# Assessing the life cycle environmental impact of Dutch ICT in 2024: baseline and intervention modeling

Industrial Engineering and Management: Sustainable Process Engineering

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# Executive Summary

Digitalization is deeply embedded in the Dutch society and economy. Almost the entire population has daily access to digital services, and organizations rely heavily on the ICT infrastructure to operate. At the same time, the Netherlands plays a central role as a European connectivity hub with the Amsterdam Internet Exchange (AMS-IX) point. Proximity to this point is ideal for datacenters, making The Netherlands one of the prime points in Europe for datacenters. This high level of digital maturity supports significant social and economic benefits, yet it also brings with it substantial environmental pressures. Despite the growing relevance of sustainability in digital policy, meaningful progress remains limited because initiatives are fragmented and stakeholders lack a clear overview and therefore, where interventions would be most effective. An action program published in 2026 by the Dutch ministry of economic affairs and climate highlights three key environmental concerns of ICT; Impact of $CO_2$ and Critical Resource Materials (CRMs) as well as dependence on energy. This study aims to gain insight and bridge this gap by providing a complete environmental baseline for Dutch ICT in 2024 across devices, networks, and datacenters and their major life cycle stages, as well as to provide interventions to mitigate these impacts.

The study applies a life-cycle assessment (LCA) methodology with a hybrid accounting approach, combining a consumption-based perspective for devices and a production-based perspective for networks and datacenters. This approach is selected based on available data given the complexity of granularity in ICT. The system boundary includes three tiers: personal and professional end-user devices (Tier 1), fixed and mobile telecommunication networks (Tier 2), and datacenters (Tier 3). Environmental impacts are assessed across six midpoints: Global Warming Potential, abiotic (resource) depletion of elements, abiotic (resource) depletion of fossil resources, land use, particulate matter formation, and water use, which encapsulate the key concerns addressed in the action program. Table 1 provides an overview of the results of the national ICT footprint baseline across the main midpoint categories assessed in this study.

Table 1: Overview of calculated national impacts of ICT in 2024 and their percentage based uncertainty.

| **Midpoint** | **Impact in 2024** |
|---|---|
| Global Warming Potential (GWP) | 5.507 Mton $CO_2$ eq |
| Particulate matter (PM) | 216.2 disease incidence |
| Land use (LU) | 2.850 billion |
| Water use (WU) | 3.156 billion $m^3$ eq |
| Resource depletion: fossils (ADPf) | 66.77 billion MJ |
| Resource depletion: metals (ADPe) | 136,900 kg Sb eq |

## Baseline

In Table 1, the baseline results shows that the total global warming potential of Dutch ICT in 2024 is approximately 5.50 million tons of $CO_2$ eq, corresponding to about 3.7% of national $CO_2$ emissions, with the divet that no exact comparison to the national $CO_2$ emissions is possible given the hybrid approach selected in this study. The sensitivity testing of these results showed that the most sensitive parameters are the server impacts, database used and the device lifespan, which have the greatest effects on Land use, particulate matter formation and metal resource depletion.

When the results are broken down by tier, the results show that end-user devices and datacenters dominate the overall footprint. Devices contribute 47.1% of total greenhouse gas emissions, datacenters account for 45.4%, and networks contribute 7.5%. Device production is the largest life cycle stage across the majority of the midpoints as shown in Figure 1. Along with device production, other major contributions to the footprint of ICT include the Use phase of datacenters, the Use phase of devices and the Production phase of datacenters. These are identified as the overarching hotspots, indicating that interventions at the device and datacenter level offer the greatest potential for environmental impact. Networks do not contribute as much as the other two tiers in any midpoint. The majority of the impacts from both networks are due to their electricity use, although the fixed network contributes 15% to the metal resource depletion midpoint due to the scale of physical infrastructure.

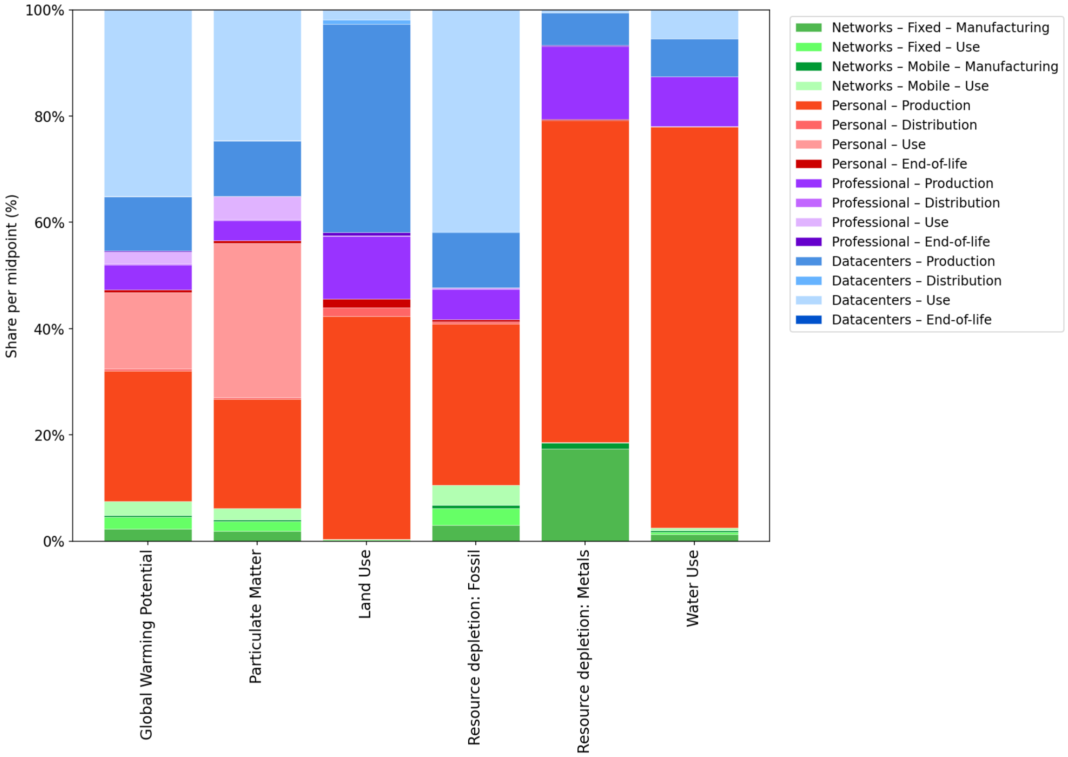


Figure 1: Share of each of life cycle phase of the three tiers (end-user devices, networks and datacenters) for each of the six midpoints relative to 100% of the total values calculated in Table 1.

These four key phases were broken down further into their individual make up. The use and production of devices is fragmented, but shows that the across the midpoints, the biggest impact comes from smart TVs which contribute to 6.5% of the total ICT $CO_2$ footprint. For metal resource depletion, which shares a correlation to the amount of CRMs used in products, the impacts are divided across the devices which have the highest quantities (smartphones, tablets, laptops and TVs). The metals involved in the manufacturing of screens, chips, circuit boards and other components in these devices is approximately 60% of the total metal resource depletion midpoint, as seen in Figure 1. The use phase of devices leans towards larger devices or devices that are continuously on. These are televisions, laptops, desktops and routers.

Looking at datacenters, the results are less fragmented. The majority of production and use phase impacts relate to servers. 37% of total $CO_2$ ICT impacts in The Netherlands are correlated with electricity use. Although many datacenters claim to use green electricity through purchase power agreements, the effective environmental impact follows the actual Dutch grid mix, which remains partially fossil based. The production of these servers also contributes 7.5% to the total global warming potential footprint. Servers with large amounts of storage have the biggest production impact.

## Interventions

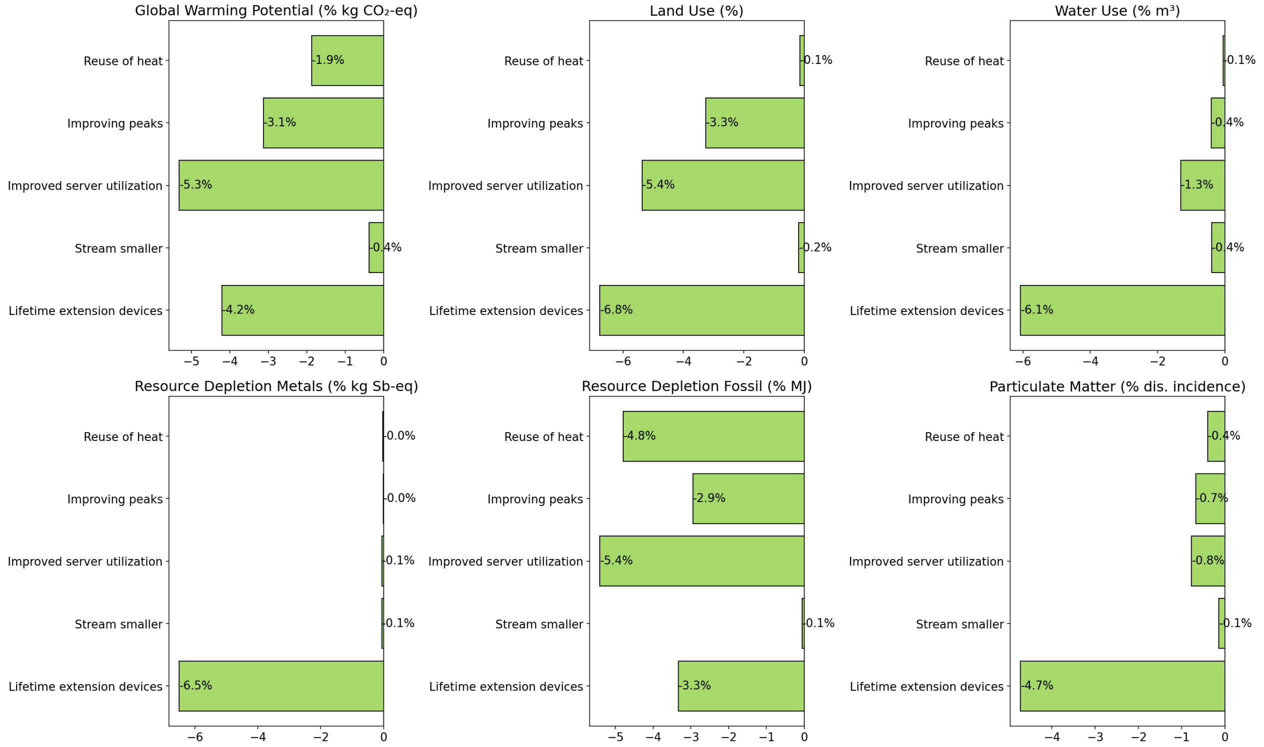


Figure 2: The five modeled interventions in this study compared by their potential improvement to the baseline impacts for each of the six midpoints shown in Table 1.

Building on these insights, the study identifies and models several interventions to mitigate their impacts, shown in Figure 2. These interventions were developed based on the hotspots, but also according to the feasibility of modeling their potential, the relevant challenges the ICT sector faces and solutions expected to cause a reduction.

The summarized results in Figure 2 identifies device lifespan extension as the most impactful intervention across the six midpoints. Increasing the average lifespan of devices by 0.5 years has strong potential for impact across all six midpoints due to the reduced allocated impact from production. The energy efficiency of devices rarely outweighs the embodied emissions from production, meaning that the extension of the useful life of the device is the best environmentally impactful intervention. Streaming using smaller devices has less of an effect on the total footprint and only shows some small improvements to global warming potential. Datacenters can meaningfully cut operational emissions by better optimizing their server utilization, this can be through aligning with traffic patterns produced daily at AMS-IX or focusing on reducing idle time of servers, which reduces both the number of servers required and their associated embodied and operational impacts. Current utilization of servers averages between 15 to 40% based on limited reporting from Dutch datacenters. Improving this value to 75% offers a 5% improvement in the global warming potential, land use and fossil resource depletion midpoints. However, with a growth in the number of AI servers, meeting this target may not be possible for every server. The final intervention modeled is the reuse of waste heat from datacenters, this is an expected solution, which improves the reliance on fossil resources and a 2% improvement to the total global warming potential impact.

Together, these results and interventions highlight potential for improvement in the environmental footprint of Dutch ICT. A potential reduction of 14.9% from the $CO_2$ eq value presented in Table 1 is possible with cumulative effect of the interventions. Furthermore, a potential reduction of 6.5% in CRMs use is found with one intervention focused on lifetime expansion, and fossil resource dependence can also potentially be reduced by 16.5% with interventions. This shows potential to target the three main pillars identified by the sustainable digitalization action program. Furthermore, this baseline establishes the quantitative foundation for long term monitoring and provides direction for reducing the environmental footprint of ICT while supporting continued digital innovation in the Netherlands.

# Contents

# 1 Introduction

Digitalization has become a defining feature of the Dutch economy and society. The Netherlands is among the most digitally advanced countries in Europe, with near universal broadband access and 98.5% household internet connectivity, the consumption of digital services in the country is very high. Not only is the consumption of these digital services high, also the production of digital services is high. This is not related to the Dutch pace of digitization but rather The Netherlands' unique position as a connectivity hub for Europe as a central location, hosting dense clusters of datacenters [1]. This high level of digital maturity creates substantial value for the population and the economy due to the interconnectivity and innovation potential it brings. However, this strong digital position also introduces a less visible environmental challenge. Information and Communication Technology (ICT) is not an impact neutral practice, and its expanding use carries energy, material and resource burdens with it.

Sustainability encompasses the intersection of social, economical and environmental practices, the so-called triple bottom line shown in Figure 3. The triple bottom line shows how sustainability is only achieved by addressing all three domains. ICT is not growing randomly, it plays an important role in society and the economy. While it has grown in an economic and social manner over the last decades, there is a need to ensure that the environmental domain is also adequately addressed to achieve sustainability. The importance of ICT is undeniable in the social and economic domains. An example of each is 98.5% of the Dutch population have access to internet in their homes and the largest Dutch company (ASML) develops the machines which make chips for digital devices [1]. ICT serves a broad purpose, benefiting the Dutch population personally and many professionally. Its usefulness and inevitability make it a challenge to live day to day without it [2].

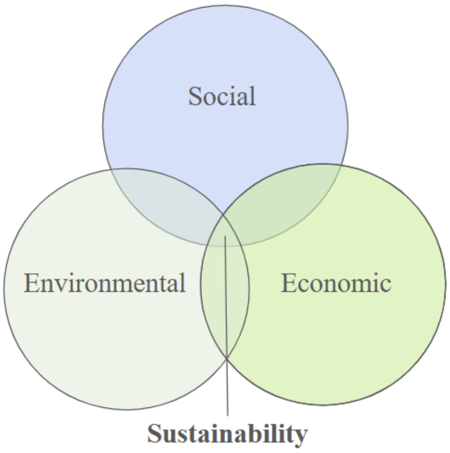


Figure 3: The triple bottom line showing the intersection of sustainability between social, economic and environmental factors.

ICT will continue to grow, and this expansion increases environmental pressures as the sector works to meet rising social and economic demands. To address this, it is necessary to identify where environmental measures within Dutch ICT can have the greatest impact. The Ministry of Economic Affairs and Climate Policy (EZK) currently oversees the country's digital and sustainability affairs. They have major goals for sustainable ICT in the country. This includes a focus towards safety and sovereignty of ICT due to the current dependence on big tech as well as goals in environmental sustainability [3]. The focus of this work is on the environmental impacts of ICT, as the first step of these goals is to establish a clear understanding of current impacts. This understanding is quantitative and presented in section 4, from which targeted interventions could be extracted from where impact could be most effective. This is presented in section 5. The purpose of the intended design of this report is therefore to quantify the environmental footprint of Dutch ICT and to make critical decisions to bring these numbers alive in recommendations and interventions. These insights can then support EZK make informed, strategic decisions about sustainable ICT.

# 2 Problem Context

The goal of this project is to build an environmental baseline of Dutch ICT in 2024. To do so, there needs to be an understanding of what ICT is and what is included. Furthermore, there needs to be clear direction in providing purpose to EZK, by understanding who they are and what they need from such a baseline.

## 2.1 Problem Definition

Digital services is a broad field that encompasses many different things. The formal name for capturing all digital services is Information and Communication Technology (ICT). ICT is defined as “all hardware, software, networks, and services used to store, retrieve, manipulate, transmit, and receive information digitally” [4]. This definition covers a broad number of physical and cyber infrastructures, these will be further scoped to the needed context in subsection 3.3. The impacts of ICT are determined by the environmental footprint of materials and energy needed to support their function. This relates directly to the hardware and indirectly to the software. Hardware can be categorized into three overarching tiers. These are 1. End-user devices, 2. Networks and 3. Datacenters. These relate to the overarching purposed of ICT which are: 1. Consumption, 2. Transportation and 3. Production. Digital resources are used to discuss this collective, which uses energy and materials to operate ICT.

Users engage directly with the social and economic sides of ICT which typically are two different manners, as shown in Figure 4. The connection to the digital economy is a more direct link with the economically beneficial sides of ICT. This includes services only offered through ICT, a direct link of what ICT has to offer to the economy. On the other hand, there is digitalization which refers to the adoption of ICT in practices which do not need it. Both of these domains continue to grow in demand as technological advances continue to be a standard. This growth in digitalization has many positive outcomes with regards to environmental metrics as it can improve efficiency and redundancies. In addition it serves economic benefits too by optimizing processes. The digital economy shares a more direct link to social use of ICT, but every aspect remains interconnected.

The digital economy shares a more direct link with users, where expansion is both on a personal and professional level. According to the CBS, 98.5% of the Dutch population have access to the internet from their homes, and 96.0% of them make use of it daily. 82.1% of the population use the internet to watch videos or films, 95.4% to send text messages, and 94.8% use it to communicate by email [1]. All of this falls under personal use of ICT. Also, for the functioning of organizations and businesses has ICT use expanded. On the professional side of ICT, 84% of the working population use the internet at work, with approximately 65% of these employees using company-owned ICT devices such as laptops or PCs, depending on the size of the company [5]. These numbers are growing, which has consequences not only for the

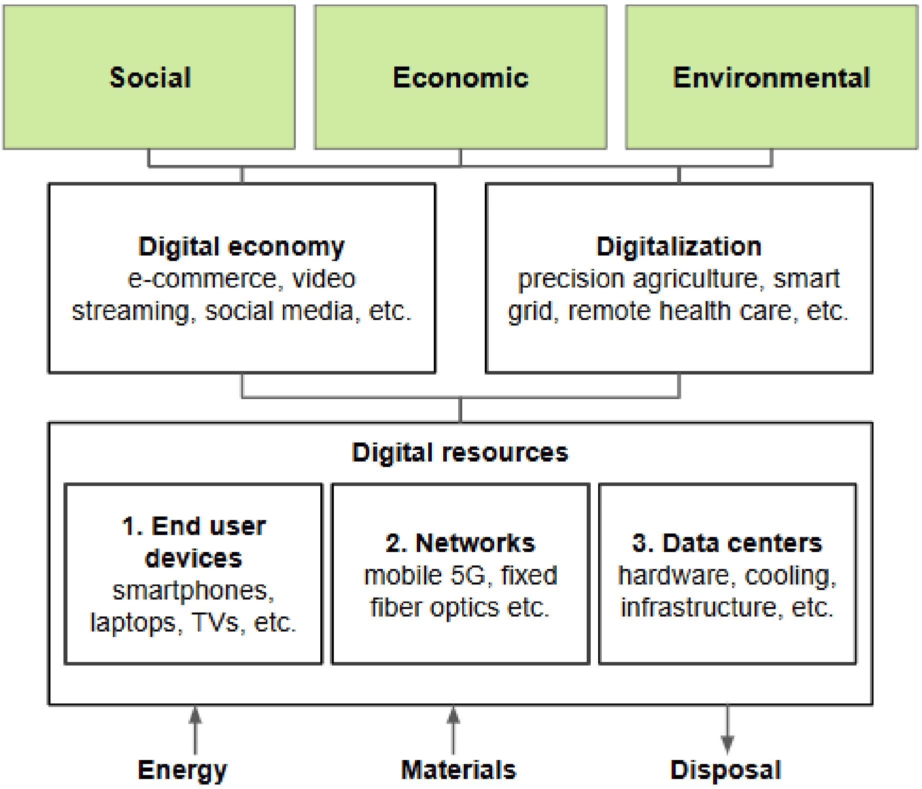


Figure 4: Schematic overview of ICT types, their uses in society and the economy and their emergence from factors which determine the consequences of ICT

number of devices, but also for the networks and datacenters which have to accommodate higher traffic. The amount of data and internet traffic is expected to double in the coming 5 years.

This growth of ICT highlights the cruciality of its sustainability. It also goes hand in hand with the market push from users, which promotes the production of more technologically advanced devices. Technological advancement comes with higher energy needs in production. This increase in devices also results in more data on the networks that require more datacenters, a major user of electricity in The Netherlands. In the datacenter domain alone, electricity consumption has increased by a factor of 4.6 since 2013 to a value of 5.093 TWh in 2024 [7]. This number far surpasses expectations from that period as shown in Figure 5 [6] and illustrates the pace at which digital demand is growing. Although the electricity mix aims to become greener in accordance with The Paris Agreement, the current electric mix on the grid is not projected to reach full carbon neutrality before 2050. The renewability of the current composition still heavily depends on fluctuating factors such as sun and wind, creating large differences in production during summer and winter [8]. Datacenters in The Netherlands currently claim to be 99% operated on green electricity [9]. However, this number only exists through purchasing power agreements with guarantees of origin, meaning that their operation in The Netherlands uses electricity from the grid, regardless of their offsetting elsewhere.

This disconnect creates a form of greenwashing that suggests better environmental perfor-

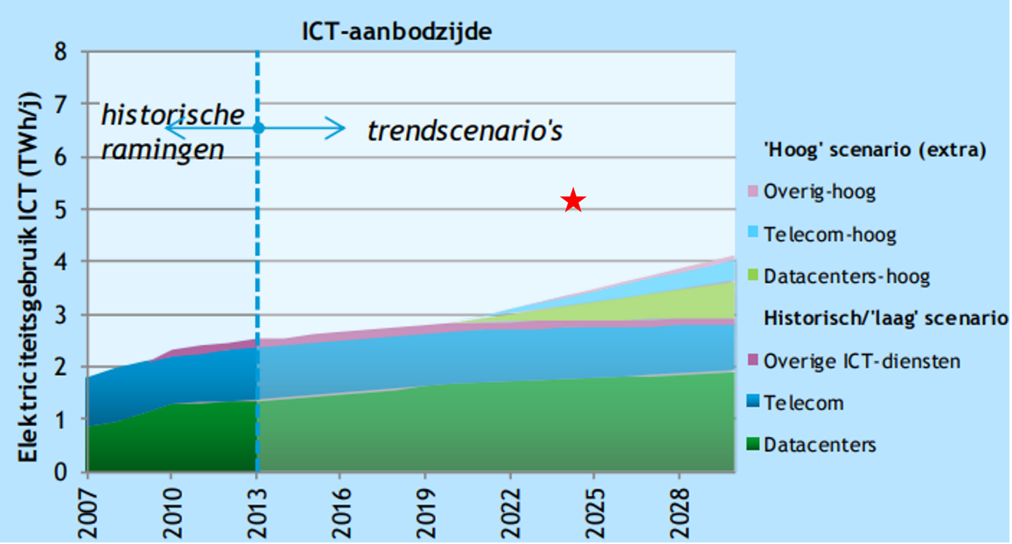


Figure 5: Data from 2013 showing then-current values of electricity usage and the predicted trends over the coming 15 years [6]. The red star indicates the current consumption of electricity by datacenters compared to what was predicted in 2013 which is green in the graph.

mance than is actually the case. The need for this sustainable illusion demonstrates the strides ICT has taken in the social and economic domains and the fall behind the environmental one. In datacenters, their continuous growth is now put on hold, not only from the environmental side, but rather economical challenges. Net congestion, which is especially severe in and around Amsterdam has become a major barrier to further datacenter expansion, a barrier to close proximity to the Amsterdam Internet Exchange (AMS-IX) Point [10]. The Noordzeekanaalgebied, the surrounding region, has already expressed that there will be inadequate power supply for datacenter demand [11].

