lifetime of computers [131, p. 22].

All these initiatives show that UCLouvain has understood the importance of the issue and challenges related to sustainable practices and tries to re-think its agenda by implementing real changes in order to steer towards an environmental-aware management of the university.

[1]UCLouvain defines this term as: « *A reality where overall emissions have been greatly reduced and residual emissions compensated* » [128, p. 21].

1.2 Fundamental concepts

Climate change The United Nations Framework Convention on Climate Change (UNFCCC) definition states: « *Climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods* » [31]. For this work, this definition is preferred since it only focuses on the anthropological causes of the phenomena, unlike the Intergovernmental Panel on Climate Change (IPCC) which has a more general definition [32].

The main cause of climate change is the release of greenhouse gases (GHG) into the atmosphere, leading to an increase in the concentration of these gases [97, 109]. There are several GHG but they all induce a similar consequence (at different intensities): they retain the solar radiation. To characterise this phenomenon, the concept of radiative forcing is used which is the difference between the radiative flux (in $W\,m^{-2}$) received from the sun and the radiated flux emitted by the Earth. GHG increase the radiative forcing of the Earth, causing an increase in the temperature of the atmosphere.

Carbon footprint It is an evaluation aiming to quantify GHG induced by a product or a service within a specific scope [10]. Several methodologies exist to quantify GHG such as GHG Protocol [122] and Bilan Carbone® [1]. Although it exists few differences between these methodologies (different presentation of the results for example), they remain very similar and both comply with the more general ISO 14064-1 standard [78]. The methodology used for this study is the Bilan Carbone® one. There are two main arguments that motivated the choice of this method. First, for reasons of continuity with previous work since the previous UCLouvain carbon footprint applied this methodology [95]. Second, because of the accessibility of the data[2].

The Bilan Carbone® methodology divides the results into three sections called «scopes» (which must not be confused with the scope of the carbon footprint which defines what is and is not included). The first scope includes all the direct emissions of GHG, typically fuel combustion or the use of refrigerant fluid. The second scope contains all the indirect emissions due to energy use, typically electricity consumption. Finally, the last scope includes all the other indirect GHG emissions.

[2] Ademe provides free access to its emission factors

In practice, to estimate a carbon footprint and obtained the total impacts of a product or service, one needs both an inventory of the concerned products or services and the associated emission factors. This is shown by the following formula:

$$I = \sum_i D_i \, F_i \tag{1.1}$$

where I is the environmental impact in kgCO2-eq (this concept is defined below), i takes into account all the inputs within the scope, D_i are the data from the inventory and F_i are the corresponding emission factors.

Emission factor It is a coefficient allowing the conversion of raw data (typically data from an inventory) into greenhouse gases emissions (typically in kgCO2-eq) [11]. Emission factors can be divided into three categories:

- Absolute factors related to a device, e.g. a laptop. The distinction is usually made between the extraction of material, the production, the transport, and the distribution emissions (often referred to as the « embodied emissions » in literature and in this work), use-phase emissions, and end-of-life emissions.
- Absolute factors related to a service, e.g. sending an email.
- Normalised factors per unit of operation, e.g. electricity in kWh or data traffic in TeraByte.

In addition, it is necessary to specify what is taken into account when evaluating an emission factor. Emission factors can either be determined for specific processes or found into databases and scientific literature. An uncertainty is always associated with the coefficient. This uncertainty « *may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology or uncertain projections of human behaviour* » [32]. The uncertainty is discussed in Section 2.3.

Kilogram carbon dioxide equivalent - kgCO2-eq For a greenhouse gas mix, it is the equivalent mass of carbon dioxide (kgCO2-eq) that would induce the same radiative forcing [32]. This parameter reflects the overall impact on global warming of the device or service which is considered. It is computed using the Global Warming Potential values.

Global warming potential Since there are several GHG, the Global Warming Potential (GWP) concept is used in order to compare the *strength* (i.e. their ability to retain solar radiation) of each. It is a measure of how much energy the emission of 1 ton of a gas absorbs over a given period (generally 100 years), relative to the emission of 1 ton of carbon dioxide (CO2) [4]. The GWP for each greenhouse gas is determined by the IPCC based on scientific literature [58, p. 212], as given in Appendix D.

Digital and ICT Digital refers to electronic equipment and services that manipulate (display, transport, transform, store, etc.) binary data [22]. Information and Communication Technologies (ICT) (a laptop, the Internet network, or a data center for example) are the technologies allowing us to use digital services (Microsoft Teams or YouTube for instance).

1.3 Evolution of the role of the ICT at a global scale

In the last few decades, ICT has spread tremendously. It has become a worldwide technology, shaping our societies and influencing policies (digital strategies exist at regional [47, 48], federal [49] and European [8] scales). Ericsson estimates than more than 70 % of global population use ICT annually [55, p. 7] while studies predict a penetration close to 80 % in 2025 [136]. This highlights another characteristic of this transition: the speed at which ICT is spreading. For instance, the exponential evolution of transferred data or the linear increase of the quantity of most devices used worldwide [27, 28, 79]. The transistor density on a chip follows the well-known Moore's law which is still relevant although Gordon Moore made his prediction in 1965 [100]. This miniaturisation of the computing power, associated with a relatively low price of these technologies has led to a world with more and more connected devices [62].

Cisco, the leading network equipment company, analyses the global Internet data traffic and derives predictions based on that. They found a 26 % annual increase for the global Internet traffic, demonstrating once again the exponential nature of the evolution of the global transferred data. This is shown in Figure 1.1. This figure, in addition of showing this growth, distinguishes two cases. On the one hand, a division by type of use is made (upper graph) and on the other hand, a distinction by type of equipment is made (lower graph). By aggregating information from both graphs, one could summarise (by a simplistic approach) this evolution in a single sentence: *We watch more and more videos on our smartphones*. Indeed, Cisco tells us that the smartphones data traffic increases by 46% annually, almost twice faster than global traffic. It is also interesting to note in the upper Figure that videos represent 70 % of the global transferred data, clearly dominating the rest. Those trends stay true for every continent proving the global aspect of this revolution. As discussed later, this increase in data consumption is also observed at UCLouvain.

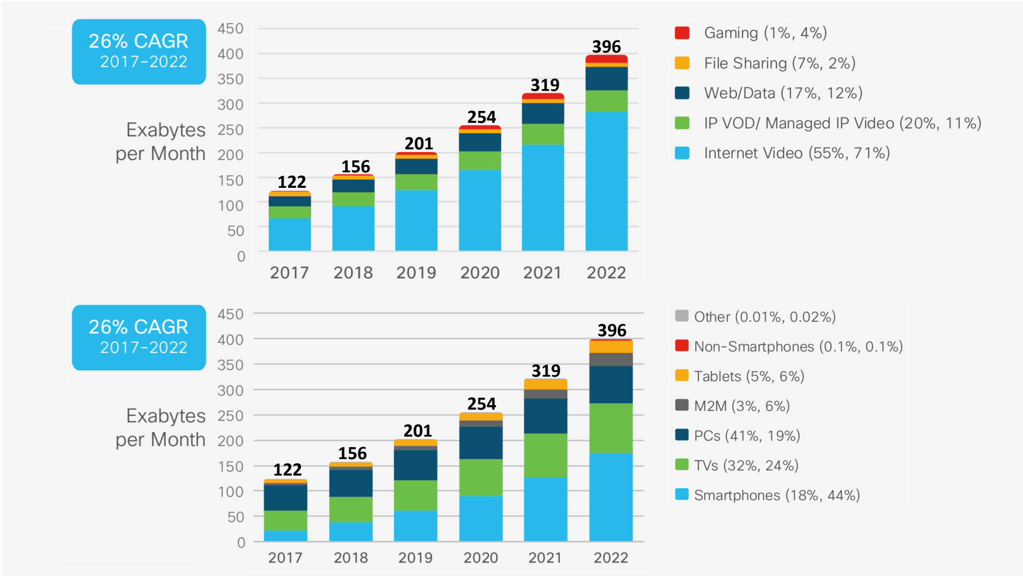


Fig. 1.1.: Estimation and prediction of Internet data traffic from 2017 to 2022 made by Cisco [27]. Videos dominate the transferred data while smartphones are becoming the most used devices. The two graphics are equivalent. The upper one shows the subdivision by type of use while the one below details the traffic by type of equipment. The percentages in brackets indicate the traffic share in 2017 and 2022.

1.4 The environmental impacts of ICT

In the previous section, it was shown that ICT is becoming more and more present in our society. It seems therefore important to be able to quantify the global impacts of these technologies. To do so, different types of impacts induced by the ICT are first introduced. Next, the difficulties to assess the ICT environmental impacts are discussed and detailed. Third, certain existing methods aimed at quantifying the environmental impacts are presented. Finally, recent studies which quantified the ICT impacts are introduced and their results are compared.

1.4.1 A methodology to understand environmental impacts of ICT: the LES model

Different classifications of the impacts induced by ICT can be made. This study focuses on the LES model from the scientist Lorenz Hilty. This methodology has the advantage of summarising this wide topic in a simple way that is easy to understand and remember.

Originally, the model is inspired by the theoretical three levels model introduced by Franz Berkhout and Julia Hertin in 2001 [18]. This model was reinterpreted by several authors, Hilty being one of them. Hilty introduced into the original model an additional distinction that distinguishes positive from negative environmental impacts (respectively, *ICT as part of the solution* and *ICT as part of the problem*) as shown in Figure 1.2. This has the advantage to be really meaningful even if reality might be more complex (this comment is addressed by Hilty himself). The LES model classifies the impacts caused by ICT in three categories:

- The Life-Cycle impacts (L): it is the direct environmental impacts caused by ICT. They are caused by manufacturing processes, transportation, electricity consumption and end-of-life management. Those impacts can be assessed with a cradle-to-grave LCA[3] of the device. By definition, these impacts are only *bad* in the sense they require raw materials and energy.
- The Enabling impacts (E): it represents all the indirect impacts enabled by the product or service. They can be divided into three categories. The first one is the optimisation processes allowing to substitute *immaterials* (labour, capital, natural resource, etc.) for *materials resources* (e.g. industrial automation). The second category is the media substitution which is the replacement of a material resource by another one (e.g. an e-book instead of printed books). Finally, the third category is the externalisation of the control where an immaterial is replaced by another immaterial (e.g. videoconferencing replacing an international event). All these categories can be part of both the solution and the problem. Those impacts are already much harder to assess but they are nevertheless essential to get a clearer idea of the advantages or disadvantages of a product or service.
- The Structural impacts (S): those impacts include all the possible long-term changes. It is moving further and further away from the exact sciences and getting closer

[3] Cradle-to-grave LCA is the more complete type of LCA, considering all steps from raw materials extraction until end of life processing.

to sociology. It can include changes in behaviour, habits, investments, etc. This category includes the long-term rebound effects which are explored further (see Section 1.4.2).

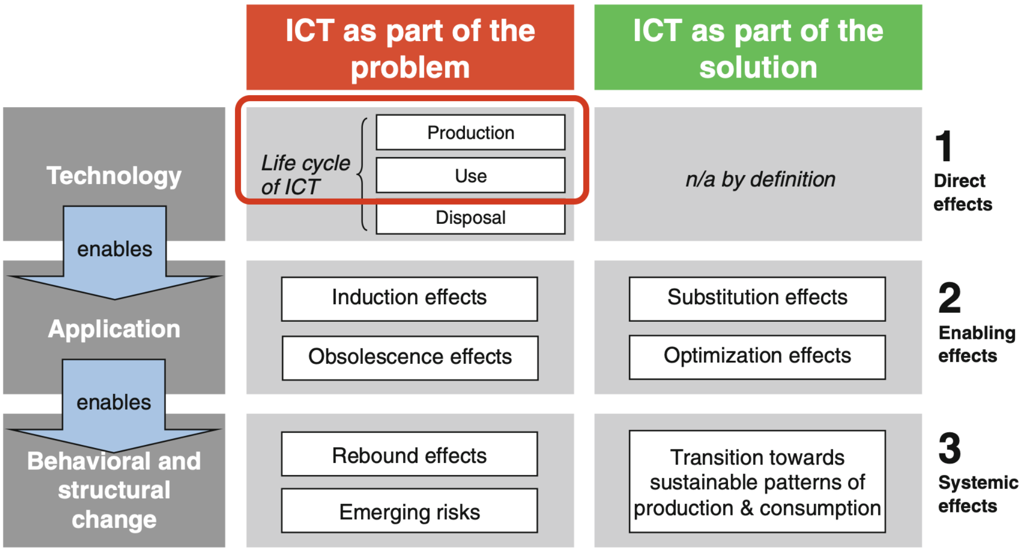


Fig. 1.2.: A representation of the LES model introduced by Hilty [69]. The red border shows what is took into account in this study. Complete information about the LES model can be found in [69, p. 21-28].

In this work, only the life-cycle impacts are considered (see the red border in Figure 1.2). As soon as the other types of impacts are tried to be integrated into the model, a lot of hypotheses must be made, which is not the main purpose of this study.

1.4.2 Barriers to assess the impacts of ICT

Traditional carbon footprint or LCA are not easy to assess in general for many reasons not detailed here. However, it seems that when working in the ICT sector, the number of difficulties increases even more. People working in this sector are aware of this and several studies or reports detail this aspect [39, 55, 99]. This section details various difficulties when quantifying the impacts of the ICT sector, without being exhaustive.
Despite the several difficulties detailed just below, it is still necessary to study the environmental impacts of the ICT doing our best. This allows to base our judgment on figures rather than believes despite the fact that these figures get uncertainty.

A fast-paced technology

It is clear that technologies from the ICT sector are evolving faster and faster since the beginning of the digitalisation (Google was created in 1998, Facebook in 2004, and the iPhone in 2007). This fast innovation and huge capacity of adaptation almost seem to have become a feature of the sector.
To make it even more complex, this fast evolution happens at different levels [55]. Indeed, it exits simultaneously for the equipment (technology, components, origin,...), the usage, and for the energy efficiency for example.
As explained further below, this characteristic leads to a whole series of other difficulties.

A non-stationary scope

Because of the changes in the usage, practices, and technologies, new classes of products appear at the border of the traditional scope defining the ICT sector. Moreover, this class of objects is far away to be negligible anymore and their growth is faster than any other type of equipment (M2M[4] equipment are predicted to represent more than half of the connected devices in the world in 2022 [27]).
This evolving scope is a direct consequence of the first difficulty developed which was the speed of the innovation in this sector.

The data

Another consequence of this fast-moving technology is the difficulty to collect accurate and updated data. The following challenges are discussed:

Missing or unavailable data Particular data simply do not exist or are unavailable when it comes to evaluate a carbon footprint.
Two types of private sectors tend not to share their data publicly. First, ICT companies choose what they want to share as information. Alternatively, companies might agree to transmit specific data with the wish to keep them confidential, prohibiting the publication of these data. This is the case in a recent study by Jens Malmodin and Dag Lundén [94]. Unfortunately, this prevents other people from reviewing the

[4]Machine to Machine. Internet of Things (IoT) devices are part of M2M.

model and the data and brings issues of transparency and reliability [59]. Second, companies whose role is to assess environmental impacts do not want to share the emission factors they used. For example, the recent publication from EPFL [67] uses private factors from GreenConcept [63] and therefore can not publish these factors. Consequently, they can not be as transparent as possible. Nevertheless, the wish from these private companies can be understood since it took time and money to properly evaluate those factors.

The missing data are mainly emission factors. This can be explained by two main reasons. First, assessing these factors takes a lot of time and financial resources. This tends to limit the number of entities or organisations able to assess these emission factors. Second, the number of new devices and the speed of innovation are so large that it seems impossible to assess the impact of all these new equipment. There is therefore a time lag between the innovation and introduction of new equipment into the market and the assessment of the emission factors of these new equipment. This could be partly solved if companies would systematically provide, on a mandatory or voluntary basis, an environmental impact assessment for their products. Several companies do it such as Dell [46], Lenovo [83], Apple [14] or HP [72]. However, very few informations about the methodology are usually given making the comparison difficult.

Outdated data A direct consequence of this fast evolution in the ICT sector is the fact that, in few years, data can become outdated. The need for a regular and updated assessment is therefore clear.

Inconsistent data Finally, even when data exist, they can be inconsistent with each other. This is true for both inventory data and emissions factors. For the inventory, it is always better to have different sources in order to compare them. Concerning the emission factors, they can vary significantly depending on the source considered. To explain that, all the points presented above could be cited. For example, the data may have been assessed with different scopes, one or both could be outdated or the assumptions made could be different. To illustrate this, several studies reported the difference of data given by various studies about the energy intensity of Internet data transmission (in kWh/GB)[5]. They found that the figures can vary up to 5 orders of magnitude depending of the year and the scope considered [15, 38, 40].

[5] It is a key and widely used data to translate the growing data traffic into environmental impacts.

Shared use

The digital sector involves many different equipment which are used by everyone. This leads to difficult questions about the way to redistribute these impacts to users. The difficulty to answer these questions highlights the issues encountered with shared-use devices or services.
Moreover, in addition to the network equipment which seems obvious when talking about shared use, it can also be a problem for personal devices. In the case of this study, the willingness to take into account the private equipment of employees and students forced us to answer the same kind of questions.

The rebound effects

The last point of interest which makes it difficult to assess the environmental impacts of ICT is the so-called rebound effects. This term reflects all the long-term indirect effects (part of the *S* category from the LES model, see Section 1.4.1) reducing or overcoming an original environmental gain permitted by a technology or a decision [62]. This is not specific to the ICT sector as it can be observed in many different cases. As an example, as microprocessors are getting always smaller, it led to a decrease of the amount of raw materials needed growing attractiveness (price, usefulness, time savings) leading to an explosion of the demand [62]. Many examples exist in daily life since, as soon as an optimisation of a process is made, there is a risk that savings (time, energy, or money) will be replaced and consumed in something else. This great diversity of rebound effects makes it almost impossible to evaluate them all. Related to these difficulties, the Swiss scientist Vlad Coroamă said recently: «*There is a large research deficit. We do not have any method today to take into account rebound effects arising at a large scale from digitalisation. The system boundaries are too wide*» [37]. Only one study taking into account the rebound effects was found [25] but it is dated from 2004, making it outdated.
Several studies come to the conclusion that rebound effects are inevitable: «*The framework and its application to 57 different cases clearly indicate that technological improvement has not resulted in "automatic" dematerialisation in these cases. [...] It seems that the future is not highly likely to reverse this finding. The results support that rebound can (and apparently usually does) overcome technological progress as far as absolute dematerialisation is concerned. The findings also provide support that environmental impact does not continue to diminish as affluence increases*» [90]. Many other examples of rebound effects in the ICT sector exist and were studied. For example, [91] studied the impacts of material

efficiency, [133] considered the possible rebound effects of cloud computing, and [44] investigated the e-materialisation field. This is a counter-argument against those who consider technical progress in the ICT sector as the only key to a sustainable ICT sector. These arguments usually overestimate the potential savings while focusing on the enabling impacts, ignoring the behavioral response (i.e. the rebound effect) [19].
Since the behavioural aspect of the rebound effect was detailed, the difficulty (or the impossibility) to assess it seems clear [43, 70, 132] although its importance in the ICT sector was also demonstrated [20, 62, 68, 80, 93].

1.4.3 Existing approaches to quantify ICT environmental impacts

In addition to the reference methodologies given by ETSI and ITU standards [6, 52], there are more practical approaches to assess the direct environmental impacts from ICT that can be divided into three main categories:

Bottom-up It consists of associating the individual impact of each piece of equipment from a detailed inventory. This methodology is preferred when the scope is circumscribed and the availability of the data is high [57]. However, for larger scopes, a precise inventory is most of the time not available. The advantage of this approach is that the model and the input data are known precisely. However, a truncation error is very likely since it is not possible to take into account every piece of equipment or process. This leads to a bias towards underestimation [42, p. 35].

Top-down Based on national or global data, normalised factor characteristic of one activity (stored data, data traffic, etc.) can be found. The main example is probably the energy intensity factor of the Internet which is almost always obtained by dividing the global electricity consumption due to data transfer and the quantity of transferred data, giving a factor in kWh/GB [38, Table 1]. The advantage of this approach is that it tends to encompass all equipment and processes. However, it leads to a very low resolution on the model and it is then difficult to understand where the overall result comes from. This approach favours a bias towards overestimation [42, p. 35].

Hybrid When both first methods are mixed, the term hybrid is used. Indeed, depending on the sector assessed, one or the other method may be the most appropriate. Major recent studies on ICT impacts use this hybrid methodology which combines the advantages of both first methods [13, 17, 21, 94] (see Table 1.1). In practice, these studies use mainly a bottom-up approach in combination with just few top-down data. Typically, the impacts from devices are known and a bottom-up approach is used while a top-down method is used for data traffic based on results such as the ones from Cisco [59]. This is what is used in this work.

