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Introducing Software Sustainability Demands into Large Organisational Procurement Processes

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Abstract

As the ICT sector saw exponential growth over the last few decades, so too did the greenhouse gas emissions caused by it, to the point where the ICT sector is at least as big, if not bigger, than the airline industry. Previous research in this field has circled around methodologies for performing life cycle assessment of ICT software products, but has not put it in an organisational context which has lead to no agreed upon way of calculating and comparing sustainable software. This study analyses existing research in the field and through a thematic analysis of qualitative interviews and a case study of Scania CV AB in Södertälje, Sweden puts it into a procurement context, focusing on key metrics and comparability over exhaustiveness. This study found that by assessing ICT software products through four different phases, or scopes, a level of accuracy suitable for large organisations are achieved. Key metrics for organisational procurement processes to take into account are those of the hosting phase, such as geographical location, source of electricity and data centre effectiveness. By putting software life cycle assessments into a business context, this study helps make ICT sustainability research more readily available to people working with ICT product procurement and makes a contribution to the interdisciplinary research in the fields of technology, business and sustainability.

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Sammanfattning

Allt eftersom ICT-sektorn sett exponentiell tillväxt över de senaste årtiondena har också sektorns utsläpp av växthusgaser ökat, till den grad att sektorn står för minst lika mycket, om inte mer, utsläpp av växthusgaser jämfört med flygindustrin. Tidigare forskning i detta fält har kretsat kring metodiker för att genomföra livscykelanalyser av mjukvara, men har inte satt resultaten i en affärsmässig kontext vilket lett till oenighet kring vilka metodiker som passar bäst för beräkning och jämförelse av hållbar mjukvara. Denna forskningsstudie analyserar existerande forskning och sätter den i ett inköpssammanhang genom en serie kvalitativa intervjuer med tematisk analys samt en fallstudie av Scania CV AB i Södertälje. Denna studie fann att genom att jämföra IT-mjukvara i form av fyra olika faser, eller omfattningar, nås en tillräcklig nivå av nogrannhet för att användas i stora organisationer. Nyckelvärden för organisatoriska inköpsprocesser att ta hänsyn till är de i datacentersfasen, så som geografisk plats, energikälla och datacentereffektivitet. Genom att sätta mjukvarulivscykelanalyser i ett affärssammanhang bidrar denna studie till att göra hållbarhetsforskning för sektorn mer tillgänglig till människor som jobbar med ICT-inköp och gör ett bidrag till den interdisciplinära forskningen i fälten teknik, affärsstudier och hållbarhet.

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Glossary

CO_2e Carbon Dioxide Equivalents. A metric used to compare different greenhouse gases by converting other greenhouse gases into the equivalent amount of carbon dioxide based on their global warming potential. Commonly expressed in million metric tonnes of carbon dioxide equivalents. One kg of methane has a global warming capacity of 25 kg of carbon dioxide, making 1 kg methane = 25 kg CO_2e (Eurostat, 2017).

ECI Energy Carbon Intensity. A metric of how much greenhouse gas is released to provide a certain amount of power generation, usually measured in kilograms of CO_2e/kWh.

EU European Union.

GHG Greenhouse gas, usually measured in CO_2e.

ICT Information and communication technology.

ISO International Organisation for Standardisation.

kWh Kilowatt hour. An electronic device using 1000 watts for 1 hour will consume one kilowatt hour.

PUE Power Usage Effectiveness. A value describing how much of the energy required to run a data centre is actually spent on the IT equipment inside the data centre as opposed auxiliary needs such as lighting, cooling and more. A PUE of 1 is perfectly efficient, meaning 100 % of the power consumed by a data centre is consumed by the servers. Obtained by dividing the total energy consumed by a data centre by the energy consumed by the IT equipment within.

SaaS Software-as-a-Service. The act of providing software as a versionless service available on a web platform where the consumer runs the provider's software on the provider's hardware, only having to manage their own device while the provider handles execution, storage, networking etcetera. Other models are available, see the different types of cloud computing per the NIST definition in section 5.4 (Mell & Grance, 2011).

SBTi Science-Based Targets initiative. An initiative helping organisations set sustainability goals based on modern scientific research on the topic (Science Based Targets initiative, 2021).

WBCSD World Business Council for Sustainable Development.

WCED United Nation's World Commission on the Environment and Development. A special commission established by the UN General Assembly in 1983 to make available a report on global environmental issues for the year 2000 and beyond, including strategies for sustainable development. This commission was led by Gro Harlem Brundtland and has come to be known as the 'Brundtland Report'.

WRI World Resources Institute.

1 Introduction

Information and communication technology (ICT) is a generic term for the technologies and equipment used for the processing and manipulation of information, such as computers, mobile phones and the peripheral equipment required to use them such as printers, servers and routers (Zapico, 2013). Over the past decades, this sector has grown exponentially, with the amount of data traffic consumed world-wide increasing every year (Malmodin, 2020) as two thirds of the global population has started using the internet (International Telecommunication Union, 2022).

Meanwhile, the rising danger of climate change during the same time period has been undeniable, with greenhouse gas (GHG) emissions caused by humans being 50 % higher in 2020 than it was in 1990 (Lindsey, 2022). Labelled humanity's number one risk during the coming decade by the World Economic Forum (2022), it has become a global problem that not only affects everyone, but must be jointly solved by everyone. In line with the need to fight climate change, climate policy has also been put into focus. With the adoption of the 2015 Paris Agreement by 196 countries around the globe, the message was clear: change is needed (United Nations, 2015). For a lot of actors, this change means *decarbonisation*, the act of making informed business decisions with the goal of reducing the carbon dioxide equivalent (CO_2e) emissions caused by the actor, such as switching to a fossil-free power source or reducing the amount of business trips made by plane.

The ICT sector's contribution to global GHG emissions, which has up until recently managed to avoid the spotlight, is not small. In 2019, it was estimated by the Shift Project to account for 3,7 % of global emissions (Lean ICT, 2019), about 50 % more than the emissions of the entire airline industry (ICCT, 2019).

As a contributing factor to climate change and global warming, this "well-kept secret of the IT industry" as it has been referred to by some has to, like all other industries, be taken into account by organisations globally in order for the goals set forth by the Paris Agreement to be met (Sundberg, 2022).

In order to increase transparency and traceability in regard to climate change, regulatory changes must be made. One example of such a regulatory change in the discussion is the European Union's (EU) Corporate Sustainability Reporting Directive (CSRD) (European Parliament, 2022). This directive, which will be rolled out in phases between 2024 and 2028, puts demands on sustainability reporting similar to financial reporting for almost 50 000 private companies operating in the European Economic Area and will be a large driving force (Crabbendam, 2022). This sustainability reporting directive sets a very broad scope on what must be reported, meaning the usage of ICT software and hardware that has previously not been mandatory to report must now be included as well, in addition to "traditional" sustainability reporting metrics.

This new directive will help to improve the traceability of the overall GHG emissions of software products and services across their entire value chain, focusing more on what the environmental impact of the products and services are rather than who caused them.

1.1 Problem Statement

Up until recently, the climate impact of ICT software and hardware has not been as actively discussed as that of other sectors, if at all (Sundberg, 2022). One example of this can be seen in the Swedish flight-shame movement declaring that individuals should be ashamed of getting on an aeroplane, while an individuals digital climate footprint passes by roughly unnoticed in the social debate despite the ICT sector causing equal emissions to the aviation industry or more depending on the calculation (Naturskyddsföreningen, 2021; Sundberg, 2022). Perhaps this might be due to the aesthetics of the ICT sector. Compared to a loud, industrial-looking airplane generating visible and smellable exhausts, an ICT data centre is quiet, modern and discreet. While calling for individuals to be ashamed of streaming their favourite TV show in ultra-high definition on screens too small to tell the difference might not be a reasonable way to reduce the GHG emissions of the ICT sector, there is arguably still plenty of room for awareness of the issue to be raised.

As the environmental and economical dangers of climate change grows, more and more institutions and governments, such as the European Parliament (European Parliament, 2022), are calling for more transparency in the carbon footprint of the ICT sector, putting pressure on private companies to not only understand the carbon impact of their ICT software and hardware choices, but also to reduce it. Although some research is available on the climate impact of ICT sector (Boccaletti et al., 2008; Naumann et al., 2011; Malmodin & Lundén, 2018; Andrae, 2020, to name a few), little research has been done on how this can be used in a real context and what implications it may have for organisations.

In order for organisations to comply with the EU CSRD, reliable ways of measuring the carbon footprint of ICT software and hardware must be identified, some sort of functional unit or metric has to be decided, and some sort of way to implement this sustainability metric into the organisation's procurement process must be found. The knowledge gap this thesis aims to fill is a brief understanding of how the GHG emissions of ICT software and hardware can be measured, what implications this has for the ICT sector as a whole, how these sustainability measurements can be put into context in a procurement process in a large organisation, and what implications that infers on the organisation and its employees.

More importantly, the thesis aims to identify what key metrics for sustainability are the most useful for ICT software product suppliers to provide to different stakeholders so that they may be compared to other metrics important to ICT software product procurers at organisations such as Scania.

1.2 Research Questions

The primary problem statement was condensed into the question "How do you calculate the GHG emissions of ICT software products, and what are the most important sustainability metrics?", which was then split into two research questions which drove the thesis forward.

1. "How are the greenhouse gas emissions of ICT software products calculated?"
2. "What are the key software product and service sustainability metrics that large organisations should consider in their procurement processes?"

1.3 Limitations of Scope

An issue with life cycle analyses is that, depending on how the analysis is made and what things are taken into account, the results of the analysis will vary wildly, as will the complexity of the overall result. For this study, the focus lied on the definitions independently laid forward by Kern et al. (2018) and Sundberg (2022) among others, which is to look at the flow of hardware from manufacturing to disposal and the flow of energy from production to waste heat and not include end-user devices or software development, which is described in slightly more detailed under the literature review section of this thesis.

The thesis will also not be delving particularly deep into the climate impact of the transport sector, other than in the context of Scania's operations, as this thesis is focused on the IT and organisational aspects.

Whenever the word sustainability is mentioned in the thesis, the author likely intends to discuss environmental sustainability, most probably in regards to greenhouse gas emissions. Although there are many forms of sustainability (as seen in section 5.1), this thesis is limited to the ICT sector from a environmental perspective.

It is also worth mentioning that while this thesis generally discusses Scania as a single entity, the findings of the thesis are based on a case study involving a comparatively small group working with a certain kind of purchasing for an organisation consisting of over 54 000 people in 100 different countries, and the findings should be considered to apply first-hand to the studied department, not necessarily the company as a whole (Scania AB, 2021).

2 Background

In this section the background behind the thesis work is explained and context as to where the thesis was written is provided.

2.1 Scania CV AB and Transport Sector Emissions

This master thesis has been written in collaboration with Scania CV AB (hereafter referred to as Scania) in Södertälje, Sweden as a case study of their operations. The researcher was employed by Scania during the duration of the thesis and received compensation for the work, although Scania had no editorial impact on the report itself.

Scania is a global provider of heavy-duty transport solutions for different applications across the transport sector, mainly operating in the sales, rental and financing of trucks and buses.

The transport sector is currently the fastest growing emitting sector in the world, accounting for 23,2 % of European Union CO_2e emissions and relying on fossil fuels to provide about 95 % of the energy required to fuel it (UNFCCC, 2020; European Commission, 2022). In the European Union, 76,7 % of the transport sector emissions were caused by road transportation. Heavy-duty vehicles (trucks and buses), the sub-sector in which Scania operates, accounted for 20,7 % - equalling about 3,7 % of all European Union CO_2e emissions (ibid.).

It is clear that the heavy-duty vehicle transportation accounts for a large part of global GHG emissions and that there is a substantial incentive to work on reducing these emissions. Claiming to drive the shift towards a sustainable transport system, Scania has adopted science based targets to align themselves with the required decarbonisation efforts necessary to achieve at most a 1,5 °C global average temperature increase as set forth by the Paris Agreement (Scania AB, 2021). These goals, set according to the Science Based Target initiative (SBTi) which is an initiative helping organisations set sustainability goals based on modern scientific research on the topic (Science Based Targets initiative, 2021), aim to bring Scania to net-zero emissions by 2050 . They are accompanied by two sub-goals, to achieve a 50 % reduction of CO_2e emissions from Scania's operations by 2025, and a 20 % reduction of CO_2e emissions from Scania's products by 2025 (Scania Sverige AB, 2015).

To achieve this, Scania must look holistically at their operation to find areas where their carbon footprint can be reduced. Based on the climate impact accounting to the ICT sector mentioned above, looking at the sustainability of their ICT products might be a good start. As a global organisation with over 50 000 employees in more than 100 countries (Scania CV AB, n.d.), Scania has a large internal IT-infrastructure of different IT software and hardware products and equipment ranging anywhere from office computers and phones used in day-to-day office work to simulation software used in research and development.

2.2 Procurement of ICT Hardware, Software, and Services

Considering the number of employees and amount of software and hardware to procure, ICT procurement is no easy task. The process is made even harder if employee opinions are considered. The Swedish worker's union Unionen stated in their (2017) IT-survey that less than two out of ten workers in Sweden felt they could affect the routines caused by procurement of new ICT software and hardware, and only two out of ten workers felt that new IT-systems were procured based on clear and established goals (Unionen, 2017). Unionen also points out the importance of sourcing software and hardware and integrating it into the organisation efficiently, estimating that the private sector in Sweden lost 133,5 million working hours due to problems with ICT software and hardware, to a cost of 44,1 billion SEK due to lost time (Unionen, 2017).