Yet, electricity consumption is only one dimension of the environmental impact of ICT. The hardware, also makes up a large footprint in production and its waste, as will also be explored and found in section 4 For example, the increasing intricacy of chip manufacturing means that even small pieces in machines have large environmental effects in their manufacturing stage. This is not only due to energy used to achieve intricacy, but also the materials involved in the process. Many of these materials needed in ICT also have their own challenges. A category of rare metals are deemed critical raw materials (CRMs). Not only are rare metals considered to be relevant to this category, but also those that are scarcely extracted within Europe. This dependence on non European sources raises questions of labor conditions and rights of those extracting them, supply security, geopolitical vulnerability, and also comes with doubts concerning environmental responsibility [12]. The increase manufacturing of devices also means more CRMs are needed. Maintaining sovereignty over material flows becomes an additional increasingly important element of sustainable ICT policy.

An overview of the central challenges that ICT currently faces is summarized in Table 2. This table serves as the basis for what the solution needs to address and the interlinking of the triple bottom line within ICT.

Table 2: Triple Bottom Line factors and their intersectional challenges relating to Dutch ICT currently.

| **Social Factors & Challenges** | **Economic Factors & Challenges** | **Environmental Factors & Challenges** |
|---|---|---|
| Extremely high adoption and daily use of ICT by the Dutch population | ICT drives the digital economy and services, growing demand for devices, network capacity, and datacenters. | Overall ICT growth increases electricity demand across datacenters, networks, and devices. |
| Societal expectations for continuous technological advancement in services and capabilities. | Net congestion (especially around AMS-IX) constrains further datacenter expansion. | Grid electricity not yet carbon neutral in The Netherlands and dependent on seasonal factors |
| Labor condition and rights concerns linked to extraction of critical raw materials (CRMs). | Dependence on non-European CRMs creates supply security and geopolitical vulnerabilities. | Hardware production has large impacts in material processing and an overabundance of e-waste. |

The complexity of ICT makes it a challenge to simply map. Each of the factors listed in Table 2 is interconnected with different factors of the triple bottom line. A global study carried out a baseline environmental impact study of ICT in the year 2023, highlighting the urgency of understanding the environmental impacts of ICT and its scale. Their findings were that at the current rate ICT adoption is taking place, the $CO_2$ budget per person compatible with the Paris Agreement is already 40% dedicated solely to ICT. This growth is not maintainable, especially since ICT is still a much smaller impact than travel or food on a personal level [13].

Globally it is a challenge to draw direct similarities from as the Netherlands is a highly advanced digital society. France and Switzerland also published this same style of study in 2024 and 2025 respectively, scoping the level down to national factors. Rather than looking at a total $CO_2$ budget with these results, the split within ICT can better be analyzed. These studies find largely varying results in the split of impact from datacenters and devices, shown in Figure 6. Both find only a small amount of impact is allocated to the national networks, but find a major difference in how much impact the datacenters have. France's footprint is half allocated to datacenters, whereas in Switzerland this is only 20% of the footprint of ICT. This variety in results highlights this need for understanding of national circumstances such as electricity system constraints, the sustainability of the electricity mix, datacenter clustering and the density of digital infrastructure. Or, to ensure that each of the factors discussed in Table 2 are addressed.

A clear discrepancy exists between the desired situation for sustainable digitalization in the Netherlands and the current reality. Ideally, national policymakers would have access to a complete, transparent, and methodologically consistent overview of the environmental footprint of ICT, one that includes all relevant life cycle stages, captures both upstream and domestic impacts, and provides the granularity needed to identify actionable hotspots. This would allow the EZK and related stakeholders to guide interventions, track progress, and

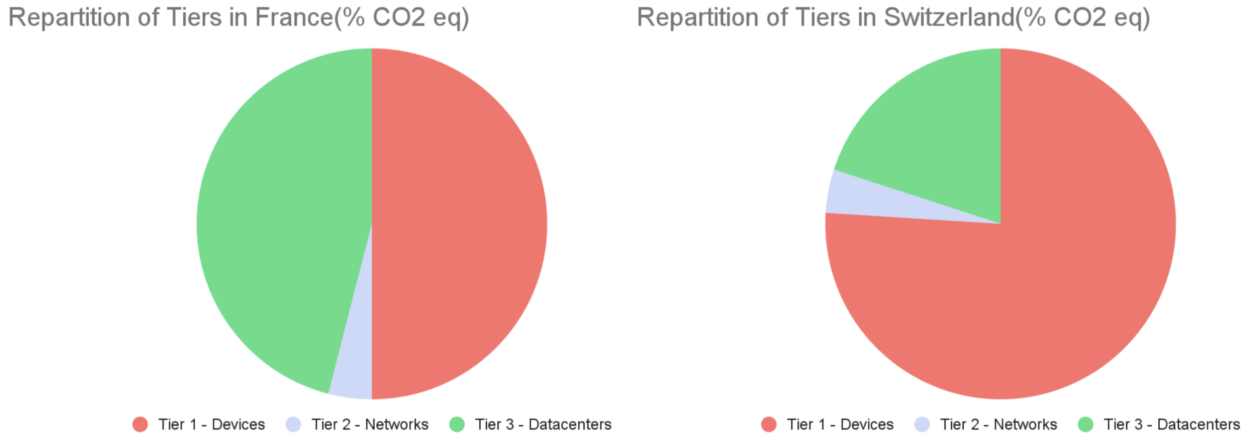


Figure 6: Baseline study results of the global warming potential (% $CO_2$ eq) of ICT in Swiss (2024) and French (2022) studies with the same goal and scope.

align national digital policy with climate and resource efficiency objectives. In contrast, the actual situation is characterized by fragmented data, incomplete reporting (particularly for datacenters and hardware manufacturing), and a dominant focus on operational electricity use rather than comprehensive life cycle impacts. Existing studies either omit large portions of scope 3 emissions, rely on partial datasets, or focus on narrow subsectors of ICT, leaving policymakers without a coherent baseline from which to act. This gap between what is needed and what is currently available motivates the development of a full national environmental baseline for ICT, providing an evidence based foundation for targeted and effective sustainable digitalization policies.

## 2.2 Problem Analysis

The Netherlands places high importance on both the environment and digital infrastructure. Understanding the footprint attached to ICT is essential for anticipating the consequences of current ICT demand as well as its continued digital growth. As the Netherlands continues to strengthen its digital capabilities with regards to cyber safety and sovereignty, it also plans to do so with respect to environmental aspects. However, creating impact through action is only possible with understanding where in the broad ICT category environmental pressures exist and what their magnitude is. Only after identifying these hotspots and directing actions in these places can impact be delivered. To identify these hotspots, a baseline is needed for the entire Dutch ICT landscape, as is presented in section 4.

The development of an environmental baseline for Dutch ICT does not emerge in isolation. On top of the studies done globally, in Switzerland and in France, in recent years, the Ministerie van Economische Zaken en Klimaat (EZK) has become involved in national action on the topic of sustainable digitalization. EZK developed a Sustainable Digitalization Action Plan (Duurzame Digitalisering Actieprogramma) [3]. This sets forwards their goals of the Netherlands being a pioneer in digital maturity and sustainable digitalization. They identified strategies that looked at public action and the importance of device lifespan, but also for datacenters working on reusing heat.

As a result of wanting to further their knowledge, in 2023 the EZK requested numerous studies to further understand the context of Dutch ICT, with regard to social, economic and environmental impact. This resulted in the studies: De digitale voetafdruk (2023) [14] and Het belang van digitale infrastructuur voor de Nederlandse digitale knooppuntrol (2024) [2].

These publications translate to The Digital Footprint and The Importance of Digital Infrastructure for the Dutch Digital Hub. The first, which by title has an objective identical to the outcome proposed in this study, has a different scope and methodological approach, leaving out relevant aspects of ICT. The study focuses on scope 1 and 2 emissions according to the GHG protocols. This addresses the electricity factors addressed in Table 2, but not concerns about the materials used in ICT, nor the impact upstream of ICT hidden in scope 3. It splits ICT into devices, networks and datacenters and finds high use of electricity from both devices and datacenters compared to networks [14]. The following publication focused on the importance of The Netherlands being a digital hub. Looking at the quality of the digital infrastructure and its interconnectedness, they conclude that this position provides the country a "(very) high value for the economy", demonstrating the importance of the digital infrastructure at the national level and strengthening the context needed for an environmental study to meet sustainable ICT goals [2].

Subsequently, the EZK requested research on where “data over duurzaame digitalisering” (data on sustainable digitalization) [15] could be found in late 2024. This research, published in 2025 was carried out by Dialogic and SEO, research institutes closely linked to the Dutch government. This study was conducted to identify public sources of information which could be used for a Sustainable ICT monitor at the national level, highlighting the importance of quantifying ICT and the idea of a national environmental baseline. It also serves as a useful starting point for developing said baseline. The national level monitoring promises a continuous look at sustainable ICT, but it needs a grounded point to have as a comparison. Conducting a thorough study of Dutch ICT of one year, beyond only publicly available numbers creates a baseline on which the monitoring system can be based..

This current research aims to address the gap in ICT environmental studies in The Netherlands by building a multi criteria environmental baseline that integrates detailed inventory data and life-cycle stages, forming a more holistic assessment of the Dutch ICT footprint. This will be done over the duration of a year to capture the dynamics of ICT and to give the functional unit enough grip of the importance ICT has in a year. This increased granularity is essential within the context of the Dutch Sustainable Digitalization Action Plan published by the EZK [3]. The methodology for doing so will be explored in section 3. The research will identify the key problems holding back the environmental performance of ICT by having a baseline picture to assess where hotspots are in section 4. Solutions for addressing these hotspots and their uncertainty will be assessed using the baseline and prospective factors in section 5. It also supports the intention to develop a national monitoring dashboard capable of tracking the environmental performance of ICT infrastructures and services for longevity of data in this domain.

The diversity and scale of the ICT system mean that reliable modeling can only be achieved through collaboration with actors holding operational, statistical, and technical knowledge. For this reason, TNO has taken on the role of developing this baseline, but not by themselves. The existence of a Dutch coalition of sustainable digitalization (Nationale Coalitie Duurzame Digitalisering, NCDD) poses as the perfect place for collaboration with stakeholders who are already committed to developing the field of green ICT. This collaborative structure enables better data, producing more accurate results.

Following the current state of the art literature on this subject and the key problems addressed in Table 2, the central problem can therefore be summarized as follows:

*The environmental impact of ICT needs to be addressed in working towards sustainable ICT. However, the environmental footprint of ICT in the Netherlands is currently not fully visualized; by developing an environmental baseline assessment of ICT over the duration of a year in The Netherlands, the key hotspots can be identified where interventions can be directed towards. By addressing this gap, the project will develop a design valuable for policymakers, organizations, and citizens, enabling them to make informed decisions about digital sufficiency and resource efficiency.*

## 2.3 Research Questions

To be able to work towards the intended results, a set of research questions have been created. The central research question to be answered in this project is:

What are the environmental impacts of Information and Communication Technology (ICT) over its different life cycle stages in 2024 in The Netherlands and where are the most significant hotspots located to enable targeted interventions?

With the following supporting sub questions:

1. What interventions hold the most potential for environmental impact in The Netherlands?
2. What split can be derived between personal and professional use of ICT and how can interventions be developed to reflect the results of this split?
3. What prospective factors are relevant to consider and in what way can these be modeled with their uncertainty?
4. Are the selected interventions robust for the future of ICT?

## 2.4 Operationalization

To bridge this knowledge gap and operationalize the research questions, Table 2 is the starting point of identifying which metrics are needed, given the current state of challenges in ICT. These key metrics concern the $CO_2$ impacts of ICT, the CRMs used by ICT and the energy use of ICT in The Netherlands. In order to gather this information, an LCA will be discussed as the key methodology of this study in the following section. The sequence of tasks to operationalize this study is as follows:

1. Data Collection for the Life Cycle Inventory
2. Model the baseline through LCA
3. Validate results with comparison and sensitivity analysis
4. Design impactful interventions for the identified hotspots
5. Test the robustness of the interventions given uncertainties

# 3 Methodology

The methodology used for this study is a Life Cycle Assessment (LCA). An LCA is the most appropriate methodological choice for this study because it provides a complete, system wide view of environmental impacts that cannot be captured through alternative methods such as Material Flow Analysis, Environmentally Extended Input–Output analysis, or carbon footprinting alone. Following the action program of the EZK, priority lies in monitoring the carbon footprint, CRMs and the energy use of ICT. Of the various environmental modeling methods that exist, LCA offers the most complete methodology. As a result, it is the only methodology capable of accurately identifying hotspots across tiers, and providing a scientifically robust foundation for targeted intervention design and long term national monitoring.

## 3.1 General principles of LCA

### 3.1.1 Definitions

Different methods exist to assess environmental impacts, one of which being a Life Cycle Assessment (LCA). LCA is a comprehensive methodology used to evaluate the environmental impacts of a product or service throughout its entire lifespan. Its main characteristics include:

- **Multi-criteria assessment:** LCA considers multiple environmental indicators including global warming potential, depletion of abiotic resources, and pollution of water, air, and soil, etc.
- **Life-cycle perspective:** All stages of a system's life are taken into account. These are raw material extraction, manufacturing, distribution, use, and end-of-life, which ensures a holistic view of environmental impacts.
- **Quantitative evaluation:** Each indicator is measured quantitatively, allowing external impacts to be compared on a shared basis and supporting objective decision making.
- **Functional approach:** The study focuses on the function that a product or service delivers. To enable a comparison between technical solutions, the functional unit is a reference unit that determines the quantities of input and output flows.

### 3.1.2 Standards

Life Cycle Assessment is governed by two primary international standards: ISO 14040 and ISO 14044. ISO 14040 establishes the overarching principles and framework, defining the goal, scope, and general structure of the study, to ensure consistency. Complementing this, ISO 14044 provides the technical requirements and guidelines for data collection, allocation procedures, and impact assessment. These ISO standards form the basis for credibility, the study will further integrate frameworks such as the Product Environmental Footprint (PEF). Developed by the European Commission's Joint Research Center, this framework offers additional precision and comparability [16].

Figure 7: Life cycle phases and their inter connectivity.

## 3.2 Phases of LCA

LCA is a method used to evaluate the environmental impacts of a product, process, or activity throughout its entire life cycle, including all stages of the life cycle: from the extraction of raw materials through manufacturing, distribution, use, and end-of-life as shown in Figure 7. LCA aims to provide a comprehensive understanding of the environmental impacts associated with a product or activity so that informed decisions can be made to mitigate these impacts

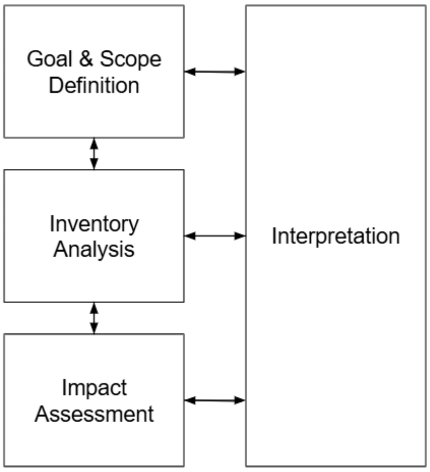


Figure 8: The four phases of LCA and their interconnectivity to each other and specifically the interpretation phase.

The methodological stages of the LCA encompass four steps. A life cycle analysis looks to examine the entire life cycle of a particular product with regards to its manufacturing, use and other involved processes. These processes then entail their own environmental impacts. The first stage of the LCA is defining the goal and scope. This defines the assessment purpose and determines the study boundaries and assumptions. This includes defining a functional unit that sets the standard for the quantitative analysis of each life stage. It sets the goals and identifies which environmental indicators will be assessed. The second step of the the Life Cycle Inventory (LCI), data is collected on all inputs (e.g., materials, energy) and outputs (e.g., emissions, waste) associated with each stage of the product life cycle. This is divided into data collection for the foreground and background systems. The former refers to activities and products directly under the study's scope, where detailed and representative data is needed. The latter includes supporting activities upstream and downstream of the foreground, where generic data from databases is typically used. The third stage of the LCA is the Impact Assessment (LCIA), this entails evaluating the environmental impacts associated with the inventory data collected in the previous step. LCIA can characterize impacts such as global warming potential, acidification, eutrophication, or resource depletion. The selection of these midpoints depend on defined goal and scope of the LCA. Finally, the interpretation step is the fourth step of the LCA. Here, the results of the assessment are interpreted and communicated to stakeholders. This step involves analyzing and visualizing results that lead to recommendations.

## 3.3 Goal and scope

### 3.3.1 Goal definition

The selected methodology and scope of the study place the focus on environmental sustainability. The goal of the study is to assess the environmental impacts of ICT in The Netherlands over one year (2024) to locate where intervention action is needed.

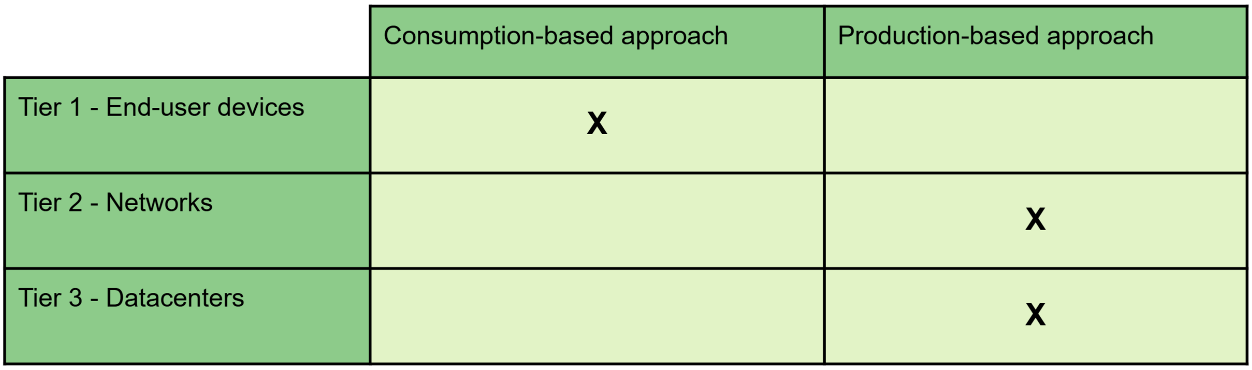
### 3.3.2 Scope of the system

The scope of the study is defined as the entirety of digital equipment and infrastructures in use in The Netherlands, for personal or professional use. This covers the three different categories of equipment defined earlier, device, networks and datacenters. These are classified as tiers, defined by the following:

1. **Tier I - End-user equipment:** This category groups all ICT equipment which the population uses. This groups together mobile devices with a battery as well as plugged in devices such as monitors, desktops or televisions and IoT, other equipment which falls under ICT categorization. These are in the LCI, presented in subsection 3.4. This data is divided into devices used for personal use owned by the user and into devices used for professional used, owned by a company or organization lent to a used.
2. **Tier II - Telecommunication Networks:** This category groups equipment that transmits data between the users and the datacenters. This includes the fixed and mobile network, which share a backbone network.
3. **Tier III - Datacenters:** This category groups equipment used in data centers. This includes the dedicated servers which process, transmit and store data, as well as the surrounding site infrastructure needed for their function such as cooling and backup energy sources.

Due to a lack of specific data for professional data about networks and datacenters, these tiers did not get split into personal and professional categorization.

Furthermore, since datacenters and networks can also cross international borders for their use and infrastructure, it is also important to define that they are only being considered within the geographical boundaries of the Netherlands, therefore taking a production approach for what is produced in the Netherlands rather than what is consumed for datacenters. This creates two different approaches which can be considered. The first of which is a **consumption-based approach**, defined in literature as an approach which **attributes impacts to the final consumers of goods and services**, regardless of where those impacts occurred globally [17; 18]. Second is the **production-based approach**, also referred to as a territorial approach, which **measures environmental impacts that occur physically within a specific geographical boundary**, such as a city, region, or country [17]. In Figure 9 the use of the two approaches is shown for this study.



| | Consumption-based approach | Production-based approach |
|---|---|---|
| Tier 1 - End-user devices | X | |
| Tier 2 - Networks | | X |
| Tier 3 - Datacenters | | X |

Figure 9: Hybrid approach method taken in this study whereby a combination of the consumption and production-based approaches is taken for accomplishing the goal of the study.

This study applies a **hybrid accounting perspective** to achieve the goal. For end-user devices, a consumption-based approach is used, because these impacts are most directly linked to Dutch ownership and use. For networks and datacenters, a production-based approach is used, because the associated impacts are challenging to reliably allocate to Dutch consumption due to cross border data flows, hosting, and storage. Adopting a production-based approach for networks and datacenters therefore provides a more feasible and transparent basis given the available data. This means that different parts of the ICT system are allocated using different logics, which becomes relevant when comparing results across tiers in section 4.

### 3.3.3 Functional unit

The functional unit needs to capture a very broad scope and the hybrid approach across tiers. It describes the function of the system, basing the LCA on an action or service. The 'function' which ICT has is provision. This is the provision needed to facilitate the social and economical Dutch ICT demand. The functional unit is defined formally as:

*"The provision of ICT hardware and software services including all equipment and infrastructure related to digital technologies in The Netherlands during a year"*

With this functional unit, both the use and the physical infrastructure are equally important as ICT cannot provide without one. The hybrid approach is also taken into account by specifying the function to the Netherlands.

### 3.3.4 Life Cycle Stages

The following life cycle stages were each considered in this study:

1. Manufacturing stage: Comprises of raw material extraction and upstream transportation, as well as manufacturing/production processes involved in creating the ICT equipment (i.e. chip manufacturing).
2. Distribution stage: Includes any transportation involved between the manufacturing location and the use site.
3. Use stage: Includes the electricity and any other resources that were consumed by the ICT during its operation.
4. End-of-life stage: Covers the disposal processes of ICT equipment such as sorting, recycling or disposal when thrown away.

These stages align with the ISO norm standards previously described, as it covers the entire lifespan and its consequential impacts of a digital product and its services.

### 3.3.5 Data Acquisition

There are two key distinctions in the data used in this project. Data consisting of the equipment related to ICT and data concerning the life cycle environmental impacts of this ICT. This distinction exists due to the scale of the functional unit. **No complete LCI can be built** which dissects all of the flows ICT in The Netherlands has from the technosphere and biosphere.

By collecting Dutch data about specific equipment and combining this with environmental data about each specific piece of equipment, the results can capture the total Dutch ICT landscape. In Figure 10, the different databases and software used to put together the results are shown. This includes Resilio and CODDE as the key providers of ICT environmental data. These sources are combined with data directly from Ecoinvent such as the Dutch electricity mix and any other equipment which Ecoinvent has but Resilio and CODDE do not. This environmental data is all then multiplied by the quantities found in the system boundary dataset, which concerns the quantities of servers and smartphones for example. Additional information is also collected concerning the electricity use and lifespan of each equipment considered.

This comes with the challenge that not a full LCI is visible through the use of intermediary databases which do not share the full inventory list. In looking to test potential interventions, this has the drawback that in the background of the LCA no changes can be made. For example, the electricity used in the manufacturing stage cannot be made renewable. In addition, it also creates dependence on these databases for which ICT equipment can be included in the study.