1.4.4 ICT carbon footprint at a global scale

The studies assessing the ICT environmental impacts are first introduced and presented globally. Their main assumptions or features are highlighted. Next, their results are reported and discussed. In addition, projections from these studies are investigated and the environmental sustainability of different scenarios are examined.

Main studies

In comparison with the importance of ICT technologies in our lives, there are not many studies assessing the global ICT sector carbon footprint [17, 59]. Indeed, many existing studies focus on the electricity consumption of ICT, ignoring the production, the transport and distribution (i.e. the embodied emissions), and the end-of-life emissions of this sector. Moreover, among the existing studies, only few are peer-reviewed. Furthermore, because the ICT sector is a fast-moving sector, studies are rapidly outdated although past studies still help us to understand the trends. This supports the need for such studies to be carried out frequently.

The three relatively recent peer-reviewed studies are those by Andrae & Edler (A&E) in 2015 who assessed the ICT global electricity consumption while providing an estimation of the carbon footprint in their supplementary material[6] [13], Malmodin & Lundén (M&L) in 2018 who estimates the carbon footprint of ICT in 2015 [94], and Belkhir & Elmeligi (B&E) in 2018 who estimates the ICT carbon footprint from 2007 to 2018 and, based on this model, made projections up to 2040 [17].

On the other hand, few organisations carried out the same type of studies although these publications are not peer-reviewed articles since the authors are not working in the academic field. Three main sources of this type are used in this section. First, The Shift Project (TSP), a french think thank about transition, published several reports about

[6] This footprint takes into account only the use phase since they convert their electricity consumption into GHG with a global CO2-eq electricity intensity factor.

ICT impacts [53, 57, 113, 123]. Their main source for the data and the model used was A&E [13]. Second, GreenIT.fr (GIT) is a French community existing from 2004 and promoting sustainable and alternative IT. Its founder, Frédéric Bordage, published two main studies of interest for this work [21, 22]. Finally, in 2020, a group of scientists led by Freitag & Berners-Lee (F&B) from both private (a Small World Consulting) and academic (Lancaster University) structures published an important literature review on this topic [59].

Results and discussion

Based on these studies, **the share of the ICT sector in the global GHG emissions is estimated at 3 % $\pm$ 0.5 % in 2020**. Details are listed in Table 1.1 and are given graphically in Figure 1.3. It shows a **linear increase until now for both the emissions and the ICT share in overall GHG emissions**. However, **this linear trend could potentially be the start of an exponential curve** as demonstrated and suggested by B&E [17, p. 458]. The authors commented: «*The linear fit is unrealistically conservative*».

This 3 % share could be considered as minor. However, what is more worrying is the particularly rapid growth of this sector. Indeed, the ICT GHG emissions, as shown in Figure 1.3, has a Compound Annual Growth Rate (CAGR) (i.e. an annual growth) of approximately 6 % while global GHG emission has a CAGR of 2 % [107], in line with the literature [13, 50, 57, 123]. This explains why the share of ICT is becoming more and more important in the global picture. Following the linear trend, ICT might represent more than 6 % of the global GHG emissions by 2040, while, in the case of an exponential growth, it might reach 14 % (see Figure 1.6). More details about projections and scenarios are detailed below.
In addition, it is interesting to note that this share is approximately the same one as the one from the global aviation sector [3, 26, 107, 108, 115], a much more exposed sector concerning non-green practices. This is one of the arguments of the ICT companies when defending their environmental impacts [55, p. 7]. Moreover, a recent study showed that 80 % of people tend to consider aviation as more polluting than digital services [26]. This would tend to confirm that the false perception of a dematerialised digital sector does exist. Two reasons might explain that. First, people, when using digital devices or services, are in direct contact with only few devices. Typically, they will never see network and data center equipment, as if they would not exist. Second, the ICT sector has the particularity to have a larger part of its emissions coming from embodied emissions

Tab. 1.1.: Overview table of the results for the global ICT impacts and its share in total GHG emissions from several studies. The abbreviations for the sources stand for : Andrae and Edler, 2015 (A&E) [13], Belkhir and Elmeligi, 2018 (B&E) [17], Freitag and Berners-Lee, 2020 (F&B) [59], Malmodin and Lundén, 2018 (M&L) [94], The Shift Project, 2021 (TSP) [57], GreenIT.fr, 2019 (GIT) [21].

Reporting year	Impacts [MtCO2-eq]	Share of the total GHG emissions^d	Methodology	Source
2015	1153	2.10 %	Hybrid	M&L^c
2015	1313^b	2.39 %	Hybrid	B&E^c
2015	1500	2.73 %	Top-Down	TSP
2015	1515	2.75 %	Hybrid	A&E^c
2017	1440^b	2.63 %	Hybrid	B&E
2019	1400	2.44 %	Hybrid	GIT
2019^a	1590^b	2.77 %	Hybrid	B&E
2019	1840	3.21 %	Top-Down	TSP
2020	1756	3.00 %	Hybrid	F&B
2020^a	1860	3.18 %	Hybrid	A&E^c
2025^a	2400	3.71 %	Top-Down	TSP
2025^a	2500	3.87 %	Hybrid	A&E^c

Legend a : Projections, b : Including TVs which was out of the scope in the original study. The methodology followed to include these impacts is the same as the one from F&B [59], i.e. add the TVs impacts found from M&L [94], c : Extracted from F&B [59], d : The data might not be exactly the one you may find in the original article. Indeed, in order to standardise the comparison, global GHG emissions data was selected from [107] (M&L use the same source [94]). Moreover, it was found that in GIT, the authors selected the CO2 global emissions instead of the GHG (i.e. CO2-eq) global emissions. The authors were contacted and confirmed their mistake. The same choice or mistake seems to be observed in B&E [17, p. 450]. The authors were contacted by email, without success.

compared to other sectors. Studies do not completely agree with each other but it seems that approximately between 30 % and 40 % of the emissions are embodied emissions [57, 59, 94] as shown in Figure 1.4. In addition, this figure reaches 50 % for user devices, further driving emissions away from the end-user. In contrast, for instance only 17 % of the emissions of a car with 200 000 km are embodied emissions [9].

Conversely, for example, only 17 % of the emissions of a 200 000 km car are embodied emissions [9].

Another point of interest would be to compare the sources of emissions to know what is the main driver of ICT impacts, either user devices, data centers, or networks. Unfortunately, when comparing literature and their results, there is a lack of consistency and each study

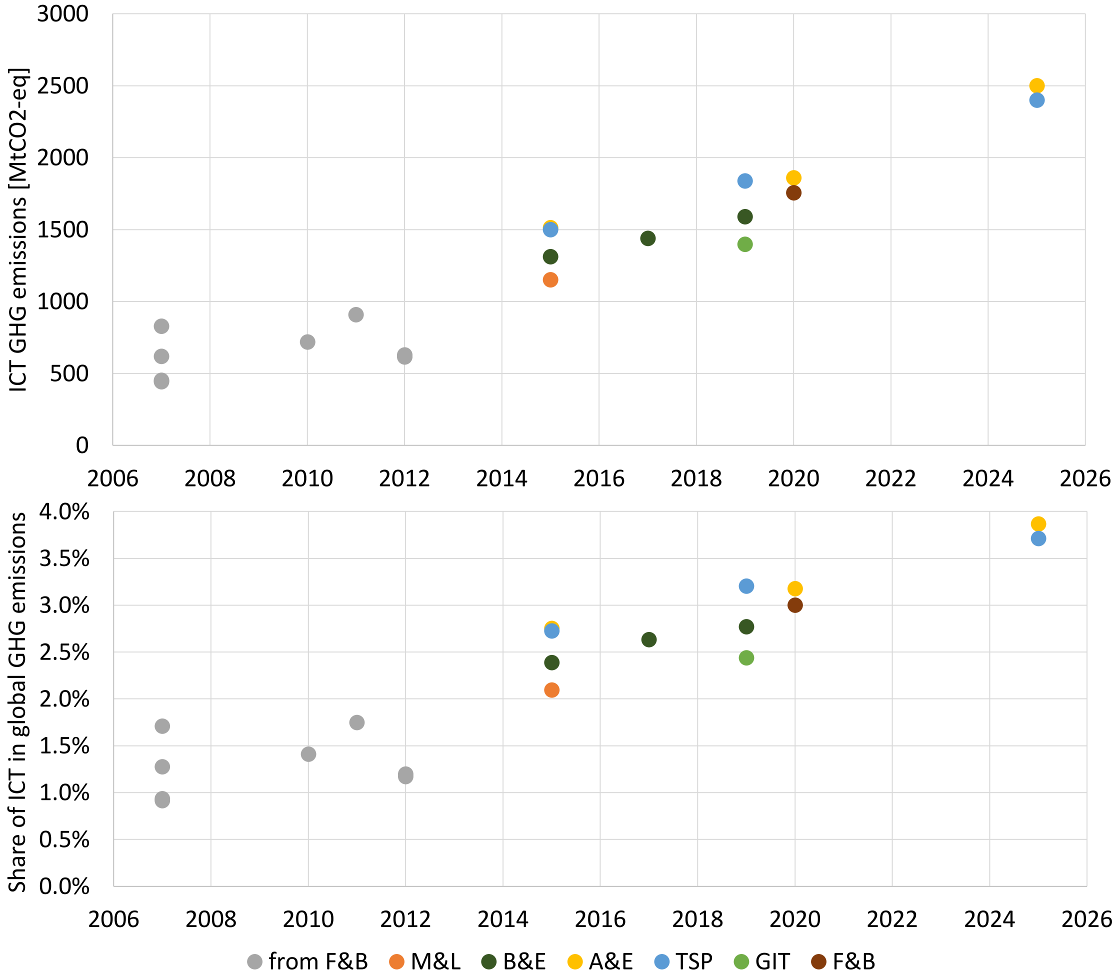


Fig. 1.3.: ICT GHG emissions evolution (above) and their share in the global GHG emissions (below). Details about data, sources and hypotheses can be found in Table 1.1. The grey data comes from [59] and are presented in order to have a better overview of the evolution.

presents relatively important differences as shown in Figure 1.5. Two main trends stand out: on the one hand, M&L and GIT found the user devices to be the major impact source; on the other hand, A&E and B&E found a relatively equal impact from the three sources. Given these differences, no conclusions are drawn other than to confirm that further studies are needed to clarify this point.

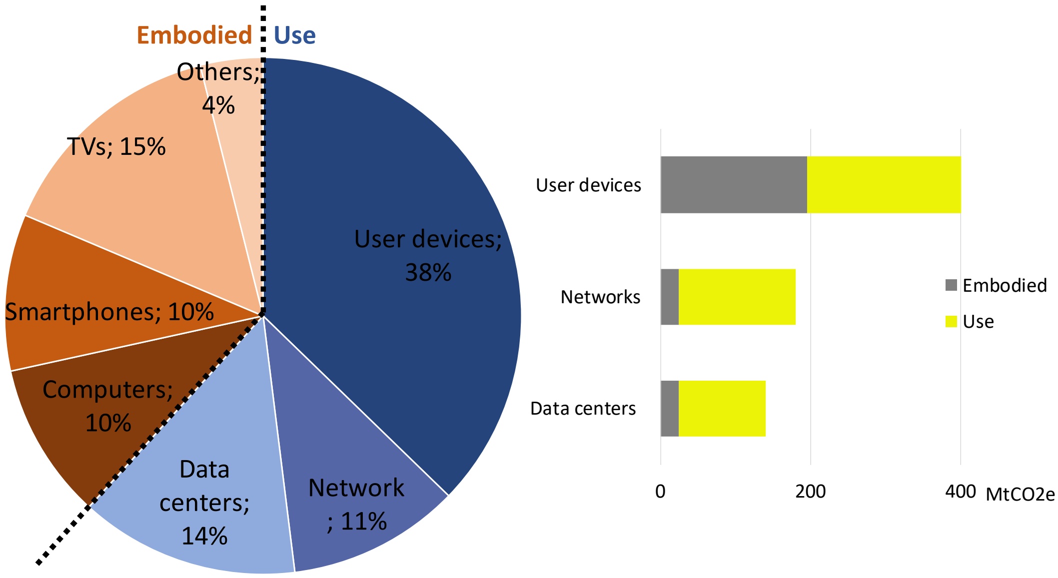


Fig. 1.4.: Fraction of embodied and usage emissions in ICT. Embodied emissions are substantial. The left graphic comes from TSP [57, Fig. 3] and the right graphic comes from M&L [94, Fig. 13].

Projections and discussion

As it is shown thereafter, many scenarios exist and all studies do not agree about the future importance of ICT in our overall future carbon footprint. However, most of the authors agree on one point: ICT are tools and as such, it is only what we do with these tools that will define the relative importance of this sector in our future footprint [12, 57, 59, 94]. Many also agree that these technologies have the potential to lower global emissions, although they do not predict necessarily that this is the direction our societies will take [21, 39, 41, 59, 70, 92].

To estimate the future emissions of the ICT sector, several studies preferred to divide their predictions into different scenarios. This option has two main advantages. First, it gives an idea to the decision-makers of the future impacts depending on different political trajectories. Second, it provides a natural range of uncertainty as these are high when making predictions in the ICT sector. For example, A&E makes three scenarios: best, expected, and worst. In their model, the number of devices, the data traffic, and the energy intensity of the Internet are different for these three scenarios. Similarly, B&E divides their estimations into a minimum and maximum threshold. In addition, for their

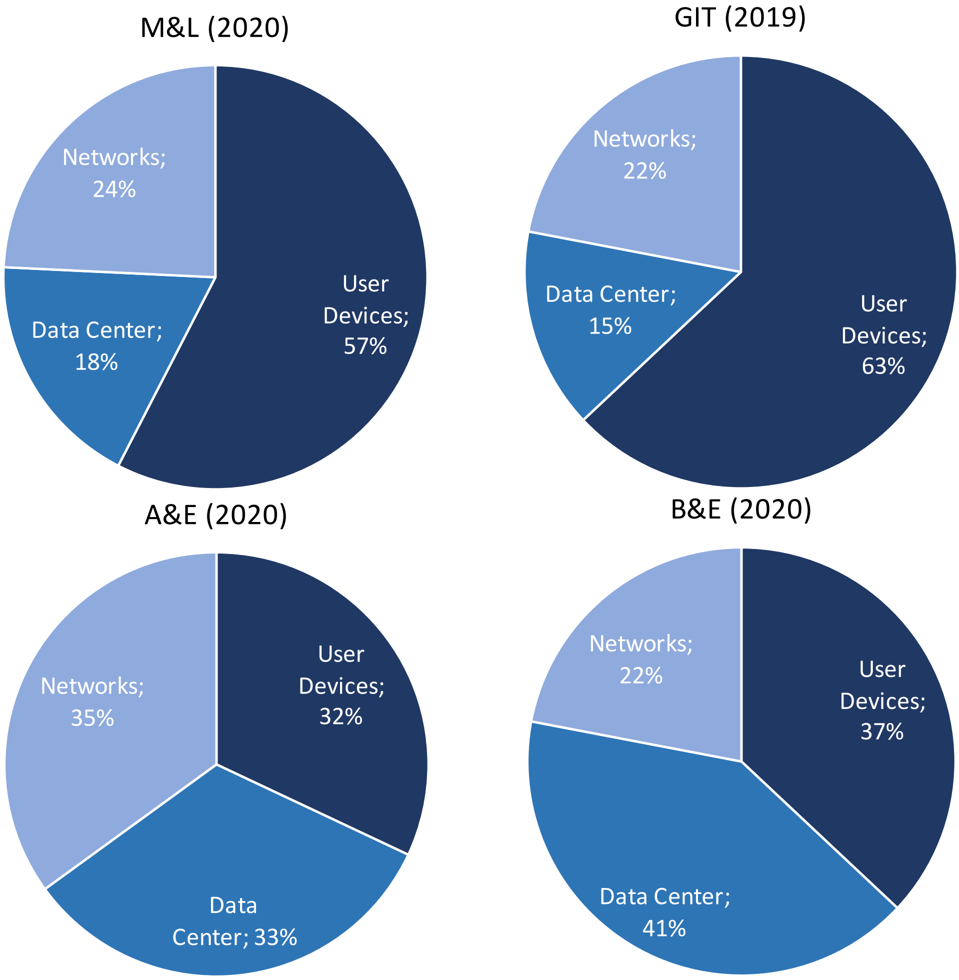


Fig. 1.5.: Sources of ICT impacts from different studies. Results from these studies are not consistent with each other. Details about data, sources and hypotheses can be found in Table 1.1. All figures expect the one from GreenIT.fr (GIT) come from F&B [59, p. 14].

prediction, they assess both a linear and an exponential increase based on previous data. Finally, TSP distinguishes four cases: conservative (current trends are extended), growth (increasing data traffic), growth less energy efficiency (same as growth but with a slight slowdown in energy efficiency gains), and new sobriety (fewer devices and data traffic). Results from the last two studies are exposed in Figure 1.6.

As shown, all scenarios result in a more or less important increase. However, depending on the scenario, the importance of the increase varies. The worse scenario from TSP (i.e. growth less energy efficiency) is the worst scenario from both studies since it predicts the ICT share to be 7% in 2025 while B&E does not exceed 5.5%.

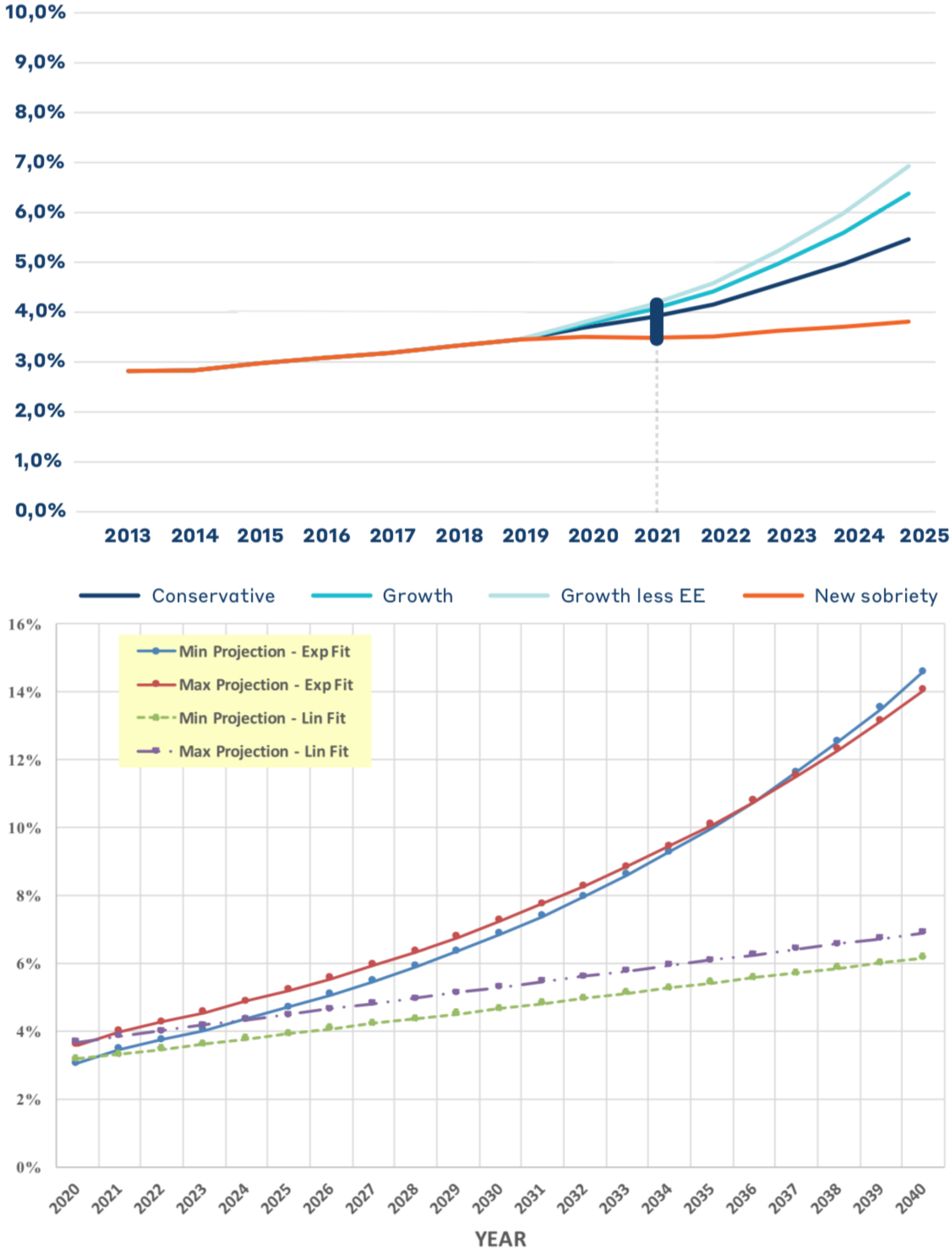


Fig. 1.6.: Projections of ICT emissions share in global GHG emissions from TSP [57] (above) and B&E [17] (below). Note the different time scale for the horizontal axis between the two graphics.