Meetings held during the pre-study for this thesis showed that the procurement process at Scania was a complex process consisting of employees sending in purchase requests to the procurement department, who then look for and compare alternatives fitting the request specifications and negotiating an agreement with the provider based on different codes of conduct, license terms and conditions, supplier requirements and more. As of writing this thesis, the different procurement departments at Scania do not prioritise sustainability metrics in their procurement processes and implement sustainability policies on a organisation-wide scale, which combined with a general lack of available data on the climate impact of ICT software and hardware makes lowering Scania's climate impact challenging.

2.3 Difficulties in Setting Expectations on ICT Suppliers

A large challenge that was brought up during the pre-study is being able to set reasonable expectations on sustainability from Scania's ICT software and service providers. Scania has a long and complex procurement process for ICT software and services including several agreements spanning across multiple departments and companies within the Scania Group and their parent company the Volkswagen Group. Because of this, it is difficult to coordinate what demands to put on IT software and services, and as such climate impact is often not considered when procuring new software. For this reason, Scania set out to discover through a thesis worker how sustainability can be considered by the procurement processes, what variables are relevant when looking at sustainability (is CO_2e enough?) and how these compare to other important metrics such as cost, efficiency, or up-time, which laid the background for this thesis work.

2.4 Life Cycle Assessments According to ISO 14040, ISO 14044, and the ISO 14060 Family

The International Organisation for Standardisation (ISO), a collection of national standards bodies from countries around the world, prepares and publishes international standards. For a draft to be published as an international standard, it needs to be approved by at least 75 % of the member bodies casting a vote (International Organization for Standardization, 2006a, 2006b).

Two of these published standards, ISO 14040 and ISO 14044, called "Environmental management — Life cycle assessment — Principles and framework" and "Environmental management — Life cycle assessment — Requirements and guidelines" respectively, helps identify improvement opportunities for the environmental performance of products throughout their entire life cycle and helps to find what indicators of environmental performance might be measurable and relevant (ibid.).

There is also an additional family of standards falling under the ISO 14060 number, which helps provide clarity and consistency in quantifying, measuring, and reporting on GHG emissions and decarbonisation efforts. It also provides guidance on how these claims can be accurately and scientifically verified (International Organization for Standardization, 2018).

2.5 GHG Protocol Corporate Accounting and Reporting Standard

Emission measurements are usually performed by an organisation only on large facilities and for direct emissions caused solely by the organisation. To get a holistic report on emissions, all emissions must be taken in account. To do this, all activities leading to emissions must be identified by the organisation which is a large challenge, but this challenge can be alleviated by using the GHG Protocol Corporate Accounting and Reporting Standard (Swedish Environmental Protection Agency, n.d.).

The GHG Protocol is a globally standardised framework on how to measure and manage emissions of GHGs (European Union, n.d.). Built on a partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), the GHG Protocol has published a Corporate Accounting and Reporting Standard, which is the most used standard for GHG emission accounting and management, used in 2016 not only by 92 % of all organisation on Fortune's list of the United States' 500 largest companies, but also by countries and cities all over the world (GHG Protocol, n.d.).

The GHG Protocol divides the emissions caused by an organisation into three categories, called scopes, based on where in the organisation's value chain the emissions are caused. This helps improve transparency and utility in organisational policies and goals, and delineates direct and indirect emissions (WBCSD & WRI, 2004). These three scopes are:

1. Direct GHG emissions from sources controlled by the organisation, such as fuel for company vehicles or oil burned for office heating.
2. Electric indirect GHG emissions caused by the generated electricity the organisation purchases for its operation.

3. Other indirect GHG emissions that do not fit into scope 1 or 2, commonly emitted as a consequence of the organisation's operations but not controlled by the organisation itself. For Scania, this could be how the natural resources used in production are sourced or how much GHG are emitted by their trucks during their lifetime after being sold.

Without the GHG Protocol, emissions reporting usually focus only on the direct emissions caused by an organisation, but this way of reporting misses a lot of emissions. As part of their science based targets, Scania estimates that approximately 96 % of their total emissions comes from how their products are used (scope 3), which showcases how much climate impact can go unnoticed when not reporting indirect emissions as well (Scania Sverige AB, 2015).

2.6 ICT Sector Guidance on GHG Reporting

Although the GHG Protocol is an effective way for an organisation to report on their GHG emissions, their sector tools for emission calculation do not cover software- and hardware-related emissions from the information and communication technology (ICT) sector (WBCSD & WRI, 2004).

Because of the very complex and sometimes convoluted nature of ICT software, the supply chains necessary to supply the hardware required for it to work and how computational resources are often shared between organisations, measuring the GHG emission from ICT products and services is very difficult. To alleviate these problems and help with organisational reporting of emissions, the Carbon Trust has published a guidance for the ICT sector on how this reporting could be performed (Carbon Trust, 2017).

The ICT Sector Guidance is built on the GHG Protocol Product Accounting and Reporting Standard and helps quantify the emissions caused by the IT and communications equipment used in organisations not only by cloud services but by personal computers and mobile phones used to access the software, the data centres and telecommunications networks used to serve the data and the sourcing of electricity required to keep it running.

The ICT Sector Guidance is divided into chapters on five different reporting areas: Telecommunications Network Services, Desktop Managed Services, Cloud Computing and Data Centre Services, ICT Hardware, and Software, with different methods for calculating the impact for each chapter.

2.6.1 Telecommunications Network Services

Telecommunications network services are the collection of local area, wide area, fixed, mobile, satellite and submarine networks in place to allow the transfer of data required to share computing resources globally. Although crucial to the functioning of today's connected society the environmental impact of telecommunications networks does not go unnoticed. In 2011, the National Institute of Standards and Technology estimated that telecommunications network services accounted for 22 % of the total climate impact of the ICT sector (Mell & Grance, 2011).

2.6.2 Desktop Managed Services

Desktop managed services are commonly outsourced services including, but not limited to, provision of desktop and mobile phone equipment, supporting infrastructure of network and server hosting and technical support of the equipment including maintenance services, service desks and software upgrades. Although the climate impact of this category is low in comparison to other categories, due to the amount of organisations using desktop managed services the Carbon Trust has an established framework on how to report the impact caused by desktop managed services (Carbon Trust, 2017).

2.6.3 Cloud Computing and Data Centre Services

Cloud and data centre services, compared to IT services that were previously hosted in-house by dedicated corporate infrastructures, has become common place in modern IT communication. Cloud computing offers hosting of applications accessible remotely over the internet, often using shared computational resources.

2.6.4 ICT Software and Hardware

ICT hardware is defined by the ICT Sector Guidance as a product meant to achieve or enable the function of information processing and communication by electronic means, including the transmission and displaying of data. In short, this refers to computers, servers, screens etcetera. Any physical electronic device could be considered hardware.

ICT software is simply referred to as the code running on the given hardware, but in life cycle assessments software is mostly described as executable programs able to be distributed via installers (such as word processors or web browsers). Software running on cloud platforms without the need for user installation, commonly referred to as Software-as-a-Service (SaaS), are differentiated a bit as they are half program, half cloud service.

For this thesis, an important distinction should be made between a software product and a software service. They will mostly be mentioned together in this thesis, but when software products are mentioned, the author is referring to individual programs such as word processors or computer-assisted drawing programs, while software services refer to the act of providing a customer with either software running on the provider's hardware (such as in SaaS) or providing server capacity in the form of data centres to customers allowing the customer to run a service themselves without worrying about the underlying hardware.

The ICT Sector Guidance also provides recommendations on how to decide on which functional units to use in life cycle assessments, suggesting that a good functional unit should take into account how large part of a function the product fulfils, the service life required to fulfil the function and what product quality can be expected by the software, as well as what boundaries should be placed on the assessment.

2.7 Internet Carbon Intensity

When talking about GHG emissions as a metric, a term that is frequently used is intensity, either as part of carbon intensity or GHG intensity. Intensity generally denotes CO_2e emissions per a given business metric such as units of production or market capitalisation (although many variations occur as per Table 3 (Hoffmann & Busch, 2008)). One example of carbon intensity in use for GHG emissions is in electricity generation, such as the European Environment Agency (2022) calculating how many grams of CO_2e is emitted, on average, for each member country of the European Union which can then be used to compare climate impact of different country energy mixes.

This idea can be applied to ICT network traffic as well, as a measurement of the amount of electricity consumed for a given amount of network traffic, such as kWh/GB. This topic is discussed in Coroama and Hilty's (2014) review of ten different studies published between 2004 and 2013. In their review, they speak of three primary approaches to calculating the energy intensity of the internet:

1. A top-down approach, where researchers look at rough estimates of total energy consumption of the entire internet or regions (such as countries) of it, and subsequently divide this demand by a rough estimate of the network traffic for that same region. Studies made using these methodologies were found to have very different results, largely dependent on the system boundaries used, but generally tended to have pessimistic results and providing an upper bound.

2. A bottom-up approach, where researchers look at specific cases where energy intensity can be calculated or even measured (such as a videoconferencing transmission between Europe and Asia (Coroama et al., 2013)) and using the observations to generalise the results for a broader scope. The results of these studies were found to be above average and should be seen as an overestimation of energy intensity.

3. A model-based approach which uses principles of network design and manufacturer data to model parts of the internet and provide direct estimates for the energy intensity of network traffic. These studies were found to often be optimistic in their assumptions, providing a lower bound.

Internet energy intensity was found by Coroama & Hilty to be a poor metric for comparison due to very large variance in results between studies. The highest energy intensity found in their review was 136 kWh/GB of data, which was 4,3 magnitudes larger than the lower energy intensity found of 0.006 kWh/GB. The review narrows this variation down to two determining factors, year of assessment and scope.

The ICT sector, especially in regards to network traffic, is a very dynamic sector that is exponentially growing (Malmodin & Lundén, 2018) while simultaneously having grown exponentially more efficient, roughly doubling in performance every two years as per the predictions made by Gordon Moore in 1965 (Shalf, 2020). For this reason, Coroama & Hilty (2014) argue that in order to compare energy intensity calculations from two different years, researchers would have to account for this downward trend.

The other determining factor is the different system boundaries used by different methodologies. The perhaps largest decision to make in regards to the outcome of the calculation is whether or not to take into account end user devices such as phones or computers. In their review, they found that the studies not taking end user devices into account resulted in a result lower by at least a factor of 4 compared to the studies that included end user devices. A white paper published by Google (2012) on the energy savings of migrating to the cloud that did not take into account end user devices stated that when the U.S. General Services Administration migrated to Google Apps in 2012, they achieved energy savings of 87 % per user compared to before the migration. Were end user devices to be included, the energy savings would instead be 39 %, speaking to the difference this choice can make.

On the note of end user devices, however, Coroama & Hilty conclude their review by suggesting that end user devices should not be taken into account when calculating the energy intensity of network traffic as it is difficult to find a useful way of averaging the power consumption for end user devices. There is no way of differentiating between a user on a smart phone compared to one using a stationary computer, so the authors instead argue for including end user devices as a separate estimate entirely, avoiding adding up totals unless necessary which allows decision-makers to draw their own conclusions based on their individual contexts.

Coroama & Hilty are not the first authors to bring up the issue of a standardised way to calculate the energy use of different aspects of the ICT sector, either. In their article on Sustainable Software Models, Kern et. al. (2018) set out to find a standardised understanding of how to determine whether or not a software product is sustainable, and her group had previously proposed a reference model called the Greensoft Model for calculating the climate impact of a software product (Naumann et al., 2011), and Anders Andrae writes in his article New Perspectives on Internet Electricity Use in 2030 (2020) a large part of the challenge in making accurate predictions is accounting for 'unknown unknowns'.

2.8 University of Bristol Research

Computer scientists at the University of Bristol researched the climate impact of digitalisation already in the early 2010's. This research was initially in partnership with Guardian Media Group in the United Kingdom but was later partnered with the British Broadcasting Corporation to specifically investigate digital distribution as an alternative to traditional physical distribution. The research found that a smart phone streaming video over 3G mobile internet generated about 16 times the GHG emissions that reading static web content did, 145 kJ as opposed to 9. While this showcases how some ICT use cases are more emission-heavy than others, the advancements made in cellular networking and mobile technology since might mean that a reevaluation of the method found might be due (University of Bristol, n.d.).

3 Purpose and Aims

It is clear sustainability has to be prioritised more in modern, ICT-driven organisations, but that there seems to be no clear idea of how it should be done. The purpose of this master's thesis is to make a contribution to the academic community in attempting to establish which aspects of software emission calculations are useful in a real context and how these could be prioritised in software procurement processes. The academic contribution should help enable future research and aid policymakers in organisations or governments such as the European Union make decisions on the future of sustainable ICT software products. Through the case study performed, the thesis also aims to help Scania gain a better understanding as to what kind of impact ICT software products have on the climate and what sort of demands Scania can put on their ICT software product providers when procuring new ICT software products in order to reduce the GHG emissions caused by the organisation's use of these products. The aim of the thesis is to provide a series of recommendations on what sort of climate impact metrics matter the most when looking at ICT software products. On a broad scope these findings might help the shift to a sustainable future worldwide, and on a narrow scope how these climate impact metrics can be implemented into Scania's existing procurement process while making the lowest amount of compromises between climate impact and other procurement metrics important to Scania such as cost or uptime.

4 Method

In this section, how the research and the following thesis were made is presented.