Collecting the Dutch data needed for the Life Cycle Inventory was approached according to the three defined tiers. The first tier data is primarily based on data collected by the Statistics

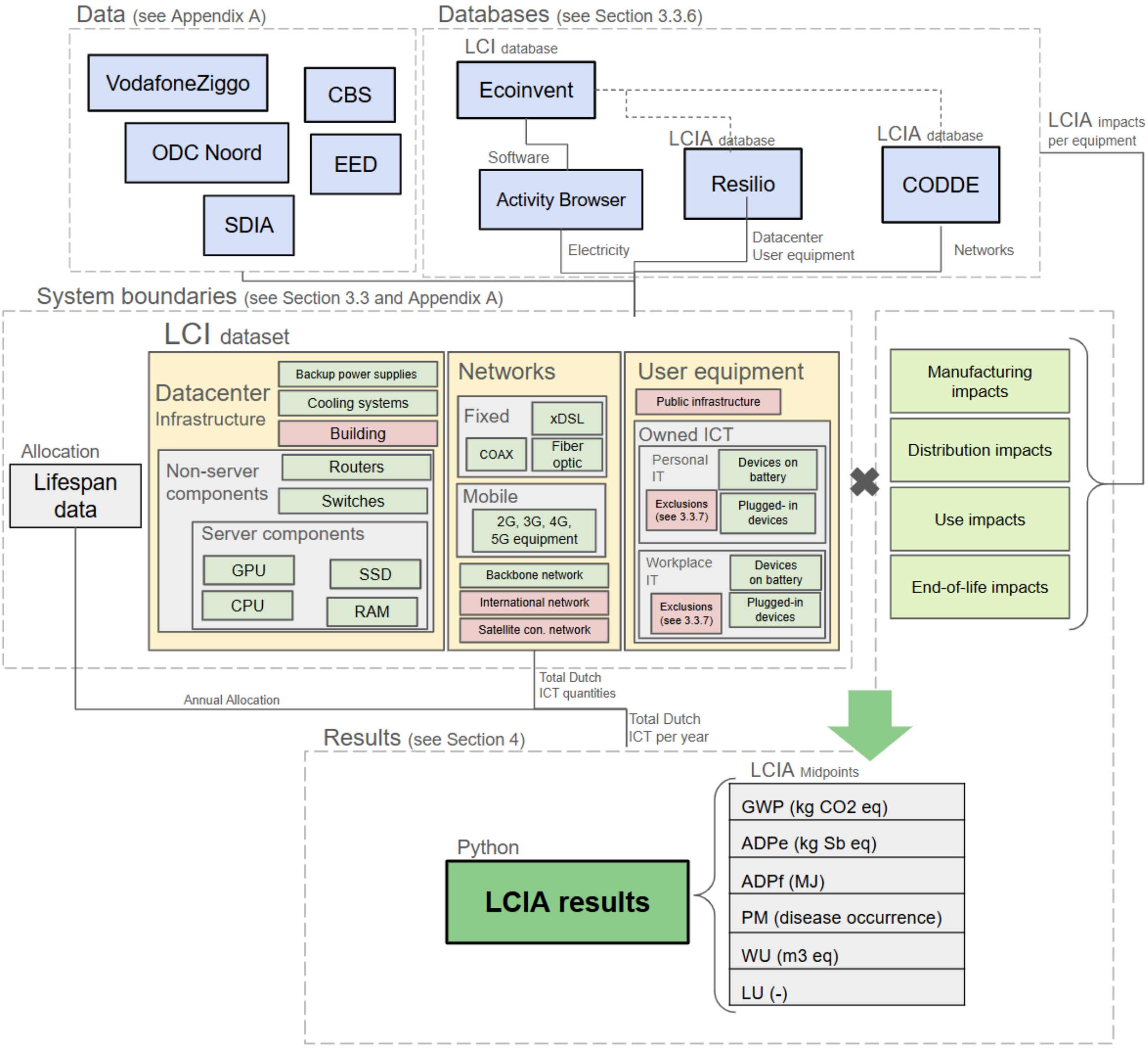


Figure 10: The methodology of this study summarized into the stages (Life Cycle Inventory (LCI), Life Cycle Impact Analysis (LCIA)) of LCA, and the datasets and databases used.

Netherlands (CBS) given the dependence on population, household and business statistics. The second tier is dependent on the three network operators in The Netherlands who operate over 95% of the fixed and mobile network. Statistics about network use and connectivity are reported by the ACM in quarterly year reports, and each of the three operators publish an annual report. For the third tier, the Dutch Datacenter Association (DDA) published a state of the Dutch datacenters report for 2024 which contains relevant quantification of the types of datacenter and their power allocation in The Netherlands. In addition, starting in 2024, the RVO began requesting energy-related data from datacenters for the European Energy Efficiency Directive (EED). This was not always delivered however, due to the possibility for companies to declare it as confidential information. Further explanation of the data acquisition is provided in subsection 8.1.

### 3.3.6 Databases Used

The LCI and LCIA data are not ideally interconnected in this project by coming together in one large inventory. In order to find supporting LCIA data to match with the LCI three different databases were used.

1. ResilioDatabase
2. CODDE
3. Ecoinvent

Resilio was used as the key database for LCIA data. They provide a comprehensive environmental database specifically tailored for the ICT sector for both digital equipment and services. This is dataset that prioritizes standardization, ensuring that there is a fair method used across the different device types. Their database offers data across the three categories, with the best and most variety being offered in the device category.

For the network LCIA data, CODDE was used. This database is derived from the original Négaoctet database. The Négaoctet database has been subject to an external critical review by an independent third party. The NégaOctet database complies with international standards ISO 14040/44, according to the EF 3.0 format and nomenclature.

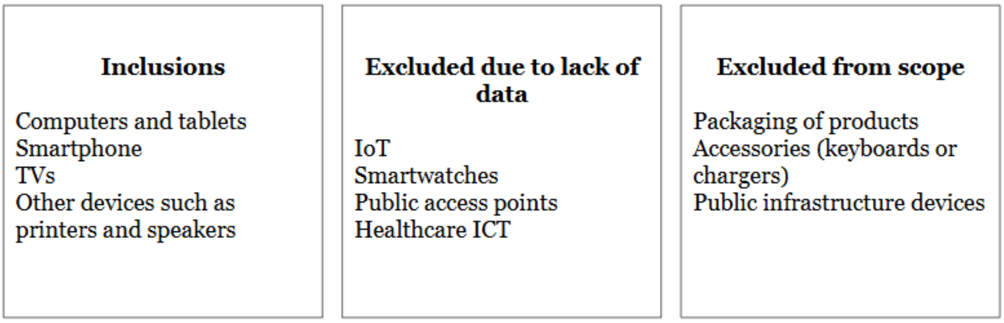
This database contains data about network equipment, with exception of COAX (coaxial cable) equipment as mentioned in subsubsection 3.3.7. In addition, it also offers data about datacenters and their particular elements, which was used to compare data to the data Resilio offers. The CODDE database offers a complete construction of the fixed and mobile networks based on the number of set subscriptions and the annual data transferred accordingly. Then, the electricity used for this phase still can be manually added. Both of these networks are constructed from European data which is allocated per average user. Given this broad approach which is not relevant to the Dutch context, it was not used in this study. Instead, both of the networks were built manually using the collected LCI data. This manual iteration was compared to the built European function CODDE offers, whereby when manually adding the amount of electricity, these numbers differ by a factor of 0.7%.

The third key source of data was directly from Ecoinvent. The electricity mix specific to The Netherlands was used from here along with printers and speakers for tier 1 data, as well as cooling and generators for tier 3 data because these could not be found in the Resilio database.

### 3.3.7 Exclusions

While the overarching aim of this study is to capture the environmental impacts of all digital products used within The Netherlands, several categories of data were excluded due to methodological, practical, or data availability constraints. Before exclusions can take place, it is first also important to define what is included in the study, to give significance to exclusions. Inclusion in the study is Information and Communication Technology across the three tiers defined in subsection 3.3. The types of ICT included are specifically those whose function is central to ICT, meaning it cannot exist without its ICT side, following the definition of the ITU [19]. An example of this study is the exclusion of healthcare ICT, which exists without its ICT side. Exclusions were therefore based on two criteria. The first is whether it was intended to be included but could not be due to a lack of data, and the second is exclusions as they did not fit into the scope.

A central exclusion concerns public infrastructure, specifically systems such as public transport screens, security infrastructures, and water management installations. All categories which can be categorized as essential ICT to Dutch society from a governmental perspective. Although these systems rely on substantial ICT, any hotspots that come from this level pose for interventions that will not be considered worthwhile due to the benefits ICT offers for the Dutch people. As a result, public infrastructure was omitted with the understanding that its inclusion would not contribute meaningfully to actionable interventions.



**Inclusions**

Computers and tablets
Smartphone
TVs
Other devices such as printers and speakers

**Excluded due to lack of data**

IoT
Smartwatches
Public access points
Healthcare ICT

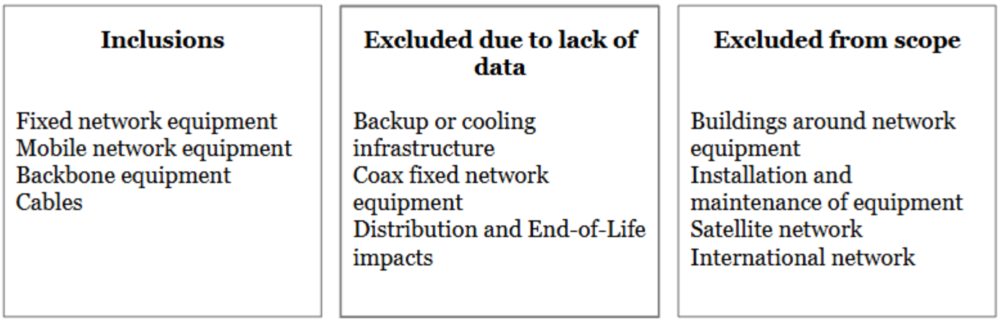
**Excluded from scope**

Packaging of products
Accessories (keyboards or chargers)
Public infrastructure devices

Figure 11: Tier 1 - End-user devices inclusions and exclusions defined by the scope and available data.

The overview of these exclusions is shown in Figure 11 along with the inclusions. The exclusions are differentiated by exclusion due to a lack of reliable data and exclusion due to it not being in scope.

Other exclusions in this study arose from the dependence on environmental data provided by the Resilio and CODDE databases. Given the dependence on these sources as explained in subsubsection 3.3.5, if insufficient LCIA data is available, they cannot be reliably modeled. These databases ultimately shaped which digital products could be included in the analysis and which needed to be excluded. Certain types of personal equipment, such as smartwatches or IoT items were excluded from the study for this reason. In addition, COAX related data was not available in the CODDE database where other network data was extracted from. This means that environmental impacts related to COAX were translated to reflect the types of equipment present in a fiber optic connection. COAX development is quite unique to The Netherlands, which makes it challenging to source reliable LCIA data elsewhere. For this reason, in the results only fiber optic and copper associated network elements are represented, which includes additional infrastructure than what is present with the added COAX subscribers. Lastly, the CODDE database does not provide LCIA results for the distribution and end-of-life life cycle phases. Given these results only make up a maximum of 1% to the total contribution in tiers 1 and 3, they were excluded from the study.

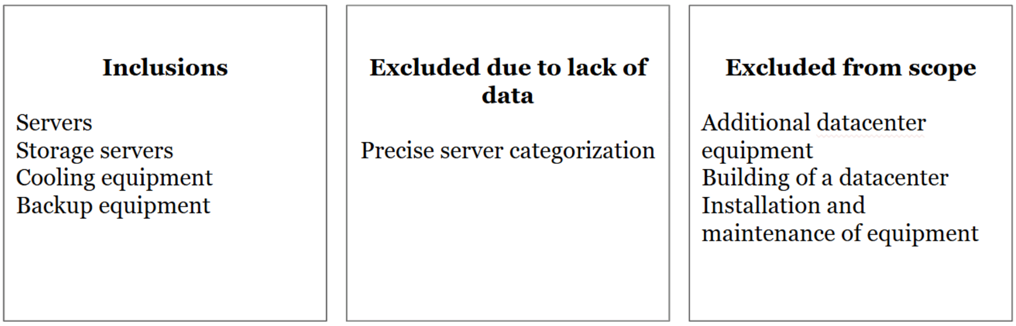


| Inclusions | Excluded due to lack of data | Excluded from scope |
|---|---|---|
| Fixed network equipment<br>Mobile network equipment<br>Backbone equipment<br>Cables | Backup or cooling infrastructure<br>Coax fixed network equipment<br>Distribution and End-of-Life impacts | Buildings around network equipment<br>Installation and maintenance of equipment<br>Satellite network<br>International network |

Figure 12: Tier 2 - Networks inclusions and exclusions defined by the scope and available data.

Building infrastructure (concrete, steel, etc.) surrounding ICT equipment was also left out of this study such as structural components surrounding antenna installations. Although this infrastructure is functionally important, it is not specific to ICT alone and therefore falls beyond the boundaries of this ICT focused assessment. Installation processes were omitted for comparable reasons, as reliable data on installation impacts is challenging and only very relevant to the Networks portion of the results.

Internet users connected by satellite were excluded from this study. This number is assumed to be low as satellite internet is a very niche market. Not only this, but given that the fixed network has very high coverage and speeds in The Netherlands, there is not much incentive for users to make use of satellite internet. Finally, the number of fixed network connections in The Netherlands (Coax, xDSL and fiberoptic), while not exclusive to only households, adds up to 8.37 million. This number aligns closely with the number of households in The Netherlands in 2024 reported by the CBS (8,374,404).



| Inclusions | Excluded due to lack of data | Excluded from scope |
|---|---|---|
| Servers<br>Storage servers<br>Cooling equipment<br>Backup equipment | Precise server categorization | Additional datacenter equipment<br>Building of a datacenter<br>Installation and maintenance of equipment |

Figure 13: Tier 3 - Datacenters inclusions and exclusions defined by the scope and available data.

Finally, for tier 3 many of the excluded factors were similar to those of tier 2. A proper classification of server types is excluded from the study due to insufficient data.

## 3.4 Life Cycle Inventory

Table 3: Summarized Life Cycle Inventory of the baseline study divided by tier.

| Tier | List of devices | Quantity | Unit | Life span (year) |
|---|---|---:|---|---|
| | Dutch population 2024 | 17,943,000 | - | - |
| | Dutch households 2024 | 8,374,404 | - | - |
| | Dutch businesses 2024 | 2,359,325 | - | - |
| Tier 1 - personal | Smartphones | 6,189,617 | Unit | 2.5 |
| Tier 1 - personal | Smartphones - mid range | 9,284,426 | Unit | 2.5 |
| Tier 1 - personal | Laptops | 3,947,000 | Unit | 5.0 |
| Tier 1 - personal | Laptops - mid range | 2,405,400 | Unit | 5.0 |
| Tier 1 - personal | Laptops - gaming | 432,800 | Unit | 5.0 |
| Tier 1 - personal | Tablets | 4,105,624 | Unit | 4.0 |
| Tier 1 - personal | Tablets - mid range | 2,043,176 | Unit | 4.0 |
| Tier 1 - personal | Desktop - entry range | 1,310,26 | Unit | 6.0 |
| Tier 1 - personal | Desktop - mid range | 688,477 | Unit | 6.0 |
| Tier 1 - personal | Desktop - gaming | 222,089 | Unit | 6.0 |
| Tier 1 - personal | Gaming consoles | 1,345,725 | Unit | 7.0 |
| Tier 1 - personal | Small screens (IoT) | 1,842,280 | Unit | 8.0 |
| Tier 1 - personal | Monitors | 1,066,028 | Unit | 6.0 |
| Tier 1 - personal | Speakers | 5,715,039 | Unit | 5.5 |
| Tier 1 - personal | Printers | 414,611 | Unit | 8.0 |
| Tier 1 - personal | Routers | 8,288,458 | Unit | 7.0 |
| Tier 1 - personal | TV boxes | 6,880,000 | Unit | 7.0 |
| Tier 1 - personal | TV (not smart) | 1,185,405 | Unit | 7.5 |
| Tier 1 - personal | Smart tv - large | 911,135 | Unit | 7.5 |
| Tier 1 - personal | Smart tv - small | 797,243 | Unit | 7.5 |
| Tier 1 - personal | Smart tv - medium | 3,986,216 | Unit | 7.5 |
| Tier 1 - professional | Smartphones | 2,263,179 | Unit | 2.5 |
| Tier 1 - professional | Smartphones - mid range | 3,394,768 | Unit | 2.5 |
| Tier 1 - professional | Laptops | 2,398,800 | Unit | 5.0 |
| Tier 1 - professional | Laptops - mid range | 702,300 | Unit | 5.0 |

Continued on next page

Table 3: Summarized Life Cycle Inventory of the baseline study divided by tier. (Continued)

| Tier | List of devices | Quantity | Unit | Life span (year) |
|---|---|---:|---|---|
| Tier 1 - professional | Tablets | 1,378,000 | Unit | 4.0 |
| Tier 1 - professional | Tablets - mid range | 620,000 | Unit | 4.0 |
| Tier 1 - professional | Desktop - entry range | 104,723 | Unit | 6.0 |
| Tier 1 - professional | Monitors | 1,358,667 | Unit | 5.5 |
| Tier 1 - professional | Smart tv - medium | 754,355 | Unit | 6.5 |
| Tier 1 - professional | Smart tv - large | 303,920 | Unit | 6.5 |
| Tier 1 - professional | Printers | 641,876 | Unit | 8.0 |
| Tier 1 - professional | Speakers | 439,500 | Unit | 5.5 |
| Tier 1 - professional | Modems | 38,120 | Unit | 7.0 |
| Tier 2 | DSLAM | 2320 | Unit | 8.0 |
| Tier 2 | Optical fiber cables 576-strands | 16,125 | km | 25.0 |
| Tier 2 | Optical fiber cables 12-strands | 1,433,800 | km | 25.0 |
| Tier 2 | Collection router | 384 | Unit | 8.0 |
| Tier 2 | IAD | 8,288,458 | Unit | 8.0 |
| Tier 2 | OLT | 3600 | Unit | 8.0 |
| Tier 2 | ONT | 6,400,000 | Unit | 7.0 |
| Tier 2 | Aggregation WDM | 224 | Unit | 8.0 |
| Tier 2 | Backbone WDM | 48 | Unit | 8.0 |
| Tier 2 | P-PE router | 96 | Unit | 8.0 |
| Tier 2 | Electricity for the fixed network | 3.19301E11 | Wh | - |
| Tier 2 | Antennas | 165,536 | Unit | 10.0 |
| Tier 2 | BBU | 55,179 | Unit | 10.0 |
| Tier 2 | Collection router (mobile network) | 4000 | Unit | 8.0 |
| Tier 2 | Aggregation router (mobile network) | 533 | Unit | 8.0 |
| Tier 2 | Aggregation WDM (mobile network) | 533 | Unit | 8.0 |
| Tier 2 | Security gateway | 191 | Unit | 8.0 |

Continued on next page

Table 3: Summarized Life Cycle Inventory of the baseline study divided by tier. (Continued)

| Tier | List of devices | Quantity | Unit | Life span (year) |
|---|---|---:|---|---|
| Tier 2 | Aggregation router (mobile network) | 144 | Unit | 8.0 |
| Tier 2 | Aggregation WDM (mobile network) | 384 | Unit | 8.0 |
| Tier 2 | Security gateway | 191 | Unit | 8.0 |
| Tier 2 | SP-GW / GGSN | 191 | Unit | 8.0 |
| Tier 2 | MME / SGSN | 72 | Unit | 8.0 |
| Tier 2 | Backbone WDM (mobile network) | 48 | Unit | 8.0 |
| Tier 2 | P-PE router (mobile network) | 128 | Unit | 8.0 |
| Tier 2 | Optical fiber cables 12-strands for mobile | 315,000 | km | 25.0 |
| Tier 2 | Electricity for the mobile network | 3.8189E11 | Wh | - |
| Tier 3 | Total computer area of DCs | 756,000 | m2 | - |
| Tier 3 | low range server | 245,750 | Unit | 5.0 |
| Tier 3 | mid range server | 414,700 | Unit | 5.0 |
| Tier 3 | high range server | 85,500 | Unit | 4.5 |
| Tier 3 | AI server | 23,400 | Unit | 4.0 |
| Tier 3 | low range blade server | 61,450 | Unit | 5.0 |
| Tier 3 | medium range blade server | 136,600 | Unit | 5.0 |
| Tier 3 | high/AI range blade server | 33,600 | Unit | 4.5 |
| Tier 3 | Storage server | 158,700 | Unit | 5 |
| Tier 3 | Switches | 94,853 | Unit | 5.0 |
| Tier 3 | Routers | 4260 | Unit | 5.0 |
| Tier 3 | Adiabatic cooling | 88 | Unit | 12.0 |
| Tier 3 | Cooling units | 1716 | Unit | 12.0 |
| Tier 3 | UPS | 39,000 | Unit | 7.0 |
| Tier 3 | Backup generators | 1100 | Unit | 25.0 |

Continued on next page

Table 3: Summarized Life Cycle Inventory of the baseline study divided by tier. (Continued)

| Tier | List of devices | Quantity | Unit | Life span (year) |
|---|---|---:|---|---|
| Tier 3 | Total energy | 5.093E12 | Wh | - |
| Tier 3 | Total water | 2,530,000 | m3 | - |

### 3.4.1 Tier 1: End-user devices

The approach of collecting data for end user devices typically followed the use of adoption rates published by the CBS and multiplying these by the population or number of households depending on the type of device. Similar data was used for the professional data where adoption rates are published per company size. Additionally, data from the ACM was used for devices relating to networks [20].

The lifespan and electricity data was taken from a variety of online sources. The full break down of the equipment number calculations is found in Appendix A (subsection 8.1).

### 3.4.2 Tier 2: Networks

In order to estimate the amount of equipment for both the fixed and mobile network, the market was first looked at for number of users. Network user numbers are published by the ACM which includes mobile data subscriptions and fixed network subscriber types (Coax, DSLx, Fiber). In the fourth quarter of 2024, these values were: 3.21 million Coax subscribers, 1.97 million xDSL subscribers and 3.19 million fiber optic subscribers [20].

The electricity used by network operators was published in each of their year reports; however, this data also includes the electricity used in their datacenters. As Vodafone Ziggo does publish a breakdown of where their electricity goes, the same split for electricity towards datacenters was assumed and subtracted from the total. The divide of mobile and fixed was adjusted based on the shares of the market KPN, ODIDO and Vodafone Ziggo have, shown in Table 4. These same numbers were applied for the scaling throughout the following section [15] [20].

Table 4: The market share of each of the network operators in The Netherlands for the fixed and mobile network [15].

| **Operator** | **Fixed Network Market Share** | **Mobile Network Market Share** |
|---|---|---|
| KPN | 35–40% | 25–30% |
| VodafoneZiggo | 35–40% | 20–25% |
| Odido | 10–15% | 35–40% |
| DELTA Fiber | 0–5% | – |
| Other | 0–5% | – |

The numbers of each piece of equipment were calculated in collaboration with one of the three major network operators for the fixed network. For the mobile network this was done with estimations based on the antennakaart data. The full break down of the equipment number calculations is found in Appendix A (subsection 8.1).

### 3.4.3 Tier 3: Data Centers

The varying types of datacenter provide context for understanding their function. These are enterprise, colocation, and hyperscale datacenters. Enterprise datacenters are owned and operated by a single organization for its internal ICT needs. Colocation datacenters lease space, power, and cooling to multiple customers who bring their own equipment. Hyperscale datacenters are massive facilities run by big-tech cloud providers (AWS, Google, Microsoft) to support globally distributed digital services [9]. In the Netherlands, no public data is available on the split of electricity use between the three categories. Power capacity of each datacenter type is estimated by the Dutch Datacenter Association [9]. This is shown in Table 5 in addition to the quantities of the types in The Netherlands [9].