Finally, the question of the sustainability of the sector is addressed. Most of the authors agree on one point: due to this future bigger ICT share on global GHG emissions, a closer attention must be drawn to this sector since it could become one of the key domain impacting global GHG emissions.

Apart from this shared opinion, there are two opposing positions.
Indeed, on the one hand, several companies or organisations defend and highlight the potential of the ICT sector to reduce overall GHG emissions thanks to enabling impacts (as described by the LES model previously introduced). This vision is argued for example by Ericsson [55, p. 19] as well as the Global e-Sustainable Initiative (GeSI) which is a think thank mainly supported by the largest ICT companies [61, 134]. Note that the recent European Green Deal also bets on reducing emissions through ICT: « *Digital technologies are a critical enabler for attaining the sustainability goals of the Green deal in many different sectors* » [36].
On the other hand, while several scientists agree about this potential of reduction [59, 113, 126], they do mainly emphasise the fact that such a decrease has never been proved or observed, in particular due to the rebound effects. For example, F&B write: «*Based on the evidence available, it is also key that regulators move away from the presumption that ICT saves more emissions than it produces. While ICT offers opportunities to enable reductions in GHG emissions in other sectors, evidence does not support their ability to achieve the sustained significant carbon savings we require by 2050* » [59, p. 38]. According to the authors, one of the solution to face this problem is a stronger legislation to regulate and encourage the necessary emission reduction [15, 57, 59, 71, 101, 113, 125].
Similarly, B&E worry about the general business model of the major ICT companies which do not put the extension of the life span and recycling at the center of their priorities [17]. This leads to an explosion of the amount of equipment, the example of the smartphones being the most striking one, as well as an increase of the energy consumption [17].
Finally, The Shift Project is the most sceptical about a future decrease based on the current evolution of many indicators [57, 113]. If nothing is done, the ICT sector will become a significant contributor to the GHG emissions mix according to them.

1.5 Similar studies: digital carbon footprint of universities

This section aims to present other universities' carbon footprint and to present how they handle the digital aspect. As it is shown, this aspect is usually not deepened by the universities or sometimes not even mentioned. The reasons that might explain such a lack are detailed. Next, the last global carbon footprint from UCLouvain is presented and the digital aspect is detailed. Moreover, the Ecole Polytechnique Fédérale de Lausanne (EPFL) has recently conducted a similar survey about the environmental impacts of the digital at EPFL [67]. Their main results are presented and discussed more specifically.

1.5.1 Overall carbon footprint of universities

With regard to universities carbon footprint, there are many reports available from all around the world (see for example [66, 137] which compare and discuss different universities' carbon footprints). However, they remain few carbon footprints published compared to the number of existing universities. One of the main challenge in this field is the homogenisation of this process in order to be able to compare two different universities' carbon footprints. Indeed, at the moment, there is a lack of consistency between different works because of different analysis methods, different impact measures, and different target definitions [66]. To mitigate this, the Stars Reporting Tool [119] is mainly used in the USA and in Canada. However, this tool aims to rate universities based on a set of common criteria although no quantifying carbon footprint is conducted.

Unfortunately, a large part of the available university carbon footprints do not threat or event mentioned the digital aspect, as if it did not exist. For example, McGill University (Canada) does not take into account any IT equipment in its last report [116] and does not give any explanation about it. Similarly, a recent study [66] that aims to compare different university carbon footprints exclude ICT equipment from its scope.

Alternatively, some studies try to take into account this aspect but with a relatively important lack of precision mainly due to the difficulty to access raw data. For example, King's College London published a recent report [34] about its carbon footprint. The ICT equipment impacts are estimated based on the total procurement, meaning they apply a single emission factor to any ICT equipment depending on its price, regardless of the type of equipment. This choice can be defended and argued but it seems clear that a lack of precision stems from it. However, they are conscious of this problem, writing: «*Currently, our procurement emissions are calculated on the basis of our spend on specific product categories. While this gives us an estimate of our emissions, many uncertainties remain*» [34, p. 12].

A global carbon footprint of UCLouvain was achieved for the year 2017 [95]. In this previous work, a deeper analysis was conducted since several IT equipment (computers, servers, and printers) were taken into account in the *Immobilisation* sector. Moreover, the transferred data were used to attempt to quantify these impacts by applying an emission factor in kgCO2-eq/GB.

These examples are far from exhaustive but it gives an idea of the global trend not to deepen this aspect further. Several difficulties to assess a digital carbon footprint might explain this.
First, as already detailed in Section 1.4.2, there is a wide range of difficulties to assess the environmental impact of the ICT sector; the ones related to data being probably the most important ones in the case of a university carbon footprint.
Second, most of the studies follow either the GHG Protocol [122] or the Bilan Carbone [1] or the more general ISO14064 [78] methodology [34, 66, 137]. Within these standards, it is recommended to present the main results by scope as introduced in Section 1.2. In the case of the ICT, the impacts can either be Scope 2 or Scope 3 which makes it more difficult to present a single ICT impacts category. Moreover, these standards are not really designed to properly present the ICT impacts. This is not especially a downside, it is simply a choice of convention. For example, by strictly following the Bilan Carbone methodology, the ICT equipment would appear in a *Purchase of products and services* category which include also non ICT equipment. Similarly, in the recent UCLouvain carbon footprint [95], several ICT equipment are taken into account but they are not presented together in a single *ICT impacts* category.
Finally, another important reason that might explain the general trend not to deepen the ICT sector is that it is still a relatively small contributor in most cases. Indeed, generally, the energy consumption for both lighting and heating as well as the students and employees commuting are the main source of impacts [66, 95, 114, 124, 137]. This stays true although these categories vary significantly depending on the location of the university. This might be a reason to spent time to get accuracy on more important aspects, leaving partially aside the ICT sector. However, this could be dangerous since this sector evolves rapidly and its importance in the global impacts increase as mentioned previously. Moreover, a closer look at this sector might reveal a much more important impact contributor than a brief approach [67].

1.5.2 Digital carbon footprint of universities

UCLouvain

First of all, the latest UCLouvain carbon footprint [95] (realised in 2019 and concerning 2017) includes several ICT equipment and services. Indeed, into the fixed assets, the author includes the desktops, laptops, servers, and printers. Moreover, electricity consumption from these equipment is indirectly considered since the total electricity consumption is included. Similarly, the IT employees are indirectly taken into account in the total employees. Finally, the transferred data (both In and Out) were obtained. Taking into account all the above, the impacts of each contribution were found and are presented in Table 1.2. The total estimated impact extracted from this study is 3387 tCO2-eq, i.e. 5 % of the total impacts (68478 tCO2-eq). The main source of impact is clearly the transferred data counting for 70 %.
In Table 1.2, the data in brackets from the last column are estimated using the same emission factors as well as the same lifetime as the ones from this study for a better comparison. For example, for the servers, the previous work used an emission factor of 2565 kgCO2-eq/device while in this study it is 600 kgCO2-eq/device. Both figures come from the Base Carbone but data evolve over time. In addition, once again concerning the servers, the previous UCLouvain carbon footprint considered a unique lifetime of 5 years for any IT equipment. For this study, a differentiation is made between each type of equipment as the servers have an approximate 8 years lifetime according to an employee of the IT department. The result, based on the latter estimation, gives a total footprint of 2873 tCO2-eq, i.e. 15 % less than the original result. This would represent 4.2 % of the total carbon footprint.

This 4 or 5 % share tells us that the digital sector is far away to be the driving contributor to the global carbon footprint. Indeed, the energetic and commuting sector are the main ones, accounting for almost 90 % of the total footprint. One of the goal of this study is to determine if a closer look at the digital sector makes this 5 % proportion to increase significantly or if a cursory approach already allows identifying the main trends.

Tab. 1.2.: Presentation of the digital aspect and their associated impacts of the previous UCLouvain carbon footprint [95]. The last column summarises the impact of each category. The first number is extracted from the previous UCLouvain carbon footprint directly from the Excel file transmitted by the author while the numbers in brackets were adapted using equivalent emission factors to those used is this work for a better comparison.

Contributor	Unit	Quantity	Impact [tCO2-eq] (with same emission factor and lifetime)
Laptop[a]	[device]	2616	88.4 (81.6)
Desktop[a]	[device]	3292	124.4 (111.3)
Printer[a]	[device]	250	147 (50)
Server[a]	[device]	280[b]	143.6 (21)
Electricity consumption[c]	[kWh]	2168662	283.8
IT employees	[person]	150	308.9[d]
Transferred Data	[PB]	15.27	2290.5 (2015.6)
Total			**3 387 (2 872)**

Legend *a* : embodied emissions. *b* : in the original report, the authors counted 95 servers. However, an employee of the IT department, confirmed me that this number was wrong. The mistake comes from the fact that these 95 servers represented only a recent purchase. *c* : estimated from personal calculation from the carbon footprint used for this study taking into account the differences in the quantity of equipment. *d* : estimated from [95], more details in Section 2.6.3.

EPFL

Second, the Ecole Polytechnique Fédérale de Lausanne (EPFL, Switzerland) published recently a study concerning the environmental impacts of the ICT at the EPFL [67]. This is the most similar existing work to this study. This study was conducted by the *Digital Sobriety* group and does not involve directly the direction of the university.
Before presenting the results, it is important to know that EPFL had, in 2020, 6369 employees and 11813 students [54]. EPFL is thus a smaller university compared to UCLouvain in terms of the number of students while being similar in terms of employees.

The context of the EPFL study is similar to this study. Indeed, for several years, EPFL assessed and published each year its global carbon footprint [114]. However, these assessments stay approximate since the scope of the study is narrow. Indeed, it only takes into account the energy consumption (electricity, gas, and fuel), the employees and student mobility, and the food served on the campus. Because of the absence of the digital aspect in these evaluations, the willingness to quantify it appeared.

The methodology followed by this study is similar to the EPFL study since they first mapped the digital inventory and addressed an emission factor to each contributor. However, this last step was conducted by an independent consultant (Frédéric Bordage and the GreenConcept database [63]). Unfortunately, this prevents the authors to publish the emission factors that were used in a transparent manner. They are aware this represents a weakness [67, p. 18]. This is a major downside that limits the comparison with this study. However, this choice allows them not to only focus on the global warming effects through the CO2-eq consideration. Indeed, they also consider the impacts of ICT on Energy Depletion (in Joules of Primary Energy), Water Use (in m^3), and Mineral Resources (in kgSbe[7]). This approach, closer to a life cycle assessment methodology, has the advantage to draw a wider picture of the impacts caused by ICT. Another advantage of such a choice is that they have access to results from previous studies conducted by Frédéric Bordage allowing a benchmarking.

The scope of their study includes all the ICT equipment from the university, as well as the laptops from the students (they suppose one laptop per student). However, the transferred data and the impacts of the network outside EPFL are not included[8]. The IT employees are considered. The end-of-life was neglected although they mentioned the amount of ICT waste in kilograms.

Finally, considering the electricity bought by the EPFL which is a 100% renewable mix, the digital carbon footprint of the EPFL is about 5950 tCO2-eq. However, the authors preferred to present the main results as the total obtained when considering the Swiss electrical mix, i.e. 7840 tCO2-eq. They justify this by considering that the purchase of a green mix by the EPFL might artificially deteriorate the electrical mix from other users. Therefore, the authors preferred to consider the 1890 tCO2-eq difference as a carbon compensation. A counter-argument could be that, consequently, the university loses interest in its ability to choose its electricity mix.
These results reported by member (employees and students) become 338 and 446 kgCO2-eq/member when considering, respectively, the EPFL and the Swiss electricity mix. Ultimately, the authors found that this 7840 tCO2-eq represents 25% of the global carbon footprint (32000 tCO2-eq) based on the studies mentioned above.

Three arguments can be given to mitigate this figure. First, the choice to use the Swiss electricity mix instead of the EPFL one. Second, the total of 32000 tCO2-eq does not

[7] Kilogram of Antimony equivalent. This indicator is similar to CO2-eq but for the use of mineral resources.
[8] The authors say (p. 7) :«*An update of Frédéric Bordage's calculation model as part of the NegaOctet project should make it possible, by mid-2021, to revise this document to take this into account*».

include ICT and it would have been therefore more rigorous to take it into account[9]. Third, as already explained, the scope used to obtain 32000 tCO2-eq could have been larger by including, for example, the fixed assets.
Considering the two first remarks, the ICT share in the global footprint is about 15.6 %. This share is still significant and shows the importance to include the ICT sector in the global footprint.

[9]One of the author was contacted and confirmed this deliberately chosen approximation.

2 Data and Methodology

In order to conduct this carbon footprint, the Bilan Carbone® methodology was followed [1]. Reasons which motivated this choice were already introduced in Section 1.2.
The first section defines precisely the scope of the carbon footprint. Next, the categories of the model are presented. These categories will help to present the results later. Third, explanations about uncertainties in a carbon footprint are given. Then, the inventory of the model, which is at the core of this study, is introduced. In addition, the assumptions, the sources, and the way this inventory was constructed are presented and explained in detail. Next, the emissions due to the usage of the equipment are detailed. The complete methodology as well as the main assumptions are presented. Finally, the last section covers the emission factors. The choice of the sources is discussed and the assumptions for the assessment for specific factors are given.

2.1 Definition of the scope

Defining a clear scope is a prerequisite to any carbon footprint in order to clarify what is or is not included into the study.
Based on the previous UCLouvain carbon footprint [95], three different scopes are defined: the temporal, the organisational, and the operational scope.

Temporal scope The main study covers the calendar year 2019. A specific section is addressed to the COVID-19 crisis, covering the year 2020.

Organisational scope UCLouvain is a multi-site university and the scope includes all the buildings and equipment belonging to UCLouvain at the Louvain-La-Neuve (LLN), Bruxelles-Woluwé (LEW), Mons, Tournai, and Bruxelles-Saint-Gilles campuses. The only campus not considered is the Charleroi one since it is negligible. The previous report [95] made the same choice.

Operational scope The scope includes all the emissions induced by the digital equipment owned by UCLouvain considering the digital definition given in Section 1.2.

This includes both the upstream emissions due to production and transport (called embodied emissions later in this report) and the usage-related emissions.
The end-of-life emissions are not considered for two reasons: the lack of reliable sources to quantify the impact (favorable or not) of recycling and the difficulty to collect reliable information about what becomes the digital equipment sent to Recupel. Moreover, EPFL and the last UCLouvain carbon footprint made the same choice [67, p.8][95] as well as other larger studies [21, 57]. In 2019, the total weight of digital equipment waste sent to Recupel by UCLouvain was 12.4 tons. In future analysis, it could be interesting to develop a methodology to take this share into account since it is far away to be a marginal amount.
In addition, a fraction of the production and usage emissions induced by personal digital equipment from employees and students is considered. As a matter of fact, it is clear today that digital equipment have become almost essential for students. This is a difference from the scope defined in 2017 [95].
As well as in 2017, the transferred data are taking into account.
Finally, the employees from the IT department were considered. Indeed, ETSI and ITU standards recommend taking these impacts into account (they do classify this into an «*Operator support activities*» category [6, 52]) and EPFL did the same choice for its study.

2.2 Classification of data

In order to make the results easier to interpret, different categories were established, as follows:

- Office equipment: all the equipment used by the employees in their offices (computers, screens, phones, etc.).
- Computer rooms: the equipment from the different computer rooms available for the students.
- Administrative data center: UCLouvain owns two administrative data centers (named *Tier II* and *Aquarium*). The servers, the cooling system, and the electricity backup system are included.
- Scientific data center: UCLouvain owns one data center dedicated to scientific purposes and managed by the CISM (Calcul Intensif et Stockage de Masse). Moreover,

it gets access to Cenearo facilities and its super calculator *Zenobe*. Based on the annual report from CISM [30], it was established that UCLouvain operated 25 % of *Zenobe* in 2019 (in terms of computing time) [30] and therefore this fraction of the total impacts goes to UCLouvain.

- Audiovisual: the digital equipment installed in the auditoriums, classrooms, and educational buildings.
- UCLouvain network: the equipment and the infrastructures necessary to offer Internet connection. It is composed of switches, modems, routers as well as optical fibre, and copper cables.
- Security: mainly video surveillance cameras and viewing screens.
- Private equipment: digital equipment from employees and students used for professional or educational reasons at UCLouvain.
- Labour: the impacts generated by the 150 employees of the SGSI (the UCLouvain IT department).
- Data transfer: emissions induced by the 23 Petabytes transferred in 2019.

For each device, both the embodied and the usage-related emissions were taken into account and calculated separately.

2.3 Uncertainties

The carbon footprint methodology consists mainly of sums and multiplications (see Equation (1.1)). However, for both data and emission factors, there exists an uncertainty on its precise value. This section discusses the criteria used to assign an uncertainty to new data as well as how to deal with these uncertainties.

Assigning uncertainty

There is not a clear and unique method to assign uncertainty [2]. In this study, the following assignment method is used:

- **0%** for a direct measurement (e.g. bills or meters);
- **15%** for low uncertainty (e.g. reliable but not measured data);
- **30%** for average uncertainty (e.g. extrapolation based on reliable data);
- **50%** for high uncertainty (e.g. extrapolation based on assumptions);

This assigning method is different from the one used in the previous carbon footprint conducted at UCLouvain [95, p. 17]. It was chosen since it is the most used by the Association Bilan Carbone (ABC) [16].

Calculation of the global uncertainty

As just mentioned, two mathematical operations are used for a carbon footprint (addition and multiplication). For both, different rules apply [2, 76].

For a multiplication [1] the resulting uncertainty is given by :

$$U_{tot} = \sqrt{U_{Data}^2 + U_{EF}^2} \tag{2.1}$$

where U_{tot} is the resulting uncertainty, U_{Data} is the uncertainty associated with the data (assigned as explained above) and U_{EF} is the uncertainty associated with the emission factor (Base Carbone always gives an associated uncertainty to all of their factors).

For addition of n parameters, the resulting uncertainty is given by :

$$U_{tot} = \frac{\sqrt{(U_1 \cdot X_1)^2 + (U_2 \cdot X_2)^2 + ... + (U_n \cdot X_n)^2}}{X_1 + X_2 + ... + X_n} \tag{2.2}$$

where U_{tot} is the resulting uncertainty, X_i is the emission (in kgCO2-eq) of item i, and U_i is the uncertainty associated with item i (usually obtained with the first equation).

[1] In the case of a carbon footprint, the multiplication rarely involves more than two parameters.

2.4 Inventory

The inventory used for this study is presented in Table 2.1. A large part of the work during this year was to collect the information from several UCLouvain departments. Complete details regarding data sources can be found in Appendix A.
This inventory is not exactly the one used by the model developed for this study. Indeed, for specific equipment, enough details were collected in order to differentiate them according to certain characteristics. Few examples are the laptops, tablets, and screens for which details about screen size were obtained. For clearness reasons, those details are not shown in this final report. More details regarding screen size impact are given in Section 2.6.3.
Uncertainty to each data was assigned as described earlier in Section 2.3.

The inventory presented might not be fully correct. Indeed, while most of the data collected from the different UCLouvain departments are reliable, those departments admit that certain equipment might be not listed in their inventory. The reason is that those different faculties, institutes, or poles do sometimes invest digital equipment with their funds. Even though any digital equipment is supposed to be reported to the IT department (SGSI), different sources from UCLouvain confirmed there are sometimes mistakes and oversights in this system. Quantify such shortcomings was not possible although it is probably minor.
The inventory used for this study might therefore be underestimated. This bias comes from the bottom-up approach as already discussed.

Tab. 2.1.: The inventory used for this study.