4.1 Research Design

At the beginning of this thesis, the intent was to perform a deductive study on the topic of sustainability in the ICT software products used in Scania products. Deductive studies are the most common way of conducting research and theorising, based around forming hypotheses around an initial theory, collecting data to either confirm or deny these hypotheses and finally revising the initial theory based on the results (possibly starting the process anew with a revised theory) (Bryman & Bell, 2011). The original theory behind this thesis was that the GHG emissions of ICT software products could be calculated by formulating different methods, such as the ones mentioned in the section on internet energy intensity, to perform life cycle analyses of the software products.

However, early findings from pre-study meetings and the start of the literature review proved life cycle analyses to be far more complex than what had been theorised due to the issues around scoping life cycle analyses that are brought up in the background section of this thesis, leading to a pivot to a more qualitative methodology.

It was thus elected to shift focus from a deductive study on how to calculate the GHG emissions of ICT software products to an inductive study on how the theoretical results of such a life cycle analyses could be used in practice. In inductive research, researchers start by observing a given environment, and through pattern recognition and observing themes formulating a theory based around what was observed. A rough order-of-operations for the two research methods can be seen in figure 1.

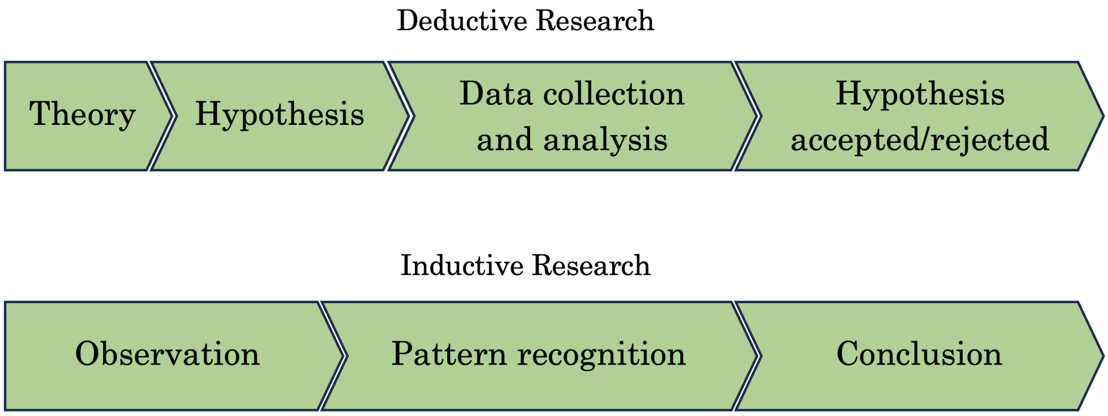

Figure 1 The deductive and inductive research methods, loosely adapted from Bryman and Bell, 2011.

4.1.1 Espistemology and Ontology

Epistemology is described by Bryman & Bell (2011) as a philosophical subfield concerning the theory of knowledge, and what is or should be considered acceptable knowledge for a given field. Epistemology for social sciences such as those of this thesis can simply (but not entirely accurately) be divided into two different standpoints, positivism and interpretivism. The former, positivism, is the notion that knowledge is obtained through objective gathering of facts and testing of theories, regardless of what humans "feel", and that reality is consistent regardless of if it is being observed or not. The latter, interpretivism, is the notion that reality does not exist purely by itself, and that knowledge stems from people's perception of reality, which makes individual beliefs, thoughts and feelings valid compared to the objective nature of positivism.

Ontology, on the other hand, is the philosophical study of being and reality. In a scientific context, ontology concerns the idea of truth, what can be considered true and whether or not more than one truth may exist. In short, social ontology is divided into two fields, *constructionism* and *objectivism*. An objectivist standpoint aligns well with objective, quantity-driven research and a objectivist researcher believes that there is one objective truth. A constructionist researcher, however, is more in line with interpretive research methods (such as the qualitative research of this thesis) and believes that there might be several truths, depending who is doing the observation (Bryman & Bell, 2017).

This thesis is based on a constructivist intrepretive standpoint. The procurement process studied is a living thing that often changes and adapts to fit the needs of the studied organisation and the beliefs of the procurement managers involved in the process are what are seen as the very much subjective truths. The qualitative research methods chosen suits this need as it allows for much greater expression from the research subjects compared to an objective quantity-driven approach.

4.2 Research Methods

The research method for this thesis was chosen to be a case study of Scania in Södertälje, accompanied by a literature review and complemented by a series of interviews of members of Scania's IT software procurement department. A thematic analysis was performed on the interview responses.

4.2.1 Literature Review

In parallel to the case study of Scania's procurement department, a literature review was also conducted where existing literature on the topic of software product life cycle assessments was reviewed. The aim of the literature review was to get a good understanding of the current state of life cycle assessments for software products and services, how they were performed and whether or not they could be a useful tool as part of Scania's procurement process for software products and services.

4.2.2 Interviews and Thematic Analysis

In this study, interviews were conducted with procurement managers working with IT software procurement at Scania as well as internal customers ordering software through the procurement process.

As the topic of procurement prioritisation is inherently a very subjective matter, as shown by the literature review, and the point-of-view of the people in the studies were more important than achieving high statistical validity of results, a qualitative research method was called for. For this reason, semi-structured qualitative interviews were chosen. Research interviews are a versatile way of allowing people to tell you about themselves (Hartas, 2010), which entails a lot of potential issues regarding induction of errors into the responses (Bryman & Bell, 2011) such as variance caused by open-ended questions or through interpretations of the interviewer.

When conducting interviews, the primary choice is between conducting a formal structured interview, where each interviewee is given the same context for questioning, or the more informal unstructured interview where the questions can be adapted to better fit the person involved based on a set topic. The latter sort, by some referred to as a qualitative interview (e.g. Rubin and Rubin, 2005), while more prone to variations due to error, was deemed more appropriate in this study considering the low amount of people being interviewed and the interview candidates being deemed knowledgeable in their field at Scania.

To reduce the variations due to error mentioned above, the interview process had to be carefully planned. The questions must be phrased in a way as to minimise "probing", where the interviewee does not fully understand a question and asks for further information, as interviewer intervention in clarifying a question to some respondents but not others might skew the validity of the results.

The interview sessions, which lasted about an hour each, were audio recorded and the audio recordings were then transcribed by the author. On this transcription, a thematic analysis was made to try and identify common themes among the interview candidates and to compare responses to each other.

A thematic analysis is a way to quantify qualitative data where the researcher subjectively looks through collected data trying to find patterns or themes that are apparent between sets, or in this case interviews (Holme & Solvang, 1991). In short, the process of thematic analysis can be summarised as familiarising yourself with data looking for patterns, formulating themes that these patterns align with and using these to compare sets of data to each other (as seen in figure 2. This means that for a series of interviews, thematic analysis is trying to understanding if two different candidates things might mean the same thing even if they word it differently.

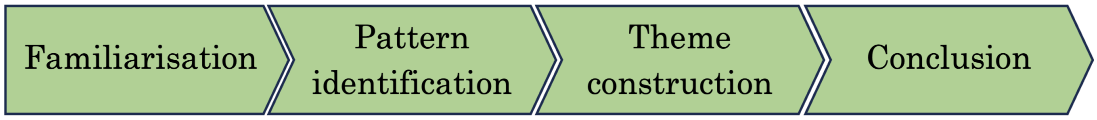

Figure 2 The steps to performing a thematic analysis (Holme & Solvang, 1991).

Because the researcher is open to interpret their data in many different ways, a thematic analysis is inherently interprevist, in line with the epistemological standpoint of the researcher. This does, however, mean that some concerns about reliability of conclusions can be raised, especially as the interview candidates and transcriptions in this study are kept anonymous.

4.2.3 Interview Ethics

When dealing with scientific data collection, research ethics quickly becomes a hot topic.

The data collected from the interview process, while not necessarily sensitive to the company, contained subjective employee opinions and as such there is a responsibility on the researchers to ensure that interviewees are clearly informed before the interview begins on what data is collected, how it is collected, how it will be handled and stored, and how and to whom it will be shared (Holme & Solvang, 1991).

Participation in any research study should always be voluntarily (Holme & Solvang, 1991; Bryman & Bell, 2015). To make sure all candidates were sufficiently informed, the interviews operated on the policy of informed consent as suggested by Bryman & Bell (2011). At the beginning of the audio recording of each interview, the informational text shown in appendix A was read to the interview candidate. The informed consent script contained information about who the researcher was, the purpose of the interview sessions, the candidates' right of withdrawal, how the collected data would be stored and used and how the participants would be anonymised. After having read the informed consent script to the interview candidates, the candidates were asked to orally consent to participating, being quoted and being audio recorded. While written consent generally is favourable over oral consent (Holme & Solvang, 1991), recorded oral consent was used due the interviews being held over video-conference and written consent being infeasible.

To ensure the privacy of the interviewees, the audio recordings from the interview process was stored securely on the author's private computer and not shared with anyone. These audio recordings were then transcribed manually by the author and the transcription stored in similar fashion. Once the transcription was made, the audio recording was deleted apart from the initial recording where the interview candidates consent to being a part of the research study, and once the thesis was approved and published the transcriptions were deleted.

Throughout the study, the interview candidates were assigned a random letter and referred to throughout as 'Procurer A' or similar. Although the recording and transcription were not to be made publicly available, the candidates were informed that their responses might be quoted verbatim in the anonymised form. No other personal information other than the interview candidates working as IT software procurement managers at Scania was disclosed. Because there is a limited number of employees at Scania whose job title matches this description and that the risk of identification could not be completely eliminated, the interview candidates were informed of the identification possibility before the interview started and were reminded that they could elect not to answer a question if they felt it to be sensitive enough to affect their work negatively, and not give a response they would not be comfortable sharing publicly. As the interview questions were somewhat uncontroversial, no interview candidate felt uncomfortable answering any questions.

5 Literature Review

Several studies has been conducted on the topic of ICT software product sustainability.

5.1 Sustainability and Climate Change

Sustainability today is a very broad term that can be used in various ways and meanings depending on the context. The Cambridge Advanced Learner's Dictionary describes sustainability as "the quality of being able to continue over a period of time" (McIntosh, 2013), Wikipedia as "a societal goal that relates to the ability of people to safely co-exist on Earth over a long time" (Wikipedia, 2023), but perhaps the most commonly used definition is that of the United Nation's World Commission on the Environment and Development (WCED) "Brundtland report": "Meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, G. H. et al., 1987; Wilkinson et al., 2001).

Sustainability, then, can be described as a holistic concept with many different faces to it. Social sustainability, economic sustainability, environmental sustainability and ethical sustainability are all valid and meaningful pursuits, but the ambiguity of the term can often leave a lot of room for interpretation on what researchers mean in a way which is not always desirable.

Robert Goodland suggests in The Concept of Environmental Sustainability (1995) that although social, economic and environmental sustainability are all interconnected and dependent on each other, environmental sustainability lies as a basis for all other types of sustainability, stating that there can be no social or economic sustainability without environmental sustainability. The ozone layer is put forth as an example, where damage to the ozone layer would lead to increased levels of ultraviolet radiation causing damage to humans and agriculture, which in turn would undoubtedly be harmful from an economic and social standpoint.

In this thesis, sustainability will be discussed purely in an environmental context. While the ICT sector could surely benefit from a critical discussion in regard to the other categories of sustainability mentioned (such as the sourcing of natural resources not only from an emissions standpoint), this thesis will be looking at the ICT sector mainly in regards to the natural resources required to produce the equipment on which it runs and the environmental impact of producing the energy it consumes. Whenever the word sustainability is mentioned, the intended definition is that of Morelli (2011):

> 'Meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them.'

The reason for this view on sustainability is that the thesis aims primarily to investigate how an organisation's choice of software and hardware can act as a driver to reduce the effects of climate change ("the periodic modification of Earth's climate brought about as a result of changes in the atmosphere" (Encyclopædia Britannica, n.d.)), specifically through the reduction of the GHG emissions caused by the organisation.

5.2 Is Sustainability Objective or Subjective?

Another big discussion within the field of sustainability is on whether or not sustainability can be objectively defined, or if its meaning can vary depending on context. Many of the definitions of sustainability, such as that of the Brundtland report (1987), imply that the environmental capital of the world (defined as the possible uses or functions of the environment and it's natural resources) should remain intact and that there therefore must exist some kind of equilibrium between what humanity takes and what humanity gives in order for these functions and resources to remain permanently available (Hueting & Reijnders, 1998). This equilibrium should be based upon metrics derived from the natural sciences and provide a basis for a "yes and no" answer on whether something is sustainable or not, and is therefore objective.

However this way of objective thinking, where the environmental remainders of a system must not be less than the environmental inputs of a system, can lead to a line of reasoning where, for a lot of systems, the only winning move is not to play. Bartlett (1994) debates in a published article that the needs of the environment often are in direct conflict with the needs of humans, that compromises always need to be made and that the word "sustainable growth" in itself is an oxymoron. In this article, he makes yet another attempt to give a firm definition of the term sustainability through a series of laws which are briefly summarised in table 1. With these laws, Bartlett reasons rather grimly that as long as growth, either in humanity's population size or its resource consumption, is involved, objective sustainability cannot truly be achieved, which makes it impossible to have any sort of constructive discourse on the state of the world we live in - what is the point of trying to be climate conscious if nothing is sustainable?