Table 5: Datacenter types in The Netherlands by quantity and their total allocated power [9].

| Datacenter type | Number in The Netherlands | Total allocated Power (MW) |
|---|---|---|
| Enterprise | 338 | 119 |
| Colocation | 191 | 924 |
| Hyperscale | 2 | 460 |

This split between the number of datacenters and their total power allocation shows the imbalance towards hyperscalers, which, despite there only being two of them, use up 30% of the allocated power to datacenters. Colocations make up the biggest user of power across multiple locations which vary dramatically in size. CBS numbers show that approximately 48 colocations have a connection to the grid greater than 10 MW. These numbers show that a few bigger players of the datacenter market make up the largest part of datacenter use related emissions [9].

The two hyperscalers in The Netherlands are Google and Microsoft, two big tech companies which are so depended on that they become challenging to regulate. This has stretched out in their ability to also not provide necessary data under the guise of corporate confidentiality. One example of this is in the Energy and Efficiency Directive (EED), which requires datacenters across the EU to deliver information about their sustainability according to several metrics [21]. This is carried out by the RVO in The Netherlands. Neither Microsoft nor Google filled in more information than their names and area, stating everywhere that the data is confidential [22].

#### Datacenter environmental metrics

When looking at the current way environmental sustainability is approached in datacenters, this is done by two key metrics, both of which were required in EED reporting. The first being the Power Usage Effectiveness (PUE) value which identifies how much excess energy is being used for things around the computing power needed. The equation is:

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power} \tag{1}$$

This is not strictly an environmental metric, but it is used as one [23]. The equations show that the ideal PUE value is 1, where all electricity goes towards IT. However, cooling, lighting, backup power supplies and inefficiencies will result in additional electricity use. Typically, new colocation datacenters strive for a value of about 1.15 to 1.2, with ultra modern designs and hyperscalers even achieving values of 1.1. However, older datacenters (built before 2019) will not be able to achieve these values with current infrastructure and try to strive for values of 1.4 depending on the time of year [9]. Throughout the year, this value can change as less cooling is needed in the winter. The current Dutch average for this value, according the DDA and the extrapolation from the EED data is 1.54 [24]. However, this does not cover the majority of the datacenters, meaning the EU average of 1.56 will be used [23].

The calculations of the equipment was based on the electricity data provided by the CBS and the area of datacenters in the Netherlands. Some scaling calculations of the EED reporting were also used, calculated by the SDIA [24]. This breakdown is found in Appendix A (subsection 8.1).

## 3.5 LCIA methodology - Midpoint selection

The midpoints selected for the LCIA phase were chosen to align with the priorities of stakeholders and the overarching objectives of this study. The selection process considered both the environmental themes that are the most relevant to ICT and the impact categories that are the most useful according to the EZK action program [3]. The following midpoints were selected for this study:

Table 6: Selected Environmental Impact Midpoint Indicators for this study, their abbreviations and their units.

| **Abbreviation** | **Midpoint** | **Unit** |
|---|---|---|
| GWP | Global Warming Potential | kg $CO_2$ eq |
| ADPe | Abiotic Depletion (Metals and Minerals) | kg Sb eq |
| ADPf | Abiotic Depletion (Fossil Fuels) | MJ |
| PM | Particulate Matter Formation | Disease Incidence |
| LU | Land Use | - |
| WU | Water Use | $m^3$ eq |

The action plan highlights three key concerns of ICT environmental impacts. These are, climate impacts measured by $CO_2$ eq, CRMs of ICT and fossil energy dependence [3]. These three midpoints correlate directly to **Global Warming Potential, Abiotic Depletion of metals and minerals (ADPe) and Abiotic Depletion of fossil fuels (ADPf)**. Furthermore, concerns for water and land use are a high priority given their relevance in ICT production, particularly with datacenters. In terms of health of the population, particulate matter was also considered to be a relevant midpoint. These six midpoints capture the needs of the EZK action program and ICT environmental impacts.

The midpoints are not a one to one correlation with what the action program wants. In

LCA, the ADPe midpoint indicator quantifies the depletion of mineral resources relative to antimony. It uses characterization factors based on an extraction to reserve ratio. This means the midpoint gives information concerning the relative scarcity of metal and mineral resources and the rate of depletion compared to estimated reserves. The water use midpoint typically quantifies the amount of freshwater consumed, or deprived from another use, across the life cycle. This does not reflect potable water consumption.

## 3.6 Allocation procedure

An allocation procedure was applied to ensure that ICT hardware impacts are assigned proportionally to their lifespan. Only temporal allocation is used in this study, this is to capture the effects of a year as defined in the functional unit. The following formula has been applied throughout the calculations:

$$\text{Impact}_{\text{LCS; IC}} = \frac{\text{Impact factor}_{\text{LCS; IC}} \times \text{Quantity}}{\text{Lifespan}} \tag{2}$$

for each independent life cycle stage (LCS) of production, distribution, use and end-of-life and impact category (IC);

**With:**

- **Impact$_{\textbf{LCS; IC}}$**: The total annual impact for an inventory data point (impact/yr);
- **Impact factor$_{\textbf{LCS; IC}}$**: The impacts of an inventory data point on a given life cycle step (manufacturing, distribution, use, or end-of-life) and on a specific environmental impact category (impact/unit). These values come from environmental databases;
- **Quantity**: The quantity of data of this specific datapoint (number of units, e.g. of smartphones, of computers, amount of electricity consumed, etc.);
- **Lifespan**: The lifespan of the data point, i.e. the considered equipment or flux (yr).

In practice, this procedure follows a simple relationship in which the total environmental burden of the asset is divided by the number of years it is expected to remain in operative service. For the use of electricity, this data was added manually per device, as their annual electricity use needs to be reflected for the total number of devices. This approach ensures that electricity consumption and hardware impacts each receive a fair share.

## 3.7 Interpretation

The results in this study were generated and processed using Python. Python scripts were used to structure, calculate, and visualize environmental impacts derived from the various LCI and LCIA datasets. Following the baseline results, several interventions were modeled. Of the five interventions modeled in section 5, four have additional methodology presented here, in order of their appearance in section 5.

### Smaller streaming

The second intervention presented focuses on smaller streaming by switching from a TV to either a tablet or laptop, as these devices use less electricity per hour compared to a TV. These two devices were selected with the assumption that screen time on a smartphone is not equivalent to the streaming done on a TV. Modeling this intervention was done by replacing 1 hour of screen time per day of a TV with 1. A tablet and 2. A laptop, deriving two sub-interventions. The electricity needed to provide 365 hours of additional screen time was added to the LCI for the tablet, followed by the laptop, and the electricity needed to provide 365 hours of screen time to a TV was taken away. The higher use of the devices is expected to have an affect on battery life, as more charging cycles will be used. It is assumed that the battery of the tablet goes through 20% more workload per day, which results in a 20% decreased lifespan of the device. For the laptop this was assumed to be a 15% decrease in lifespan.

### Improving peaks

The following interventions focus on datacenters. The first of which is improving utilization through the matching of the duck curve, an intervention which follows the AMS-IX traffic patterns over the course of a day [25]. This is further explained in section 5. To test the impact of this intervention, a number of assumptions are necessary for modeling the duck curve internet patterns. The first assumption is that this intervention only focuses on electricity used and that no changes are made to server count or configuration. Based on the standard curve, it is assumed that the absolute minimum is met between 2 and 6am, which counts for 50% less power allocation for 4 hours. Furthermore, a 15% reduction of power allocated between 23:00 and 2:00 and 6:00 and 16:00 [25]. This equates to:

$$Reduction(time) = 0.5 \times 4\ hours + 0.15 \times 13\ hours = 3.35 \tag{3}$$

This is equivalent to 3.35 hours of reduced electricity needed per 24 hour period. Which as a percentage of total IT electricity equates to:

$$Reduction(\%) = \frac{24 - 3.35}{24} = 0.1396 \tag{4}$$

This equates to a 13.96% reduction in electricity used per year directly used for IT power, which is 568.38 GWh per year less. The results of this are shown in section 5.

### Server Utilization

The other utilization reduction potential looked at quantifying the utilization of datacenters more specifically, the effects of improving server utilization to 75% can be measured using the model. A very conservative value that datacenter server utilitization is currently 40% for medium and low configuration servers is taken. High processing, storage and AI servers are excluded from this calculation as they need higher redundancy levels meaning 75% utilization is not realistic. Mapping an intervention where these servers run at 75% utilization means that the necessary servers are:

$$\frac{40}{75} = 54\% \tag{5}$$

This 54th percent is rounded up. This means a 46% decrease in server count needs. To make this assumption more fair, the increased utilization of these servers will reduce their lifespan to 4 years rather than 5.

To calculate the difference in electricity from running at a higher utilization rate, it is assumed that the idle energy needed is 40% of what a running server needs.

$$E = (1 - u) \times E_{idle} + u \times 1 \tag{6}$$

$$E_{total} = E \times Servers \tag{7}$$

Where E idle is the percentage of energy used compared to full power and u is utilization.

$$0.6 \times 0.4 + 0.4 \times 1 = 0.64 \times 100 = 64\% = E_{before} \tag{8}$$

The ratio is multiplied by the percentage of servers needed. With the new set of assumptions:

$$0.4 \times 0.25 + 0.75 \times 1 = 0.85 \times 54 = 45.9\% = E_{new} \tag{9}$$

Finally, the difference between the two can be calculated in a percentage.

$$\frac{64 - 45.9}{64} = 0.283 \tag{10}$$

This improvement finds that 28.3% of electricity is reduced with the improved utilization assumptions. The effects of this are shown in section 5.

### Reuse of heat

The final intervention is the reuse of heat by datacenters. This intervention is modeled through offset, meaning that rather than decreasing any input to the LCI, an additional negative input of heat is added. This is 4.79 TWh of heat, as calculated by the SDIA [24]. There is no accounting for the additional equipment needed to facilitate this intervention in this study.

# 4 Results

Carrying out the methodology results in the creation of the life cycle impact assessment results, stage three of an LCA in Figure 8. The results of this study first look at the combined baseline results across all tiers before breaking down the results by tier. Subsequently, these will be compared to previous studies and a sensitivity analysis is performed on the most sensitive data. Thereafter, interventions derived from the hotspots will be analysed.

The total values across the tiers for all six midpoints are summarized in Table 7.

Table 7: The results of the baseline study represented in total values for each midpoint calculated by the LCI data

| **Midpoint** | **Unit** | **Value for Dutch ICT in 2024** |
|---|---|---|
| Global Warming Potential | kg $CO_2$ eq | 5,507,000,000 |
| Particulate Matter Formation | Disease incidence | 216.2 |
| Land Use | - | 2,850,000,000 |
| Resource Depletion (Fossil) | MJ | 66,770,000,000 |
| Resource Depletion (Elements) | kg Sb eq | 136,900 |
| Water Use | $m^3$ eq | 3,156,000,000 |

The total $CO_2$ *eq* footprint calculated of ICT in The Netherlands is just over 5.5 Mton according to this baseline study. This captures the $CO_2$ emissions of scope 1,2 and 3. The national value of $CO_2$ emissions calculated in 2024 is 148.5 Mton [26]. This makes ICT 3.7% of the total national footprint, but with the use of hybrid approach in mind, this comparison is unfair. The national footprint is measured only with a production-based approach, where this study instead used a hybrid approach as discussed in subsection 3.3. Similar to this, all midpoints and their comparisons are shown in Table 8. The other three midpoints with a % also are not directly comparable given they use a consumption-based approach. In the case of resource depletion, this is also not characterized in the same manner as ICT, leading to a discrepancy in its comparison. No comparison is possible for particulate matter formation and land use as these are monitored with different units. Nevertheless, these indications provide some context of national footprint while not being directly comparable.

Table 8: Approximated comparison of Dutch ICT environmental impacts against total national values for 2024.

| **Midpoint** | **ICT Result (2024)** | **Estimated NL Total (2024)** | **ICT % Share** |
|---|---|---|---|
| GWP | 5.507 Mton $CO_2$ eq | 148.5 Mton eq [26] | 3.7% |
| PM | 216.2 disease inc. | ≈38,000 kg [27] | - |
| LU | 2.850 billion | 12.0 M hectare [28] | - |
| ADPe | 136,900 kg Sb eq | ≈84.0 Mton [29] | 0.16% |
| ADPf (Fossils) | 66.77 billion MJ | ≈1,950 PJ [30] | 3.42% |
| WU | 3.156 billion $m^3$ eq | 14.8 billion $m^3$ [31] | 21.0% |

## 4.1 Baseline Results

The split from the three different tiers for the numbers in Table 7 is shown in Figure 14. Professional and personal devices are split from each other but together show that devices make up the largest tier with a total share of 47.1% of the total global warming potential of ICT in The Netherlands, followed by datacenters at 45.4%. Networks, or tier 2, make up the smallest share at only 7.5% of the total ICT GWP footprint.

The other midpoints with exception to fossil fuel depletion (ADPf) show personal devices as the largest footprint. This is especially prevalent in water use and metal and mineral resource depletion. Metal and mineral resource depletion shows the largest share for networks at 18.5% and a smaller share for datacenters at only 6.6%. Fossil fuel depletion is the only other midpoint to show datacenters being the largest share at 52.3%.

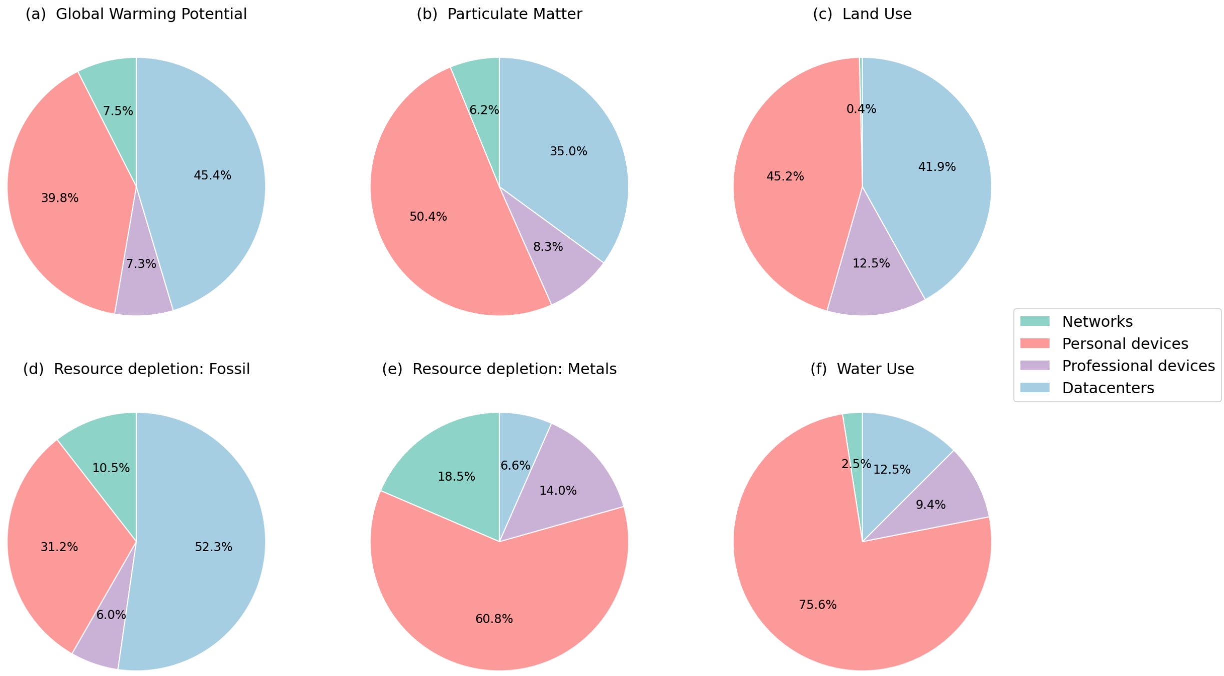


Figure 14: The repartition of results of each tier for the total ICT picture. These graphs show the shares per tier that make up the values of Table 7. These are per midpoint; a. Global Warming Potential, b. Particulate Matter, c. Land Use, d. Resource depletion: fossil use, e. Resource depletion: metals and minerals, f. Water Use.

Breaking down the information shown in Figure 14 can be done through the life cycle phases. This is done in Figure 15. The largest share of the GWP footprint lies in the use phase of datacenters, which is purely comprised of electricity with some water. This water usage is not reflected as high, however, in the footprint of water usage, where the production of devices makes up 85% of the total footprint combining personal and professional devices.

Land use and metal and mineral depletion midpoints are also majority attributed to the production stage, being approximately 95% of the Land use midpoint and 99% of the mineral and metal depletion midpoint. Fossil resources are highly attributed to the use phase of dat-

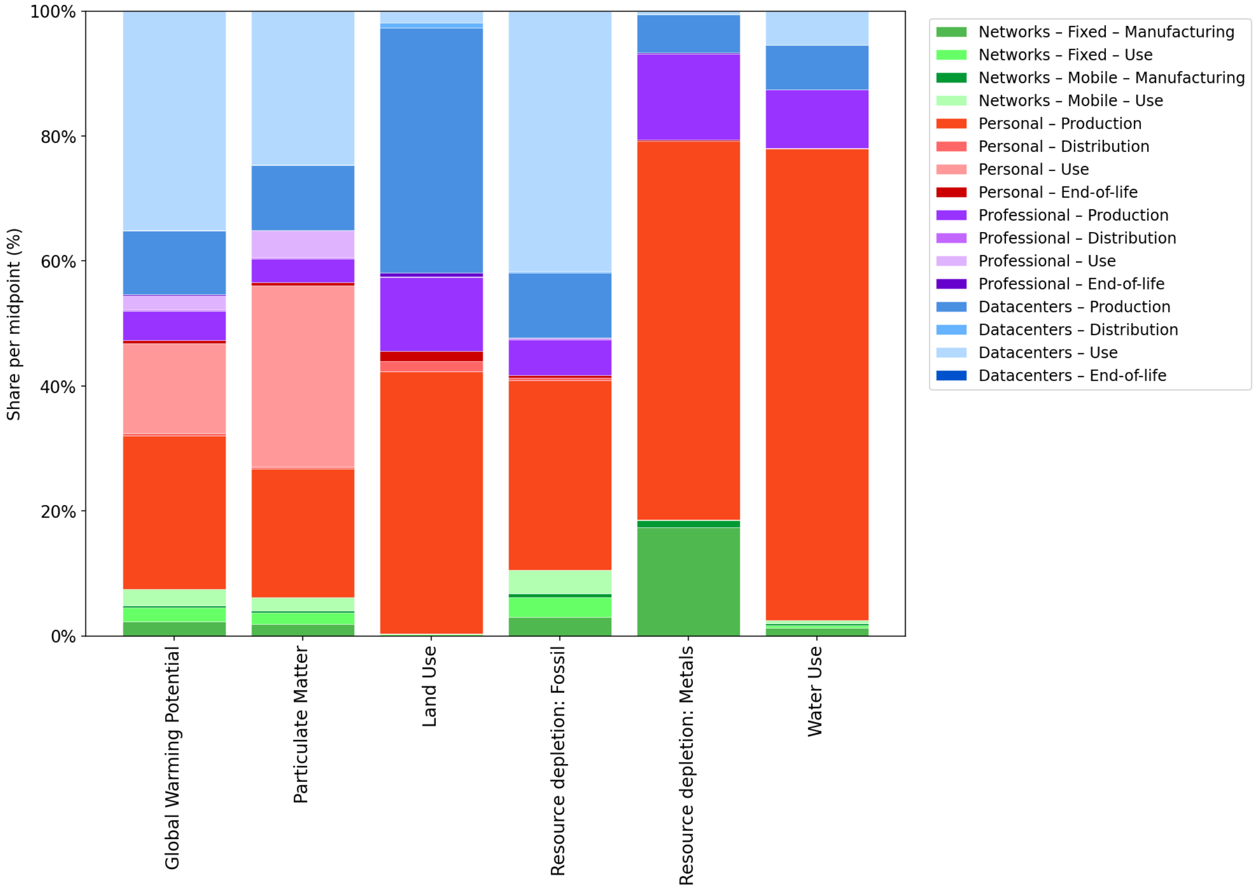


Figure 15: Share of each of life cycle phase of the three tiers (end-user devices, networks and datacenters) for each of the six midpoints relative to 100% of the total values calculated (found in Table 7).

acenters and networks, but not for that of devices, where, instead, majority lies again in the production stage. The impacts from the distribution and end-of-life phases make up a very small part of the total impact, ranging from smaller than 0.001% to 1.5%.

The shares of the charts from networks show that the mobile and fixed network have a similar share in the use phase across the six midpoints, but only that the fixed network has an impact from physical infrastructure. A small contribution from the fixed network infrastructure is shown in the global warming potential, particulate matter, fossil depletion, water and land use midpoints and a larger share in metal and mineral resource depletion.

### 4.1.1 Tier 1: End-user devices

The split between personal and professional devices is shown in Figure 16. This ranges from a maximum of a 25% share to a minimum of a 13% share of the total tier 1 footprint. This range in difference is fair because, despite the types of equipment being similar, the distribution of devices is not, including their average power consumption during the use phase.

The breakdown in tier 1 by device is shown in Figure 17. The largest contributor is the medium smart TV, which holds the biggest footprint for global warming potential, particulate matter, fossil depletion, water use and metal resource depletion midpoints. Medium size

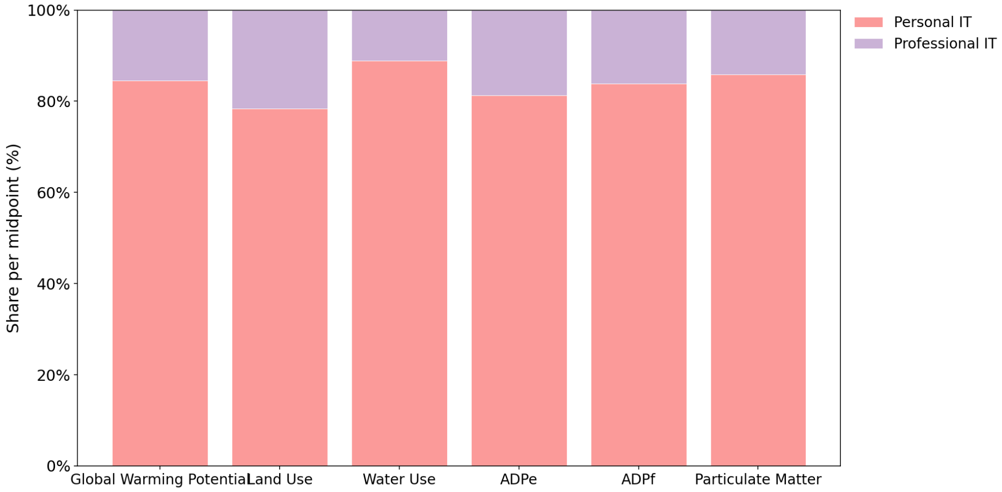


Figure 16: The divide between the footprint of each of the six midpoints for personal and professional devices in tier 1: End-user devices.