Category	Equipment	Unit	Common	LLN	Woluwe	Mons	Tournai	St-Gilles	Uncer.	Lifetime [y]
Number of members	Employees			4700	1033	250	71	67	0%	-
	Students			22142	6754	1131	437	490	0%	-
Office Equipment	Desktop Comp. & Screen	devices		2848	583	11	10	27	15%	5
	Laptop	devices		2757	404	118	11	31	15%	5
	Additional Screen	devices		3068	445	119	53	51	30%	5
	Printer	devices		492	109	26	7	7	50%	5
	Photocopier	devices		353	53	11	3	0	50%	5
	Office Phone	devices		4160	1280	210	20	42	15%	10
	Tablet	devices		300	29	17	6	6	30%	3
	Hard Disk Drive	devices		319	34	16	7	7	30%	5
	Smartphone	devices		373	57	10	5	5	30%	3
Comp. Rooms	Desktop Comp. & Screen	devices		970	407	317	46	6	15%	5
Labour (IT employees)		persons	150						30%	1
Administrative Data Centers (*TierII* and *Aquarium*)	Server	devices	280						30%	8
	Infrastructure	m^2	173						15%	40
	Elec. Consumption	MWh	1106						15%	1
	Generator Set	devices	1						0%	15
	Battery Module	devices	4						0%	10
	Hard Disk Drive (DC)	devices	1500						50%	8
Data Transfer		PB	22.81						0%	1
Scientific Data Centers (*DC3* and *Cenearo*)	Server	devices		445					30%	8
	Infrastructure	m^2		126					15%	40
	Elec. Consumption	MWh		1661					0%	1
	Battery Module	devices		3					15%	10
Audiovisual	Projector	devices		175	36	31	10	12	30%	5
	Monitor	devices		116	36	15	2	3	15%	6
	Speaker	devices		199	62	56	4	4	50%	5
	Polycom (LLL)	devices		4					0%	5
UCLouvain Network Infrastructure	Wifi Modem	devices		619	408	88	24	46	15%	5
	Core Router	devices		6	1	2	1	1	15%	10
	Data Center Switch	devices		34	1	2	0	0	15%	5
	Distribution Switch	devices		71	25	4	1	1	15%	5
	Access Switch	devices		341	120	17	8	9	15%	5
	Firewall	devices			CONFIDENTIAL				50%	5
	Copper Wires	km		402	142	20	9	11	50%	25

Category	Equipment	Unit	Common	LLN	Woluwe	Mons	Tournai	St-Gilles	Uncer.	Lifetime [y]
	Optical Fiber	km		31	37	65	100	30	15%	40
Security Equipment	Surveillance Camera	devices	CONFIDENTIAL						15%	10
	Monitor	devices		8					15%	6
	Walkie-Talkie	devices		98					15%	10
Private Equipment (employees)	Desktop Comp. & Screen	devices		579	167	32	8	7	30%	5
	Laptop	devices		1492	458	108	18	17	30%	5
	Additional Screen	devices		888	188	62	12	12	30%	5
	Tablet	devices		537	154	32	8	7	30%	3
	Smartphone	devices		2609	614	163	36	34	30%	3
	Printer	devices		289	96	27	2	1	30%	5
	Hard Disk Drive	devices		1575	301	108	24	23	30%	5
	Webcam	devices		438	159	30	5	4	30%	3
Private Equipment (students)	Desktop Comp. & Screen	devices		2683	838	148	75	84	30%	5
	Laptop	devices		23853	7454	1255	471	528	30%	5
	Additional Screen	devices		3552	572	210	143	161	30%	5
	Tablet	devices		3658	2498	211	109	122	30%	3
	Smartphone	devices		19003	6067	983	396	444	30%	3
	Printer	devices		1849	713	69	89	99	30%	5
	Hard Disk Drive	devices		12358	3325	607	314	352	30%	5
	Webcam	devices		5926	1028	355	102	115	30%	3

Legend: Black figures were collected from different UCLouvain departments. The complete details about the sources can be found in Appendix A. Purple and Green figures are extrapolations for others campuses based on one or more campuses for which data were available based on the number of employees or students on each campuses, respectively. Blue figures are extracted from the online survey.

2.4.1 Online survey

In this study, the digital equipment from employees and students used for their activities at UCLouvain is considered inside the scope. In order to get the most precise inventory for both the type of equipment and the usage patterns, an online survey among the university community was conducted. This survey was developed on Limesurvey software [87] and sent by email to every employee and student. In total, 2561 answers were collected. Details about participation can be found in Appendix B.

Validity of the online survey data

This section aims to verify the validity of this survey. To do so, the Cochran sampling technique [33] is used:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \qquad \text{with} \qquad n_0 = \frac{Z^2 p(1-p)}{e^2} \tag{2.3}$$

where n is the sample size, n_0 is the sample size for an infinite population, N is the population, Z^2 is the abscissa of the normal curve that cuts off an area of α at the tails (1-α being the desired confidence level), p is the proportion of an attribute in the population (if unknown, equal to 0.5 meaning a maximum variability) and e is the desired level of precision.

To obtain data inside a 95 % confidence interval with an error of 5 %, approximately 380 and 360 answers from, respectively, students and employees were needed, which was achieved in this study (see details in Appendix B).

Nevertheless, as a precaution and because the population was split and analysed by sector or faculty (thus reducing the size of the samples), a 30 % error is associated with the results extracted.

Finally, although answers were collected in march 2021, they were used for this carbon footprint which focuses on 2019. Potential changes for both the quantity of equipment owned and the usage patterns are neglected. Moreover, data were collected specifying that it concerned normal circumstances, without COVID-19.

Data extracted from the survey

To analyse the raw results, the following general formula was followed:

$$\begin{aligned} \text{GHG emissions} &= \sum \text{Embodied} + \sum \text{Use} && \text{kgCO2-eq} \\ &= \sum_i n_i\, f_i\, F_{e_i} + \sum_i n_i\, p_i\, t_i\, F_{elec} && \text{kgCO2-eq} \qquad (2.4) \end{aligned}$$

where n_i is the number of equipment of type i, f_i is the fraction of the private equipment attributed to UCLouvain (details are given in Section 2.4.2), F_{e_i} is the embodied emission factor for equipment i, p_i is the power consumption of equipment i, t_i is the time spent on equipment i and F_{elec} is the emission factor of the electricity (220 [tCO2-eq/GWh] which is the Belgian mix [9]).
The results from the survey were classified depending on the status (employee or student) and the sector or faculty of the participant. This allows to differentiate the answers for different campuses.

2.4.2 Assumptions

This section presents the main assumptions regarding the inventory data.

Deduction for missing data

As described in Table 2.1, when data were missing for specific campuses, extrapolations based on other campuses were made. These extrapolations were based either on the number of employees or students according to what was most appropriate.

Distribution of common emissions

For several categories, it would not make sense (i.e. it would not be representative) to assign fully the impacts to Louvain-La-Neuve campus while the entire UCLouvain community benefits from it. This is the case for example for the administrative data centers, the IT employees, or the transferred data. For these categories, their impacts were distributed following the number of members (employees and students) of each campus.
For the scientific data centers, the choice to fully assign the impacts to Louvain-La-Neuve campus was made. Indeed, the faculties and institutes using those data centers are mainly based there.

Network wires

There are two types of wires between network equipment: copper wire and optical fibre. For the fibre, precise values were collected while an estimate is made for copper wire as detailed below. We differentiate three types of wires:

i) The copper wires between the digital equipment and the closest access switch. This connection allows both internet access and power source through Power Over Ethernet (POE). To estimate these cables, an average value was computed from 100 tests carried out by the network team (SIPR) during recent work in one of the buildings. The average value is 37 meters between each equipment and the closest switch. Based on estimations given by the SIPR, it is found that on average, 30 equipment are connected to each access switch (UCLouvain uses both 24 and 48 ports access switches).

ii) The copper wires between the access switches and the distribution switches. The network team (SIPR) gives an average value of 70 meters per cable.

iii) Between the distribution switches and the routers, optical fibre is used and lengths are known precisely. Moreover, Mr. Fabrice Charlier from SGSI informed us that each site is connected to Louvain-La-Neuve by optical fibre. These distances are estimated.

Private equipment

Unlike the EPFL, we do not consider 100 % of the embodied impacts of the private equipment (EPFL only takes into account one laptop per student). Indeed, these equipment are also used for personal purposes.
It was possible to determine the figures presented in Table 2.2 based on the online survey results and on private use assumptions.

Tab. 2.2.: Fraction of the embodied emissions allocated to UCLouvain for both employees' and students' equipment. These results were obtained by looking at the fraction of use for UCLouvain based on the online survey results and private use assumptions.

Equipment	Employees	Students
Laptop	65 %	60 %
Desktop Computer screen	65 %	80 %
Tablet	60 %	65 %
Smartphone	10 %	10 %
Peripherals (printer, hard disk, webcam)	30 %	30 %

2.5 Usage emissions

In order to determine the usage-related emissions, the consumption of equipment as well as the usage scenario must be clearly defined. The main data are summarised in Table 2.3. For the last column, hypotheses must be made on working days. For equipment related to teaching, 27 weeks of courses (14 in the first semester, 13 in the second one) are considered. For the employees' equipment, 253 working days are considered. For the network, data center, and security equipment, continuous use is assumed.
The only equipment for which the consumption was precisely known are the data center since the reading of electricity meters was obtained.
The consumption listed in Table 2.3 comes from different sources: product specifications, indications of UCLouvain employees, literature review, assumptions.

2.6 Emission factors

The determination or the choice of the emission factors has a key impact on the final results. This is even more true for the IT sector for which important differences between factors from different sources can be found. For this study, it was decided to **select the majority of the emission factors from the Base Carbone from ADEME** [9].

This choice was made for the following reasons. First, the previous UCLouvain global carbon footprint used this source. It is therefore a way to continue and compare more easily the work which was already carried out. Second, since this study follows the Bilan Carbone® methodology, these are the emission factors recommended. Next, ADEME is a national organisation attached to a ministry without any financial purpose. Therefore, data are easily available and methodologies are exposed in detail. Finally, doing so, the majority of the emission factors used are coming from a single source, making it more consistent.

Despite these advantages, there are counter-arguments to the use of the Base Carbone factors. The main one is that the figures are sometimes outdated (remember ICT is a fast-paced technology) or highly uncertain [99, p. 7] [45]. Moreover, important differences can be found with alternatives sources. Those are the reasons why EPFL decided not to use these data but rather to use private factors.

Tab. 2.3.: Usage scenarios and consumption of the main digital equipment used in this study. Certain minor equipment which are included in the model are not written here for clearness reasons. Blue figures are the ones extracted from the online survey.

Equipment	**Normal power consumption (off mode) [W]**	**Usage [h/day]**	**Energy consumption per year [kWh/year]**
UCLouvain Equip.			
Video-projector	400 (0.5)	6	328
Television	75 (0.5)	10	104
Photocopier	1700 (1)	1/2	224
Printer	400 (0.5)	1/2	55
Desktop computer	150 (0.5)	5.5	206
Screen	75	7	132
Laptop	50 (0.5)	7	92
Tablet	10 (0.2)	2	6.5
Security camera	13	24	114
Modem	10	24	88
Switch	66	24	578
Employee Equip.			
Desktop computer	150 (0.5)	2.5	95
Laptop	50 (0.5)	3	38
Tablet	10 (0.2)	2	5
Student Equip.			
Desktop computer	150 (0.5)	3	114
Laptop	50 (0.5)	4.2	53
Tablet	10 (0.2)	2.8	7

Because of these downsides, a sensitivity analysis using different emission factors is conducted in Section 3.5.

2.6.1 Electricity

Since the emissions due to usage consumption of digital equipment need to be investigated, the emission factor of the supplied electricity need to be determined. When appropriate, the global Belgian electricity mix factor of 220 [tCO2-eq/GWh] can be applied. For example, for private equipment consumption, this value is used.
However, for the UCLouvain electricity, others emission factors need to be determined. This is because UCLouvain has the particularity to produce part of its electricity on the

Louvain-La-Neuve campus with a cogeneration plant and to buy specific electricity mix for others campuses. This leads to electricity more or less carbon based depending on the year (the purchased mix changes) and the campus.
The final emission factors can therefore be calculated using the general formula:

$$EF = \sum_i x_i EF_i \tag{2.5}$$

where x_i is the fraction of the electricity source i in the mix and EF_i is the emission factor associated.
The emission factors for different electricity production methods and parameters used are listed in Table 2.4.

Tab. 2.4.: Emission factors and parameters used to compute the UCLouvain's electricity emission factors.

Source of electricity or parameter	Unit	Value	Sources
Combined Cycle Gas Turbine	[tCO2-eq/GWh]	440	[35]
Cogeneration	[tCO2-eq/GWh$_g$][2]	279	[35]
Nuclear	[tCO2-eq/GWh]	15	[35]
Wind (onshore)	[tCO2-eq/GWh]	10	[35]
Solar	[tCO2-eq/GWh]	45	[35]
Hydro	[tCO2-eq/GWh]	6	[35]
Power grid losses	[%]	6.39	[56, 96]

Electricity emission factor in Louvain-La-Neuve

The electricity in Louvain-La-Neuve comes from both UCLouvain personal cogeneration plant and a mix supplied by Electrabel (Engie). UCLouvain authorities chose to take out a 0 % renewable electricity mix from Electrabel as they consider they have enough green electricity thanks to the cogeneration plant. This policy will change as of 2022 since UCLouvain has decided to take out 100 % renewable electricity from Electrabel from this date onwards. The current mix from Electrabel is mainly composed of fossil fuels (gas) and nuclear energy, in varying proportions every month. The electricity emission factor from the UCLouvain cogeneration was determined by taking the fraction of electricity produced compared to heat. In Louvain-La-Neuve, the cogeneration produces on average 40 % of electricity and 41 % of heat (i.e. an average of 81 % efficiency).

[2] g means gas. Indeed, this value is for the combustion of the gas, regardless of the resulting production of electricity and heat.

Equation (2.5) gives an **average[3] emission factor of 132 [tCO2-eq/GWh] for 2019**.

Electricity emission factor in Bruxelles-Woluwé

The electricity for Bruxelles-Woluwé site is 100 % purchased from Electrabel. However, the supplied mix is different from the one of Louvain-La-Neuve. For this site, an **average emission factor of 125 [tCO2-eq/GWh] is found for 2019**. However, this figure is highly dependent on the fraction of nuclear electricity in the mix. For example, in 2020, the emission factor reached 180 [tCO2-eq/GWh] simply because the nuclear share decreased in the total mix supplied.

Electricity emission factor for the other sites

Because of the relatively small importance of the other sites compared to Louvain-La-Neuve and Bruxelles-Woluwé, the electric mixes for each site are not treated. The same emission factor from the electricity purchased in Louvain-La-Neuve is used as an estimation for these sites[4]. The value obtained is an **average emission factor of 125 [tCO2-eq/GWh] for 2019**.

These results tell us that Louvain-La-Neuve campus would have a less carbonated electricity if UCLouvain would buy 100 % of its electricity to Electrabel. Indeed, as long as Belgium will have an important fraction of nuclear-based electricity, this will stay true. However, at the time of publication of this report, Belgium was planning to go completely nuclear-free by 2025. This might have an important impact on the carbon content of the Belgian electricity depending on the substitute source of energy.
Moreover, the choice of the cogeneration plant has to be perceived from a wider point of view. First, the obvious advantage of the simultaneous production of heat. Second, UCLouvain has a financial advantage from the Walloon Region for making this choice. This aspect is not explored further in this report.

[3] It is actually the median that was used for Louvain-La-Neuve because the data were widely spread out.
[4] This hypothesis was approved by one of the cogeneration plant manager.

Case of 100 % renewable electricity purchased by UCLouvain

As just mentioned above, UCLouvain will purchase 100 % renewable electricity from Electrabel as of 2022. The new emission factors for this case are estimated in this paragraph. To do so, the model takes a Belgian renewable electricity mix similar to the one existing in 2019, i.e. approximately 8 % from hydraulic power, 65 % from wind power, and 27% from solar power [75]. This mix has an emission factor of 20 [tCO2-eq/GWh] using data from Table 2.4, including grid losses. This value applies to all the sites except Louvain-La-Neuve's one. For this site, taking into account similar production from cogeneration as in 2019, the model finds an emission factor of 100 [tCO2-eq/GWh]. These numbers show us the importance of this change with a 25 % and 84 % decrease of the carbon intensity of the electricity compared to 2019 for, respectively, Louvain-La-Neuve and the other sites.
The environmental benefits in this case are quantified in Section 3.6.1.

2.6.2 Impact of transferred data

The UCLouvain employees in charge of the network record the transferred data which enter or leave the UCLouvain network. This includes all the data when someone logs on to a website hosted by UCLouvain from anywhere in the world as well as all the transferred data when someone logs on to any website from UCLouvain internet connection. These figures are therefore underestimated compared to real transferred data caused by UCLouvain since all the internet searches done from a private internet connection are not included and therefore not accounted for.
Those data are considered inside the scope and this section aims to present the methodology followed to quantify their carbon impacts.

In 2019, UCLouvain had a total of transferred data of 22.81 Petabytes (PB). More precisely, 13.03 PB entered the UCLouvain network (In) and 9.78 PB went off the UCLouvain network (Out). In 2017, for the last UCLouvain carbon footprint, this value was only 15 PB, i.e. a **50 % increase in only two years**. Unfortunately, an analysis over a larger period was not possible since the data before 2017 were not available anymore.

The last UCLouvain carbon footprint already took into account these transferred data. To do so, they used the so-called *energy intensity factor* in [kgCO2-eq/GB][5]: « *The use of energy intensity as an impact factor for network data transfer was pioneered by Koomey in 2004 [97] and is now widespread. Energy intensity is a useful metric, but it is fast-moving. [...] It is thus of critical importance to ensure temporal consistency when comparing energy and data factors.* » ([121, p. 82].

In the last UCLouvain carbon footprint, an energy intensity factor of 150 [gCO2-eq/GB] coming from an UCLouvain professor is applied. However, due to the complexity of evaluating such an emission factor [42], the choice to present several studies and their results was made for this study. Table 2.5 summarises the emission factors found in different studies. These data only include the global fixed network and the data centers while excluding the mobile network and the edge devices. All these data were reported for 2019 using the empirical law which states that intensity is halved every two years [15]. This law stands initially for the fixed network. However, in this study, it is also used for the data centers. This choice is strong as the improvements in the data centers are probably not so fast [121, p. 83]. Moreover, a recent study from the Swiss scientist Vlad Coroamă suggests that this approximation of emissions halved every two years is probably optimistic [42, p. 38], in line with Paul Teehan which stand that the energy intensity factor is halved every 4 years, both for fixed networks and data centers [121, p. 161, 162]. Because of these two issues, the data presented in Table 2.5 are probably underestimated.

The last row below the dotted line is given for comparison. It is the impact using the same value as the previous UCLouvain carbon footprint, reported for 2019 with the same empirical law that was just introduced.

Finally, considering the data given in Table 2.5, the impact of the transferred data for the UCLouvain in 2019 is estimated at 1500 tCO2-eq with a 50 % uncertainty. This represents an emission factor of 66 [gCO2/GB]. Once again, this figure has probably a bias towards underestimation both because the quantity of transferred data and the factor associated are probably underestimated.

[5]Sometimes expressed in [kWh/GB]. The link between both is made by multiplying by an electricity emission factor.

Tab. 2.5.: Table summarising the comparison between different sources for the energy intensity factor of the Internet. The data given above the dotted line come from different scientific studies while the ones given below the dotted line are given for comparison (it is the impact when considering the same source as the previous UCLouvain carbon footprint [95]).

Year[a]	Internet intensity factor [kWh/GB] (FN + DC)[b]	Impacts[c] [gCO2-eq/GB]	UCLouvain (23 PB) [tCO2-eq]	Sources[d]
2015	0.375 (0.115 + 0.26)	47	1080	M&L
2015	-	61	1400	M&L
2015	0.32 (0.06 + 0.26)	40	917	[15]
2017	0.27 (0.07 + 0.2)	68	1556	[121]
2020	0.164 (0.066 + 0.098)	83	1894	A&E
2017	-	75	1710	[95]

Legend: *a* : It is the year under study. When different from 2019, data must be adapted. To do so, the empirical law which states that intensity is halved every two years is followed [15]. *b* : In brackets, it is the data for the Fixed Network (FN) and the Data Centers (DC). The main data is the sum of these two numbers. The mobile network is not considered in this case since it does not enter into account for the UCLouvain transferred data. *c* : using the average world electricity mix of 475 gCO2-eq/kWh [74] and taking into account the grid losses. *d* : Abbreviations for the sources are the same used in Table 1.1.

2.6.3 Assumptions

Assumptions were required regarding the screen size of laptops as well as the work of IT employees.