1	Population growth and/or growth in resource consumption rate is unsustainable.
2	The larger a society or consumption rate, the harder it is to make it sustainable.
3	The response time to a change in a population's fertility rate is approximately 50-70 years.
4	Sustainable standards of living and population sizes are inversely related to one another.
5	Sustainability requires population size to be less than or equal to the carrying capacity of the ecosystem.
6	The benefits of societal growth benefits the few, the costs are paid by the many.
7	For non-renewable resources, a growth in consumption rate means a decrease in life-expectancy for the resource.
8	The life-expectancy of non-renewable resources can be extended through technological and sustainable means.
9	The savings from an increase in efficiency are wiped out by the increased population it allows.
10	The efforts of environmental preservation are cancelled by increases in human population.
11	When pollution can no longer be cleansed by the ecosystem, it is easier to pollute than it is to clean up the environment.
12	Solutions are the chief cause of problems.
13	Agriculture will always be a necessity to humans.
14	If humanity fails to stop its growth, nature will.
15	Sustainability matters little to the starving.
16	Talking about sustainability does not make society sustainable.
17	Extinction is forever.

Table 1 A summary of Bartlett's Laws of Sustainability (Bartlett, 1994).

Ismail Serageldin and Andrew Steer (1994) argue instead that there are different levels of sustainability. In the epilogue "Expanding the Capital Stock" published in "Making development sustainable", they describe that there are four different types of capital:

Human-made, natural, human and social. Using these four types, they then divide sustainability into different levels – weak, sensible, strong, and absurdly strong, depending on how much consideration is taken into the different capital types.

- Weak sustainability sees the different types of capital as interchangeable, and allows free consumption from any form of capital as long as it is made up for by growth in other types. For example, mining for iron ore (natural capital) can be seen as weakly sustainable as long as the iron gets turned into steel (human-made capital) of equivalent value.
- Sensible sustainability is like weak sustainability but also requires some concern to the maintenance of each individual type of capital. Oil may be extracted as long as the gains are invested into different sorts of capital (such as social capital through heating homes), but efforts should also be made to define critical levels and ensuring these are not exceeded (the oil must not run out).
- Strong sustainability requires that the value of each individual type of capital must remain intact, regardless of growth to other capital. If a forest is to be cut down, it should be replaced by a new, planted forest elsewhere of similar proportions. This view on sustainability recognises that the different types of capital are not interchangeable, but complementary – a sawmill (human-made capital) may not exist without a forest (natural capital).
- Absurdly strong sustainability seems to follow the same reasoning that Bartlett (1994) does – the remainder of a system must not be less than the inputs. On this level, nothing can be depleted to any degree. Non-renewable resources must not be used at all, while for renewable resources only the net annual growth rates can be harvested.

Serageldin and Steer (1994) reason that these levels could be applied to a person, process, organisation or government as a sort of sustainability classification, meaning that according to them, the word sustainability is indeed subjective as it is turned into a social construct determined by the present generation. They finish their article by suggesting that, methodologically, it is better to focus on taking small, imperfect steps to a more sustainable world, rather than to waste time debating what the "perfect" formulation of sustainability is, advocating instead to try and make choices with sustainability in mind.

This leads back to what definition for sustainability is used in this thesis. As mentioned above, this thesis is primarily talking about sustainability from a climate standpoint, not considering the social, economic or ethical aspects but rather focusing on the emissions of GHG caused by the ICT sector. In addition, it is the belief of the author that sustainability is indeed subjective, aligning ideologically towards sensible sustainability. Since ICT can be inherently hard to defend from objective standpoints (seeing as how it consumes material resources to produce immaterial things), it is more useful to discuss it in a subjective, comparative way. When considering between two different computer models to purchase, neither would be sustainable in the objective yes or no type of thinking as the production of both consume more resources than they produce, but one might still be subjectively more sustainable than the other.

5.3 Calculating the Climate Impact of the ICT Sector

Due to the intangible and immaterial nature of software products, the climate impact of the ICT sector is often easy to overlook. While a "traditional" industry building (such as a power plant or manufacturing plant) might often have a coarse, dated façade of concrete and brick, complemented by large, billowing smokestacks and constant noise, buildings housing cloud data centres are virtually silent, recently constructed buildings with modern aesthetic and no outside indicators of what happens within.

It is also important to make a distinction when it comes to the usage of the word measure in the context of the climate impact of the ICT sector. While the word measure is frequently used (Hoffmann & Busch, 2008; Andrae, 2020; Yavnika, 2021), to actually measure the emissions of ICT software the same way as you would measure the emissions from a factory chimney is not feasible. Instead, one needs to rely on educated calculations based on different approaches, such as the ones discussed in the section on internet energy intensity.

Even if the methodologies mentioned in the previous paragraphs are used, calculating the environmental impact that these software products infer in a methodological way is difficult, as there is no standardised system of boundaries to include into life cycle analyses. Kern et al. (2018) and Sundberg (2022) use a simplistic approach, stating that the two main environmental impact flows related to ICT within an organisation is hardware flow, from new purchased hardware such as computers and phones to obsolete hardware destined for recycling, and energy flow from purchased energy necessary to run the software being turned into waste heat. Others try to include a more detailed scope, such as Malmodin (2018), who take a more holistic approach, not only looking at the hardware and energy consumption within an organisation, but including the hardware systems required outside of the organisation, such as in data centres and routing networks.

Another big issue when discussing ICT sector climate impact is what type of quantifiable metrics can be put on software products and used as a means not only to measure sustainability, but to compare the sustainability of an ICT product to other important procurement metrics such as cost. Traditionally, the environmental impact of both the hardware and energy flow could be measured by performing a life cycle assessment of the hardware used for the software product and the GHG emissions caused by the electricity used to power the software product, but whether or not there are other ways to measure this has not been as well researched.

5.3.1 Ways of Making Software More Sustainable

Kern et al. (2018) suggests asking the following questions when looking at how to make software more sustainable:

1. How efficiently resources are used:
   (a) What type of hardware is needed to be able to run the software product and how well is it utilised?
   (b) How much energy does the software consume in execution by the required hardware?
   (c) How efficiently can the software manage its energy usage.

2. Extending hardware life:
   (a) Is the software backwards compatible? Can it be used on older devices, and will current-generation devices still be able to run the software in the future?
   (b) Is the software platform independent? Can it run on different system environments or will an organisation need to switch to a new type of hardware.
   (c) Is the required hardware capacity static or will it grow over time? Will the organisation need to add hardware capacity in the future as additional functions have been added?

While these questions might be important in software development, for large organisations such as Scania with a vast software and hardware infrastructure, a lot of times they must be ignored during development phases in favour of other matters, such as security, infrastructure matching, technical debt or simply being limited by the choices of software products available when procuring instead of developing in-house.

5.4 Limitations of Life Cycle Assessments

Performing life cycle assessments of software products is far more difficult than making a life cycle assessment of a traditional, physical product. This is because a software product is in practice a combination of both hardware and software resources that all vary in their climate impact during manufacturing and running, not only within the systems but between systems as well. In figure 3, the different hardware and software layers that go into a computing setup is illustrated in each column.

To make matters worse, a software product in modern times of cloud computing are made up of a network of different hardware nodes located in different parts of the world, especially when looking for network traffic. For example, this thesis was written using the LaTeX markup language through a popular online editor application distributed online as a service (SaaS). To connect from the author's laptop in Uppsala to the cloud server on which the platform runs, a total of eight steps were necessary for the network traffic according to the Microsoft Windows command-line utility ´tracert´, as shown in table 2.

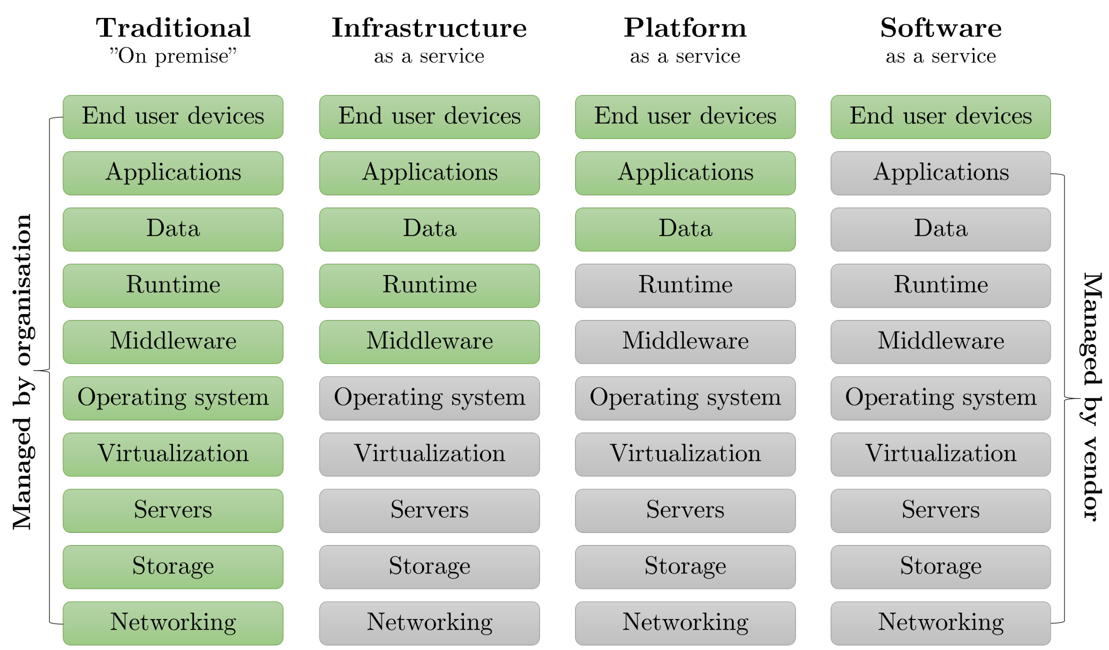

Figure 3 Division of control between the organisation (green) and cloud provider (grey) for different cloud service types as per the NIST definition of cloud computing with the addition of end user devices (Mell & Grance, 2011).

This means that the data sent is being routed eight different times by routing hardware at different geographical locations, owned by different companies and powered by different energy sources. To get an idea of what kind of emissions are generated as a result of this query, one would have to contact the companies responsible for the hardware operating at each of these steps and hope that they would willingly share the power draw of their hardware, the energy carbon intensity of their sourced energy and how much total network traffic they process, things that internet providers, especially government-owned, might not be keen to share.

Even if the energy usage of each device used in this network was readily available, there is also the issue of resource allocation. Can you assume that if you account for 1 % of the traffic through a network, are you accountable for 1 % of the power usage? If so, how do you estimate what percentage of the network traffic running through these eight nodes are caused by you connecting to an online LaTeX markup editor?

1	Uppsala, Sweden
2	Oslo, Norway
3	Nesoddtangen, Norway
4	Oslo, Norway
5	The Dalles, Oregon, U.S.A
6	Mountain View, California, U.S.A.
7	Mountain View, California, U.S.A.
8	Kansas City, Missouri, U.S.A.

Table 2 Routing steps taken to connect from the author's device to the online platform used to write this thesis as of 2023-04-12 based on lookups of IP-address through the Windows command prompt ´tracert´ command.

Electing to ignore network hardware and other hardware that you simply cannot account for, there are still issues in estimating resource allocation in end-user devices. This thesis has, during the duration of its creation, been worked on using a personal Apple laptop, a Scania-provided Windows laptop and a stationary desk computer. As of the time of this writing, the Apple laptop was drawing 18 Watts of power at a CPU utilisation of around 25 %, approximately half of which being allocated to the web browser in use (according to the Windows task manager). The browser in use has 32 browser tabs opened, with the active editor tab using 12 % of the CPU resources allocated to the web browser, and the laptop is connected to an LCD monitor drawing 5 Watts of power.

How many of these 23 Watts of power can be attributed to the online LaTeX markup language editor? And what percentage of the GHG emissions caused in the manufacturing of the two laptops, the stationary computer and monitor can be attributed to the online LaTeX editor? Perhaps most relevant, what is the GHG emission impact caused by the writing of this thesis?

As for the emissions caused by software development, said online LaTeX editor has been in continuous development since 2011 (Overleaf, 2023). As it is not a software with clear ”releases”, do you attribute the emissions caused by running an office and developing software for twelve years to parts of the emissions by using the software? If so, how do you decide how much? The ICT Sector Guidance (2017) suggests considering each major version released as its own product and to divide the emissions caused by the development spent on that specific version over the number of copies of the software that is going to be distributed for that version, but versioning is a very arbitrary concept so an organisation could theoretically release a major version shortly after another to allow for lower development emissions to be reported. Having users as a functional unit also brings into question how the word ”user” should be used. As the software is provided as a service (SaaS), at what point do you consider a new copy made? Is it enough for a user to create an account on the platform, or must they use the service for a certain amount of time?

In short, these are things that the author can not even begin to accurately answer. Estimations could be made, attempting to guess how many hours were spent on the thesis, how many of which were spent on each device and how much power on average was needed by each device and then multiplying all this by the average energy carbon intensity of the municipality where it was written (ignoring the work done abroad during the summer). This would provide a number, sure, but the confidence interval would be huge to the point of uselessness. Now imagine you are the company behind said popular online LaTeX markup language editor and someone asks you to estimate the climate impact caused by end users using your service. It simply is not feasible.

On the topic of network traffic it also should be mentioned that while the amount of data traffic has been increasing exponentially each year over the last few decades, since 2010 the carbon footprint has remained functionally the same due to increases in computing efficiency and power generation (Malmodin & Lundén, 2018), even throughout the Covid-19 pandemic despite the large data increase caused by videoconferencing as a result of working from home (Malmodin, 2020).