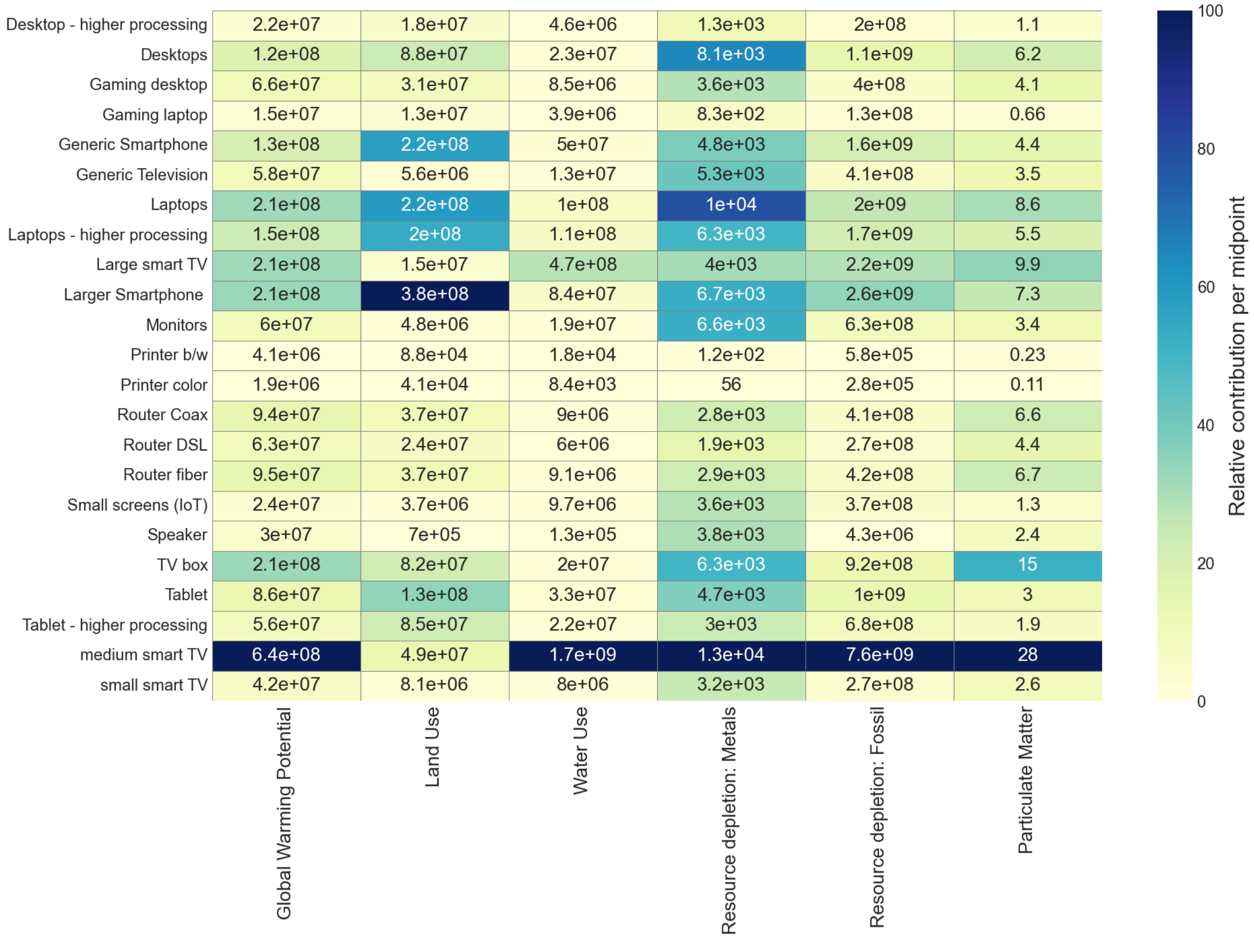
smart TVs cover the majority of TVs used in homes and offices, which also contributes to their dominance across the midpoints. The rest of the device footprints share a fairly even split, with devices such as TV boxes, laptops, large smart TVs, smartphones, desktops and the combination of routers also having larger shares on the heatmap.

The water usage midpoint is the only midpoint to show heavy bias towards one type of device, namely, smart TVs. The generic television does not have a major contribution, only smart TVs, particularly medium and large smart TVs. The land use midpoint shows that the larger shares are all from devices which have a higher device count, with smart phones, tablets and laptops making up these largest impacts. The metal depletion midpoint shows the contribution being much more even across the different device types. The higher device count devices, such as phones and routers make up a high contribution as well as larger devices such as TVs and desktops. Figure 17 shows that the majority of the midpoints show similar behavior with regards to distribution of devices except for ADPe, some bigger contributions from the most frequently used devices and the largest contribution from smart TVs. Insights can be further broken down to include life cycle phases and distribution of devices with GWP and ADPe being the most representative interesting midpoints shown in Figure 18 and Figure 19.

In Figure 18, there is a clear relation shown concerning the share of the use phase in the footprint and the size of the device. Looking at the key personal devices; smartphone, tablet, laptop and TV, the use phase becomes incrementally larger. Reaching the highest share for the large smart TVs, of 42%.

Other devices which have a high use phase footprint are each of the routers and TV boxes. The footprint of the production of the devices is smaller than its use in one year.

Again, the impacts of distribution and end-of-life remain an insignificant share in these graphs, with the only small contributions of 1% being the distribution phase of battery personal devices like smartphones, tablets and laptops. The only device to to have a contribution above 1% for the end-of-life phase impact is medium sized smart TVs.



| | Global Warming Potential | Land Use | Water Use | Resource depletion: Metals | Resource depletion: Fossil | Particulate Matter |
|---|---|---|---|---|---|---|
| Desktop - higher processing | 2.2e+07 | 1.8e+07 | 4.6e+06 | 1.3e+03 | 2e+08 | 1.1 |
| Desktops | 1.2e+08 | 8.8e+07 | 2.3e+07 | 8.1e+03 | 1.1e+09 | 6.2 |
| Gaming desktop | 6.6e+07 | 3.1e+07 | 8.5e+06 | 3.6e+03 | 4e+08 | 4.1 |
| Gaming laptop | 1.5e+07 | 1.3e+07 | 3.9e+06 | 8.3e+02 | 1.3e+08 | 0.66 |
| Generic Smartphone | 1.3e+08 | 2.2e+08 | 5e+07 | 4.8e+03 | 1.6e+09 | 4.4 |
| Generic Television | 5.8e+07 | 5.6e+06 | 1.3e+07 | 5.3e+03 | 4.1e+08 | 3.5 |
| Laptops | 2.1e+08 | 2.2e+08 | 1e+08 | 1e+04 | 2e+09 | 8.6 |
| Laptops - higher processing | 1.5e+08 | 2e+08 | 1.1e+08 | 6.3e+03 | 1.7e+09 | 5.5 |
| Large smart TV | 2.1e+08 | 1.5e+07 | 4.7e+08 | 4e+03 | 2.2e+09 | 9.9 |
| Larger Smartphone | 2.1e+08 | 3.8e+08 | 8.4e+07 | 6.7e+03 | 2.6e+09 | 7.3 |
| Monitors | 6e+07 | 4.8e+06 | 1.9e+07 | 6.6e+03 | 6.3e+08 | 3.4 |
| Printer b/w | 4.1e+06 | 8.8e+04 | 1.8e+04 | 1.2e+02 | 5.8e+05 | 0.23 |
| Printer color | 1.9e+06 | 4.1e+04 | 8.4e+03 | 56 | 2.8e+05 | 0.11 |
| Router Coax | 9.4e+07 | 3.7e+07 | 9e+06 | 2.8e+03 | 4.1e+08 | 6.6 |
| Router DSL | 6.3e+07 | 2.4e+07 | 6e+06 | 1.9e+03 | 2.7e+08 | 4.4 |
| Router fiber | 9.5e+07 | 3.7e+07 | 9.1e+06 | 2.9e+03 | 4.2e+08 | 6.7 |
| Small screens (IoT) | 2.4e+07 | 3.7e+06 | 9.7e+06 | 3.6e+03 | 3.7e+08 | 1.3 |
| Speaker | 3e+07 | 7e+05 | 1.3e+05 | 3.8e+03 | 4.3e+06 | 2.4 |
| TV box | 2.1e+08 | 8.2e+07 | 2e+07 | 6.3e+03 | 9.2e+08 | 15 |
| Tablet | 8.6e+07 | 1.3e+08 | 3.3e+07 | 4.7e+03 | 1e+09 | 3 |
| Tablet - higher processing | 5.6e+07 | 8.5e+07 | 2.2e+07 | 3e+03 | 6.8e+08 | 1.9 |
| medium smart TV | 6.4e+08 | 4.9e+07 | 1.7e+09 | 1.3e+04 | 7.6e+09 | 28 |
| small smart TV | 4.2e+07 | 8.1e+06 | 8e+06 | 3.2e+03 | 2.7e+08 | 2.6 |

Figure 17: Heatmap representing the intensity of contribution by each of the devices used in Tier 1: end-user devices to each midpoint.

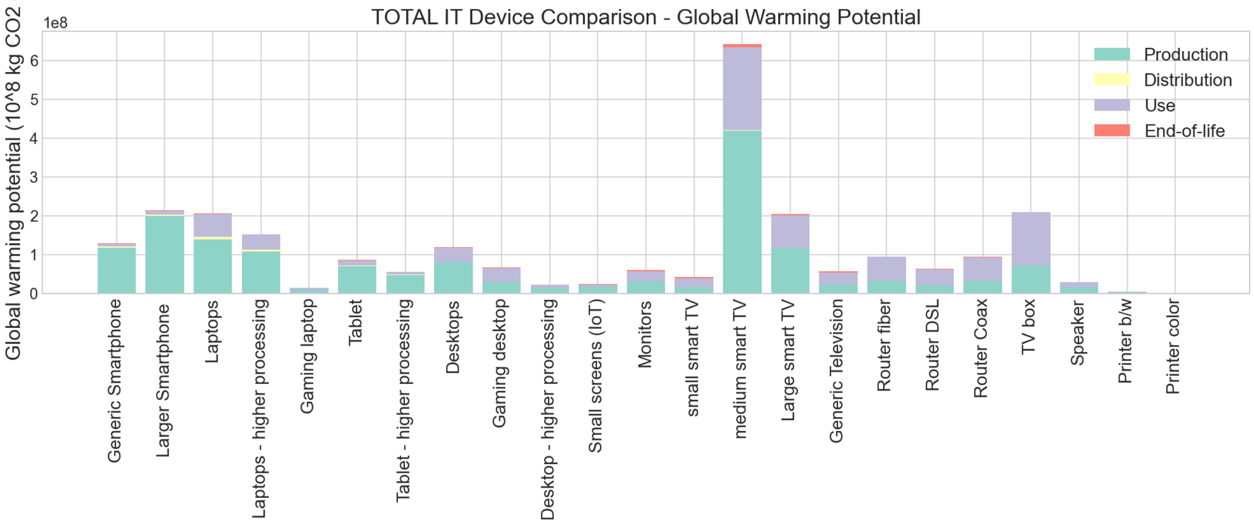


Figure 18: Global warming potential (kg $CO_2$ eq) impact of ICT in the NL in 2024 for user devices (tier 1), showing the contribution of each of the life cycle stages per device type

In the breakdown of the metal depletion midpoint, 99.6% of the impacts are due to the production phase and 0.3% are due to end-of-life impacts. These results demonstrate the

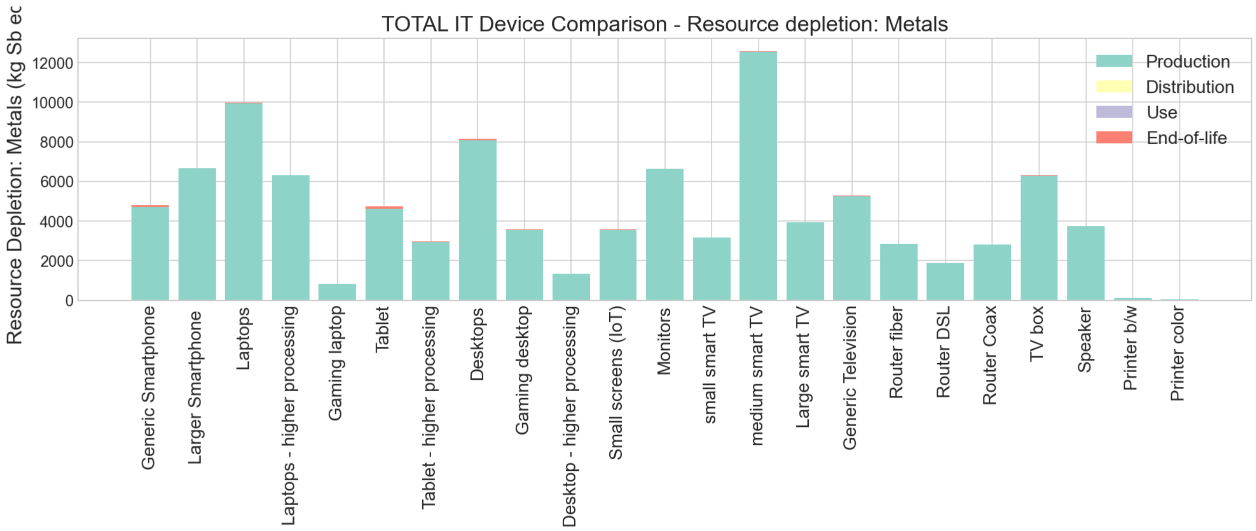


Figure 19: Metal and mineral resource depletion (kg Sb eq) impact of ICT in the NL in 2024 for user devices (tier 1), divided per device type and showing the contribution of life cycle stages

link to CRMs being relevant in the production of ICT devices but the lack of circularity that exists. Recycling or recovery processes would have a larger associated impact if they were carried out at a large scale.

### 4.1.2 Tier 2: Networks

The networks tier shows a consistent split between the mobile and fixed network across the midpoints global warming potential, particulate matter, fossil depletion and land use. The contribution of the mobile network makes up approximately 40% of the impacts and the fixed networks the other 60%. For water use, this split is instead 30 to 70% towards the fixed network. Metal depletion is the only midpoint to show a significant difference in the impact split, where the fixed network makes up 93% of the impacts.

In Figure 21, the breakdown of the devices that make up the fixed and mobile network is shown. The biggest shares are all from the electricity used by both the fixed and mobile network. These total impacts are similar, despite the fact that the fixed network uses much more data than the mobile network. Some of the bigger other contributors to the midpoints are the ONTs, optical fiber cables, IAD routers from the fixed network, and from the mobile network the BBUs and antennas. These are the most prevalent equipment items with regards to quantity from the physical infrastructure. In particular, IAD routers and ONTs are present in almost all households, making them the biggest contributors specifically to the metal depletion midpoint, where together they make up over 90% of the impacts. The same is true for antennas and BBUs from the mobile side, but their contribution is much less noticeable in the mineral and metals use.

Lastly, the life cycle phases for the networks. This is shown in Figure 22 where, as shown in Figure 21 the electricity used by the networks plays a significant role in their footprint. The physical infrastructure of the fixed network is reflected by the production midpoint.

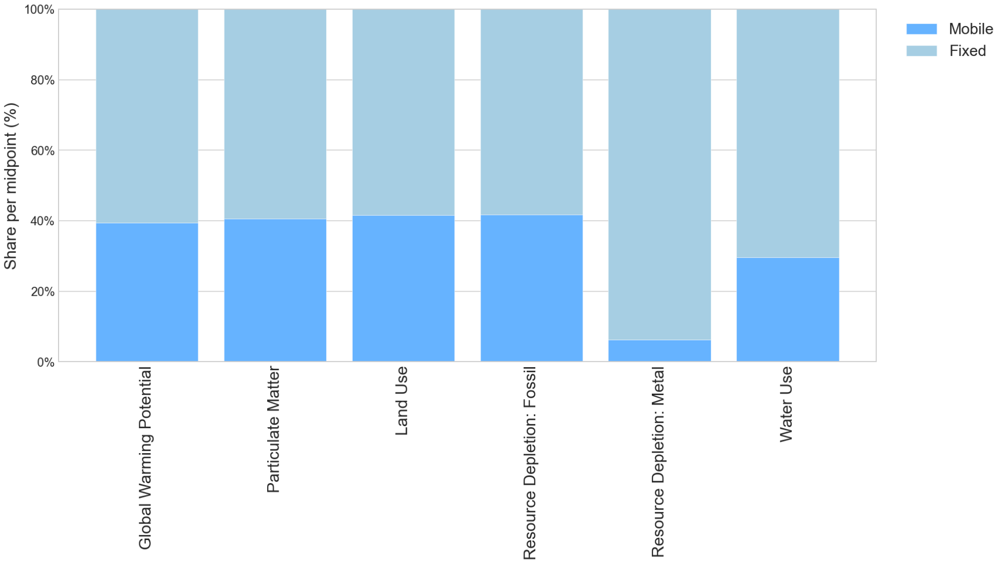
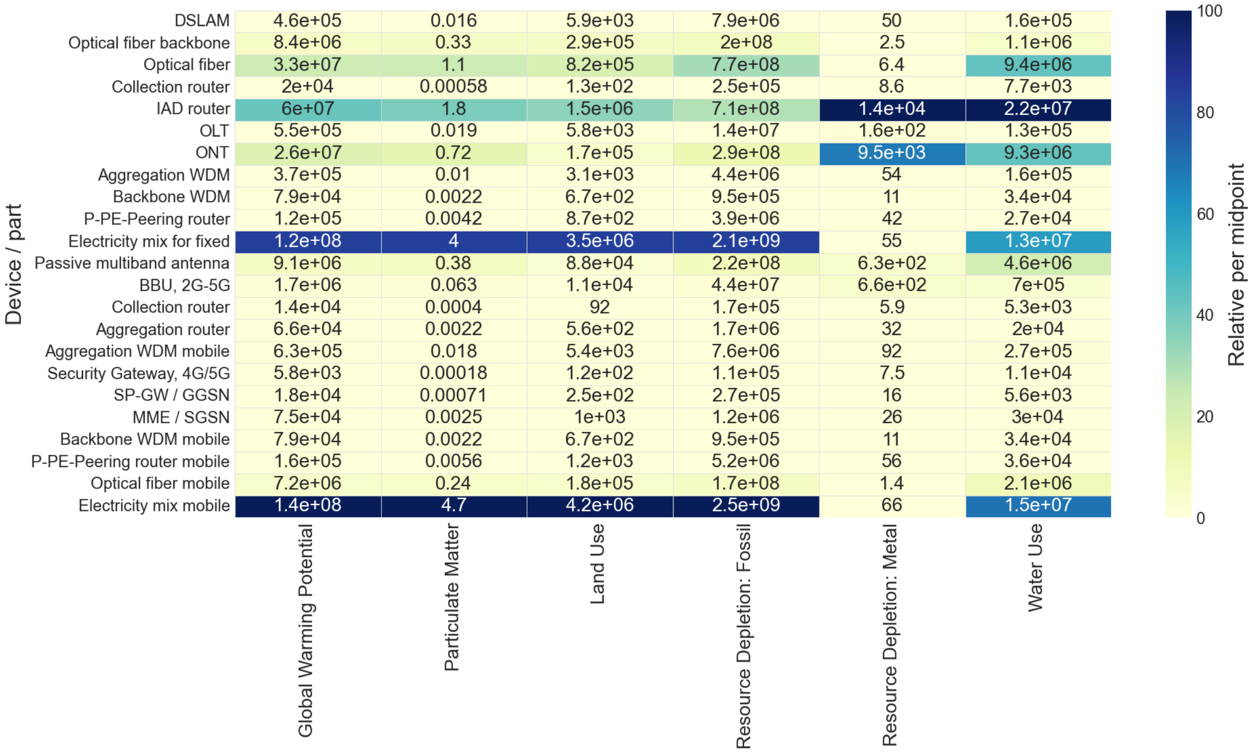


Figure 20: The share between the footprint of each midpoint for the fixed and mobile networks as a part of the total contribution to tier 2: Networks.



| Device / part | Global Warming Potential | Particulate Matter | Land Use | Resource Depletion: Fossil | Resource Depletion: Metal | Water Use |
|---|---|---|---|---|---|---|
| DSLAM | 4.6e+05 | 0.016 | 5.9e+03 | 7.9e+06 | 50 | 1.6e+05 |
| Optical fiber backbone | 8.4e+06 | 0.33 | 2.9e+05 | 2e+08 | 2.5 | 1.1e+06 |
| Optical fiber | 3.3e+07 | 1.1 | 8.2e+05 | 7.7e+08 | 6.4 | 9.4e+06 |
| Collection router | 2e+04 | 0.00058 | 1.3e+02 | 2.5e+05 | 8.6 | 7.7e+03 |
| IAD router | 6e+07 | 1.8 | 1.5e+06 | 7.1e+08 | 1.4e+04 | 2.2e+07 |
| OLT | 5.5e+05 | 0.019 | 5.8e+03 | 1.4e+07 | 1.6e+02 | 1.3e+05 |
| ONT | 2.6e+07 | 0.72 | 1.7e+05 | 2.9e+08 | 9.5e+03 | 9.3e+06 |
| Aggregation WDM | 3.7e+05 | 0.01 | 3.1e+03 | 4.4e+06 | 54 | 1.6e+05 |
| Backbone WDM | 7.9e+04 | 0.0022 | 6.7e+02 | 9.5e+05 | 11 | 3.4e+04 |
| P-PE-Peering router | 1.2e+05 | 0.0042 | 8.7e+02 | 3.9e+06 | 42 | 2.7e+04 |
| Electricity mix for fixed | 1.2e+08 | 4 | 3.5e+06 | 2.1e+09 | 55 | 1.3e+07 |
| Passive multiband antenna | 9.1e+06 | 0.38 | 8.8e+04 | 2.2e+08 | 6.3e+02 | 4.6e+06 |
| BBU, 2G-5G | 1.7e+06 | 0.063 | 1.1e+04 | 4.4e+07 | 6.6e+02 | 7e+05 |
| Collection router | 1.4e+04 | 0.0004 | 92 | 1.7e+05 | 5.9 | 5.3e+03 |
| Aggregation router | 6.6e+04 | 0.0022 | 5.6e+02 | 1.7e+06 | 32 | 2e+04 |
| Aggregation WDM mobile | 6.3e+05 | 0.018 | 5.4e+03 | 7.6e+06 | 92 | 2.7e+05 |
| Security Gateway, 4G/5G | 5.8e+03 | 0.00018 | 1.2e+02 | 1.1e+05 | 7.5 | 1.1e+04 |
| SP-GW / GGSN | 1.8e+04 | 0.00071 | 2.5e+02 | 2.7e+05 | 16 | 5.6e+03 |
| MME / SGSN | 7.5e+04 | 0.0025 | 1e+03 | 1.2e+06 | 26 | 3e+04 |
| Backbone WDM mobile | 7.9e+04 | 0.0022 | 6.7e+02 | 9.5e+05 | 11 | 3.4e+04 |
| P-PE-Peering router mobile | 1.6e+05 | 0.0056 | 1.2e+03 | 5.2e+06 | 56 | 3.6e+04 |
| Optical fiber mobile | 7.2e+06 | 0.24 | 1.8e+05 | 1.7e+08 | 1.4 | 2.1e+06 |
| Electricity mix mobile | 1.4e+08 | 4.7 | 4.2e+06 | 2.5e+09 | 66 | 1.5e+07 |

Figure 21: Heatmap of the devices in Tier 2 showing the highest contribution to the midpoint per piece of equipment.

### 4.1.3 Tier 3: Datacenters

Finally, datacenter impacts can also be analyzed by their individual contributions. In Figure 23 the servers make up the majority of the impact, especially the mid range rack server configuration. Cooling is the only significant non-server impact. This is due to the electricity usage of cooling. Some of the other electricity which was attributed towards non-IT such as the backup generators and UPS does not have much significance in the total picture.