Impact of the screen size

The size of the screen has a significant impact on the final environmental impact of a laptop [84, 85]. To take this into account, the data given by ADEME are used [85, p. 67]. They estimated a 30 % increase of the carbon footprint between an 11-inch screen laptop and an 18-inch screen laptop (the increase is linear). Based on that and using the value for 13-inch screen laptop from the Base Carbone [9], the equation of the line giving the impact as a function of the screen size is found as follows:

$$impact = 6.2 \cdot size + 75.9 \qquad \text{[kgCO2-eq]} \qquad \text{(with } size \text{ in inches)}$$

Thanks to the online survey, details about screen size for both private and UCLouvain laptops were collected.

Consideration of the IT employees

In the same way as the EPFL [67], taking into account the impacts generated by the IT sector seems important to be the more exhaustive as possible. These impacts are assigned to a section called *Labour*.

To assess the impacts of these employees, data from the last UCLouvain carbon footprint was used [95]. As energy and displacement sectors account for nearly 90% of the global carbon footprint, the calculation is made focusing on those. Moreover, this study already takes into account several fixed assets (computers, etc.).

This previous work was for the year 2017. Since no reason might explain a major change between 2017 and 2019 regarding the fixed assets, these data are considered to be still relevant.

The kgCO2-eq per employee due to displacement as well as the kgCO2-eq per member (employees and students) due to energy in Louvain-La-Neuve are extracted [95, Table 4.2]. These values are, respectively, 560 and 1500 kgCO2-eq/year/employee. The number of the employee in the IT department is 150.

3 Results and Discussion

This section first gathers the main results of this study. Then, a comparison with other similar works is provided together with a sensitivity analysis of the carbon footprint with respect to key parameters. Finally, different improvement scenarios are introduced while the last section discusses the potential influence of the COVID-19 crisis on the UCLouvain digital carbon footprint.

Although the main characteristics of the Bilan Carbone methodology are followed in this work, the results are not presented by scopes. This is mainly due to the specificity of a digital carbon footprint. Indeed, such a presentation would not mean much and the identification of the key contributors would not be possible. Moreover, the same choice was made in the last UCLouvain carbon footprint [95].

3.1 Evaluation of the digital carbon footprint of UCLouvain

Following the methodology detailed in Chapter 2, this study estimates the global digital carbon footprint of UCLouvain in 2019 at **5446 tCO2-eq with a 10 % uncertainty**. This is equivalent to driving 30 600 000 kilometers by car[1] which is more than 760 times the Earth's circumference.

The two first contributors of this footprint are the private equipment from the students as well as the transferred data representing, respectively, 33 % and 27.7 % of the total footprint as shown in Figure 3.1. This means that the main impacts are not directly under the control of UCLouvain but are rather external. This is probably the main barrier to the reduction of the UCLouvain digital footprint.
Considering the students' private equipment, the associated footprint mainly comes from the laptops and the desktops as well as the additional screens. Most of these impacts (about two-thirds) come from the embodied footprint of the devices (see Figure 3.4). Regarding data transfer, a more detailed analysis is difficult. Indeed, a top-down approach

[1] Using the Base Carbone average of 178 gCO2-eq/km [9].

was used which prevents a more detailed understanding of the data as discussed in Section 1.4.3. In addition, UCLouvain does not get details about the type (videos, file sharing, web queries, etc.) of data that are transferred.
The third emission sector is office equipment. The footprint of this sector mainly comes from the desktops, the additional screens, and, to a lesser extent, from the laptops. The footprint of these devices is mainly driven by their embodied footprint (see Figure 3.2).

In the recent UCLouvain Plan Transition, it is written: « *Within the framework of the Plan Transition, the university aims to systematise and standardise the collection of information linked to the major themes of sustainable development with the aim of facilitating reporting, in particular through the systematisation of a carbon footprint* » [131, p. 42-43]. Since there is a wish to monitor the evolution of the results, Table 3.1 summarises the results per employee, student, and member (employees and students combined) as it could serve as a reference in case of future studies for comparison.

Tab. 3.1.: UCLouvain digital carbon footprint results per employee, student, and member (employees + students). The unit is kgCO2-eq/year.

	Per employee	**Per student**	**Per member**
UCLouvain Equipment	572	110	92
Employee private equipment	32		
Student private equipment		57	
Total	900	173	145

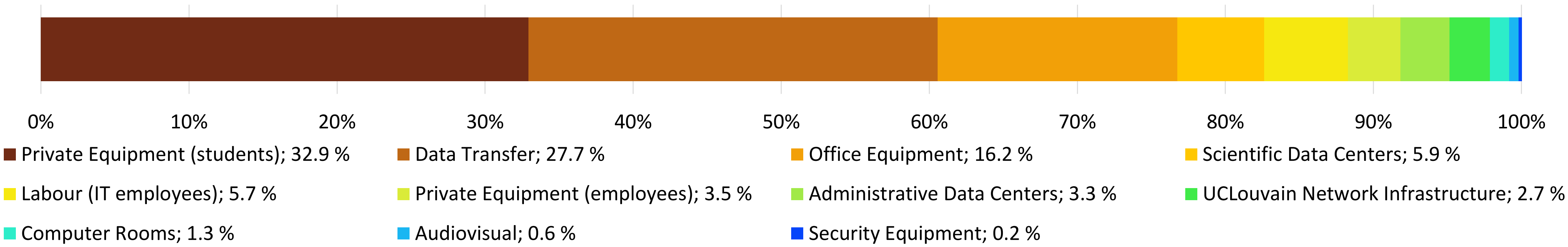
Tab. 3.2.: UCLouvain digital carbon footprint per sub-category. The unit is tCO2-eq/year (except for the two first lines). The data given are the sum of the embodied and the use-phase emissions except for the data centers for which the electricity consumption is known precisely. The uncertainty for certain equipment is particularly high. This is mainly due to high uncertainties from several emission factors from the Base Carbone (few reach 80 % uncertainty).

Category	Equipment	Common	LLN	Woluwe	Mons	Tournai	St-Gilles	Total	Fraction	Uncer.
Number of members	Employees		4700	1033	250	71	67	-	-	0%
	Students		22142	6754	1131	437	490	-	-	0%
TOTAL			**2973.9**	**718.7**	**138.5**	**52.5**	**57.2**	**5446.1**	**100%**	**10%**
Office Equipment	**Sub-Total**		**726.0**	**124.2**	**17.6**	**5.9**	**7.7**	**881.3**	**16.2%**	**20%**
	Desktop Comp. & Screen		299.72	60.6	1.1	1.0	2.8	365.3	6.7%	36%
	Laptop		125.1	18.0	5.2	0.5	1.4	150.2	2.8%	28%
	Additional Screen		189.7	27.2	7.2	3.2	3.1	230.4	4.2%	44%
	Printer		12.2	2.7	0.6	0.2	0.2	15.9	0.3%	52%
	Photocopier		81.0	12.1	2.5	0.7	0.0	96.3	1.8%	51%
	Office Phone		7.7	2.3	0.4	0.04	0.1	10.5	0.2%	48%
	Tablet		6.2	0.6	0.3	0.1	0.1	7.4	0.1%	49%
	Hard Disk Drive		0.4	0.04	0.02	0.01	0.01	0.4	0.01%	85%
	Smartphone		4.1	0.6	0.1	0.1	0.1	4.9	0.1%	58%
Comp. Rooms	Desktop Comp. & Screen		39.7	16.5	12.9	1.9	0.2	**71.2**	**1.3%**	**44%**
Labour (IT employees)		**309**						**309**	**5.7%**	**23%**
Administrative Data Centers (*TierII* and *Aquarium*)	**Sub-Total**	**181.6**						**181.59**	**3.3%**	**20%**
	Server	21.0						21.0	0.4%	85%
	Infrastructure	1.9						1.9	0.03%	52%
	Elec. Consumption	145.4						145.4	2.7%	21%
	Battery Module	1.2						1.2	0.02%	52%
	Hard Disk Drive (DC)	12.1						12.1	0.2%	71%
Data Transfert	**Sub-Total**	1505.5						**1505.5**	**27.6%**	50%
Scientific Data Centers (*DC3* and *Cenearo*)	**Sub-Total**		**319.2**					**319.2**	**5.9%**	**21%**
	Server		53.4					53.4	1.0%	85%
	Infrastructure		1.4					1.4	0.03%	52%
	Elec. Consumption		263.8					263.8	4.8%	30%
	Battery Module		0.6					0.6	0.01%	52%
Audiovisual	**Sub-Total**		**22.8**	**5.6**	**3.7**	**0.9**	**1.1**	**34.1**	**0.6%**	**25%**
	Projector		12.6	2.5	2.2	0.7	0.8	18.8	0.3%	35%
	Monitor		8.4	2.6	1.1	0.2	0.2	12.3	0.2%	43%
	Speaker		1.7	0.5	0.5	0.03	0.04	2.8	0.1%	54%
	Polycom (LLL)		0.1					0.1	0.0%	80%
UCLouvain Network Infrastructure	**Sub-Total**		**97.1**	**36.4**	**7.8**	**3.2**	**3.6**	**148.1**	**2.7%**	**26%**
	Wifi Modem		17.4	11.2	2.4	0.7	1.3	32.97	0.6%	36%
	Core Router		3.4	0.6	1.1	0.6	0.6	6.14	0.1%	32%
	Switches		67.3	22.3	3.3	1.4	1.5	95.82	1.8%	37%
	Firewall	CONFIDENTIAL						3.13	0.1%	35%

Category	Equipment	Common	LLN	Woluwe	Mons	Tournai	St-Gilles	Total	Fraction	Uncer.
	Copper Wires		6.1	2.2	0.3	0.1	0.2	8.88	0.2%	71%
	Optical Fiber		0.1	0.17	0.29	0.45	0.1	1.18	0.02%	52%
Security Equipment	**Sub-Total**		**8.3**	**1.6**	**1.0**	**0.1**		**11.0**	**0.2%**	**33%**
	Surveillance Camera	CONFIDENTIAL						9.9	0.2%	37%
	Monitor		1.2					1.2	0.02%	33%
	Sub-Total		**140.1**	**38.9**	**9.4**	**1.8**	**1.7**	**191.9**	**3.5%**	**17%**
Private Equipment (employees)	Desktop Comp. & Screen		41.7	12.9	2.3	0.5	0.5	57.96	1.1%	31%
	Laptop		45.2	13.9	3.4	0.5	0.5	63.54	1.2%	26%
	Additional Screen		40.5	8.6	2.8	0.6	0.5	52.98	1.0%	39%
	Tablet		6.1	1.8	0.3	0.1	0.1	8.47	0.2%	36%
	Smartphone		3.2	0.8	0.2	0.04	0.04	4.24	0.1%	52%
	Printer		1.5	0.5	0.1	0.01	0.01	2.19	0.04%	58%
	Hard Disk Drive		0.8	0.1	0.1	0.01	0.01	0.94	0.02%	63%
	Webcam		1.1	0.4	0.1	0.0	0.01	1.55	0.03%	58%
	Sub-Total		**1266.4**	**390.4**	**68.1**	**31.9**	**35.8**	**1792.6**	**32.9%**	**18%**
Private Equipment (students)	Desktop Comp. & Screen		233.6	76.8	12.9	6.4	7.2	336.89	6.2%	31%
	Laptop		743.1	229.4	38.6	15.2	17.1	1043.37	19.2%	27%
	Additional Screen		185.3	29.8	10.9	7.5	8.4	241.89	4.4%	41%
	Tablet		51.6	39.0	2.9	1.5	1.7	96.76	1.8%	37%
	Smartphone		23.5	7.6	1.2	0.5	0.6	33.40	0.6%	51%
	Printer		9.7	3.8	0.4	0.5	0.5	14.87	0.3%	58%
	Hard Disk Drive		5.0	1.5	0.2	0.1	0.1	7.07	0.1%	67%
	Webcam		14.5	2.5	0.9	0.2	0.3	18.37	0.3%	58%

Legend: Black figures were collected from different UCLouvain departments. The complete details about the sources can be found in Appendix A. Purple and Green figures are extrapolations for others campuses based on one or more campuses for which data were available based on the number of employees or students on each campuses, respectively. Blue figures are extracted from the online survey.

Fig. 3.1.: Share of different sectors in the UCLouvain digital carbon footprint.



3.2 UCLouvain equipment footprint

This section focuses on UCLouvain equipment, i.e. equipment owned by UCLouvain. In addition, the IT employees and the transferred data are also included. The aim of this section is to focus on the sectors over which UCLouvain has direct control. This choice is made since the answers from UCLouvain regarding impacts over which they have direct control or not might be different.

The total footprint for the sectors considered is estimated at 3442.5 tCO2-eq. The detail is represented graphically in Figure 3.2. Data transfer is the first sector of emissions. In addition, it was discussed previously that this figure might be underestimated. The second most emitting source from the sectors considered comes from the office equipment mainly driven by the desktops and the additional screens. Finally, the third place goes to the scientific data centers. This is surprising knowing that only 245 UCLouvain members (employees or students) used the CISM installation in 2019 [30]. This aspect is detailed below in Section 3.3.

Another characteristic of a digital carbon footprint that can be highlighted from Figure 3.2 is the importance of the embodied emissions compared to use-phase emissions. This is true for all the sectors except for data centers for which consumption largely dominates. These results are in line with the trends from different studies [13, 21, 57, 94]. However, since the emission factor of the electricity at UCLouvain is smaller than the worldwide electricity emission factor [74], the dominance of the embodied footprint for the devices is even stronger at UCLouvain compared to the global trend. Concerning the data centers, it is the opposite and the dominance of the use-phase is smaller at UCLouvain compared to global tendency, in line with other studies [21, 94].
When considering data centers footprint, a key parameter that has to be controlled is the so-called Power Usage Effectiveness (PUE) [118, p. 121]. This parameter is defined as the ratio between the power consumption of the data center and the power consumption of the IT devices (e.g. the servers, routers, etc.) over a certain time [15, 86, 88, 118]. This parameter characterises the efficiency of the entire facility[2]. The closer the PUE is to 1, the better. The PUE for the administrative data center is not known. For the scientific data center located at Louvain-La-Neuve (i.e. the *DCIII*), the PUE is estimated at 1.3 for 2019 [30]. This figure is satisfying since the worldwide PUE average is estimated at 1.6 (despite a significant variance) [86, 88]. The determination of the PUE for the two

[2]Without considering specifically the efficiency of the servers [127].

administrative data centers should be a priority in order to assess their environmental performances.

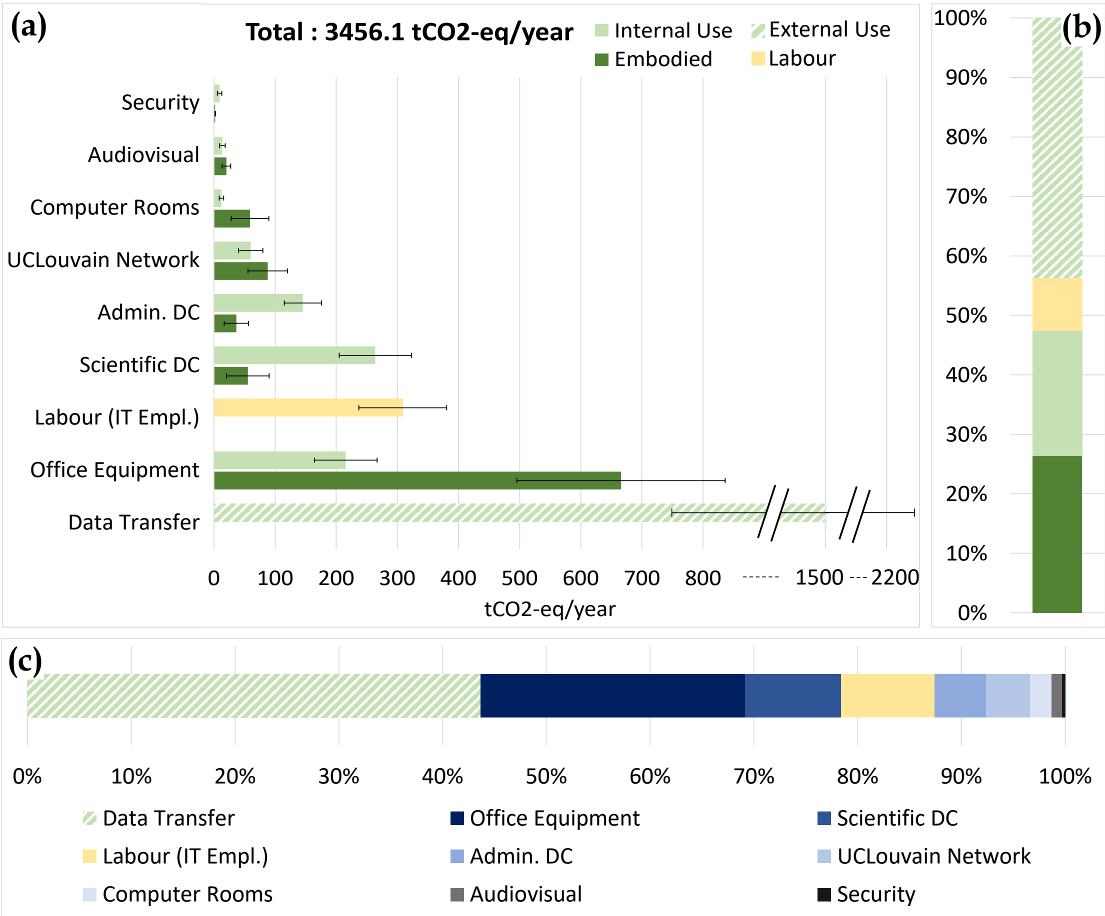


Fig. 3.2.: Detailed UCLouvain digital carbon footprint when excluding private equipment, given in tCO2-eq/year. **(a)** Details about the footprint of each category. The data transfer sector dominates. **(b)** The relative contribution of each type of emissions. Embodied emissions are not negligible compared to use-phase emissions. **(c)** The relative contribution of each category. Data transfer and office equipment sectors dominate the footprint.

3.3 Employee and student footprint

This section aims to evaluate what an employee and a student represent in terms of digital footprint. In order to do so, the different categories from the carbon footprint were classified. Specific categories were considered as common between students and employees (e.g. the administrative data centers or the transferred data) since it benefits or is used by everyone. For these categories, a similar footprint for each member is assumed, mainly due to the lack of more detailed data. Other categories are specifically assigned to employees (e.g. office equipment) or students (e.g. computer rooms). This differentiation was made considering the equipment that employees or students use directly. The results for the employees and the students are represented in Figure 3.3

and Figure 3.4, respectively. These two figures show that, while employees have their impact mainly coming from the office equipment (i.e. their daily digital equipment), students « import » their impact to UCLouvain through their private equipment. This difference shows that the responses might need to be different for these two populations in order to reduce the overall footprint. Indeed, UCLouvain could more easily have a direct control on office equipment since they own and control those equipment. However, for the students' private equipment, UCLouvain does not have direct control. Therefore, UCLouvain could adopt a strategy of awareness-raising measures concerning this issue. Another important highlight is the impact of the scientific data centers. When looking

at the global results (Table 3.2), they represent only 6 % of the total UCLouvain digital footprint and this sector might be considered secondary. However, when reporting and showing the results per employee, the difference between an employee using or not the scientific data centers is substantial (Figure 3.3). An employee using the scientific data centers has a digital footprint almost 7 times higher than an employee who does not use these facilities. The reason is that there were only 245 employees using the scientific data centers facilities in 2019 [30].
The benefits of simulations for scientific or educational purposes were highlighted in different studies [112, 117, 135]. For instance, 70 scientific publications benefited from the CISM facilities for their studies in 2019 [30]. In addition to the benefits for UCLouvain members, the CISM facilities are part of the « Consortium des Équipements de Calcul Intensif (CÉCI) » in the Wallonia-Brussels Federation. Additionally to the 245 UCLouvain users, 395 external users have benefited from the data centers. However, UCLouvain members consumed most of the computation time [30, p. 16-17].
The results from this study simply point out that these simulations have an important carbon impact. It could be considered as a baseline to open a reflection on the global use of simulations at UCLouvain. Since the use of these facilities is growing [30, p. 12], a particular attention should be paid to this sector. To this end, scientists from the University of Cambridge recently developed an open-access tool aiming to assess simulations' footprint [81].