5.4.1 Calculating Data Centre Emissions

Indeed, calculating the power usage caused by software products is difficult. Removing the aspects of a software system that can not be predicted or accurately calculated, such as end user devices, network equipment or development tools, one of the few things remaining to base calculations on is server usage which, for once, is something very easily obtained.

Most cloud computing providers today bill their customer based on the customer’s usage of the service - meaning you pay more the more computing power you use. To be able to do this, cloud computing providers must provide their customers with detailed usage reports on how much computing power a website, service or database has used over the last billing period, often including daily or hourly data points.

One such usage report is the Amazon Web Services (AWS) Cost and Usage Report (CUR), which contains everything from virtual CPU (vCPU) clock speeds and memory usage to network traffic and processing times (Amazon Web Services, 2023). Using these usage reports, an organisation can calculate the approximate power usage for their portion of the server usage using a model titled *Cloud Jewels* developed by the online marketplace Etsy (Adler & Etsy, 2023). This method approximates cloud energy usage based on vCPU, solid-state drive (SSD) and hard-disk drive (HDD) usage [1]. Their usage is then multiplied by three constants, derived by Etsy from the U.S. Data Center Energy Usage Report, The Data Center as a Computer, and the SPEC power report, as seen in table 3 (Etsy, 2020).

vCPU	2,3 Watts per vCPUh
SSD	1,52 Watts per TBh
HDD	0,89 Watts per TBh

Table 3 Power consumption per functional unit for virtual CPU:s, SSD:s and HDD:s (Etsy, 2020).

These hours, similar to watt-hours, are calculated by multiplying the capacity of hardware with the duration of use as seen in equation 1. That means if you were to rent a 2 terabyte hard drive for a full day, you would be billed 48 terabyte-hours. For vCPU:s, this is simply the amount of vCPU:s available times and for how long, meaning running 4 vCPU:s for a full day would net you a bill for 96 vCPU-hours.

$$FunctionalHour = Capacity * Duration \tag{1}$$

Once these values have been fetched from the cost and usage reports and multiplied by

[1]The AWS CUR also includes numbers for how much network traffic your service has amounted to and how memory (different from storage) has been used, but in line with the findings of this thesis Etsy could not find a good way to calculate the power usage of network traffic, and as was found by Pereira et. al. 2017, there is little correlation between memory usage and power usage.

the watt constants derived by Etsy, it remains to translate this into total power usage for the data centre. To do this, a final value from the data centre usage reports is needed, called power usage effectiveness (PUE). The PUE is a value that describes the effectiveness of a data centre, meaning how much of the energy required to run a data centre is actually spent on the computers themselves as opposed to lighting, climate control and the like. The PUE is calculated by dividing the total power consumption of the data centre by the power consumption caused by the IT equipment as seen in equation 2.

$$PUE = \frac{Total\ energy\ used\ by\ data\ centre}{Energy\ used\ by\ IT\ equipment\ within} \tag{2}$$

A PUE of 1,5 would therefore mean that for every 1 watt of power used by IT equipment and storage in a data centre, an additional 0,5 watt is used in auxiliary equipment, resulting in a total consumption of 1,5 Watts for the data centre. This metric is commonly reported by cloud service providers, usually to compete with other service providers, and is therefore a useful tool and a baseline for calculation services such as Gaia Gen, an online tool that allows organisations to get a good overview of their cloud service footprint, the developers of which have been a great help in the writing of this thesis (Gaia Gen, 2023).

5.5 Energy Carbon Intensity as a Metric

Although calculating the energy consumed by a given software product is very difficult and attributing energy consumption to a given computer process is even more difficult, as Coroama & Hilty points out, looking at the energy carbon intensity (ECI) might still be a useful metric when dealing with GHG emissions of software.

In the United States of America, the ECI of the power mix (average ECI for all power sources) during 2021 was 386,6 g CO_2e/kWh on average, varying between power grid subregions with NPCC Upstate New York (NYUP) being the lowest at 105,7 g CO_2e/kWh and Hawaii's HICC Oahu being the highest at 740,7 g CO_2e/kWh (United States Environmental Protection Agency (EPA), 2023). For the European Union, the average GHG emission intensity of the 27 European Union member states (EU-27) was 275 g CO_2e/kWh in 2021, with the lowest being Sweden at 9 g CO_2e/kWh and the highest being Estonia at 946 g CO_2e/kWh (European Environment Agency, 2022). As is highlighted by table 4, the difference in energy carbon intensity between countries can vary up to a factor of 105 depending on if a cloud-hosted software product is hosted in Sweden or Estonia.

Region	**Carbon Intensity**	**Factor Increase Over Sweden**
Sweden	9 g CO_2e/kWh	1
Upstate New York	106 g CO_2e/kWh	11,78
Denmark	130 g CO_2e/kWh	14,44
Spain	232 g CO_2e/kWh	25,78
California	241 g CO_2e/kWh	26,78
Germany	402 g CO_2e/kWh	44,67
Florida	378 g CO_2e/kWh	42,00
Tennessee	423 g CO_2e/kWh	47,00
Hawaii Oahu	741 g CO_2e/kWh	82,33
Estonia	946 g CO_2e/kWh	105,11

Table 4 Comparison of energy carbon intensity between different EU countries and US regions for the year 2022 highlighting the large gap between ICT software product GHG emissions depending on where hardware is located (European Environment Agency, 2022; United States Environmental Protection Agency (EPA), 2023).

This means that although you might not be able to exactly pinpoint the energy consumed by a given software product running on a cloud platform, you could still imagine the potential proportional reductions of GHG emissions that a change of location could provide. For example, a company in Oahu, Hawaii operating with an on-premise data centre could potentially lower their software-related CO_2e emissions by approximately half a kilogram per kWh consumed by moving their data centre off-shore to California, at the cost of a slight increase in connection latency, or an even further reduction by moving it to the US east coast with slightly higher latency.

These moves to ”green” energy might also make for a good marketing opportunity which adds additional incentive. While a company moving data centres from Denmark to the neighbouring country of Sweden would only see a change of 121 g of CO_2e/kWh, far less than the previous example moving from Hawaii to the US west coast, it would still be a 93 % decrease of GHG emissions regardless of how energy intensive the given software product actually is. The marketing and community goodwill opportunities that sustainable energy sourcing provides might be part of the reason that more and more organisations moving operations to countries with a lower GHG emission intensity in their power mix such as the Nordics. This can be seen in Facebook opening their most energy-efficient data centre to date in the northern Swedish city of Luleå, Apple opening a data centre in Viborg, Denmark and Microsoft & Google opening data centres in Finland (PA Knowledge Limited, 2017).

If the green marketing from green energy is not enough, organisations can make their data centres even greener by repurposing their waste heat, for example by warming up water used for district heating in the proximity of the data centre such as a Bahnhof data centre in Stockholm, Sweden heating 1 050 apartments with their waste heat (Tofani, 2022), or by making them literally green and using waste heat to run a greenhouse, which the Facebook data centre in Luleå, Sweden is doing (SVT Nyheter & Wänkkö, 2021). Locating data centres in the far north also have the added benefit of a significantly cooler climate, which reduces the need for data centre cooling which is where a very large portion of data centre energy consumption is spent, leading to a more competitive PUE for the data centre.

Of course, a country's energy mix is just that - a mix. Within a given country's energy mix, there is a potentially large difference in climate impact depending on how an organisation's energy is produced. In the United States during February 2023, 44,0 % of the energy produced was from sustainable sources (including nuclear), while 55,8 % were from fossil fuels (United States Energy Information Administration, 2023). Since the ECI of 241 g CO_2e/kWh provided for California in table 4 is an aggregate of all energy sources in California, a potential GHG emission reduction could be achieved by organisations without moving data centres by ensuring sustainably sourced energy when entering agreements with energy providers meaning that an international data centre move could remain only a secondary option.

6 Results and Analysis

In this section the thesis findings from both the literature review and analysis as well as the interview series will be put forth. First, the identified ”best” way to measure sustainability of ICT software products and what aspects of ICT software make the biggest impact on GHG emissions will be discussed. Later, the findings from the thematic analysis of interviewee responses. The results will be continuously analysed throughout and as such might not be as objective as the results of a quantitative study could be.

6.1 Assessment Methodology Analysis

In short, the current state of software life cycle assessments is rather unstructured. Plenty of different researchers and software engineers have been attempting to create a reliable, universal way of calculating the environmental impact of a software system but due to the large amount of variables involved in such a system no common ground has seemingly been found. This has the added problem of making life cycle assessments between organisations and software systems non-comparable since a number derived by one method would be very different from the number derived by a different method. It also means that organisations could very easily market any software system as environmentally-friendly by simply removing a lot of the variables, such as end-user devices, from the equation.

Due to the sheer extent of calculations, assumptions and research that are needed to decide upon life cycle assessment methods this thesis will not be attempting, perhaps to the detriment of the subject reviewer, to find a universal ”best” standard on how to make a life cycle assessment for ICT software products or services (which has the added benefit of avoiding the situations posed in figure 4).

6.1.1 Calculating GHG Emissions of Cloud Services

As was shown in the assessment methodology analysis, calculating the climate impact of software products and services is difficult, with results varying greatly in not only

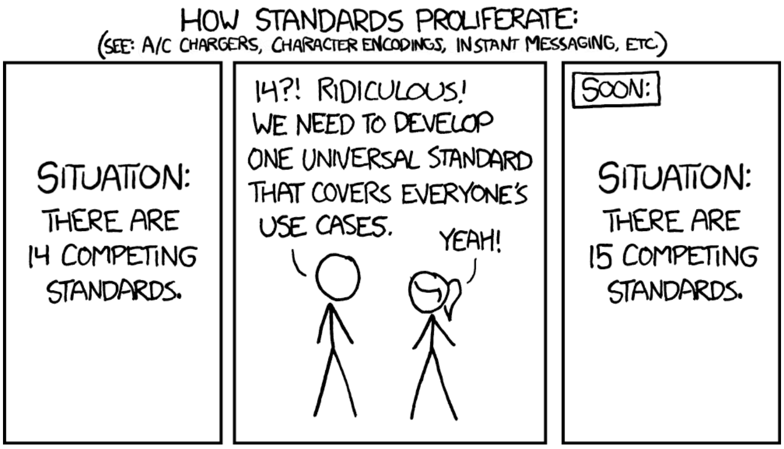

Figure 4 The current state of life cycle assessments and why this thesis will not be attempting to decide which way of calculating GHG emissions for software products is best (CC BY-NC 2.5 www.xkcd.com).

confidence but in comparability due to the varying factors that are taken into consideration. One of the few viable metrics that could be calculated accurately enough to use in comparisons was the power consumption caused by IT equipment usage in data centres. In section 5.4.1, multiplying the data centre power usage effectiveness by the power usage consumption factor and resources was proven to be a useful utility for comparing service providers and GHG emission impacts of software services.

To showcase this and give a concrete result, consider the thesis author's personal website which is hosted by a french server provider in a Paris-based data centre. During the month of July 2023 the website had a single vCPU running to handle requests and a 20 GB SSD to store the website, meaning that for the 31 days of July provider billed for 745 vCPU-hours and 14 880 GB-hours or 14.88 TB-hours. During the same month, the data centre's reported PUE was approximately 1,42, and the energy carbon intensity for France was 39 g CO_2e/kWh (Electricity Maps, 2023; Scaleway, 2023).

Adding all of these together, we can approximate that the author's personal website, during the month of July 2023, consumed 1713,5 Wh of vCPU power and 22,6 Wh of SSD power, for a total of 2465,3 Wh of data centre power consumption, which for France during the month of July would be 96,15 g of CO_2e emitted. Not too much, although it should be mentioned that the website only served 884 kB of data, most of which was to a handful of web crawlers from the USA and Singapore. Now consider a large website which has a lot more data needed to be transferred from the website and perhaps millions of requests over the same time period rather than a handful - the GHG emissions caused suddenly multiplies enormously.

6.2 Interview Results

Out of the eight people actively working in the IT and Service group at the general purchasing department at Scania, five were available to be interviewed during the interview period. In addition, an internal customer from Scania's Server Virtualization and Storage Technologies department was interviewed to get a better understanding of the technical aspect of the procurement demands. There was also a short interview conducted during the pre-study with two procurement managers to get greater insight into the procurement process. This meant that seven interviews in total were conducted, six of which over a period of 14 days between May 10th and May 24th 2023 and one during the early literature review.

While the amount of interviews might seem low, as the interview candidates could be considered experts in the scope of a case study of Scania's procurement process and the population size of procurement managers at Scania was quite low, five interview participants were deemed to be sufficient and the answers provided were nuanced and offered different perspectives.

Interview	**Date**	**Duration**
Pre-study interview	2023-01-31	00:40:00
Procurement manager	2023-05-10	00:41:18
Procurement manager	2023-05-15	00:32:44
Procurement manager	2023-05-16	00:40:06
Procurement manager	2023-05-17	00:19:47
Procurement manager	2023-05-22	00:25:19
Internal customer	2023-05-24	00:20:20

Table 5 The interviews conducted, the date they were conducted, and their duration.

In the result section below, these five procurement managers have been assigned a letter in random order after the interview series was finished, meaning Procurement Manager A was not necessarily interviewed first. The internal customer is referred to by the letters IC. Note that the word customer is from the perspective of the procurement departments, who see themselves fulfilling orders placed by other Scania employees, but they are not customers in a traditional sense.