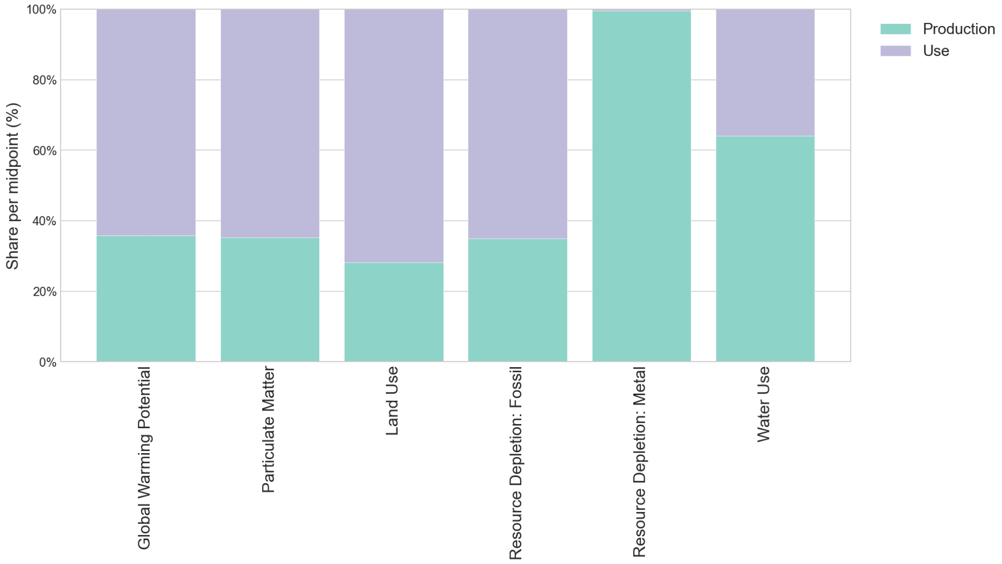
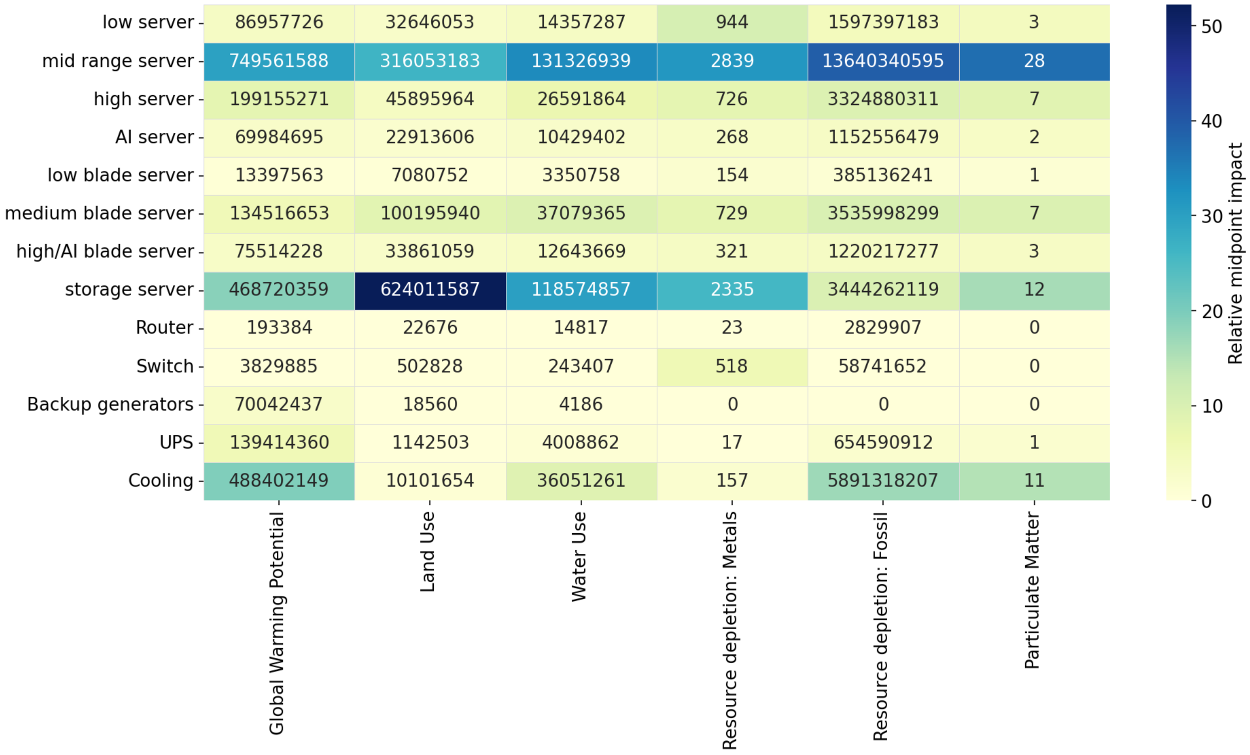


Figure 22: The contribution to each of the six midpoints by the life cycle stage relative to the total impact of tier 2: Networks



| | Global Warming Potential | Land Use | Water Use | Resource depletion: Metals | Resource depletion: Fossil | Particulate Matter |
|---|---|---|---|---|---|---|
| low server | 86957726 | 32646053 | 14357287 | 944 | 1597397183 | 3 |
| mid range server | 749561588 | 316053183 | 131326939 | 2839 | 13640340595 | 28 |
| high server | 199155271 | 45895964 | 26591864 | 726 | 3324880311 | 7 |
| AI server | 69984695 | 22913606 | 10429402 | 268 | 1152556479 | 2 |
| low blade server | 13397563 | 7080752 | 3350758 | 154 | 385136241 | 1 |
| medium blade server | 134516653 | 100195940 | 37079365 | 729 | 3535998299 | 7 |
| high/AI blade server | 75514228 | 33861059 | 12643669 | 321 | 1220217277 | 3 |
| storage server | 468720359 | 624011587 | 118574857 | 2335 | 3444262119 | 12 |
| Router | 193384 | 22676 | 14817 | 23 | 2829907 | 0 |
| Switch | 3829885 | 502828 | 243407 | 518 | 58741652 | 0 |
| Backup generators | 70042437 | 18560 | 4186 | 0 | 0 | 0 |
| UPS | 139414360 | 1142503 | 4008862 | 17 | 654590912 | 1 |
| Cooling | 488402149 | 10101654 | 36051261 | 157 | 5891318207 | 11 |

Figure 23: Heatmap of the equipment types used in datacenters (tier 3) showing the highest contribution to the midpoint per equipment type.

The midpoint global warming potential is 86% attributed to servers and the other 14% is attributed to cooling. The largest share of the servers are mid-range servers, the type that is used by most colocation datacenters and by hyperscalers. Higher range servers, despite there being less of them, have a larger share of impact than low range servers. The impact of the physical server production is reflected in the metal resource depletion midpoint, which is the only midpoint to show a higher share towards low range servers than high range servers. This is also the only midpoint where switches make up a share of the impact of approximately 6%.

Across all of the midpoints, the rack servers make up a larger impact than the blade server. Given the type count is very different, it shows that the environmental impact of servers depends on their quantity and configuration rather than their type.

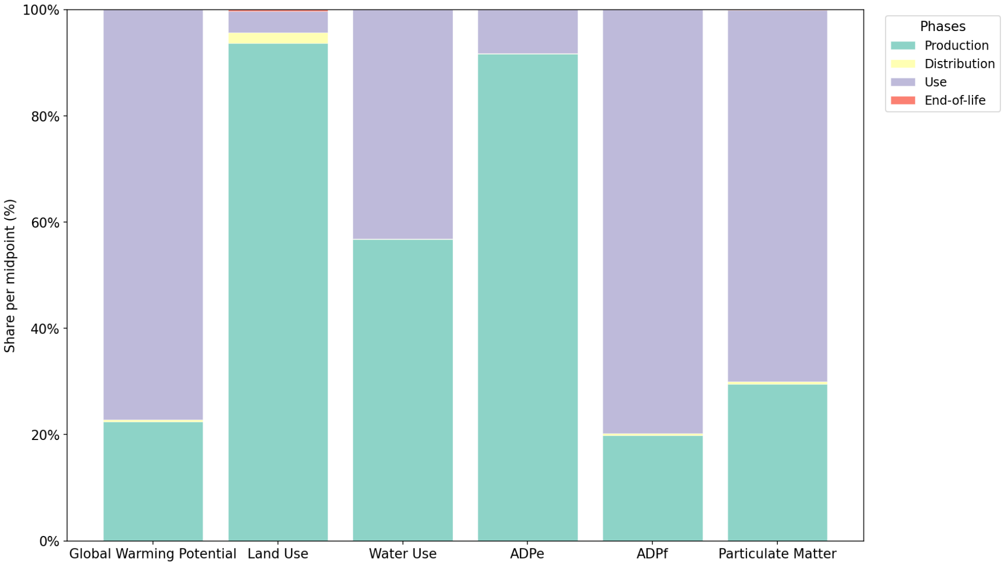


Figure 24: The impacts per life cycle stage relative to the total impacts for tier 3: datacenters.

In Figure 24 the impact of the electricity used by datacenters is emphasized to be impactful in global warming potential, water use, fossil depletion and particulate matter. The water usage midpoint stands out as the most unexpected result. The impact share of the use phase is just under 40% despite the use phase including the water that datacenters report using. This difference shows the significance of the water used in the production of 1.2 million servers, as its contribution is greater than the 2.53 million $m^3$ of water in the use phase.

The electricity mix in The Netherlands still being highly fossil fuel dependent is reflected in the fossil resource depletion midpoint, where 90% of the impact is attributed to the use phase, unlike in tiers 1 and 2. However, likewise to tiers 1 and 2, the metal resource depletion midpoint is heavily weighted towards the production of the physical infrastructure.

## 4.2 Comparison with Literature

To gain insights into the reliability of the data, other studies can be used as a starting point metric. The per capita impact is the most comparable metric used in other literature published on this topic. Swiss, French, EU, Global and the work done to quantify the footprint earlier in The Netherlands can all be used as comparative metrics.

The total number of devices calculated was equal to **86,919,848**. Based on the total numbers of devices, an average of 4.8 devices per person is found. Accounting only for the population above 12, this quantity is 5.5 devices per person. Professional devices on the other hand have an average of 2.1 devices per employee. The allocation of impact per capita is shown in Table 9.

Table 9: The ICT environmental footprint per-capita for the personal devices impact, professional devices impact and total ICT impacts for each midpoint.

| Midpoint | Personal ICT | Professional ICT | Total ICT |
|---|---|---|---|
| Global Warming Potential(kg $CO_2$ eq) | 122.2 | 22.43 | 306.9 |
| Land Use (-) | 71.82 | 19.86 | 158.8 |
| Water Use ($m^3$) | 133.0 | 16.55 | 175.9 |
| Metal resource depletion (kg Sb eq) | 0.0046 | 0.0011 | 0.0076 |
| Fossil based resource depletion (MJ) | 1161 | 223.9 | 3721 |
| Particulate matter (disease incidence) | 0.0000061 | 0.0000010 | 0.000012 |

At the Networks level, the individual contribution is best mapped through the amount of data on both networks. These are measured to total be 130 GB per person on the mobile network and 3,590 GB on the fixed network.

Datacenters and networks do not have a comparative quantity for their individual contribution because they both used the production approach defined in subsection 3.3. These impact per capita are therefore not fairly representative of a per capita responsibility and are instead only used to be a comparison to other studies in Table 10.

The comparison to the other studies is done in Table 10. The Swiss, French and EU studies use the same hybrid approach as presented in subsection 3.3. The World study is global and hence does not find a difference between the two approaches. The study by Dialogic in 2023 uses a production-based approach across each of the three tiers, highlighting a key difference in the methodology. The study also only focuses on tiers 1 and 2 in their results, creating an entirely different perspective. Nevertheless, the similar goal to the study makes their results relevant in comparison.

The biggest glaring difference of this study compared to the other completed studies is the highest data traffic per user (3,720 GB). The other studies range from 1,133 GB (EU, GreenIT) to 3,214 GB (World, GreenIT). Despite this extremely high data volume, the climate change impact per user of 307 kg $CO_2$ eq falls in the middle of the international range: higher than Resilio ADEME, but lower than the EU study and global study.

The difference between the climate change impact from the study done on the Dutch footprint in 2023 [14] and this study shows the significance of tier 3. Tier 3 represents between 35 and 80% of the total impact of the range presented in [14].

For resource depletion, metals and minerals as well as fossil based, the data collected in this study sits on the lower end. Both resource depletion midpoints are comparable to the global scale, which is unexpected due to The Netherlands' high ICT proficiency.

Table 10: Comparison of per capita impacts from this study and other similar studies done in Europe, Globally and in The Netherlands

| | Netherlands 2024 (TNO) | Switzerland 2024 (Resilio) [32] | France 2022 (ADEME) [33] | EU 2021 (GreenIT) [34] | World 2025 (GreenIT) [35] | Netherlands 2023 (Dialogic) (excluding tier 3) [14] |
|---|---|---|---|---|---|---|
| Number of end-user (personal and professional) equipment per user (without IoT) | 6.9 | 8.5 | 6.9 | N/A | 5.7 | N/A |
| Total data consumed per user (GB) | 3,720 | 1,245 | 2,711 | 1,133 | 3,214 | N/A |
| Total electricity consumption per user (kWh) | 659 | 759 | 725 | 551 | 425 | 840 |
| Resource use per user, minerals and metals (ADPe) (g Sb eq.) | 7.6 | 20.1 | 14.1 | 11.2 | 7.7 | N/A |
| Climate change per user (kg $CO_2$ eq.) | 307 | 247 | 253 | 361 | 342 | 59 - 189 |
| Usage of fossil resources per user (GJ) | 3.7 | 5.7 | 11.9 | 7.7 | 4.7 | N/A |
| Fine particles per user (disease incidence) | 1.21E-5 | 1.03E-5 | 1.71E-5 | 1.56E-5 | 1.48E-6 | N/A |

## 4.3 Comparison with Sectors

The baseline can be compared by sector in order to reflect the value that ICT brings, as another way to compare the footprint of ICT to other large sectors. This is done by creating an intensity metric, which measures the impact of a sector, weighted by its value to the Dutch economy. Given only $CO_2$ eq data is available per sector, this is the only midpoint that will be compared. According to the Eurostat indicator, the Dutch ICT sector accounts for 5.28% of the total Gross Value Added (GVA) of the economy [36] in 2023. This value was used because no data has been published for 2024 and between 2022 and 2023 the value changed by 0.05%.

The percentage share is first converted into an absolute value in Euros. This requires multiplying the sector's share by the total GVA of the Dutch economy for 2024:

$$\text{ICT Sector GVA} = \text{Total Dutch GVA} \times \text{ICT \% Share} \tag{11}$$

According to CBS National Accounts, the total Gross Value Added at basic prices for the Netherlands in 2024 was approximately €1.007 trillion [37]. Which establishes the economic baseline for the Dutch ICT sector at approximately €53.19 billion. The global warming potential impact is then divided by GVA.

$$\text{Carbon Intensity} = \frac{\text{Environmental Impact of Sector (kg } CO_2 \text{ eq)}}{\text{Sector GVA (€)}} \tag{12}$$

This means that every €1 generated by the Dutch ICT sector corresponds to an impact of roughly 103.5 grams of $CO_2$ eq. The impacts of other sectors are shown in Table 11, using the data from CBS [38].

Table 11: Global Warming Potential comparison of the Dutch sectors by their contribution to Gross Value Added in 2024 [36; 38; 37]

| **Sector** | **Total GVA** (Billion €) | **Total Emissions** (Mton $CO_2$ eq) | **Carbon Intensity** (kg $CO_2$ eq / €) |
|---|---|---|---|
| Agriculture | 17.2 | 25.3 | 1.47 |
| Manufacturing | 129.4 | 46.8 | 0.36 |
| Transport & Storage | 53.9 | 28.8 | 0.53 |
| **ICT Sector** | **53.2** | **5.50** | **0.10** |
| Financial Services | 75.5 | 1.2 | 0.02 |
| Electricity | 14.5 | 20.1 | 1.39 |

Table 11 shows that ICT sector has a lower associated footprint compared to other sectors. It generates roughly the same economic value as the entire Transport sector (€53B) but with only one fifth of the carbon footprint. The manufacturing, transport and electricity sectors overlap with ICT emissions, so some double counting has occurred. This table also only accounts for four fifths of the Dutch footprint measured in Table 8, so it is not a complete comparison of every sector, the other emissions are categorized into smaller categories that either are not quantified with GVA or are counted as other.

## 4.4 Sensitivity Analysis

The extended sensitivity analysis can be found in Appendix B (subsection 8.2). The five key parameters tested for their sensitivity were: Device kWh per year, professional to personal split of devices, the impact of ADPe from using the CODDE database, the device lifespan

Table 12: Representation of the sensitivities in the data by selection of uncertainties and testing these for their influence on the total impact footprint.

| Sensitivity | GWP(%) | PM(%) | LU(%) | ADPf(%) | ADPe(%) | WU(%) |
|---|---|---|---|---|---|---|
| Device electricity+25% | 3.59 | 7.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| Device electricity-25% | -3.59 | -7.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| Device lifespan+0.5yrs | 4.81 | 5.44 | 7.39 | 3.32 | 7.19 | 6.22 |
| Device lifespan-0.5yrs | -4.20 | -4.71 | -6.87 | -3.28 | -6.48 | -6.11 |
| Pers/prof split +40% | 2.92 | 3.33 | 5.00 | 2.41 | 5.61 | 3.77 |
| Pers/prof split -25% | -1.83 | -2.08 | -3.13 | -1.50 | -3.51 | -2.35 |
| CODDE database | -0.91 | 0.06 | -9.90 | -0.90 | 9.54 | -0.13 |
| Server impacts +25% | 2.51 | 2.57 | 9.81 | 2.57 | 1.41 | 1.77 |
| Server impacts -25% | -2.51 | -2.57 | -9.81 | -2.57 | -1.41 | -1.77 |

and server configuration. These focus on tiers 1 and 3 as they are the biggest contributors. Figure 25 shows these boundaries relative to the calculated total values of the study in Table 12.

The sensitivity testing shows that the most uncertain results of the baseline are those of land use, particulate matter formation and Metal resource depletion.

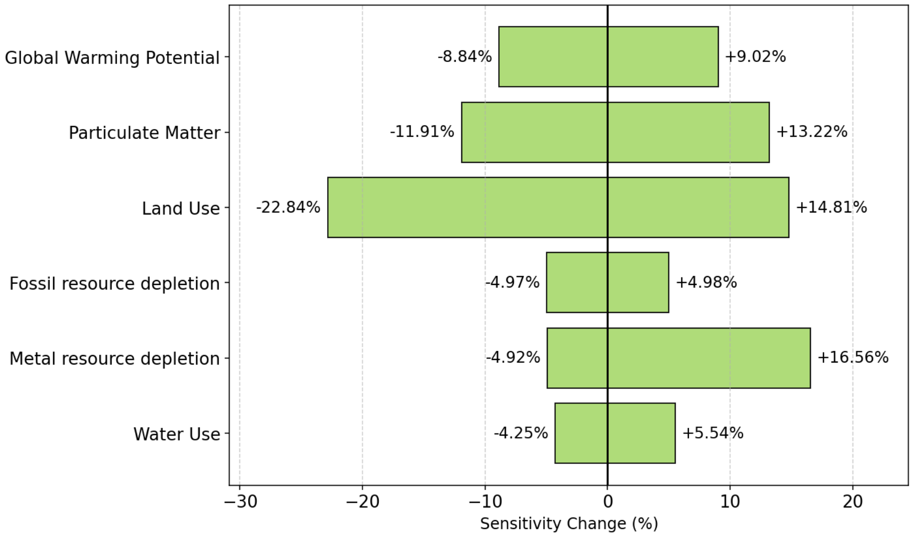


Figure 25: The cumulative effects of the sensitivity testing in Table 12 on each of the midpoint baseline results, the zero line represents the values found in Table 7.

## 4.5 Hotspot Identification

From the results of the study there are several hotspots that emerge. From the total baseline picture presented in Figure 15, there are four major standouts from the life cycle phases; Datacenter use, device production, device use and datacenter production. These four highlight the main contributions to ICT impacts. Together they make up over 98% of each of the midpoint impacts, with the exception of ADPe. Within these four hotspots, particularly on the production side of devices, it can also already be zoomed in on two of the bigger points, namely servers from datacenter production and televisions from device production. These two individual equipment pieces make up a significant contribution to their categories, with servers being more than 90% of the production share of datacenters.

The four key categories will therefore be the core focus in the following interventions section, section 5.

# 5 Interventions

With the baseline results, the next step is to identify the reasons for hotspots and what feasible interventions can be implemented to resolve their impacts.

## 5.1 Selection of Interventions

The hotspots identify where interventions are best needed but not which interventions are most qualified for selection. The selection of interventions was made on the basis of four criteria:

- **Feasibility to model:** Ability to find data which can reflect potential of the intervention.
- **Relevance of factor:** ICT sector current challenges.
- **Expected mitigation potential:** Solutions expected to have high potential.
- **Feasibility of implementation:** Solutions that are feasible for impact

This combination of criteria selects the interventions. The first criterion leads to the exclusion of solutions such as recycling, which has potential, but cannot be feasibly measured with the data of this study given the lack of a full LCI, this will be fully discussed later in section 6. The relevance of factors criteria dictates that interventions are relevant and stem from topics which are frequently discussed as challenges in the industry, specifically those at the datacenter level. Next, there is expected mitigation potential, where solutions expected to have effect are considered.

The fourth criteria goes hand in hand with the EZK action program. To be able to create impact it needs to be feasible. It is a greater challenge to change the behavior of 18 million users rather than the actions of approximately 200 datacenters. Given their equal share of some impacts in the baseline results, the centralization of datacenters means there is an easier pathway for large scale impact than through users. Ultimately, interventions should target the challenges presented in section 2 in Table 2 to have the biggest societal and economic impact along with environmental impact.

### Interventions

Five interventions have been mapped to show their potential against the baseline study results. These are: Lifetime extension, Streaming smaller, Improving datacenter utilization, Adjusting non-peak power procurement and Reuse of heat by datacenters. Each of their modeling methods is summarized in Table 13. The interventions will be described according to their **Impact** (in subsection 5.2 and subsection 5.3) and **Robustness** (in subsection 5.4).

Table 13: Overview of the selected interventions and their modeling method, summarized from subsection 3.7.

| **Intervention** | **Modeling method** |
|---|---|
| **Extension of lifespan** | Adding a 0.5 year lifetime expansion to every device |
| **Streaming smaller** | 1 hour screen time per day from TVs is converted to either a. Tablets or b. Laptops |
| **Improving datacenter utilization** | Improving server utilization average from 40% to 75% with the assumption that there is a 1 year shorter lifespan per server as a result. |
| **Adjusting non-peak power consumption** | Datacenters use less electricity, following a correlation with the AMS-IX daily electricity patterns |
| **Reuse of heat by datacenters** | Using heat related impacts as a negative input to the LCI |

## 5.2 At the Device Level

In looking for potential mitigation strategies, two key hotspots stand out. The first is the production phase outweighing any other life cycle stage, far more than what occurs in either other tiers (Figure 15). Second, is the use phase of devices, which primarily has a hotspot impact towards the formation of particulate matter and global warming potential. The fourth criterion of intervention selection limits the number of interventions feasible at a device level.

Looking at the production phase hotspot, the most valuable intervention is to extend the lifespan of devices to reduce the impact of their production annually. The other intervention tested by this model was the potential impact of streaming smaller, using a laptop or tablet in stead of a TV. The potential impact these interventions can have is shown in Figure 26 relative to the baseline values of Tier 1.