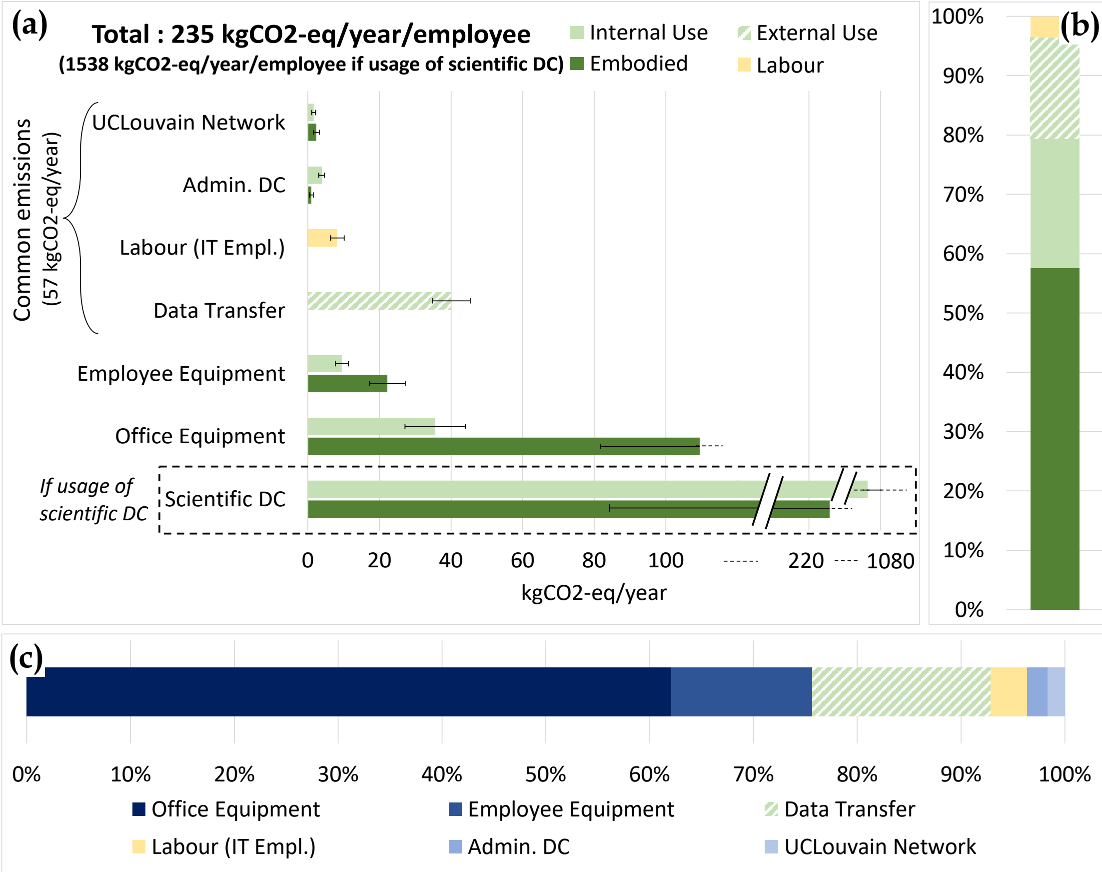


Fig. 3.3.: Detailed digital carbon footprint of an UCLouvain employee, given in kgCO2-eq. Security sector is not shown since its impact is nominal. The common emissions are the ones also assigned to students. **(a)** Details about the footprint of each category. The office equipment sector dominates unless one uses scientific data centers. **(b)** Relative contribution of each type of emissions. Embodied emissions dominate. **(c)** Relative contribution of each category without considering scientific data centres.

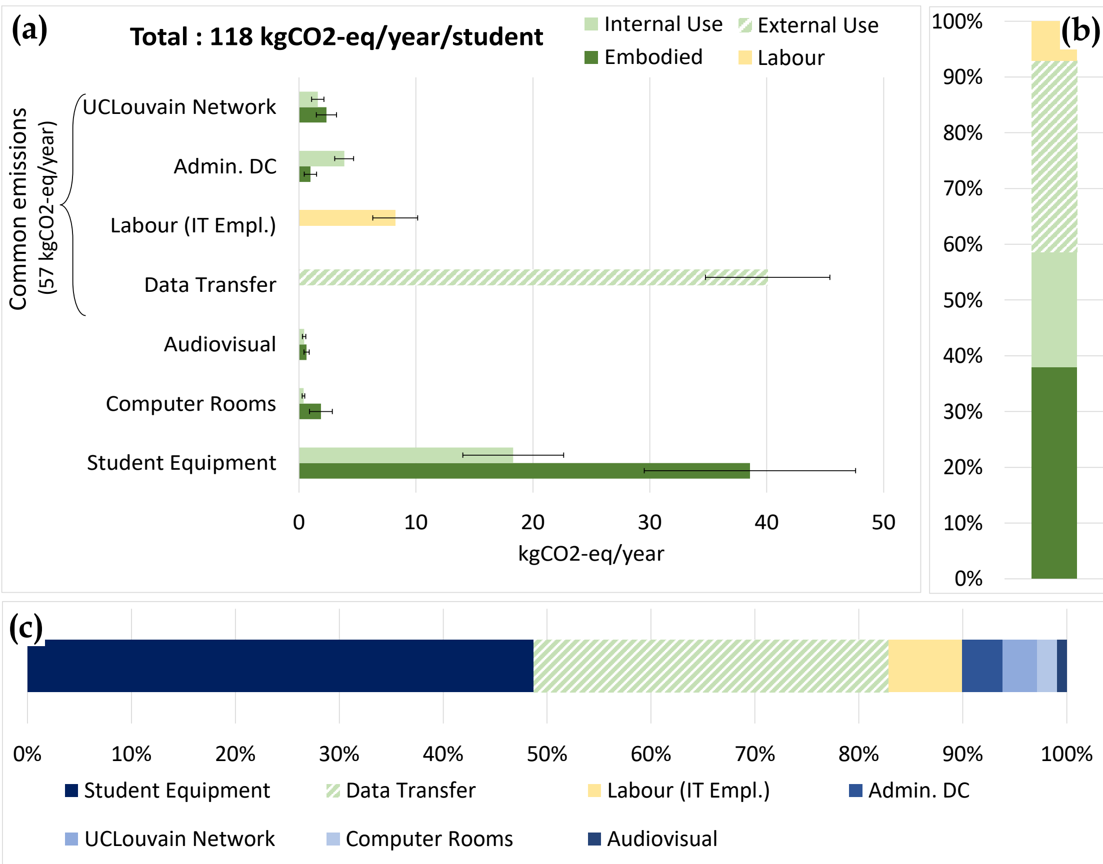


Fig. 3.4.: Detailed digital carbon footprint of an UCLouvain student, given in kgCO2-eq. **(a)** Details about the footprint of each category. **(b)** Relative contribution of each type of emissions. Embodied emissions are significant. **(c)** Relative contribution of each category. The private equipment sector dominates.

3.4 Comparison with similar works

In this section, the results of this study are compared with those obtained from the previous UCLouvain carbon footprint and the recent study from EPFL. In the case of significant differences, assumptions are discussed and explanations are proposed.

Regarding the last UCLouvain carbon footprint, it was found that the digital share was estimated between 4 and 5 % of the global UCLouvain carbon footprint. The result from this study, if considering the same scope (i.e. without private equipment), found slightly higher results (an increase of 20 % in this study). This tends to highlight that a cursory approach already captures the order of magnitude of the overall impact of the digital sector providing that the most impactful equipment are taken into account.
In addition, one of the reason for this similar result is that, while emissions from many other equipment were added, the emissions from the transferred data decreased. In the previous UCLouvain carbon footprint, this sector represented 70 % of the digital impacts (see Table 1.2) while in this study it is 43 %. However, this figure has high uncertainty and it is probably underestimated (see Section 2.6.2). In the case of a more impactful transferred data sector, the value of a more detailed approach would be enhanced. Finally, the choice to include private equipment seems essential to catch the global picture of the emissions sources.
Despite the scopes being slightly different between this study and the previous global UCLouvain carbon footprint, it is interesting to compare them to get the order of magnitude of the digital aspect in the global picture. The digital sector share is estimated at nearly **8 % of the global UCLouvain carbon footprint**, i.e. the third emissions sector after transportation and energy sectors [95].

Regarding the EPFL study, their results are highly different from UCLouvain. Their global digital footprint is 5950 tCO2-eq, similar to the one found in this study. However, while the number of employees is about the same, there are half as many students. This result represents 15.6 % of the global EPFL carbon footprint which is twice more than for UCLouvain as found in this study.
In order to understand the reasons for these differences, the inventory and the calculations made by the EPFL were obtained and analysed. However, the emissions factors they used are not available since they come from a private consultant. This limits the comparison. Three main reasons explain the difference between UCLouvain and EPFL. First, their scope is not exactly the same, the main difference being they included 100 % of the students' private laptops. Second, a significant difference comes from the inventory, EPFL

having a high rate of over-equipment. For example, while there are 6134 employees, 10624 laptops and 9785 desktops are allocated to employees. EPFL is aware of this: « *Our institution suffers from a problem of over-equipment. According to the EPFL inventory, an average staff member at EPFL is equipped with 3.3 computers (desktop and laptop combined)* » [67, p. 6]. At UCLouvain, based on the inventory data (Table 2.1), this coefficient is estimated at 1.1. This smaller figure reduces significantly the global footprint. Finally, there is a good chance that the emissions factors they use are larger than those used in this study. Indeed, using their inventory and applying the same emission factors that the ones from this study, the digital EPFL carbon footprint is roughly estimated at 4150 tCO2-eq. Moreover, one of the author of the EPFL study was contacted and he mentioned that Base Carbone emission factors are usually underestimated according to him, justifying their choice to choose a private actor to get their emission factors.

3.5 Sensitivity analysis

This section aims to discuss the variation of the UCLouvain digital carbon footprint when certain emission factors or assumptions vary. The Base Carbone emission factors were chosen for this study. However, due to a high diversity of factors, it is interesting to analyse the case when different factors are used to determine if this causes a significant change or not. The choice of the factors which are studied in this section was made on the basis of significant differences between Base Carbone and figures from alternative scientific studies.

3.5.1 Computers emission factor

The emission factor from the Base Carbone for the embodied emissions of a laptop is 156 kgCO2-eq per device. Obviously assigning a single number to any laptop is a first barrier to accuracy. For example, it has already been introduced that the screen size has an important impact on the final footprint.
When considering other sources, it seems that Base Carbone underestimates this emission factor, as suggested by EPFL. For example, the Ecodiag service [99] counts 260 kgCO2-eq per device and the WeNR tool [106] counts 203 kgCO2-eq and up to 392 kgCO2-eq for a

laptop smaller and larger than 14 inches, respectively[3].

In addition, when looking at different carbon footprints of laptops from manufacturers, the environmental impacts are also larger than the ones from Base Carbone. To get a better overview on this point, 100 carbon footprints of laptops from different manufacturers (Apple [14], Dell [46], HP [72], and Lenovo [83]) were analysed and the embodied emissions of each were extracted. Details on the methodology followed can be found in Appendix C. Based on this data set, a linear regression of the embodied carbon footprint of a laptop as a function of its screen size was obtained and is compared to the ADEME results (see Section 2.6.3) as shown in Figure 3.5. For an 11 inches laptop, the regression (red curve) predicts a footprint 29 % higher than ADEME. For an 18 inches laptop, this figure reaches 66 %[4].

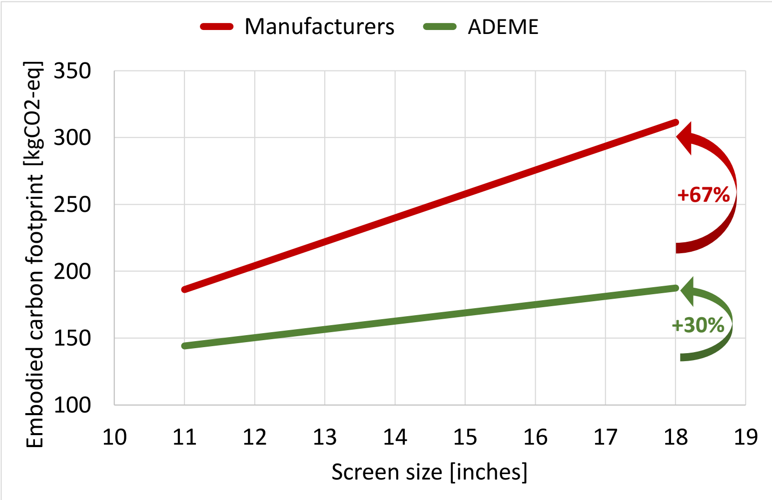


Fig. 3.5.: Comparison of laptops' embodied footprint regarding screen size between ADEME and a personal analysis based on manufacturers' data (details in Appendix C). ADEME results seem to underestimate the footprint. The percentages on the right represent the increase of the footprint between an 11" and an 18" laptop in both cases.

When considering the emission factors extracted from the manufacturers' carbon footprint, the UCLouvain digital carbon footprint reaches 5827 tCO2-eq, i.e. an increase of 7.3 %. This significant result shows the importance of the choice of the emission factors. A deeper analysis of this result is conducted. To do so, the focus is made on three categories. First, the UCLouvain equipment which includes all the equipment owned

[3]The WeNR tool authors were contacted and they transmitted their database which is still confidential for now.

[4]Although these percentages are almost the same ones which are represented in Figure 3.5, these different figures should not be confused.

by UCLouvain. Second, private equipment from employees and third, private equipment from students. The IT employees and the transferred data are not considered. Although both the UCLouvain and the private carbon footprint increase, they are doing so in different proportions as represented in Figure 3.6. For the UCLouvain equipment, the increase is more limited since laptops represent only 3 % of the carbon footprint. However, for employees and students, this increase is higher because of the importance of laptops in the total share. This tends to highlight the importance of prevention and awareness-raising among employees and students as they represent the largest potential for improvement.

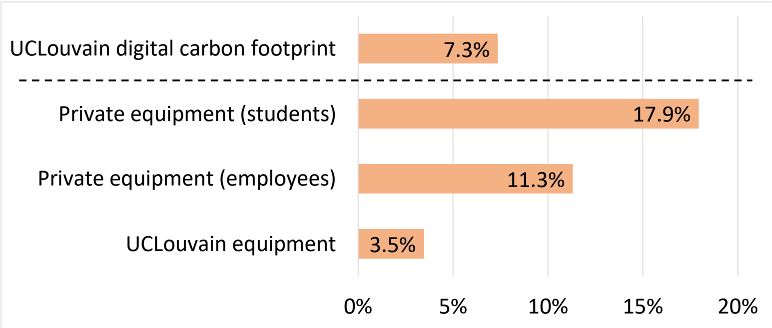


Fig. 3.6.: Sensitivity of the carbon footprint to laptops' emission factor. The global increase is 7.3 % but this result hides differences between private and UCLouvain equipment.

Regarding desktops, the emission factor from the Base Carbone for the embodied emissions is estimated at 169 kgCO2-eq per device. Once again this is probably an underestimation [106, 99]. Although a more detailed analysis as the one conducted for the laptops was not carried out, few examples illustrate this probable underestimation. For example, a recent purchase from UCLouvain to equip the computer rooms is the Dell Optiplex 7470 AIO. Dell provides and estimates the embodied carbon footprint of this model to be 287 kgCO2-eq per device [46]. This result is used to conduct the sensitivity analysis. Moreover, it is in line with data used by Malmodin and Lundén [94, p. 18], Ecodiag [99], and WeNR [106].

When considering this new desktop emission factor, the UCLouvain digital carbon footprint increases up to 5635 tCO2-eq which is an increase of 3.8 %.

Although this global increase is smaller than the one from laptops, it is interesting to observe in Figure 3.7 that UCLouvain direct emissions increase more than private emissions. This is the opposite of laptops. This means that UCLouvain can easily have direct control on these emissions and increase its potential of reduction compared to laptops. This shows that particular attention should be paid to the carbon footprint of desktop models when making a purchase, especially as Dell communicates their carbon footprints [46]. This is already one of UCLouvain's objectives for the coming years: « *When ordering a computer from the IT department, a summary table of the carbon footprint of the few models available will be provided to the user.* » [131, p. 23].

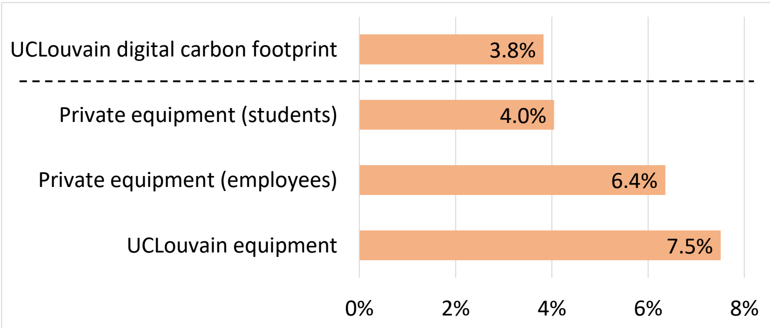


Fig. 3.7.: Sensitivity of the carbon footprint to desktops' emission factor. The global increase is 3.8 % but this result hides differences between private and UCLouvain equipment.

3.5.2 Servers emission factor

Another concerned equipment for which emission factors vary widely are the servers. For example, the previous emission factor from Base Carbone was 2565 kgCO2-eq per device while it is 600 kgCO2-eq nowadays. In the same way as laptops, it is highly uncertain to assign a unique factor given the wide variety of models when dealing with servers. The models owned by UCLouvain are not known precisely or, at least, this information could not be collected.
Since there are few sources for servers emission factor, an analysis of the carbon footprints provided by Dell was conducted [46]. 39 models were analysed and the embodied emissions were extracted. Based on these results, an alternative emission factor for the servers is estimated at 1290 kgCO2-eq per device. This is in line with the figures from the WeNR tool [106], the Ecodiag service [99], and the CLEER Model [82].

The new digital carbon footprint when considering this server emission factor is 5505.5 tCO2-eq, a 1.4 % increase. This relatively small increase shows a small sensitivity to an alternative emission factor of the global carbon footprint. This is because the servers count for 1.3 % of the global share. In addition, the footprint of a data center comes mainly from the use phase as shown in Figure 3.2.

3.5.3 Allocation for personal laptops

Similarly to the EPFL report, it could be argued that a laptop became « *an essential tool* » to any university student [67, p. 14]. Therefore, assigning 100 % of the embodied emissions of these personal laptops to UCLouvain would make sense. Although this option was not chosen for this study, it still seemed interesting to investigate this case. Only laptops are considered while the other personal equipment keep their initial fraction allocated to UCLouvain (see Section 2.4.2).

When 100 % of the embodied emissions from personal laptops from both employees and students are considered, the UCLouvain digital carbon footprint reaches nearly 5908 tCO2-eq, an increase of 8.5 %. This significant increase highlights the importance of that point. The assumptions made in this study about the fraction allocated to UCLouvain from personal equipment are purely subjective but alternative choices would have led to very different results.

3.5.4 Transferred data factor

In order to determine the emission factor of the transferred data, an annual reduction rate for both the fixed network and data centers of 0.7 was considered in this study [15]. However, this result is considered as too optimistic by certain authors [42]. Alternatively, other studies claim that this reduction rate is rather 0.85, i.e. emissions halved every 4 years instead of 2 [42, p. 38] [121, p. 83]. In this case, results from Table 2.5 would increase as shown in Table 3.3 and the data transfer sector would rather have an estimated footprint of 2000 tCO2-eq, i.e. an emission factor of 88 gCO2-eq/GB. In this case, the UCLouvain digital carbon footprint is estimated at 5948 tCO2-eq, i.e. an increase of 9.2 %. This significant result highlights the attention that should be paid to this sector since it could be an even larger contributor to the digital carbon footprint.

Tab. 3.3.: Calculation of the data transfer sector using alternative energy intensity factor decrease rate. Instead of considering this factor being halved every 2 years [15], it is considered to be halved every 4 years [42, p. 38] [121, p. 83]. A significant increase is observed. The data given above the dotted line come from different scientific studies while the ones given below the dotted line are given for comparison (it is the impact when considering the same source as the previous UCLouvain carbon footprint [95]).

Year[a]	Impacts[c] [gCO2-eq/GB]	UCLouvain (23 PB) [tCO2-eq]	Relative increase compared to Table 2.5	Sources[d]
2015	99	2257	+109 %	M&L
2015	84	1916	+109 %	[15]
2017	99	2249	+45 %	[121]
2020	83	1894	0 %	A&E
2017	108	2472	+45 %	[95]

Legend: see Table 2.5.

3.5.5 Worst case combination

If the cases exposed previously in this section are combined, the new UCLouvain digital carbon footprint would reach 7330 tCO2-eq, an increase of 35 %. This increase is bigger than the addition from each study case. Indeed, there are non-linear phenomena since the impacts associated with the fraction allocated to private equipment and the laptops' emission factor are correlated. A graphical overview of the importance of each parameter is shown in Figure 3.8. This result is far away from the 10 % error associated with the primary result. This highlights the importance of the choice of the emission factors as well as the assumptions. This result would represent nearly 10.4 % of the global UCLouvain carbon footprint, making the digital sector even more important.