6.2.1 Scania's Complex Procurement Process

Some of the interview questions regarded the current procurement process at Scania. The procurement process of IT software and services at Scania turned out to be a long and complex one. The process starts with either an employee at Scania sending in a procurement request for new software and a specification of the requirements the software is meant to fulfil, or a contract with an existing piece of software reaching the end of its life. If the cost of the proposed software is lower than a certain amount, the procurement is handled by procurers from the Volkswagen Group in Poland, while larger deals are handled internally at Scania by their own procurement department. The procurement department assigns a procurement manager depending on the field, who then looks at the market to find similar software fulfilling the same requirements and compiling them into a list of suitable programs. The procurement department then analyses these programs and after analysis a few are presented to the requester for input.

In parallel to this, before negotiations start with any supplier, the suppliers must fill out a suitability questionnaire and be approved by the procurement department using a three-tiered rating system as described in section 6.3.2.

Once these suitable alternatives to the requested software are located, negotiations with the software suppliers start, but climate impact is rarely touched on. Instead, the demands put on IT software and service providers are based on a collection of combined agreements which differ based on the type of software or service negotiated (such as hardware, cloud services or software licensing). Scania has a main IT-contract for IT services and a Supplier Code of Conduct that each supplier must agree to and, among other things:

- General Terms & Conditions for IT Purchases

- Specific Terms & Conditions for that particular IT purchase
- Informational Security Requirements
- Agreements on Processing of Personal Data
- Non-Disclosure Agreement

In addition to these agreements, the Volkswagen Group has some legal requirements for software products. Depending on which department at Scania will be using the software additional documents might also be required for the software supplier to sign. Apart from these different agreement appendices, the demands set on IT software also differs depending on which department at Scania is responsible for the procurement. Due to the size of the Scania Group, there are several different procurement managers involved depending on what type of IT software or service is being procured. Office software might be handled by one procurement manager, while software for connected trucks might be handled by a different procurement manager. Due to this, and the nature of the context where the different software will be used, the demands naturally differ.

All in all, a software procurement might take anywhere between a few days up to a year's time depending on the scope of the request and the workload of the department. Because of this, the procurement process is sometimes ignored by employees, meaning any potential sustainability demands could easily be overlooked even if they were in place.

6.3 Identified Themes

From the thematic analysis ten themes were identified during the interviews and throughout the thesis work. Summarised in table 6, the themes presented are points brought up by interview respondents or observed throughout the case study. Table 6 also highlights which respondents raised which themes during their interview. While the respondents might not have used these exact words, the themes are generalised to a degree of capturing the meaning of all listed respondents for each theme. Note also that a respondent not being listed under a theme does not mean the respondent opposes the theme or has no opinion in the matter, it only means it was not brought up during the interview as a consequence of the semi-structured interview method used during the interview sessions.

No.	Theme	Respondent
1.	Scania's procurement process is complicated and with a lot of different actors.	A, B, C, D, E
2.	Nuts and bolts are not bits and bytes.	B, C, E
3.	Sustainability should account for the whole company, not just the finished product.	B, C
4.	Climate impact can not be easily compared to other metrics.	C, D, E, IC
5.	Strict requirements might limit supplier selection.	D
6.	Scania is less open to new suppliers compared to existing ones.	A, C, D
7.	Scania might be willing to pay more for sustainable products.	D, E
8.	Scania prefers purchasing software rather than developing it themselves.	A, C, E, IC
9.	Technical demands are decided by the business unit ordering the software, not the procurement department.	A, B, C, D, IC
10.	Employees sometimes ignore the procurement process due to complexity or waiting times.	A

Table 6 The identified themes and which interviews they were identified in.

6.3.1 Theme 1: Scania's procurement process is complicated and with a lot of different actors

The first theme identified was that the procurement process Scania uses is complex, with a lot of different actors involved and involving a lot of work.

As Scania's complex procurement process has already been explained in detail in section 6.2.1 it will not be repeated here. Worth mentioning for this theme, however, is how every procurement manager interviewed seemed to agree that Scania's procurement process is very extensive. This should not, however, be interpreted as the procurement managers being of the opinion that Scania's procurement process is *too* complex, only that they are all in agreement about the fact.

As explained in theme five and ten, some procurement managers are of the opinion that some aspects of the complex process might be detrimental to the organisation but not to the point of wanting it removed.

6.3.2 Theme 2: Nuts and bolts are not bits and bytes

The second theme identified relates to how a lot of policy-making revolves around Scania's main product - the trucks - and how a lot of policies revolving sustainable supplies of truck parts often inhibit sustainable software choices.

Scania currently has a solid foundation for working with sustainability in their procurement, using what they call a Sustainability Rating to score every supplier on a three step scale. Before any supplier can start working with Scania, regardless of the type of supplier, the supplier must answer an extensive Sustainability Self-Assessment Questionnaire. This questionnaire is developed by Drive Sustainability, a partnership facilitated by CSR Europe between some of the largest actors in the transport sector, including Scania and the Volkswagen Group (Drive Sustainability, 2023). Based on the answers of this survey, Scania categorises the supplier into one of three different categories, *Approved*, *Approved with modification* or *Not Approved*. Should a supplier be categorised as Not Approved, the supplier will not be considered for a contract in a procurement process.

The questionnaire (available online on the DriveSustainability website) is very extensive, asking questions on topics such as human rights, business ethics, social sustainability and climate impact. While this is a good way of getting an overall impression about a potential supplier, and the questionnaire easily can be modified by Scania to add or remove questions as their needs change over time, it is still a questionnaire designed by a consortium of transportation sector companies. As such, a lot of the questions in the questionnaire relates to things such as production sites, production lines and physical resources in use which are often not applicable to software products apart from the equipment required to run it.

This fact was brought up independently by several different candidates during the interviews. In general, there seems to be a moment of irritation among procurement managers that policies regarding sustainability, especially in regards to GHG emissions, are too broad to effectively implement into ICT contexts. One example brought up was how to make factory site requirements designed to be applied to suppliers of vehicle parts fit data centres. ”The sustainability questionnaire doesn’t vary between departments”, Procurement Manager C said, ”meaning we have the same expectations from a supplier of bolts as we do a supplier of software”. Procurement Manager C continued by questioning whether or not this meant that a supplier that gets a passing sustainability rating can be assumed to create sustainable software.

Procurement Manager A also pointed out that GHG emission reductions are often economically incentivised in resource production plants as being more efficient. This usually means wasting less resources and therefore saving more money, but this might not necessarily be true in a digital context as usage patterns of software is often harder to predict. This would mean implementing sustainability measures could be easier to economically justify for physical parts but not so much for digital ones.

The frugality notion also goes hand in hand with the fact that sustainability policies and targets are usually organisation-wide, such as the science-based targets set forth by Scania as described in section 2 where Scania has set a target of a 50 % reduction of carbon dioxide emissions by 2025. While this might be an easier policy to make, it makes it unclear whether or not that means the organisation should strive to reduce their emissions by half at all stages or if they should prioritise the areas that are causing the most emissions. There seems to be disagreements within the organisation on whether or not ICT software products and services are large enough polluters to be considered by an organisation-wide decarbonisation effort, as decarbonisation within ICT usually comes at a higher cost.

6.3.3 Theme 3: Sustainability should account for the whole company, not just the finished product

The third theme identified was that sustainability-mindedness should apply to all parts of an organisation, not only the value chain leading to the finished product.

In line with what was mentioned at the last paragraph of theme 2, concerns were raised by two procurement managers whether or not sustainable choices that were not necessarily affecting the climate impact of a finished truck would be approved by Scania directors. They mentioned that a lot of focus, understandably, is on reducing the climate impact of the trucks themselves as that is Scania's main product, after all. While this is good for marketability purposes the two procurement managers seemed to feel that software procurements that were not directly tied to the product such as salary administration software was not deemed as important as software used in the making of trucks, such as computer-assisted drawing software.

This could possibly be because a life cycle assessment of a truck might not take employee salary administration into account, but it probably would take design software into account meaning there is a marketable opportunity in spending more to reduce truck-related emissions at the expense of office-related emissions.

6.3.4 Theme 4: Climate impact can not be easily compared to other metrics

The fourth theme identified was that sustainability is difficult to compare to other metrics of business taken into account by the procurement managers.

This theme could be summarised by it being difficult to put a price on environmental sustainability. Three procurement managers stated an annoyance over not being able to gauge to what degree sustainability in software should be prioritised when compared to other important procurement metrics - most notably price. The internal customer experienced a lack of room in Scania's budget process to be able to request more efficient, albeit more expensive, hardware in their procurement requests, saying that it often felt like there was a constant battle between climate and cost.

When Scania procures a product, whether it be software or truck parts, its procurement managers try to drive value across five keywords, called TQDCS:

- Technology - using the latest technology and driving innovation
- Quality - striving for high quality throughout their products
- Delivery - ensuring continuity of their business

- Cost - optimising production chains to maintain profitability
- Sustainability - lowering the impact their products have on the world

The goal is to keep these five value drivers in mind when procuring products for the company, aiming to strike a good balance between all five without compromising the others. Procurement Manager C thought that the procurement department generally did a good job at balancing these five values, although they felt that different directors usually emphasised one value over another. This is to be expected of large organisations with multiple actors, but it does highlight that it could be beneficial to set a monetary value on each driver to make trade-offs easier. Is, say, a 2 tonne reduction of CO_2e worth a €10 000 increase in cost? If the organisation was to implement an internal carbon price to help decision making, that answer could be reduced from ”it depends” to ”yes” or ”no”.

6.3.5 Theme 5: Strict requirements might limit supplier selection

The fifth theme identified was that making procurement requirements more strict could have the consequence of reducing the amount of suitable suppliers to compare in the procurement process.

An important step of Scania’s procurement process is the gathering of alternative products matching the internal customer requests, looking at different suppliers and negotiating with them in order to reach the most favourable contracts in regards to price and quality. Due to the sustainability rating system and the at times very complex requests made by internal customers, the amount of suppliers able to match all requirements are sometimes limited.

Procurement Manager D raised concerns during the interview that adding further climate-related criteria to the sustainability rating questionnaire used by Scania to determine whether or not a supplier is suitable could potentially limit the supplier selection even further, to the point where only a few single suppliers might remain. This could mean having to compromise on quality by rejecting a supplier who would otherwise be given an approved sustainability rating but might not be able to meet software climate impact demands, perhaps simply by having a different method of calculation climate impact.

This is not to say that climate impact requirements should not be put in place, but it does highlight that doing so will come at a cost to other areas of the business.

6.3.6 Theme 6: Scania is less open to new suppliers compared to existing ones

The sixth theme identified was that Scania prefers working with their existing suppliers over new ones.

Due to their method of rating suppliers based on sustainability, getting supplied as a supplier means having to fill out the sustainability questionnaire mentioned in section 6.2.1. As this is a large form requiring several documents, and suppliers have to be approved before negotiations can begin, Procurement Manager A said, getting new suppliers approved is quite a long and tedious process which often requires a lot of time. Because of this there might be an unconscious bias towards suppliers that are already approved in the system despite the fact that a contract with a new supplier could prove to be better.

It is worth mentioning that the procurement manager's opinions on this topic were quite varied. While Procurement Manager A, C and D seemed more inclined to work with existing suppliers or at least admitting to the fact that there might be conscious or unconscious bias towards already approved suppliers, the two others saw no issue in taking on new suppliers. The trade-off here would be that a new supplier's product would in a lot of cases have to be markedly more beneficial than the product of an already approved supplier for it to be worth the time and effort to wait for the potential new supplier to be approved. This means that while Scania might not object to taking on a new supplier with a more climate-friendly software product, the product would have to markedly better.

6.3.7 Theme 7: Scania might be willing to pay more for sustainable products

The seventh theme identified was that there is a possibility for Scania to spend more money on more sustainable software products.

Similar to theme four, this theme revolves again around the seemed uncertainty about the perceived organisational value of a sustainable software product. Procurement Manager D and E both shared the impression that Scania would be willing to pay more for a more sustainable software product, i.e. compromise on the cost value driver in favour of the sustainability driver.

This was explained by the procurement managers having some leeway in their own work as the five keywords are more guidelines than requirements. As long as the suggested procurement products are approved by senior management who have final say in all agreements entered by Scania due to firm signing authorisation requirements procurement managers are free to interpret the value drivers as they see fit.

This view was not shared by all, however. The internal customer interviewed instead felt the opposite and found decisions were more often made in favour of cost savings than environmental benefits. ”I've often asked if [sustainability] can cost more”, the internal customer said, ”but never gotten a clear answer”. The internal customer went on to say that they had experienced differences in the purchasing ethos of Scania's Swedish purchasing department and the people working for the Volkswagen Group in Germany, as the internal customer often have to deal with both due to the corporate group structure.

In the internal customer's experience, there are a few suppliers that are really good from a climate standpoint, but purchasing has ranked other suppliers higher for being cheaper, and being cheaper is no surprise, the internal customer reckons, as these suppliers usually have a disregard for reducing their climate impact. In short it seems the organisation as a whole could benefit from clarifying what value sustainability has in the organisation.

6.3.8 Theme 8: Scania prefers purchasing software rather than developing it themselves

The eight theme identified was that if a software product matching internal needs is available on the market, Scania would prefer to purchase the existing software product over developing a similar software product themselves.