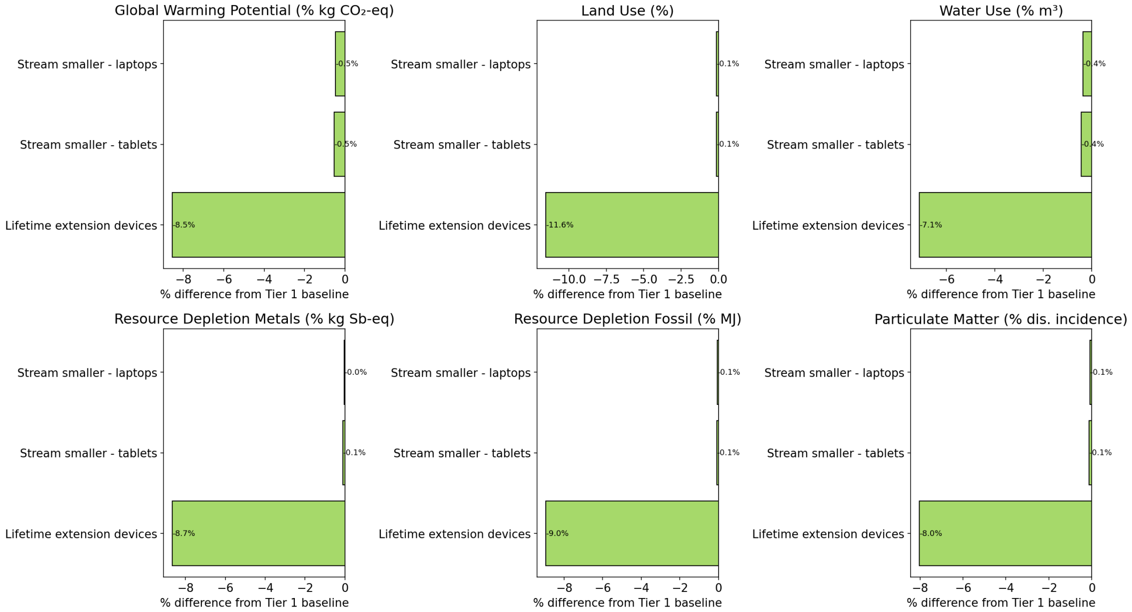


Figure 26: The three identified interventions compared by their potential improvement to the tier 1: end-user baseline impacts for each midpoint.

### Production phase interventions

The easiest intervention to identify is the **extension of the lifespan**. In order to reduce the impact of the production phase, it needs to become smaller either by allocation or by improved production. Improving production is a factor that The Netherlands has limited control over from the demand side. But, consumers can choose devices that have a lower production footprint or that last longer. A bigger impact on the production phase focuses on lifespan; a longer lifespan means the share of impact becomes smaller per year. This is a useful intervention as less hardware is consumed while providing the same access to ICT. It was modeled by increasing the average lifespan of each device by 0.5 years.

In Figure 26, this intervention has an impact on each of the midpoints. It reduces impacts between 7 and 12 % from the tier 1 baseline results. A 220,000 ton difference in $CO_2$ eq emissions results in a 8.5% decrease in Tier 1 related emissions, or a 4.2% decrease to the total national baseline. Also in midpoints such as land use, resource depletion and water use is the difference significant. The increased lifespan of 0.5 years for TVs accounts for 150 million m3 of water. Given that TVs are also not a battery operated device, their lifespan can be much longer before maintenance is needed, demonstrating large potential. Finally, devices make up over 70% of metal resource depletion impacts, these impacts are reduced by 8.7% showing the effect device lifetime can have on supply chain dependence.

### Use phase interventions

The next intervention at the device level, looks at the pattern displayed between the size of the device and the share of the life cycle stages (from Figure 18 and Figure 19). There is a direct correlation between **smaller devices and having a smaller use phase footprint relative to the total footprint**. Comparing the use phase of TVs to Laptops to tablets, this trend becomes clear. Streaming represents the biggest share of screen time of a TV. Mitigating the hotspot could, therefore, potentially be done through public action to use smaller devices, such as tablets or laptops, instead of TVs.

This was tested for both personal tablets and laptops, with the assumptions and methodology of modeling shown in subsection 3.7. Screen time affects the electricity usage of a device per year, hence targeting the use phase hotspot of devices. Replacing 1 hour of screen time from a TV per day with 1 hour of screen time per day on 1. A tablet and 2. A laptop was done to show the potential of feasible behavioral change.

These results have less impact, as shown in Figure 26, compared to the results of the lifetime expansion. The results of more screen time on smaller devices show a 0.5% difference in GWP impacts for tablets and a 0.47% difference in GWP impacts for laptops. These are the largest % based impacts from the midpoints. With this intervention, it would be expected that the number of televisions would decrease with new behavior over time, however, this was not accounted for in this study. The combined effects of this intervention, using two hours less screen time from a television, one to a tablet and one to a laptop is shown in Figure 29.

## 5.3 At the Datacenter Level

The datacenter results point directly to the use phase as the biggest contributor of the footprint of GWP, fossil resource depletion and particulate matter. The results show that the water use midpoint is insignificant for the use phase of datacenters compared to the production of devices and other equipment. This means that use phase targeting interventions should focus on reducing electricity use of datacenters.

Considering the feasibility of action against the footprint requires understanding of this electricity context. The easiest ratio of players to impact lies in the hyperscaler category, as earlier discussed in Table 5 in section 3; however, this is also the most challenging level to have impact in given the size of the companies and importance they know they have on the national economic domain. Interventions for hyperscalers may be harder to accomplish by this design, and hence, solutions will be more directed towards colocations.

The interventions tested for tier 3 look at the procurement of electricity for datacenters, the server utilization and the potential reuse of heat. The reuse of heat and procurement of electricity interventions focus only on the use phase hotspot. Improving server utilization focuses on both the production and use phase hotspots. The overview of the impacts of these interventions is shown in Figure 27.

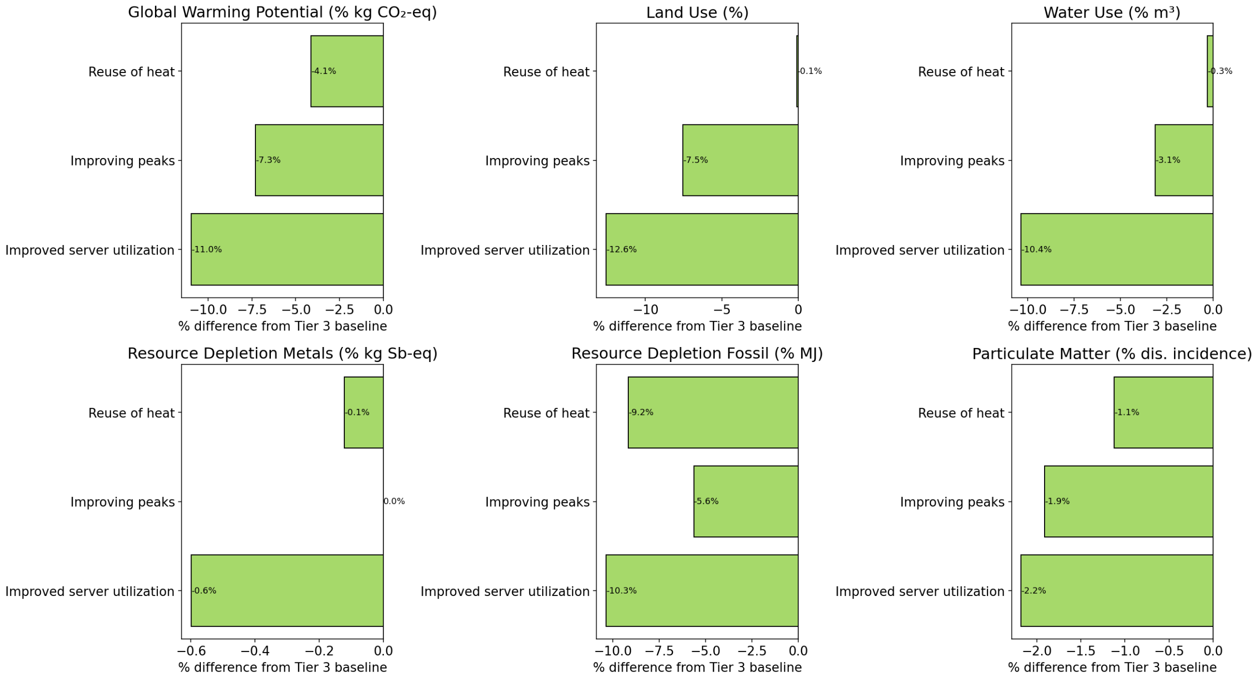
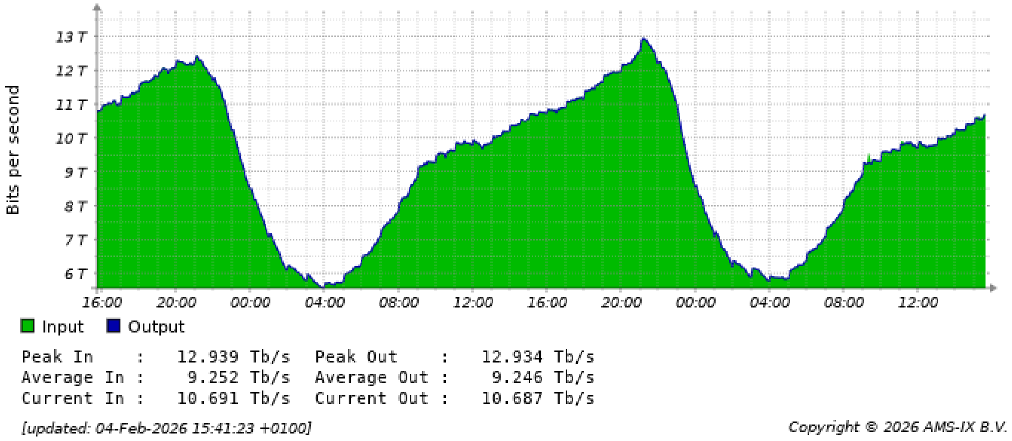


Figure 27: The three identified interventions compared by their potential improvement to the Tier 3: datacenters baseline impacts for each midpoint.

### Utilization

Within the IT equipment power (the 1 of the PUE) is not something typically covered for approaching change. This is due to the necessity of datacenters, whereby any electricity being used by servers is considered functional and therefore not needing further assessment. Colocation datacenters also do not investigate this number as the costs of this lie purely on the client side. Nevertheless, at the national level it is clear when looking at the AMS-IX data shown in Figure 28, the so called 'duck curve' is present. Internet activity, while never zero, has clear peaks in it. This same duck curve is not always reproduced by datacenters, meaning that some are currently using much more electricity where not always necessary.



```
Peak In    :   12.939 Tb/s  Peak Out    :   12.934 Tb/s
Average In :    9.252 Tb/s  Average Out :    9.246 Tb/s
Current In :   10.691 Tb/s  Current Out :   10.687 Tb/s
[updated: 04-Feb-2026 15:41:23 +0100]
```

Figure 28: The AMS-IX data reported on 4 February 14:00. This curve is repetitive over the total 24h cycle, with small differences in peak height and length [25].

This assumption of not all datacenters carrying out this power optimization is based on collaborations with datacenters that Zirrow had. When looking at energy saving potentials with their customers, with full access to their data Zirrow located this lack of power consumption difference throughout the day. An example of this is the use of Power Management Settings being prohibited by certain softwares. At most colocation datacenters clients are 100% responsible for their operation of their allocated power. They do not always need the amount of energy they are allocated but simply need to be able to allocate any peaks that might occur in their computer workload, resulting in them purchasing more power from the datacenter.

In subsection 3.7 it was calculated that a potential of 568.38 GWh of electricity per year would be saved if datacenters **better followed the duck curve with their use patterns**.

This effect only becomes visible at the national level, where this reduction in electricity usage offers a 3.1% reduction in the ICT climate change footprint. This is equivalent to 0.187 Mton of $CO_2$ eq. Otherwise, this intervention also has some effect in reducing the particulate matter, reducing its value by 1.24.

Another way to model the potential of utilization is a focus on it's percentage. This server utilization rate is typically low, commonly estimated at only 15–30% across the sector. Despite the servers not being in use, they continue to draw substantial amounts of power while idle, as these states still consume a significant portion of peak electricity use (30-60%). While this intervention cannot be directly derived from the baseline results, data from the EED supports this claim, as several companies filled in data about their utilization. These values ranged from 20% to 50% from the following EED reporting companies: Interconnect, Interxion Nederland, Equans, KLM, Radboud, ING and Previder BV. Other companies did not fill in this data [22].

The effects of **improving server utilization to 75%** can be measured using the model. The detailed methodology for this can be found in subsection 3.7. A very conservative value for server utilitization was taken as 40% for medium and low configuration servers. In addition, an assumption was made that a higher utilization reduces the life span of servers by 1 year; in subsection 3.7 this set of assumptions was calculated to have a potential reduction of 1.44 TWh electricity per year and 46% reduction of servers needed.

The results in Figure 27 show this intervention is the most impactful across the datacenter interventions. GWP is reduced by 274,000 ton $CO_2$ eq, which is 11% of the total tier 3 footprint. There is also a 10.3% reduction in the fossil resources used, a 10.4% decrease in water use and a 12.6% decrease in land use from the tier 3 baseline. The GWP, land use and fossil resource reductions are especially relevant for the total baseline, where tier 3 makes up over 40% of national impacts. This intervention only contributes minorly to reducing the impact of metal depletion, meaning better interventions are needed to address the hotspot of server production.

### Use of heat

In addition to excessive use of server electricity, looking at **using the excessive heat servers produce** is a different method to use resources more effectively. Almost all electrical energy used by servers ends up as heat physically. Moving electrons through processors and components creates resistance and this resistance releases energy as thermal output. In practice, over 95% of the electricity consumed by servers becomes waste heat [39; 40]. The calculations performed by the SDIA show that the total potential heat that can be reused by datacenters is 4.79 TWh of heat. The EED reports share that only 21 GWh of heat is currently being reused, making this intervention highly under-utilized. This intervention would also remove some of the pressure for solutions only on the demand side of electricity. The results of this intervention in Figure 27 show a potential decrease of 9.2% of fossil resources needed from the baseline of tier 3 and a 4.1% decrease from the GWP footprint of tier 3.

With each of the five interventions detailed and compared within their own tiers, they were also compared for their impact against the total baseline. This is shown in Figure 29. The stream smaller intervention combines both of the reduction impacts from tablets and laptops.

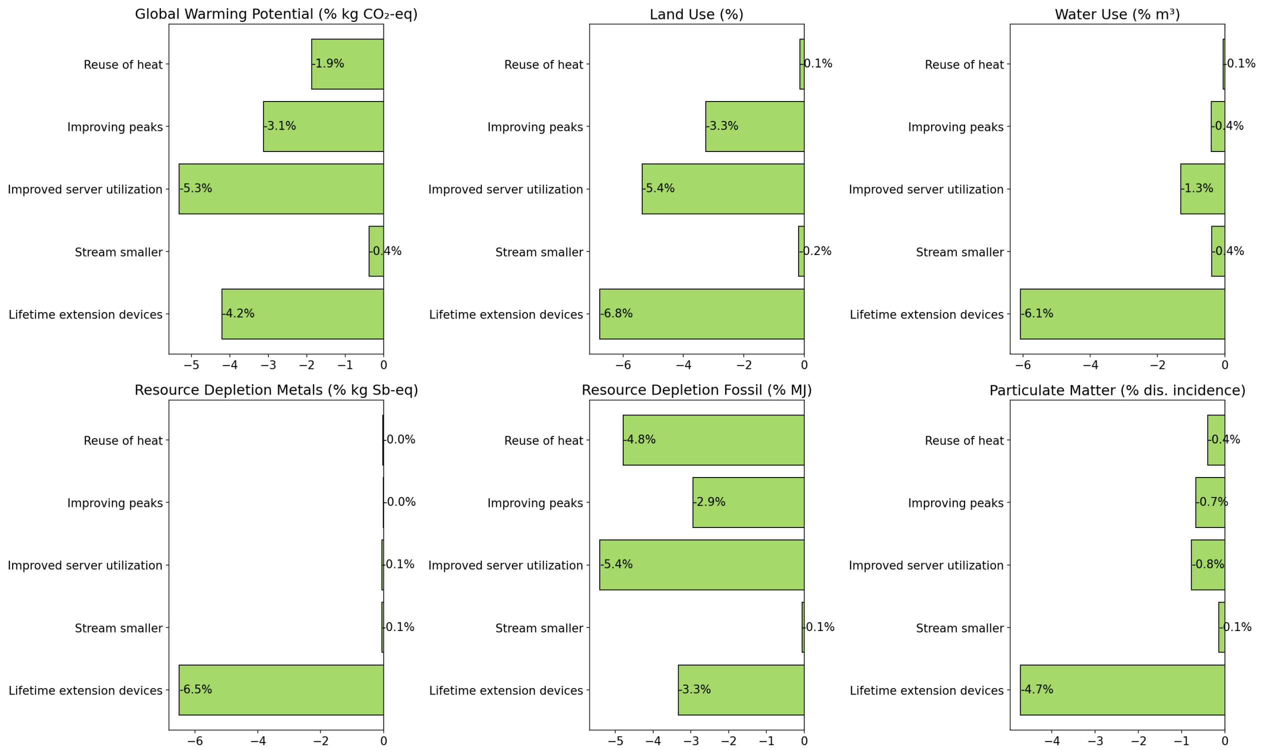


Figure 29: The five identified interventions compared by their potential improvement to the baseline impacts for each midpoint.

## 5.4 Robustness of the Interventions

Along with impactful, interventions need to be feasible and useful, irrespective of what happens in the coming 25 years in the dynamic field of ICT. In this study this combination of **feasible and useful** is defined as robustness, which reflects that an intervention is resilient to future changes. The future changes used to test this were external factors selected as the most uncertain and important to ICT and its dynamics. The selected factors are shown in Figure 30, which are derived from two drivers: policy and innovation. These factors influence the feasibility of an intervention and its efficacy. This determines how they will be quantified to compare robustness to impact in Figure 32.

The first driver is the political climate and attention towards sustainable digitalization. This holds significant power in measuring success at a national level. Attention towards sustainability is something that has fallen back in late 2024 after a spike of focus in early 2024. This time period introduced sustainable ICT at a higher level for the first time, an example being the upcoming regulation planning for digital product passports (DPP) including electronics as a priority. At the EU level, a focus on digitalization also stems from the dependence on American 'big tech' and how this dependence can be reduced [3]. Current policymaking of Dutch

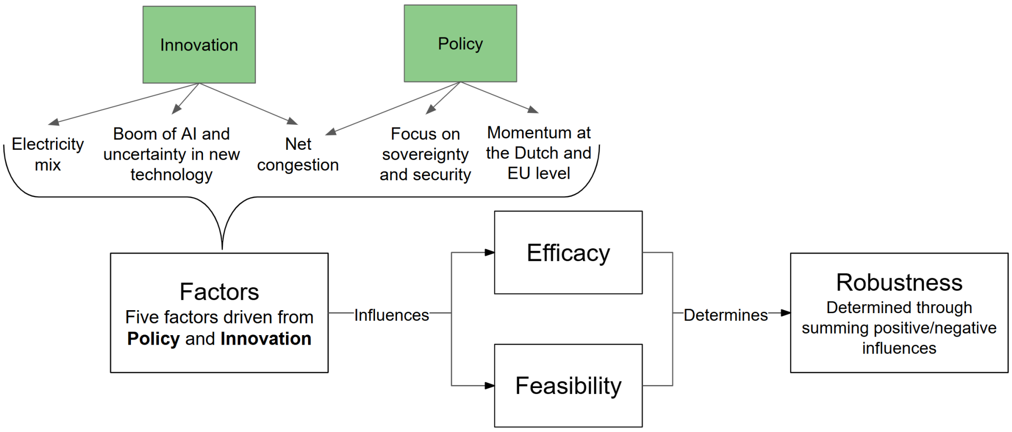


Figure 30: The flow chart of determining an intervention's robustness, this is determined for the interventions reactions to five factors derived from Innovation and Policy drivers.

ICT lies on sovereignty and safety, taking the forefront from sustainability in the ICT domain.

Innovation couples several different topics together for robustness of the interventions. These topics are net congestion, the electricity mix, and the uncertainty of ICT. Net congestion and the electricity mix are two factors that have some certainty in their solution but still highly depend on innovation to progress. The Netherlands currently has insufficient infrastructure to accommodate more connections at this moment. Grid operators expect this problem to resolve steadily from 2032 onward, but intermediary targets have not been met yet, indicating uncertainty [41]. The electricity mix is currently dependent on fluctuating renewable sources, keeping it more dependent on fossil resources compared to other EU countries. The final topic is the uncertainty of ICT with AI as a specific example.

Table 14: The expected change in efficacy (left) and feasibility (right) of each intervention as a result of each of the five factors.

| | Innovation | | | Policy | |
|---|---|---|---|---|---|
| Efficacy<br>Feasible | **Electricity mix becoming greener** | **Boom of AI or other new technology** | **Net Congestion** | **Focus on sovereignty and security** | **High level of momentum at EU level** |
| **Reuse of heat by datacenters** | −<br>− | +<br>+ | =<br>− | +<br>+ | +<br>+ |
| **Improving off-peak electricity purchased** | −<br>− | −<br>− | +<br>+ | =<br>= | +<br>+ |
| **Improved server utilization** | −<br>= | −<br>? | +<br>+ | −<br>− | +<br>+ |
| **Stream smaller** | =<br>− | =<br>− | =<br>= | =<br>− | =<br>+ |
| **Lifetime extension of devices** | =<br>= | =<br>? | =<br>= | +<br>+ | +<br>+ |

The estimated effect of each of these factors on the robustness is shown in Table 14, derived from the flow chart in Figure 30. The expected change in the efficacy and feasibility of each intervention is shown for each of the factors with a positive, negative, unknown or equal sign. These signs reflect the expected changes to the current intervention results (shown in Figure 29), meaning that an equal sign still shows relative robustness.

### Electricity mix

An innovation of the future is the greening of the Dutch electricity mix. Currently, the average Dutch electricity mix over a year produces 347 g$CO_2$ per kWh, much higher than an average green electricity mix which sits between 30 to 50 g$CO_2$ per kWh. Datacenters already claim to be using fully green electricity. If this were the case, their use phase share would make up a much smaller part of the total impacts. This is shown in Figure 31, where a 1.72 Mton reduction in $CO_2$ eq in the datacenter use phase makes the datacenter impacts much smaller.

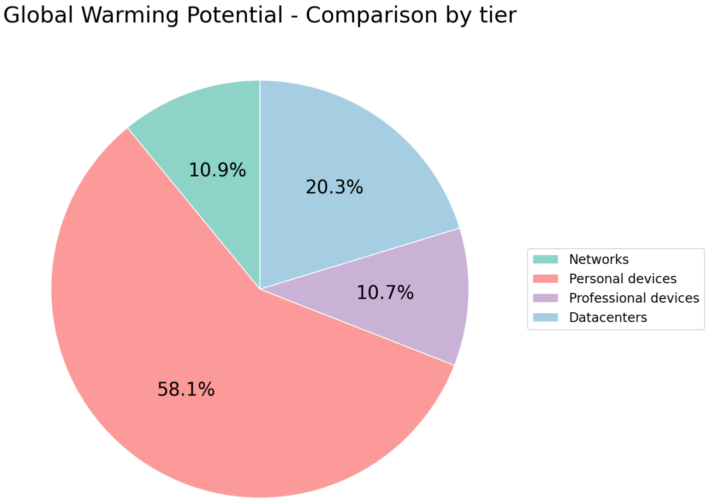


Figure 31: Global Warming Potential (% $CO_2$ eq) mapped for datacenters using as green electricity as they claim to be.

Many of the solutions proposed so far would become redundant with an abundance of green electricity. If The Netherlands can facilitate sufficient green electricity for datacenters, it would not be necessary to focus on changing their operation dynamics. Therefore, the efficacy indicators for datacenter interventions in Table 14 are all negative. However, given the need for green electricity in almost all industries in The Netherlands, it would still be worth implementing the recommendation to use less unnecessary electricity.