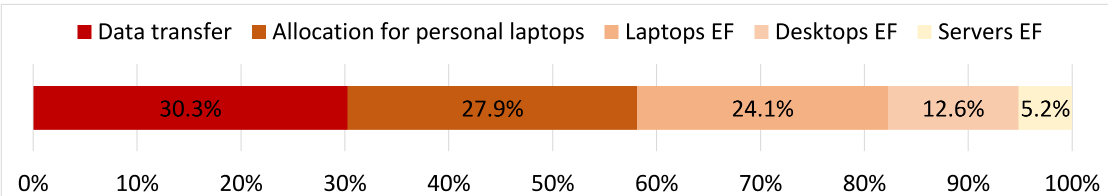


Fig. 3.8.: Relative importance of different parameters' sensitivity. Data transfer and private equipment sectors show significant sensitivity to variation of specific parameters. EF stands for emission factor.

3.6 Impact of possible improvement scenarios

As UCLouvain desires to be carbon neutral by 2035, they recently published a Plan Transition which detailed the different measures to put in place to reach this goal [131]. This section aims to quantify and identify key actions that could help to reduce UCLouvain digital carbon footprint. Most of the studied actions are inspired by statements from the Plan Transitions for consistency reasons with work already carried out.
It is found that the actions that have the most impacts are either the ones which tend to limit the number of devices or the ones which promote lifetime extension.

3.6.1 Purchase of 100 % renewable electricity

UCLouvain will purchase 100 % of renewable electricity by 2022. This section aims to quantify the benefits of this transition for the digital sector. To do so, the emission factor of the new electricity mix from UCLouvain was determined in Section 2.6.1 for the different UCLouvain campuses. The emission factor for private equipment is considered unchanged.

The new UCLouvain digital carbon footprint is estimated at 5235 tCO2-eq when purchasing 100 % renewable electricity, which is a 3.5 % increase compared to actual results. There are two reasons that can explain this relatively small decrease. First, due to the cogeneration plant in the Louvain-La-Neuve campus, a large fraction of the electricity is not purchased but rather produced on this site. Therefore, switching from non-renewable to renewable purchased electricity does not change much to the global emission factor for this campus (which is the largest one). Specifically, the emission factor decreases by 25 % while, for the other campus without a cogeneration plant, it is 84 % (see Section 2.6.1). Second, as already introduced in Figure 1.4, many ICT equipment have their carbon footprint mainly driven by the embodied emissions, the usage phase being much less carbon emitter.

3.6.2 Towards a generalisation of 13" laptops

It was shown that the screen size of a laptop has an important impact on its embodied impact (see Figure 3.5). Although differences were found between the carbon footprints of the Base Carbone and those of the laptop manufacturers as discussed earlier, the Base Carbone standards are used for this section.

Based on the online survey, a significant fraction of the UCLouvain laptops (without considering private equipment) has a screen size between 15” and 16.5” (see Appendix E). If all UCLouvain laptops would be 13” laptops, the UCLouvain digital carbon footprint would decrease by 0.7 %, reaching 5408 tCO2-eq. This minor result is global, i.e. considering the total UCLouvain digital carbon footprint. However, Figure 3.9 shows us differences between improvements when considering UCLouvain and private equipment. The decrease is even smaller for UCLouvain equipment, i.e. the ones on which UCLouvain authorities have direct control over. This option to decrease the digital footprint of the university seems therefore not the most appropriate choice. A deeper approach aiming to inform and raise awareness of the employees and the students about these questions seems therefore more relevant. This would be in line with the UCLouvain goals as written in the last Plan Transition: « *Like many transition issues, consumption is everyone’s business [...] Obtaining broad support from the community is a necessity. It is therefore a question of communicating and raising awareness on the one hand, and involving the members in concrete and effective actions on the other. Thus, a dashboard with concrete quantitative indicators will be created to raise the awareness of the university community on the impact of behavioural changes in the areas of purchasing, waste and Green IT, in order to create a positive emulation.* » [131, p. 24].

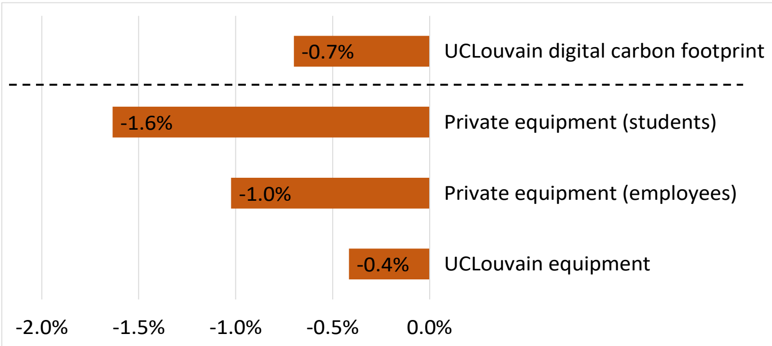


Fig. 3.9.: Relative emissions reduction when 13” laptops become widespread. The decrease is minor despite differences between UCLouvain and private equipment.

3.6.3 Extend the lifetime of equipment

At UCLouvain, most of the digital equipment have a lifetime of 5 years. After this period, the devices are either replaced regardless of their state of wear or sometimes reallocated for new employees (for example, for employees for which computer are not provided initially) [131]. When possible, these equipment are sent to other universities (mainly in Africa). Despite these efforts, the digital waste in 2019 was about 12.4 tons, mainly send to Recupel[5]. Another example of equipment which is replaced despite their good state are the projectors in the auditoriums. Because the auditoriums are already saturated, UCLouvain can not tolerate having auditorium non-available. To avoid this, UCLouvain replaces systematically the projectors every 5 years. This example is representative of certain practices at UCLouvain which prevent to minimise the purchase of new devices. UCLouvain is aware of the importance of this topic as pointed in its Plan Transition [131, p. 22]

The selected scenario extends the life of all equipment by one year. In this case, the digital carbon footprint of UCLouvain would be 5044 tCO2-eq, i.e. a decrease of 7 %. This is a good practice that can have a significant impact on the digital carbon footprint of UCLouvain. Therefore, particular attention should be given to lifetime equipment. Moreover, for certain devices this extension of the lifetime could be larger than a year, increasing the environmental benefits. Additionally, a recent study stated: « *The energy efficiency of new computers with respect to old computers was considered and discussed, and it is concluded that the benefit of continuing to use an old computer (i.e. making the best use of the carbon invested in its creation) far exceeds the benefit from any potential energy efficiency gain from replacing it even under optimistic assumptions around improvements in energy efficiency* » [65].

3.6.4 Replacement of desktops by laptops

In the last Plan Transition, UCLouvain commits itself to generalise homeworking: « *The university is committed to implementing a simple and unified homeworking policy so that from September 2021 onwards, homeworking for one or two days per week (for full-time workers) will become the norm* » [131, p. 19]. Since global emissions reduction from homeworking goes beyond the scope of this study, this section focuses on the digital aspect.

[5] Information collected from an UCLouvain employee who works in the department in charge of collecting digital waste, i.e. the SERP.

According to an employee of the IT department, this increase in homeworking might lead to a greater need for laptops and thus fewer desktops: « *We are probably heading towards a situation where there are more laptops and fewer fixed stations* ». In the extreme case where all the office desktops are replaced by 13" laptops (while keeping desktops for the computers rooms) and without reducing the number of additional screens, the UCLouvain digital carbon footprint decreases by 8.8 % reaching 4954 tCO2-eq. The feasibility of this option should therefore be seriously considered. In addition, in the case of a decrease of the number of additional screens by 25 %, the reduction would reach 10 %.

3.6.5 Combining best practices

In the case all the improvement scenarios presented above are set up together, the reduction of the UCLouvain digital carbon footprint can decrease by more than 20 %, reaching 4420 tCO2-eq. Those results show that **isolated actions have minor effects while their combination can reach a significant reduction. The actions that have the most impact are either the ones that tend to limit the number of computers and in particular high environmentally damaging models or the ones which promote lifetime extension.** In addition, although not clearly analysed in this section, an effective

Tab. 3.4.: Summary of the improvement actions and their associated emissions reduction. Isolated actions have minor effects while their combination can reach significant reduction.

Actions	Improvement
Replacement of desktops by laptops with reduction of additional screens by 25 %	9.8 %
Extended lifetime of one year for all devices	7.1 %
Renewable electricity purchase	3.5 %
Generalisation of 13 inches laptops	0.7 %
Total	**21.1 %**

manner of reducing UCLouvain digital footprint is to limit the number of devices. A general reflection on digital purchases and the real need of each piece of equipment could be conducted. In addition, the transfer of data is a key contributor to the UCLouvain digital carbon footprint (accounting for 28 %). The reduction of this figure should therefore be an additional priority. Informing and raising awareness among employees and students might be a first step. The advantage is that the amount of transferred data is an easily accessible figure and so the control of the evolution of this value is straightforward.

3.7 Impact of the COVID-19 crisis

As discussed previously, the increase of the uses in the ICT sector is not recent. A clear transition towards a more digital and connected world has started. However, the actual pandemic has boosted this already ongoing transition, among other things due to the widespread use of teleworking. Cisco estimates that 4.7 more employees were working from home during the lockdown compared to before the pandemic [29, p. 7]. This deep modification of our habits has a direct impact on networks. Nokia estimates that the increase of Internet traffic at a global scale increased by 30% (with peaks up to 50% during the first weeks of lockdown) compared to the traffic before the COVID-19 pandemic [105]. However, Ericsson observed a return to normal since the end of 2020 mainly due to the shift of data traffic from offices to homes, the total remaining relatively similar [55].
This crisis had also a more direct impact on UCLouvain leading to significant changes in the way employees work and teach as well as for students. Although the COVID-19 crisis is not part of the main scope of this study which focuses on the year 2019, this section aims to quantify specific aspects of the digital footprint of such a transition. First, the investments made by UCLouvain and its members are inventory and quantified in terms of carbon footprint. Second, the massive use of Teams is analysed and a methodology to quantify its carbon impacts is presented.

3.7.1 UCLouvain investments

To face this unprecedented situation, UCLouvain had to invest quickly to meet the challenges of both teleworking and distance teaching.
The UCLouvain investments can be divided into two mains categories. On the one hand, the purchases made directly by UCLouvain authorities. The latter were supervised by the IT department (SGSI) and the Louvain Learning Lab (LLL) to best meet the needs. These purchases were easy to inventory and the associated uncertainty is weak. On the other hand, the different faculties, institutes, and administrative services did several investments with their own funds. For those, each faculty, institute, and administrative

service were contacted by email. Based on the answers (approximately 40 %), an estimation of the total investments was done. These figures have therefore a really high uncertainty. The purchases are listed in Table 3.5.
In addition to these investments, 200 desktops were purchased in May 2020 to provide extra computers for the exams sessions. However, this purchase was just part of the regular annual renewal of computers. They were purchased few months in advance but, in the end, the UCLouvain inventory was not modified on this point. For these reasons, they are not considered as a COVID-19 investment.

Tab. 3.5.: Number of digital equipment invested by UCLouvain during the COVID-19 crisis. The middle row shows the investments from UCLouvain authorities while the right row gives the investments made by UCLouvain departments with their own funds.

Equipment	SGSI and LLL	Faculty, institute and others
Polycom	83	
Camera or webcam	50	56
Logitech Brio camera	80	
Wacom graphic tablets	29	98
Laptop		3
Tablet		46
Additional screen		8
Printer		3

The totality of these purchases has an embodied carbon footprint estimated at 6.6 tCO2-eq with a 35 % uncertainty. This result is insignificant compared to the global UCLouvain digital carbon footprint. This is probably because the COVID-19 crisis accelerated a change already underway since the university had already begun a conversion to increase the digital aspect [23]. An UCLouvain employee said: « *UCLouvain was already relatively well equipped with digital technology, which may explain the low investment for the lockdown* ». As a result, few major investments had to be made. In addition, those devices will probably be used in the future.

3.7.2 Personal investments

As demonstrated by different studies, the sales of digital devices were impacted by the COVID-19 crisis, both increase and decrease depending on the type of device [5, 24, 73, 89]. At UCLouvain, the online survey allowed to determine that about 40 % of members invested in at least one digital equipment due to the lockdown. No differences were observed between employees and students. The goal of this section is to establish an inventory of the digital purchases made by UCLouvain employees and students during the lockdown and then to quantify their associated carbon footprints.

Data collection was done via the online survey described in Section 2.4.1. For these COVID-19 related questions, it was specified that responses should only concern equipment used for UCLouvain. Purchases inventory is given in Table 3.6. These results represent a significant amount of digital purchases, in particular for students' laptops. However, this result is in line with global figures which show an important increase in the sales of the laptops at the beginning of the lockdown [24, 73].

Since these devices have also a private use, the same shares of the embodied emissions as the ones used for 2019 were applied as given in Table 2.2.

Tab. 3.6.: Number of digital equipment invested by UCLouvain employees and students during the COVID-19 crisis.

Equipment	Employees	Students
Laptop[a]	160	3593
Desktop	88	378
Additional screen	696	2248
Tablet[a]	195	1276
Printer	172	159
Hard disk drive	228	1556
Webcam	68	268

Legend a: Despite screen size details are not given here, these details were obtained and took into account into the model.

The embodied carbon footprint of these purchases is estimated at 208.3 tCO2-eq with a 26 % uncertainty. This footprint is nearly the same per employee and student, 4.7 and 5.7 kgCO2-eq respectively.

3.7.3 Evaluation of the impacts due to the increased use of Teams

In order to estimate the footprint of the massive use of Microsoft Teams during the lockdown, the following equation is used:

$$\text{GHG emissions} = b\,t\,F_u \qquad \text{kgCO2-eq} \tag{3.1}$$

where b is the bitrate in [GB/s], t is the time in [s] and F_u is the use-phase emission factor of the internet in [kgCO2-eq/GB]. Only video calls[6] are considered. First, because they largely dominate compared to the audio calls (see Figure F.1). Second, because the transferred data associated with an audio call is much lower than for a video call [98].

For the time of use t, the usage profile over a 3 months period was obtained from the UCLouvain IT department. Based on this, the total time of video calls was estimated at 330 million minutes for 2020. Complete details about the calculation can be found in Appendix F.
For the emission factor F_u, the same value as the global internet energy intensity factor is used. Its value (66 [gCO2-eq/GB]) was determined in Section 2.6.2. This value is chosen since no additional information could be collected concerning Microsoft services (they were contacted without success).
Finally, for the bitrate b, two sources are available. On the one hand, an employee of the infrastructure and networks department (SIPR) gives a value between 2 and 3 [Mb/s]. This value was obtained for a group video call by SIPR at the beginning of the lockdown while conducting tests to ensure the feasibility of full remote courses. On the other hand, Microsoft provided values between 1 and 2 [Mb/s] (complete details in Appendix F). Finally, a bitrate of 2 [Mb/s] (i.e. 0.25 [MB/s]) with a 30 % uncertainty is chosen. Microsoft allows users to limit their data usage on mobile only [120].

The impact of Microsoft Teams during 2020 is estimated at 327 tCO2-eq with a 66 % uncertainty. This very important uncertainty comes from the methodologies which only increase uncertainty when multiplying data (see Equation (2.1)). This result does not represent a full year of remote courses since the COVID-19 lockdown arrived in March 2020. The same methodology applied to a hypothetical full year gives a footprint of 434 tCO2-eq. This figure represents approximately 29 % of the transfer data impacts. No conclusion about possible advantages or not from distance courses compared to a normal situation can be drawn since it would require a much deeper study.

[6] Video calls are any call with at least one member with its camera on.

Conclusion

The current COVID-19 crisis has only accelerated an already existing dynamic of a widespread digitalisation of our society. Indeed, the number of devices and their uses have been growing continuously for years now [27, 28, 29]. Although these technologies seem to have the ability to reduce GHG emissions [61, 71, 134], the current use of these technologies does not follow this trend [20, 101]. With the growth of ICT, comes an increasing impact on the environment; it was indeed shown that the impact on global warming of these technologies is rising.

Considering this growing importance of the ICT sector, studying the environmental impact of such a sector is important. Current studies estimate the impact of this sector to represent 3 % of the global GHG emissions. Although this figure may seem small, two facts among others balance this result. First, the evolution of this figure indicates that this sector is likely to become increasingly important in the global carbon balance. Second, it is important to note that this 3 % only concerns GHG emissions. The ICT impacts encompass other environmental and social issues [67].

For several years now, UCLouvain has adopted an environmental policy and has set itself the objective of becoming carbon neutral by 2035 [131]. It was shown in the previous global carbon footprint of the university that the most GHG emitting sectors are the daily transport of employees and students as well as the production or purchase of heat and electricity [95]. However, as the digital aspect was not studied in detail, this work aims to examine the impact of this sector. To do so, a carbon footprint methodology was followed. The data for the model comes from both the inventories of various UCLouvain departments and an online survey sent to the university community. To translate these data into GHG emissions, emission factors from the Base Carbone were used [9]. A specificity of this work was the inclusion of private equipment inside the scope of the study.

This study estimates the UCLouvain digital carbon footprint to be 5446 tCO2-eq with a 10 % uncertainty. This is nearly 8 % of the global UCLouvain footprint and it is equivalent to drive more than 760 times the Earth's circumference by car. The most impactful sectors

are students' private equipment, data transferred to and from the UCLouvain network, and office equipment.
Three arguments suggest that this result is probably underestimated. First, alternative emission factors have shown that the Base Carbone probably underestimates certain emissions. Second, the inventory obtained is probably not entirely complete. This is due to possible purchases of equipment from UCLouvain departments with their own funds. However, this error is probably not significant. Third, it was discussed that the methodology chosen to quantify the impacts of the data transfer probably underestimates the GHG emission associated with it. it was argued that the methodology chosen to quantify the impact of the data transfer sector (which accounts for 28 % of the digital carbon footprint) is probably underestimated.

Finally, different emission reduction scenarios inspired by the UCLouvain Transition Plan were investigated. Three efficient reduction measures were identified. First, the limitation of the number of devices. Second, the purchase of computer models which have a lower embodied footprint. Third, the maximisation of the lifetime of the equipment. In addition, given the importance of the data transfer sector, particular attention should be paid to the evolution of this parameter. An increase of 50 % in two years seems to indicate a rapid and significant growth. One major insight of this study is the identification of a significant fraction of the environmental impact coming from employees' and students' private equipment. Raising awareness about this issue among the UCLouvain members could help align with the university's will to mitigate its environmental impact.

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Inventory sources

A

Tab. A.1.: Complete informations about the different sources of the data.