This theme is related to the ninth theme, in that technical demands are usually quite hard to set on external suppliers because the amount of variables in play quickly becomes too large leading to compromise and the software products available might not meet requirements anyway. One solution to this is to hire developers and develop software products in-house, which would make it easy to design software according to the technical demands of the company.

In-house development, however, is not too common within Scania. It happens, most procurement managers agreed, but three procurement managers and the internal customer all underlined that while Scania is capable of developing their own systems, Scania is not a software development company at its core. Therefore, in line with Quality keyword of their procurement mindset, in most cases hiring an external supplier to either purchase or commission a new software product is preferred by the organisation, allowing Scania to instead spend employee competence and resources on their core product. Procurement Manager C stated that Scania IT in general had a ”Buy before make”-mentality, saying that spending time making something you could simply purchase is not a part of their strategy.

6.3.9 Theme 9: Technical demands are decided by the business unit ordering the software, not the procurement department

The ninth theme identified was that technical demands were decided not by the people responsible for the actual product or service procurement, but perhaps more reasonably by the business unit placing the internal procurement order. This means that technical demands put on software are more in line with what the actual needs of the Scania employees using the software product or service will be, increasing efficiency of use and reducing workload for the procurement managers of this study.

However, this does also entail the drawback that any sustainability-related requests made by Scania management towards the software product procurement department most likely would conflict with the technical demands set by the internal customer. Pereira et al. (2017) found that the Python programming language might be up to 76 times as energy intensive as the C programming language. From this, one could for example say that using an energy-efficient programming language might be a reasonable technical demand to put on a potential software system, but that does not take into consideration the fact that organisations usually have entire digital eco-systems built around certain technological choices. A senior manager implementing a policy forbidding, say, Python from being a part of procured software products could cause the entire platform to need remodelling, something which was brought up by the internal customer interviewed. ”Programming in machine code is the most efficient, of course”, the internal customer said, ”but it’s far too expensive to develop in”.

Further, it also means that any sustainability-related targets set by management should reasonably not be set on the procurement managers but rather on the internal business units themselves. Should a procurement manager wish to prioritise software using sustainable technology they can ask the business unit requester to prioritise such software but other than this implementing technical demands such as choice of programming language for procurement managers should be made directly towards the requesters to reduce workload on procurement managers having to forward these demands.

6.3.10 Theme 10: Employees sometimes ignore the procurement process due to complexity or waiting times

The tenth and final theme identified was that, due to the complexity of the procurement process, employees sometimes ignore the procurement process, either because of a need for speed, because of a lack of understanding or because they do not bother.

As was briefly mentioned in theme nine, the internal customers at Scania requesting things to be procured usually have very specific demands designed after their at times very niche contexts - new software to design a specific truck part or server hosting for a system they wish to put into production. This adds to the time and complexity of the procurement process and sometimes all the requirements of the requester can not be fulfilled, or potential suitable suppliers matching all the technical requirements have to be turned away over other issues such as not being assigned a passable sustainability rating or not reaching an agreement on cost. In some cases, it is simply a matter of time - a department needing server hosting for a system they need to deploy quickly might not be eager to wait upwards to six months for the procurement process to finish.

This, Procurement Manager A brought up, sometimes led to employees or departments at Scania trying to circumvent the procurement process and instead order software products themselves. This was seemingly not too big of an issue as it was only brought up in the interviews by Procurement Manager A, but when it happened it often led to frustration among the procurement department as circumventing the procurement process meant opening up to potentially hiring suppliers that go against company policy, or spending money on software that could perhaps already be in the process of being procured by a different department.

As the technical demands are decided by the internal customers requesting software, implementing sustainability demands (or any other demand for that matter) on a procurement department level or an executive level could potentially cause more internal customers to try and circumvent the procurement process due to frustrations over not getting the products they need in a timely manner or being asked to consider a competing software product that might not meet all the technical requirements.

7 Discussion

As was described in the literature review chapter, many different methodologies for software life cycle assessments are available, each with their own benefits and drawbacks. These methodologies were summarised by the author as dividing a given software product into four different parts - development, hosting, networking and use - and for each respective part different boundaries and methods were used to calculate the GHG emissions caused by that part. However, there seemed to be a lack of existing knowledge and more importantly agreement in the scientific community as to whether or not any certain methodology is more suitable than another when making life cycle assessments for organisational purposes.

This thesis set out to answer whether or not any one methodology might be more suitable by attempting to identify what the key metrics were in software life cycle assessment methodologies. The study found that from an organisational standpoint and regardless of the methodology chosen, focusing on the *hosting* phase of a software product would provide the most consistently accurate results which was shown to be an important factor for the procurement managers at Scania.

However, one should be cautious to the fact that the hosting phase might not be a significantly large part of the overall GHG emissions caused. Malmodin & Lundén (2018) states that networking traffic might account for up to a quarter of the ICT sector energy usage, and Malmodin (2020) states that the end-user equipment in the use phase might account for approximately half of the ICT related emissions worldwide. This leaves at best a quarter of the total GHG emissions for the hosting and development phase to share, so the hosting phase might account only for less than a quarter of the total sector emissions.

This being said however, the author still believes that the best approach to start with for an organisation interested in making their operations more sustainable is making the hosting phase a priority not only when calculating GHG emissions but also when comparing two software products to each other. While this thesis might not answer the question of which software life cycle assessment methodology is the best or which methodology should be used as a sector-wide standard, it does help provide a basis for what aspects an organisation should look out for and prioritise in a methodology. An academic contribution has thus been made to the field filling in the gap in the existing literature, mainly through the aforementioned comparisons of key metrics filling in the gap of what methodology metrics are most important from an organisational procurement standpoint. The thesis also contributes to the academic field and through providing future researchers and thesis workers with direction as to where their efforts should be aimed.

8 Conclusions

In this section, the conclusions of the thesis will be put forth and takeaway suggestions for Scania and the reader will be presented. Again, it is worth reiterating that the case study studied less than ten employees out of 50 000 and as such the found conclusions might not be applicable outside of the Swedish IT department, but the thesis could still provide solid grounds for making informed business decisions (Scania AB, 2021).

8.1 Research Questions

In this section, an attempt to answer the research questions posed in section 1.2 will be made and the scientific contribution of the study proposed.

8.1.1 RQ1: Calculating ICT Software Product GHG Emissions

The first research question posed was *"How are the greenhouse gas emissions of ICT software products calculated?"*.

This question was primarily answered through the analysis of the information found in section 5. In short, there are many different ways to conduct a life cycle assessment for software products or services, but there is yet to be an agreed upon standard way of performing one due to the high levels of uncertainty involved in many aspects of the life cycle assessment.

In an ICT software product or service, or more generally within any ICT organisation, two flows could be said to exist from a climate impact point of view. The first is a hardware flow from purchasing of new equipment through to the disposal of obsolete hardware, and an energy flow from electricity into waste heat as seen in figure 5 (Sundberg, 2022). These two flows are heavily abstracted but allow for easier categorisation of emissions in a life cycle assessment.

For the hardware flow an organisation will have to look at the greenhouse gas emissions caused by creating the device, usually provided by the hardware manufacturer, as well as the greenhouse gas emissions caused by the disposal of the equipment, usually also provided by the hardware manufacturer provided the hardware is returned to the manufacturer for recycling. For the energy flow an organisation simply has to look at the energy required to run the given piece of hardware, which is usually as simple as measuring real-time energy consumption or looking at the technical specification for the equipment and multiplying each kWh consumed by the energy carbon intensity for the electricity supplied to the organisation. These two flows in combination can then be divided over the estimated life time for the equipment to get a metric for the greenhouse gas emitted by running ICT software products or services.

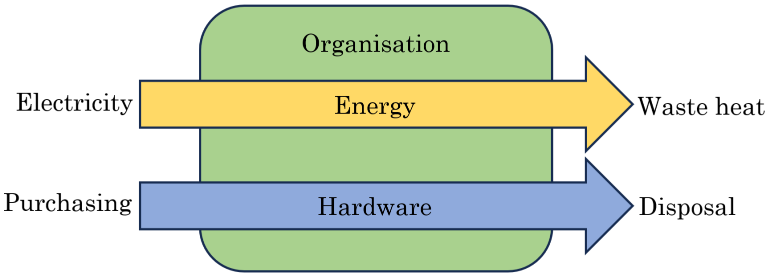

Figure 5 The two flows of an organisation in regards to climate impact (Sundberg, 2022).

A software product or service usually consists of four phases or parts from a sustainability perspective:

1. Development
2. Hosting
3. Networking
4. Use

Each of these phases have both a hardware flow and an energy flow within in, requiring a specific set of hardware to perform correctly and energy required to run said hardware. The level of abstraction as to what should be considered hardware to be taken into consideration when making assessments vary between methods, should for example lighting of the office space during the development be considered to contribute to the emissions caused by a software product? The four phases of a software product and some of the things that might be considered part of the hardware flow are displayed in figure 6.

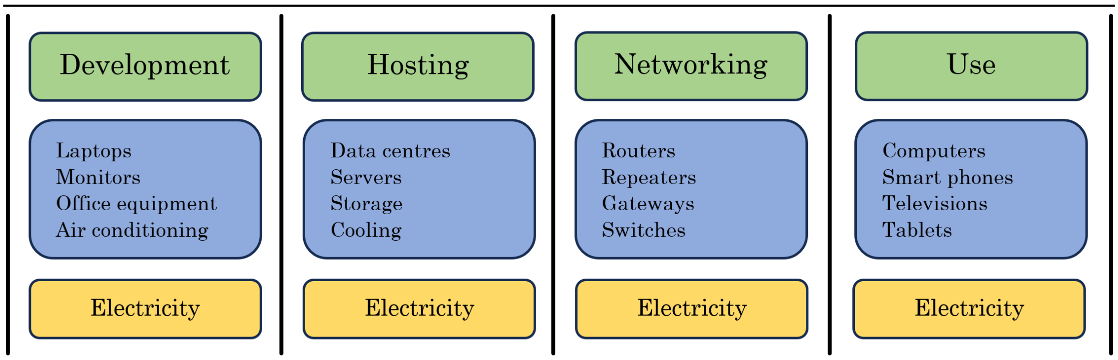

Figure 6 The four phases of a software product or service, examples of the hardware required in each phase and the energy flow.

The current state of life cycle assessing consists of calculating what the energy and hardware flow is for each phase of a software product or service, combining them and ultimately dividing it by some kind of functional unit, such as amount of users for an online service or terabytes downloaded for a file hosting website. Of course, as will be explained in the following section 8.1.2 on the second research question, it is often not that simple.

The thesis result of dividing ICT software product and service emissions into four phases should prove a good addition to the research done on sustainable software products by Kern et. al (2018) and the Greensoft model of Naumann et al. (2011) that struggled with including hardware into software sustainability assessment.

8.1.2 RQ2: Key ICT Software Sustainability Metrics

The second research question posed was *"What are the key software product and service sustainability metrics that large organisations should consider in their procurement processes?"*

As was described in the previous section, there are many sustainability metrics involved in life cycle assessments of software products and services, which can generally be categorised into the four different phases described in figure 6 and further divided into energy-related emissions from power production and resource-related emissions from the production and disposal of hardware.

However, all of these metrics are not equally useful because a lot of them are dependent on external actors not always available to the organisation performing the life cycle assessment. For example, as was shown in table 2 in section 5.3.1, the networking phase of an online software-as-a-service product can involve different networking equipment owned by multiple different companies in different countries, each with their own energy carbon intensity, and as such accurately calculating the greenhouse gas emissions caused by the networking phase of a software product is unfeasible. You can try to generalise the networking phase by measuring the amount of data transferred from your service and multiplying it by a given data energy intensity - such as 0,06 kWh/GB in 2016 (Carbon Trust, 2021) - but this introduces a very large amount of uncertainty.

The same goes for the development phase, where the lines between software releases for modern software products have become blurry over recent years. Microsoft Word Online is the result of decades of development since its first release in the 1980's, but how much of this can be attributed to the current major version in production? Taking the development phase into account might be good when trying to assess the climate impact of software an organisation has developed themselves, but using it as a metric for comparison between two potential suppliers would give an unfair bias towards whichever software has had the shortest development time which usually comes down to how development time is measured.

The use phase, although a very large part of the ICT sector as a whole and causing approximately half of all ICT-related emissions worldwide (Malmodin & Lundén, 2018; Malmodin, 2020) - suffers from a similar problem in that you can not accurately say how emitting the use phase of your software product is, instead having to resort to making assumptions with wild confidence intervals. For a music streaming service such as Spotify an end user could be streaming music on a small smart phone which values energy efficiency due to battery life while another user could be streaming music on a giant smart television connected to an extensive sound system. Both are valid use cases, but the greenhouse gas emission caused by the two users would be hugely different. Furthermore, even if you knew the greenhouse gas emissions caused by a computer streaming music, there is still the issue of attribution. A computer streaming music will have a certain power draw, but a majority of that power consumption is caused by simply running the computer itself, not necessarily the streaming of music. How do you know how many percentages of a computer's greenhouse gas emissions can be attributed to the streaming of music?

Alas, this leaves the hosting phase of a software product as the only phase that can be accurately calculated thanks to both the hardware and energy flow being in the hands of the data centre provider as shown in section 6.1.1. A data centre's greenhouse gas emissions are calculated by looking at the power consumption of the server equipment in it (processing, storage, memory and networking) and multiplying it a power usage effectiveness value to get the total energy required to run the data centre. In reality, memory was found to have a minimal impact on data centre energy use (Etsy, 2020), and networking can not be accurately measured as recently shown, leaving the life cycle assessment to use processor power consumption and storage power consumption. These values can all be acquired from billing if data centres are external, or internally by measuring and provide a good basis for calculating greenhouse gas emissions when combined with the energy carbon intensity for the generation of the electricity used.