Category	Equipment	Source 1 (Department)	Source 2 (Department)	Source 3 (Department)
Office Equipment	Desktop Comp. & Screen	Sébastien Lambay (SGSI)	Christian De Brauwer (SIHN)	
	Laptop	Sébastien Lambay (SGSI)	Christian De Brauwer (SIHN)	
	Additional Screen	Sébastien Lambay (SGSI)		
	Printer	Jean-Michel Karkan (GDEP)		
	Photocopier	Jean-Michel Karkan (GDEP)		
	Office Phone	Sébastien Lambay (SGSI)		
	Tablet	Online Survey		
	Hard Disk Drive	Sébastien Lambay (SGSI)		
	Smartphone	Jean-Michel Karkan (GDEP)		
Comp. Rooms	Desktop Comp. & Screen	Sébastien Lambay (SGSI)		
Labour (IT employees)		UCLouvain website		
Administrative Data Center (*TierII* and *Aquarium*)	Server	Sébastien Lambay (SGSI)	Christian De Brauwer (SIHN)	
	Infrastructure	Pierre Allard (GPLO)		
	Elec. Consumption	Pierre Allard (GPLO)		
	Generator Set	Pierre Allard (GPLO)		
	Battery Module	Pierre Allard (GPLO)		
	Hard Disk Drive (DC)	Sébastien Lambay (SGSI)		
Data Transfer		Quentin Hunin (SIPR)		
Scientific Data Center (*DC3* and *Cenearo*)	Server	Thomas Keutgen (CISM)		
	Infrastructure	Pierre Allard (GPLO)	Laurent Brognara (Cenaero)	
	Elec. Consumption	Pierre Allard (GPLO)	Laurent Brognara (Cenaero)	
	Battery Module	Pierre Allard (GPLO)	Laurent Brognara (Cenaero)	
Audiovisual	Projector	Nicolas Migeot (GPLO)	Christian De Brauwer (SIHN)	Mikaël Vandezande (GTPW)
	Monitor	Nicolas Migeot (GPLO)	Christian De Brauwer (SIHN)	Mikaël Vandezande (GTPW)
	Speaker	Nicolas Migeot (GPLO)	Christian De Brauwer (SIHN)	Mikaël Vandezande (GTPW)
	Polycom (LLL)	Nicolas Migeot (GPLO)		
UCLouvain Network Infrastructure	Wifi Modem	Sébastien Lambay (SGSI)		
	Core Router	Quentin Hunin (SIPR)		
	Data Center Switch	Quentin Hunin (SIPR)		
	Distribution Switch	Quentin Hunin (SIPR)		
	Access Switch	Quentin Hunin (SIPR)		
	Firewall	Fabrice Charlier (SIPR)		
	Copper Wires	Quentin Hunin (SIPR)		
	Optical Fiber	Quentin Hunin (SIPR)		
Security Equipment	Surveillance Camera	Frédéric Viatour (GSPP)		
	Monitor	Frédéric Viatour (GSPP)		
	Walkie-Talkie	Frédéric Viatour (GSPP)		
Private Equipment (employees + student)		Online Survey		

B

Online survey participation details

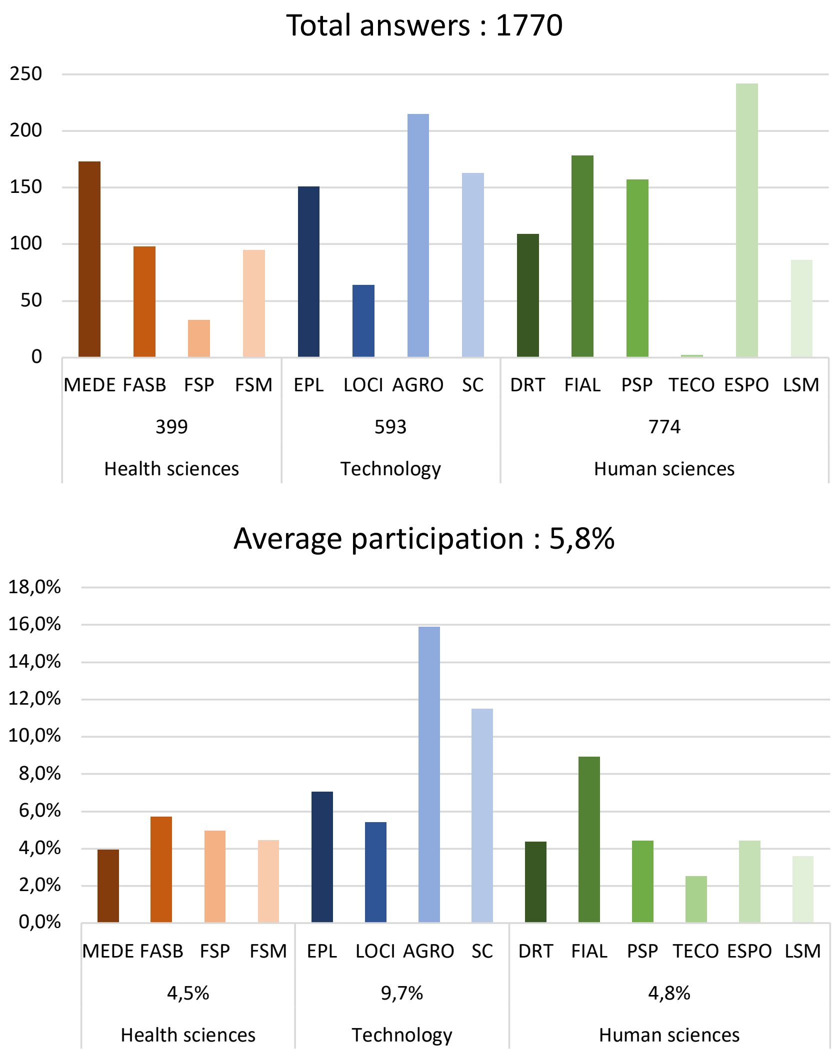

Fig. B.1.: Students participation at the online survey (above) and the participation rate (below), by faculty.

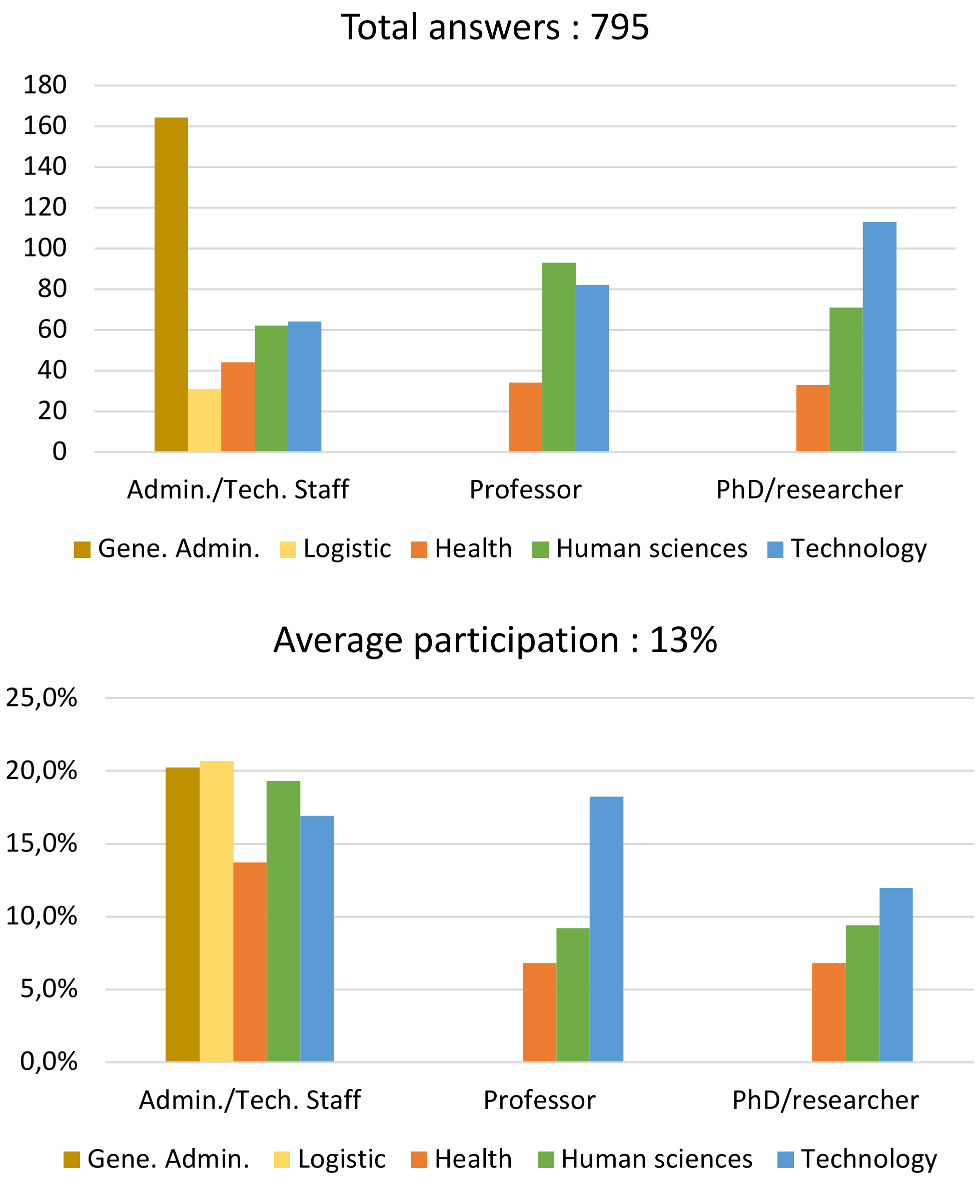

Fig. B.2.: Employees participation at the online survey (above) and the participation rate (below), by sector.

C Emission factors from laptops manufacturers

In order to have a better overview of the relation between the screen size of a laptop and its carbon footprint, 100 laptops' carbon footprints were analysed. These carbon footprints come from four different manufacturers (Apple [14], Dell [46], HP [72], and Lenovo [83]). To determine these carbon footprints, all these manufacturers used PAIA (Product Attribute to Impact Algorithm) tool which is a streamlined Life Cycle Analysis (LCA) tool developed by MIT's Materials System Laboratory and operated by Quantis [7]. As a private service, not much informations are available about the scope, the data which are used and the methodology followed.
Although there is a clear increasing trend of a laptop footprint with its screen size, reality might be more complex. Indeed, the correlation shown in Figure C.1 with the red curve (linear regression) has a correlation coefficient r of 0.15, a rather weak result.

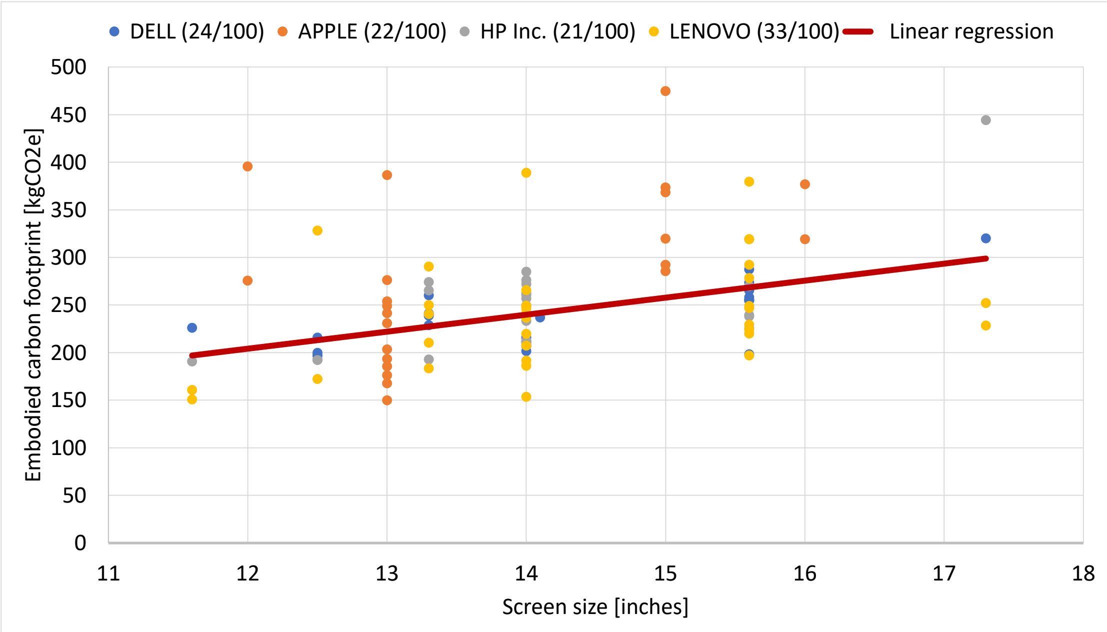

Fig. C.1.: Variation of the embodied emissions of 100 laptops regarding screen size. The red line is a linear regression of the data set. The laptops come from four different manufacturers (Apple [14], Dell [46], HP [72], and Lenovo [83]). The numbers in brackets give the detail of how many carbon footprints from each manufacturer were analysed. The embodied emissions were extracted from the original publications.

Global Warming Potential Values

D

Greenhouse Gas	Lifetime (years)	GWP time horizon: 20 years	100 years	500 years	Report Reference
Carbon dioxide (CO_2)	Complex	1	1	NA	IPCC 2013 – AR5
		1	1	1	IPCC 2007 – AR4
		1	1	1	IPCC 2001 – TAR
		1	1	1	IPCC 1996 – SAR
Methane (CH_4)	12.4	84	28	NA	IPCC 2013 – AR5
	12	72	25	7.6	IPCC 2007 – AR4
	12	62	23	7	IPCC 2001 – TAR
	12	56	21	6.5	IPCC 1996 – SAR
Nitrous oxide (N_2O)	121	264	265	NA	IPCC 2013 – AR5
	114	289	298	153	IPCC 2007 – AR4
	114	275	296	156	IPCC 2001 – TAR
	120	280	310	170	IPCC 1996 – SAR
HFC-23	222	10,800	12,400	NA	IPCC 2013 – AR5
	270	12,000	14,800	12,200	IPCC 2007 – AR4
	260	9,400	12,000	10,000	IPCC 2001 – TAR
	264	9,100	11,700	9,800	IPCC 1996 – SAR
HFC-134a	13.4	3,710	1,300	NA	IPCC 2013 – AR5
	14	3,830	1,430	435	IPCC 2007 – AR4
	13.8	3,300	1,300	400	IPCC 2001 – TAR
	13.8	3,400	1,300	420	IPCC 1996 – SAR
CF_4 (PFC)	50,000	4,880	6,630	NA	IPCC 2013 – AR5
	50,000	5,210	7,390	11,200	IPCC 2007 – AR4
	50,000	3,900	5,700	8,900	IPCC 2001 – TAR
	50,000	4,400	6,500	10,000	IPCC 1996 – SAR
Sulfur hexafluoride (SF_6)	3,200	17,500	23,500	NA	IPCC 2013 – AR5
	3,200	16,300	22,800	32,600	IPCC 2007 – AR4
	3,200	15,100	22,200	32,400	IPCC 2001 – TAR
	3,200	16,300	23,900	34,900	IPCC 1996 – SAR
Nitrogen trifluoride (NF_3)	500	12,800	16,100	NA	IPCC 2013 – AR5
	500	12,300	17,200	20,700	IPCC 2007 – AR4
	740	7,700	10,800	13,100	IPCC 2001 – TAR
	740	NA	NA	NA	IPCC 1996 – SAR

Fig. D.1.: Global Warming Potential Values from the IPCC for specific greenhouse gases. As observed, the GWP evolve over the years: data evolve with science. Figure from [64].

E

About laptops' screen size at UCLouvain

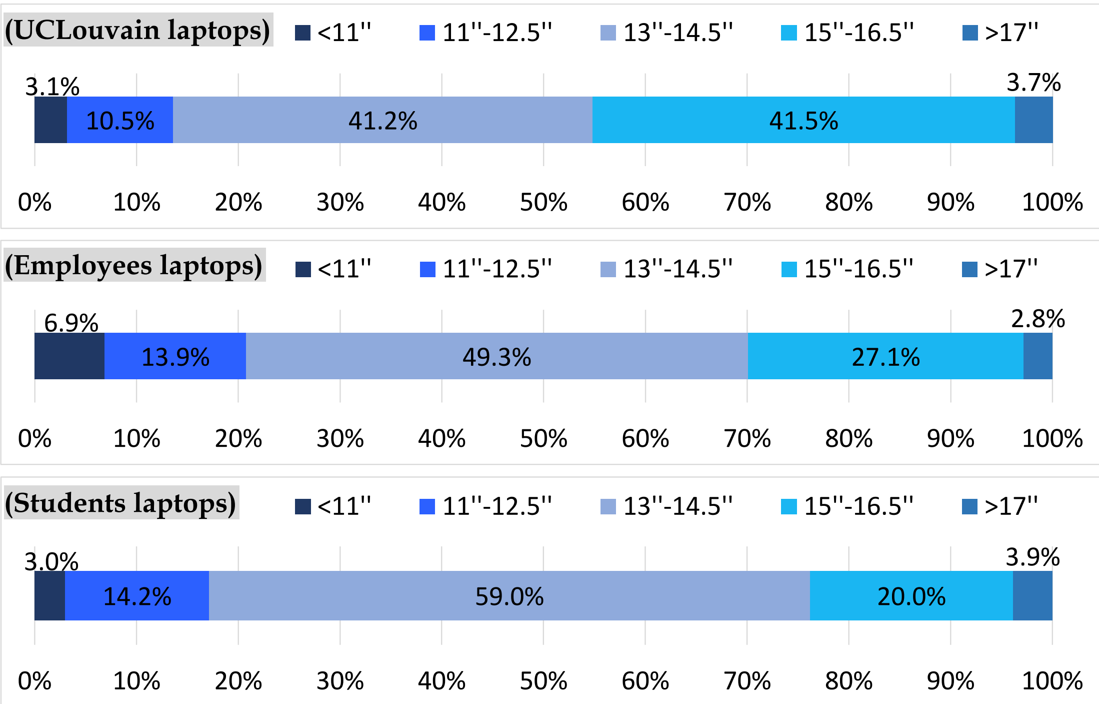

Fig. E.1.: Fraction of laptops regarding screen size for UCLouvain, employees, and students devices. While 13”-14.5” category dominates for both employees and students, the 15”-16.5” category is significant for UCLouvain laptops. ” stands for inches. These results come from an online survey conducted among UCLouvain members (see Section 2.4.1).

About Teams

F

F.1 Use of Teams

The usage profile represented in Figure F.1 was given by an employee of the IT department. It covers a 3 months period, from 9 December to 8 March (a longer period were unavailable).

The curve of interest is the *Video time* one. Two main types of periods can be identified: the normal week of work and classes and the exam session. From what is observed on a normal week of classes, there is 2.5 million minutes of video calls each working day and approximately 0.5 million on Saturdays. For the exam sessions period, it is 0.5 million per day all week long.

The lockdown began on 16 March 2020. From this date until the end of the year, there was: 20 weeks of classes (and 20 Saturdays associated) and 20 weeks without courses. The partial end of lockdown at the beginning of September with several courses in face-to-face mode is neglected.

Knowing this, the Teams video call time is estimated 330 million of minutes in 2020.

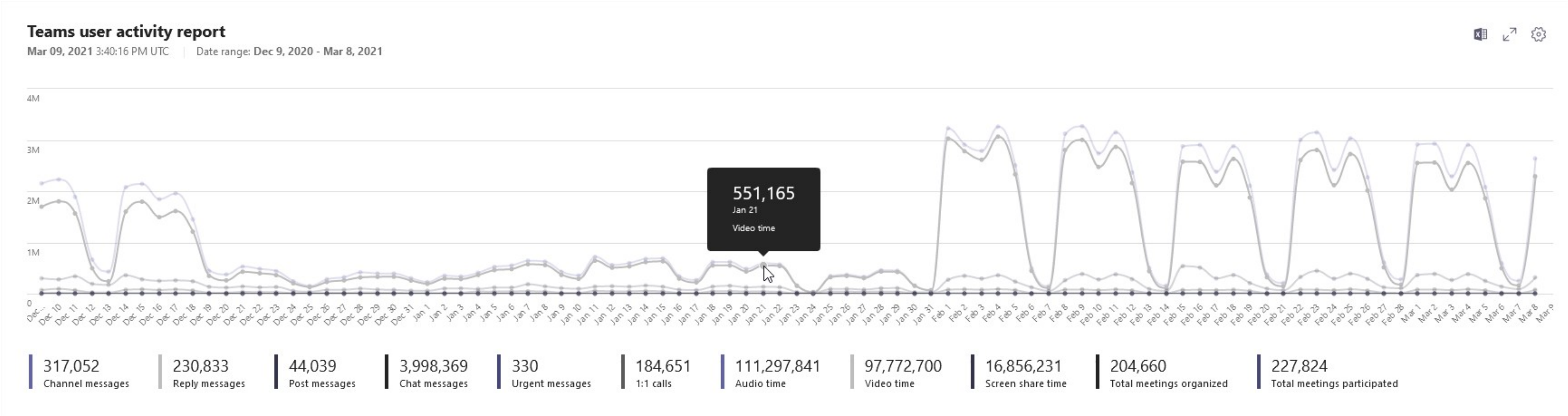

Fig. F.1.: Usage profile of Microsoft Teams at UCLouvain over a 3 months period (from 9 December to 8 March). The y-axis is the time in minutes. Figure given by an UCLouvain employee form the IT department (SGSI).

F.2 Bitrate of a Teams call

The birate estimated by Microsoft are shown in Figure F.2. However, they precise: « *The actual bandwidth consumption in each audio/video call or meeting will vary based on several factors, such as video layout, video resolution, and video frames per second. When more bandwidth is available, quality and usage will increase to deliver the best experience.* » [98].

Bande passante (haut/bas)	Scénarios
30 Kbits/s	Contenus audio de pair à pair
130 Kbits/s	Appels audio et partage d'écran de pair à pair
500 Kbits/s	Qualité d'appels vidéo 360p à 30 fps de pair à pair
1,2 Mbits/s	Appels vidéo HD de pair à pair avec résolution HD de 720p à 30 fps
1,5 Mbits/s	Appels vidéo HD de pair à pair avec résolution HD de 1 080p à 30 fps
500 Kbits/s ou 1 Mbits/s	Appels vidéo de groupe
1 Mbits/s ou 2 Mbits/s	Appels vidéo HD de groupe (vidéos 540p sur écran 1 080p)

Fig. F.2.: Bitrate values for a Teams call. The figure came from [98] and was captured on 23 April 2021. However, this web page does not provide this table of value anymore.

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