In short, the found key metrics for comparing sustainability between software products are then **data processing power consumption**, **data storage consumption**, **power usage effectiveness** for the data centre and **energy carbon intensity** for the consumed power. The last metric, ECI, has the **highest** possible potential impact on the greenhouse gas emissions caused by the software product as a whole, since as the ECI approaches zero from using fossil-free and renewable energy sources, the amount of energy actually used quickly becomes irrelevant.

It should be mentioned that the other phases of a software product, such as end user devices, can still be included in a life cycle assessment as long as the organisation is aware of its effect on the accuracy of the results and ensuring that all software products are assessed using the same method. The aforementioned data centre-related metrics are the suggested key metrics for a *procurement manager* to keep in mind as these are much easier to set requirements for as they are easier to get accurate information about.

The findings for the second research questions helps make the two flows described by Sundberg (2022) more granular and accurate to make them more useful in a software procurement process, an aspect needed to make the findings of both Sundberg and the research team led by Kern (2018) more useful in business settings. The latter of which, Kern et al., also suffers from difficulties in taking hardware into account in software life cycle assessments, something that the four phases of the first research question and the key metrics (which are primarily hardware-related metrics) of the second research questions, something that is considered by the author of the thesis to be a valuable contribution to the pre-existing research in the field.

8.2 Suggested Actions Based on Identified Issues

In this section, suggested actions for Scania will be presented based on the issues identified during the thesis.

8.2.1 Introduce ICT-specific Sustainability Policies

As was described in the interview results in section 6.3, a big issue that procurement managers experienced was frustration over how the policy-making within Scania was often revolving around the finished product. While understandable, a software product is throughout its entire value chain an inherently very different product from a truck, and as such making procurement decisions on software products and services based on a rule set not designed for the ICT sector is inhibiting the procurement process as a whole. As it stands, suppliers can be rejected by the sustainability rating questionnaire for entirely unrelated issues, such as not having a policy set in place for preventing unsustainable harvesting of rare earth resources for production lines, which a software company would probably have no involvement in anyway.

Investing the resources required to differentiate software procurement from physical component procurement would pay dividends, not only from a more efficient procurement process but from increased preparation in front of the pending change in EU legislation on sustainability reporting.

8.2.2 Set a Carbon Value for Procurement Managers

The value that Scania as an organisation places on decarbonisation is not very clear to the procurement managers, as seen in theme four and seven in section 6.3. Most procurement managers agreed that Scania values sustainability and is willing to pay more money to decrease their impact on the environment, but there seemed to be no shared idea on to which degree this was the case. Scania should therefore strive to implement an internal set value on decarbonisation, measured for example in SEK per tonne reduction of CO_2e emitted.

Such a carbon price could be determined based on the current values of EU emissions trading market which has been proven to be an efficient tool in decarbonisation (Abrell et al., 2022) or by the perceived value in regards to the Scania science-based targets or marketing opportunities. It would also allow for procurement managers to quickly compare two products of different decarbonisation value without having to resort to guesswork or waste time on procurement suggestions that would ultimately be rejected by senior executives or budget restrictions. It would also further benefit the organisation as a whole as it would help alleviate the issues brought up by theme three in section 6.3 in that it would anchor the decarbonisation efforts of the ICT procurement department as a part of the company-wide aspiration to decarbonise, rather than feeling they have no part in it.

8.2.3 Decide a LCA Standard to Hold Suppliers to

Blindly relying on the life cycle assessments of potential suppliers means making comparisons between different providers practically useless. Different cloud providers use different ways of measuring their climate impact, and as such the data they present to Scania procurement managers is not entirely reliable. Since Scania is a very large organisation and the agreements the procurement managers reach with suppliers, Scania should have influence enough over suppliers to request any life cycle assessments made to follow a certain methodology or standard.

As such, Scania should invest time in deciding on a solid method for performing life cycle assessments for software products that suit their context, and add to their software product requirements not only a certain emissions threshold but also methods of calculating if said threshold is exceeded or not.

8.2.4 Focus on Setting Requirements for the Phases Scania can Control

When procuring ICT software products, focus should be on the phases of the software product that are able to be in Scania's control. This, in practice, means setting demands both internally and from suppliers on data centre standards in regards to geographical location, choice of electricity production, and power usage effectiveness. The other three phases of software products are still too inaccurate and non-standardised to be a reliable metric in a procurement process.

The ideal choice of data centre is one with a PUE number as close to 1,00 as possible, in a geographical region with an energy carbon intensity as close to 0 as possible and preferably with a cooler climate, such as Sweden which has a country-wide energy mix with an ECI of 9 g CO_2e/kWh. Regardless of geographical location, require your data centre suppliers to use renewable energy sources for their energy flow as this a really simple, albeit slightly more costly, way of potentially zeroing out the greenhouse gas emissions caused by data centre energy flows.

This can even further be improved by building or choosing data centres that attempt to also use waste heat for productive purposes such as district heating or greenhouse heating, which provide many opportunities for marketing Scania's products and services as green in more than one way which might provide a competitive advantage over other manufacturers.

8.2.5 Prioritise Purchasing over Developing

A small suggestion and already in the mind of some of the procurement managers interviewed, but regardless of which method of life cycle assessing is used, it is clear that the higher the functional unit (such as amount of users), the lower the relative climate impact will be. This, combined with the notion that software development is not a core competency of Scania, means that purchasing already developed software if such exist would be better for the environment compared to developing it in-house.

9 Future Work

Naturally, the thesis is limited both in scope and time, and there are some things that the author of this thesis would have liked to do but did not have the time or resources. As with any academic work, any readers of this thesis who find the subject interesting are encouraged to make their own contributions to the research field. Should someone wish to continue the work of this thesis, these are two suggestions from the author for future work:

9.1 Generalisation

The first suggestion is that of generalising the thesis. One potential drawback of the thesis result is that the context is somewhat narrow, with the interview series only interviewing procurement managers for the IT field at the Södertälje office of a global company. Potential future work could therefore be to try and expand the scope of the thesis by attempting to apply the principles found on other aspect of the organisation, in Sweden or globally - or perhaps outside of the company in either the parent Volkswagen Group in Germany or in an entirely different industry that also use ICT software and hardware as part of their operations.

Generalising the thesis results could help prove whether or not the findings are relevant outside of the given context and perhaps to help spread awareness about how other organisations can adapt their procurement processes to become more environmentally sustainable.

9.2 Standardisation

The second suggestion for future work would be to work on comparing different life cycle assessment methodologies to each other. The researcher could then make an attempt to decide which of the different available life cycle methodologies as discussed in this thesis would be most suitable for use in corporate software life cycle assessment.

Trying to compare the different methodologies to each other in order to find which might be more suitable than others proved to be a very time-consuming task, and without access to real data any such attempt would not have a solid enough basis in reality to be reliable. While the author of this thesis does not suggest trying to define a *new* standard methodology for software life cycle assessment (again, refer to figure 4 for the reasoning), looking at the existing methodologies and trying to decide on which are most pragmatically useful for an organisation should be feasible. Combine this with real usage data, more in line with the thesis work of Bryan Lopez Londoño (2023) where a detailed life cycle assessment of a specific Scania software is made, and a valuable contribution to the field could probably be made. For an organisation such as Scania to advertise a thesis position such as this could prove doubly fruitful as they might be large enough of an organisation to affect the industry as discussed in the suggestion for Scania in section 8.2.3.

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A Informed Consent Script

The following text was read to each interview participant at the start of every interview, and this initial part of each audio recording (where they give their consent to participate) was kept by the author of this thesis.

My name is Albin Antti and I am a IT engineering masters student at the department of Information Technology at Uppsala University. For my master thesis, I am investigating what role climate sustainability can play in the IT software procurement process at large organisations. I'm specifically interested in procurement demands, and therefore procurement managers at your department. If my thesis is approved, it will be published by Uppsala University and publicly available online. Scania will also archive a copy of the finished thesis internally accessible to anyone in the organisation.

You do not have to take part in this study, and the consent you give can be withdrawn at any stage of the interview without reason. After the interview, you can contact me within 7 days to retroactively withdraw your consent. If you have any questions, you can ask them before we begin or throughout, or contact me after the fact through Scania's Microsoft Teams platform. If you choose to be a part of this study, here is what will happen:

We will have a conversation, up to about an hour, where I will ask you a range of semi-structured questions about Scania, the IT software procurement process and sustainability and you respond freely in your own words. Some questions ask your opinion on certain matters, and your responses need not necessarily be factual in nature, what matters is what you think.

After the interview session, I will perform a thematic analysis of your responses where I try to interpret your responses in a way that allows for them to be compared to the responses of other interviewees. Although your responses will not be shared in their entirety, I might quote certain responses you give word for word in the final published report.

Your responses will be anonymised to a degree. In the published report, you will only ever be referred to by a handle, such as ”Procurer A”, and the only information about you made available will be that you work as procurement manager at Scania working with, among other things, IT software procurement. Your name or contact information will not be shared with anyone.

However, as there are only a handful procurement managers within IT at Scania, while answers can not be confidently traced back to you I can not guarantee anonymity. This will hopefully not pose an issue as the interview questions do not cover controversial topics, but if you should feel uncomfortable answering a question, let me know and we will skip it.

What you and I say during this session will be audio recorded. This audio recording will be stored on my private computer and will not be shared with anyone, nor will it be accessible by any Scania employees. This audio recording will then be transcribed by me, and the transcription will form the basis for the thematic analysis. This transcription might be shared with my supervisor within Scania, Huifen Cong, or my subject reviewer at Uppsala University, Annika Skoglund, but will not be shared or published with anyone else in its entirety.

Once the transcription has been made, the audio recording will be permanently deleted, apart from this initial section on informed consent.

So to summarise, this session will be audio recorded to be turned into a transcription, which will only ever be shared in its entirety with my supervisor and subject reviewer. Certain responses might, however, be directly quoted or summarised in the final report, in the form of ”Procurer X thought so and so, while Procurer Y disagreed”. Do you have any questions?

Great. Then, for the informed consent: Do you give your permission for me to interview and audio record you? Do you give me permission to quote you directly without identifying you? Finally, are you happy to take part?

Okay, thanks. Let’s start.

B Interview Questions

To better understand the procurement situation at Scania and how sustainability metrics could be inserted into the procurement process, a qualitative interview study was conducted. The interview was semi-structured to allow some leeway in responses while still remaining somewhat similar between interviewees. Through these interviews, the goal was to gain insights into the procurement employees subjective view on the matter and identifying any issues that might interfere with the research goal. The following are the questions asked to the interviewees during the procurement manager interviews as per described in the method chapter of this thesis.

B.1 Introductory questions

Read the informed consent script.

Introduce yourself and ask interviewee to present themselves and explain what work they do.

1. Could you please introduce the work you do?

B.2 Regarding the current procurement process

1. Could you explain how Scania procures IT software today What's the process like?
2. How often does Scania procure a new software product?
3. How often does Scania develop their own software instead of purchasing external software?
4. How often would you say Scania procures a software product that is intended to replace an older software product?
    (a) Why does Scania replace older software products?

5. Would you prefer existing suppliers over new?

B.3 Regarding software criteria

1. When purchasing or developing new software products, what technical critera are taken into consideration?
2. Are these criteria organisation-wide or do they vary between projects or departments?
3. Are these requirements strict or flexible in regard to software meeting them?
4. Where do these criteria come from? Who decides them?

B.4 Regarding sustainability in procurement

1. When procuring software products, how often is environmental sustainability and greenhouse gas emissions taken into account?

   If needed, clarify that the question is in regard to the emissions of the software itself, not necessarily "greening with IT" or similar.
2. Is sustainability driven by suppliers as well, or do you need to push them?
3. Would you say you have a good understanding of Scania's sustainability goals? The whole team?
4. Do you think there would be room for additional criteria regarding sustainability, such as greenhouse gas emissions per user, in Scania's IT software procurement process?
5. If sustainability was to implemented as a part of the procurement process, do you think compromises could be made?
   (a) If so, what criteria would be most likely to compromise on?

C Developer Questions

In addition to the procurement managers interviewed, one interview was also conducted with a developer at Scania who had recently ordered a new software to be procured. This was to get a better understanding of the technical demands involved in the procurement process which according to the procurement managers interviewed were demands set by the internal customer ordering the procured software, not by the procurement department themselves. This interview was less structured compared to the procurement manager interviews, and these were the questions asked.

C.1 Introductory Questions

Read the informed consent script, introduce yourself and ask the interviewee to present themselves.

1. Could you briefly introduce the work that you do?

C.2 Regarding Current Demands

1. Could you briefly explain what different sort of technical demands Scania put on their IT suppliers?
2. Where do these technical demands come from? How and by whom are they decided?
3. How often are they changed?
4. How well are these criteria usually met?
5. What technical demands would you say are the most important?

C.3 Regarding Possibility to Change Demands

1. To what degree would you say demands are usually met?

2. Does Scania usually compromise on these demands?

C.4 Regarding Sustainability in Technical Demands

1. How often would you say sustainability is discussed at your department?

2. Would there be room for additional technical demands in regard to climate sustainability, such as avoiding certain inefficient programming languages or demanding ”right-sizing” or scaling measures?