### Boom of AI or new technology

The rapid rise of AI, and the fact that ICT is a highly innovation dependent field means there is no certainty in how technology will look in 20 years. Although current projections assume stable or marginally increasing demand, AI workloads could dramatically change electricity needs. This uncertainty affects several interventions.

Both the interventions targeting end-user devices (tier 1) remain equally effective as they are largely unchanged. Their feasibility is less certain, however, because it is not clear how a growth in AI or new technology will change these patterns.

A 75% utilization target of servers may be unrealistic for AI systems since they require higher redundancy and availability, making this intervention less useful. Adjusting non-peak electricity consumption becomes weaker if AI inference workloads run continuously or shift toward more predictable 24/7 baseload patterns [42]. On the other hand, heat reuse becomes more robust, because AI systems generate higher amounts of thermal output, making continuous waste heat availability more useful and feasible for district heating systems [42].

### Net congestion

Net congestion represents a structural barrier to almost all datacenters currently. The electricity grid in the Netherlands is currently full in many regions, limiting the ability of datacenters to expand. The issues of net congestion persisting beyond 2032 means that interventions that rely on operational optimization, such as increasing server utilization or improving non peak electricity alignment, remain the most robust, because they do not require additional grid capacity and in the case of peak mitigation even improve the amount of electricity datacenters take from the grid if power supply and demand became more fluctuate. However, the feasibility of implementing heat reuse systems decreases as these systems also use a highly fragmented grid. The relative robustness of device level interventions remain equal, as they are independent of the electricity grid.

### Focus on sovereignty and security

Current Dutch policy discourse has shifted strongly toward technological sovereignty, digital resilience, and the strategic position of datacenters. This shift has two consequences for intervention robustness. Firstly, operational interventions at datacenters become harder to mandate. If uptime and security become the dominant policy priorities, datacenter operators may resist changes to utilization changes. Off-peak electricity changes would see little change in robustness. Secondly, hardware oriented interventions gain political support. Policies that extend device lifespan, promote repairability, or encourage procurement standards reduce dependence on foreign ICT supply chains.

### Momentum at the EU level

The final factor which is used to shape robustness is the degree of political momentum at the European level. This factor reflects a positive for all interventions. At the device level, EU legislation, such as the Ecodesign Regulation, the Right-to-Repair directive [43], and forthcoming Digital Product Passport (DPP) requirements [44] create a regulatory environment that supports interventions related to device lifespan, repairability, and transparency.

For datacenters, EU momentum around energy efficiency, measurement obligations, and reporting supports operational transparency, which ultimately leads to better set up of regulations. This better access to data supports the interventions proposed further, making them all more feasible to implement and more effective given wider scale application.

## 5.5 Impact and Robustness

This study identifies several intervention opportunities in devices and datacenters that could reduce the environmental footprint of ICT in the Netherlands. Figure 29 shows the impact of interventions compared to the baseline study. The interventions robustness was tested in Table 14 by looking at the interventions future feasibility and efficacy. The $CO_2$ reduction impacts and sum of the changes to efficacy and feasibility of robustness are shown in Figure 32, mapping out a balance between the two.

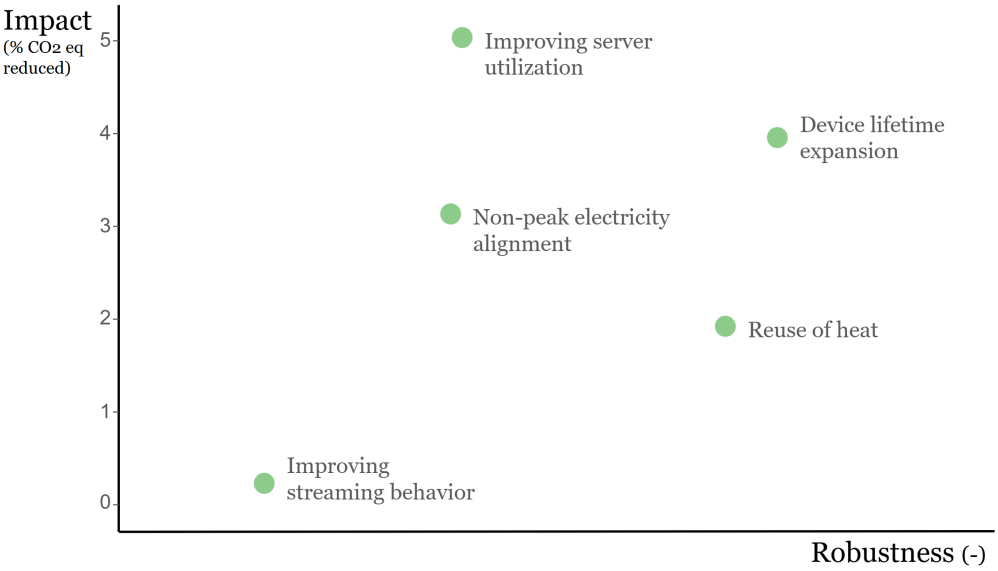


Figure 32: The expected robustness of a solution measured against its potential Global Warming Potential impact reduction from the baseline (% $CO_2$ eq)

This combined view of impact and robustness of each intervention shows that the most useful intervention is the extension of device lifetime. Literature consistently identifies the production phase of end-user electronics as the primary driver of environmental impact. This is also a key takeaway from both the Swiss and French studies, and has been identified by the German Environment Agency that hardware longevity is the most effective lever for mitigating the embodied emissions of the ICT sector [39]. Figure 32 supports these claims, as it is the highest combination of robust and impactful. In the datacenter interventions, the high impact of improving server utilization is a useful strategy identified by the International Energy Agency (IEA). The IEA highlights that energy proportionality in servers is currently low, meaning that servers consume a disproportionate amount of energy when idle; thus, increasing utilization to 75% is a recognized concept for decoupling digital growth from energy consumption or turning off servers to match the patterns of the AMS-IX point [45]. The potential for heat reuse to displace fossil fuel based heating in the Netherlands is also a well supported strategy both in the Netherlands and abroad. In the Netherlands it is highlighted as a missed opportunity by the SDIA [24] and one of the key ways currently known for datacenters to be greener [3]. This has gained greater traction in hyperscalers through the Open

Compute Project from Microsoft. This project argues that over 90% of datacenter electricity is recoverable as thermal energy [39] and should therefore be put to effective use.

# 6 Discussion

## 6.1 Data Uncertainty

Although this study required the use of several assumptions, these do not invalidate the dataset as a whole. However, they necessitate a transparent discussion regarding their influence on the final results. The most important and biggest uncertainties in inventory were explored in a sensitivity analysis, the results of which are shown in Figure 25 and is extensively shown in Appendix B (subsection 8.2).

There are three essential uncertainties in the inventory data. These are the electricity usage of devices, the configuration of servers and the ratio of personal to professional devices. There are more uncertainties that are less essential to the results of the study. The main uncertainty in inventory here is in the networks tier, where COAX equipment impacts were assumed to be equivalent to fiber equipment. The effects of these uncertainties was not modeled due to their lack of influence on the results.

Of the three main uncertainties, the largest uncertainty was caused by limited availability of server information, given that high quality input was received from only one datacenter. Testing the effects of this uncertainty resulted in a ±9.81% shift in Land Use, and a ±2.5% shift for GWP, PM and ADPf midpoints. Operational electricity consumption for end-user devices represents another key area of uncertainty. Usage patterns vary widely across households and workplaces, making an average difficult to quantify, especially for larger displays like televisions or items with high screen time in workplaces. Relying on a variety of online sources introduces higher variance into the results. Global warming potential values varied by ±3.59% and it had a more pronounced effect on Particulate Matter formation at ±7.26%. However, it is not fully explored whether this 25% difference is fair and not more for some larger devices. The split between personal and professional devices is also uncertain. This stems from no consideration of work-at-home devices. The results would expect a higher split between personal and professional devices. This change resulted in an uncertainty of the Land use and ADPe midpoints by 5%.

Based on the sensitivity analysis, it can be concluded that the impact analysis data is an uncertainty source alongside the inventory data. This was tested on datacenter servers, which already have high inventory uncertainty. Using the CODDE impact analysis data instead of Resilio for servers resulted in changes specifically to the metal resource depletion midpoint, 9.54% difference of value and a 9.90%. This uncertainty is reflected in the results, looking at Table 10 where this study has a much lower result compared to the others.

The results of sensitivity testing show that the most uncertain overall results are those of land use, particulate matter formation and metal resource depletion. The metal resource depletion is a key concern in the EZK action plan, making this a limitation of the report.

## 6.2 Limitations

These data uncertainties intersect with several methodological limitations and create several others. Without an extensive sensitivity analysis such as a Monte Carlo assessment, it is not possible to quantify whether there are other uncertainties that are greater and hold more influence over the final results than those mentioned in the previous section. Additionally, while individual parameters can be identified as uncertain, the cumulative effects remain unknown.

This study is limited by the databases it depends on, which required the use of proxies for some components that were not included in their data set, but more importantly requires dependence on methodologies they used, which were not fully tested in this study. The databases do share similar results when they overlapped for server data. However, as explored in the previous subsection, a difference of 9.54% was found in the metal resource depletion midpoint where between CODDE and Resilio. The choice between the two is dependent on data which is not shared, which leads to a core limitation being the lack of transparency in the LCI.

The lack of a LCI is the reason a Monte Carlo analysis cannot be done but also the reason a more detailed examination of CRMs was abandoned. While the study utilizes the metal resource depletion as a midpoint indicator, this remains a calculated proxy, normalizing all metals and minerals to Antimony (Sb), which cannot substitute for a full CRM mapping. This is further challenged by being one of the key data uncertainties given the differences of values between the different datasets. It also has limited some of the selection of interventions as detailed in the criteria for intervention in section 5.

Another limitation of the study is the selection of a hybrid approach. Ideally, Dutch ICT would reflect the consumption-based approach, looking only at what the Dutch population uses rather than what is also produced, which then highlights the exact responsibility of the use of ICT, which still carries embodied emissions. A separate look at the production-based approach of datacenters is still useful to policymakers given the territorial boundaries of influence. However, a hybrid approach makes it challenging to compare to other Dutch industries. In addition, it can have some attribution overlaps or gaps, but these cannot be located.

## 6.3 Reusability of Results

Although the results of this baseline are specific to the Dutch ICT landscape, they continue to build using the same hybrid LCA methodological approach used in France and Switzerland. The Netherlands therefore becomes the third country that can be used as a reference point in the European digital landscape. Comparing the results of this study to those done in France and Switzerland shows that The Netherlands is much more closely aligned with France, sharing an almost identical split between the three categories from a carbon footprint perspective. This supports the knowledge that both France and The Netherlands are both datacenter hub countries in Europe. The electricity mix in section 5 also demonstrates the effect of greener electricity on the total picture, showing that with a greener electricity mix the Netherlands matches Switzerland's pattern.

The reusability of results also considers the long term monitoring plans of the EZK as mentioned in the action program [3], this study proposes a foundation for this monitoring of the Dutch digital sector which will be carried out by the Netherlands Enterprise Agency (RVO). There are several qualities which make it suitable as the basis for this dashboard. Unlike existing Dutch monitoring efforts, this study includes scope 3 impacts, which are incredibly relevant for ICT, as highlighted by the difference found between the study done by Dialogic [14] and this study. Second, the methodological framework includes partners willing to share data about their own processes. Third, the approach follows the results of Switzerland and France, providing a baseline comparison to other countries given the same methodology applied.

## 6.4 The Triple Bottom Line and Governance

The findings of this study highlight a persistent discrepancy between the ideal data landscape for sustainable digitalization and the current situation as described in section 2. The focus of the study is on the environmental domain of ICT; quantifying it and proposing solutions to reduce the larger impacts. Looking at the challenges present in the problem definition, defined in Table 2, the challenges ICT faces are interlinked with social and economic factors. The scope of the study isolates the environmental domain, but from the results and interventions, the question arises of *whether the Netherlands can maintain its social and economic digital maturity if it enforces interventions which are necessary to meet climate targets?*

For example, in the intervention extending device lifetime, if a device can no longer update given that the software is no longer compatible with an older model, users are encouraged to inevitably purchase new devices. This places pressure on the social domain of sustainability as a trade-off of more environmentally conscious behavior. Furthermore, the utilization improvement intervention suggests a shift towards a 75% target from 15-40%. This would significantly reduce the energy and material footprint of datacenters. However, this reduces the redundancy buffer that exists. In a high-utilization scenario, the Netherlands, which is a premier European connectivity hub, might face increases in latency during peak traffic at the AMS-IX, placing pressure on the economic sector as it is highly dependent on ICT [2]. Some of the overarching trade-offs that exist in making choices regarding social and economic factors are shown in Table 15.

The trade-offs presented in Table 15 follow extreme examples of outcomes, as no full analysis has been done in this study. Generally, extending the average device lifespan by 0.5 years will not result in the device being completely unsuitable for software updates. Neither will improving the average utilization of servers result in large latency issues in day to day internet users. However, these changes will on average need to come with some acceptance of an average slightly lower quality than what currently exists.

The power which Dutch policymakers do have only exists in finding whats best for these trade-offs. Otherwise, the development of greener solutions needs to come from not only the Netherlands, but stem from the ICT companies themselves, such as Apple, Google, Microsoft, HP, etc. who provide a lot of the overarching context of ICT in the Netherlands. The issues of sovereignty of ICT therefore also bring an environmental sustainability aspect with them for

Table 15: Examples of social and economic trade-offs that could occur with implementing interventions for environmental sustainability.

| **Sustainability Pillar** | **Performance Trade-off** | **Long term Gain** |
|---|---|---|
| **Economic** | Placing regulatory pressure on 'big tech' datacenters could result in them going elsewhere or potentially slower hardware turnover in professional sectors means lower quality outputs | Slow decoupling digital growth from global resource volatility and rising energy prices. |
| **Social** | Potential for higher latency and worse customer experience of devices built to last longer | Improved environmental justice by reducing the 47.1% GHG share primarily outsourced to global production. |

the Dutch dependence on them. To achieve the 14.9% potential $CO_2$ eq reduction identified in this study, the Netherlands must leverage its position as a digital leader to demand greater transparency and collaboration standards at the EU level.

# 7 Recommendations

Many of the interventions identified in this study are known within their specific sector, as literature has shown. However, translating these actionable interventions to policymakers has so far been insufficient in achieving goals set in their action programs. The value this study provides is a centralized point of actions built on data. This data quantifies the environmental picture of ICT in a baseline and quantifies solutions based on their reduction potential. This can be summarized in the following five key recommendations.

### Prioritize Device Lifespan Extension

The most impactful and feasible intervention is to extend the lifespan of end-user devices, which directly reduces the annual production burden. Increasing device lifespan by just 0.5 years yields substantial reductions across all midpoints for both personal and professional ICT. In Figure 32 it is the highest combination of robust and impactful.

Lifespan extension is also an expected outcome of this study, regulation already looks to better implement right to repair policies, availability of spare parts, longer software support, and incentives for repair or refurbishment. Additionally, extending warranties on devices, especially those that do not need batteries, such as TVs, can also incentivize users to continue use. These actions should be prioritized by policy makers for the most impact across midpoints.

### Improved reporting from Datacenters

One of the simplest methods to improve datacenter operation is collecting data which is more relevant to electricity use. The interventions proposed in this study are in part supported by data and in part by assumptions about the data. By altering which reporting metrics are gathered in the EED, better insights can be gained such as data about utilization or daytime use patterns. These two specific metrics show whether direct action is necessary in a datacenter which can have major impacts for improvement. Datacenter utilization is already listed in the EED reporting, with the further enforcement of filling in the EED next year, this metric visibility could already improve.

### Utilization

With better utilization insights from improved reporting, there will also be more incentives to tackle the issues of low utilization. One example of solutions that exist to improve utilization is the power management settings, which can be used to reduce power consumption during idle time. Datacenters striving to better match the duck curve traffic patterns and utilization patterns are useful intervention methods to improve the electricity and hardware use of datacenters, especially for colocation and hyperscale datacenters.

### Reuse heat from datacenters

Not only is the input into equipment essential, but also utilizing the waste products from datacenters is a robust solution. Reusing waste heat from servers is an impactful and robust way to use the flaws in server design. This will only become more useful with the expansion of AI and heavy workload servers, which produce more heat.

**Change Power Allocations**

Finally, power allocation mechanisms must evolve to better reflect real world usage patterns. Dynamic rightsizing is the effective manner in which this can be tackled. This study looked at the potential for electricity reduction by better following the daily patterns of AMS-IX internet traffic. This electricity can be used elsewhere, supporting the net congestion problem while also reducing the footprint associated with datacenters, making this a favorable solution to contribute to multiple problems.

Finally, EZK should continue to monitor the impacts of ICT to have access to a feedback loop. This is currently in the hands of the RVO, who are responsible for the development of a national monitor for sustainable digitalization. By consistently identifying where hotspots lie and which interventions have the most impact, this framework can provide concrete and actionable input for policymakers at EZK. Continued transparency, data sharing, and stakeholder collaboration is needed to improve future iterations of the baseline and ensure that ICT contributes to a sustainable and resilient digital society.

## 7.1 Future Work

This study establishes a foundational environmental baseline for Dutch ICT in 2024, but it also reveals several opportunities for further research based on its shortcomings as highlighted in section 6. A key direction for future research lies in strengthening data transparency of datacenters. The EED reporting is set to become stricter in 2026. With improved reporting from datacenters, not only will the baseline data quality improve, but also the potential from the interventions. Furthermore, future work should include insights for server configuration from several datacenters rather than only one to improve the quality of the impacts related to the datacenter production life cycle phase.

A second area for future development concerns the Life Cycle Inventory (LCI) itself. As mentioned in the limitations, this prevented further exploration of interventions and useful insights to the ministry EZK. Including a full LCI would enable a more detailed examination of supply chain impacts, particularly those centered around CRMs. Future work should center more around the physical waste of ICT including CRM recycling and reuse. A full LCI would also enable proper sensitivity testing, which could be done through a Monte Carlo analysis. Beyond improving the modeling itself, the evaluation framework for interventions requires further expansion. Robustness analysis provides a useful starting point, but future work should integrate economic and social dimensions.

In addition to improvements to this work, additional work should also explore a purely consumption-based perspective for ICT in the Netherlands, especially for datacenters. The baseline presented here follows a production-based perspective for datacenters, attributing all impacts of Dutch datacenters to the national footprint regardless of where processed data is consumed. As international data flows continue to grow, particularly due to AI workloads and global cloud services, a parallel consumption-based perspective would provide valuable insights on fair responsibility allocation. Developing a methodology to distinguish between domestically consumed and internationally exported digital services will therefore be an important piece of future work. This also better enables interventions targeted at users as it becomes easier to attribute.

Furthermore, a study towards a prospective LCA would be a more useful tool in evaluating forecasting. For example, the demands on circularity and recycling sides, but also looking at the effects of implementing 6G. By aligning long term scenarios with Dutch and EU targets, the model could provide insights into whether projected developments remain within national carbon budgets or circularity pathways, and where corrections may be needed.

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# 8 Appendicies

## 8.1 Appendix A: Life Cycle Inventory Calculations

This section outlines the methodological approach used to calculate the inventory for ICT equipment, network infrastructure, and data centers in the Netherlands.

### Tier 1: End-user devices

**Demographics baseline**
Dutch Population, numbers of households and businesses were extracted directly from CBS [46], these are found in subsection 3.4. These values were used in combination with adoption rates to calculate number of total devices with different assumptions made at each step. This will be explained throughout the current section. These numbers were extracted from the reporting done at the end of 2024.

**Smartphones**
Smartphones are both a work and personal device. The calculation of total smartphones shares a direct link to the amount of subscriptions active for mobile data usage. There were 23.31 million mobile data connections established to smartphones in 2024 [20]. Two main considerations were taken into account with adjusting this number to find the number of phones. Firstly, the number of Dual Sim phones in The Netherlands was subtracted (-10.3%) [47]. Sequentially, this number was multiplied by the 1.5% of users who use a phone but do not have a connection to the mobile network [48]. This number equals 21131990 phones. This number estimates that users above the age of 12 have an average of 1.34 phones, which is similar to other numbers found [49]. These 0.34 phones were attributed to being used for professional use.

Smartphone were categorized in two ways, OLED and LCD screens, which has effects on the production phase of the product. This split is assumed to be 60 to 40 percent according to ADEME reporting in France. This same principle was assumed to carry over into The Netherlands, with OLED screens being mid-range and accounting for 60% and LCD being generic and counting for 40% of both professional and personal device counts [32].

Smartphones have been assumed to have an average lifespan of 2.5 years. Energy consumption is calculated based on a daily full charge of a typical battery which is approximately 3.4W. This results in an estimated energy consumption of 2.48 kWh/unit/year [50]. This value is used for both device types. The total quantities of smartphones and types is shown in Table 16.

**Tablets**
The number of tablets was first calculated through the adoption rates of CBS [48]. This estimated 47.8% of the population owned a tablet above the age of 12. This results in 7421224 tablets for personal use in the population. This was derived into a split of size using ADEME numbers, the totals are shown in Table 17. For the professional number of tablets in use, 16% of employees use tablets according to the CBS data about ICT in companies, an additional

Table 16: Allocation of smartphones by type of smartphone and personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| Generic smartphone | 6,189,617 | 2,263,179 |
| Smartphone mid-range | 9,284,426 | 3,394,768 |

3% was added to account for excess, these tablet counts are also available in Table 17.

Tablets have a lifespan on average of 4 years. Energy consumption is calculated based on a daily full charge of a typical battery which is approximately 4.4W. For the larger tablets, this value is 5.5W for larger tablets. This results in an estimated energy consumption of 3.12 kWh/unit/year for the generic tablet and 6.80 kWh/unit/year for the higher range tablet [51].

Table 17: Allocation of tablets by type of tablet screen and personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| Tablets | 5,105,623 | 1,378,000 |
| Tablets mid-range | 2,315,601 | 620,000 |

**Laptops**
The total stock of laptops is derived by applying device adoption rates to population figures. This produces an estimated 6785200 laptops. The types of laptops are found by splitting in types of devices owned by applying ADEME's distribution of device classes, shown in Table 18. The similar split was applied for professional laptops, but without gaming laptops, this share goes towards mid range. Majority of major company employees have laptops, but its a much lower rate for companies with less than 50 employees. The total estimated number of laptops based on the CBS data is 3101100 laptops [52].

The lifespan of each type of laptop was assumed to be the same at 5 years. The power consumption changed slightly due to the processing power of a laptop compared to a mid range or gaming laptop. This was 21.56 kWh/unit/year. But with a higher number of cores this consumes more power during use, estimated at 30.60 kWh/unit/year [53].

Table 18: Allocation of laptops by type of laptop and personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| Laptops | 3,947,000 | 2,398,800 |
| Laptops mid-range | 2,405,400 | 702,300 |
| Laptops gaming | 432,800 | - |

**Desktops**
The total number of desktops is based on the adoption rate of 35.1% in 2024 for households, given that they are typically shared devices. These are divided into entry-level, mid-range,

and gaming systems using Resilio's classification logic, which is shown in Table 19. The latter category is further cross-checked using Statista market forecast data [54]. For professional devices, these were once again calculated through Statista's data [54]. Desktops have seen a sharp decline, resulting in only 104723 units being counted. Presumably some home devices are also used professionally for one or two person businesses.

Desktops use different amounts of electricity depending on their type. Gaming desktops are the most advanced and therefore, use the most electricity. Their total kWh per year is also based on 2 hours more screen time for personal devices, assuming people who game on them have a higher average screen time. Through data published by Coolblue, their total kWh/unit/year is 68.65, 87.6 and 138.0 accordingly. Work desktops sit on the higher end, assumed to all use the average of 138 kWh/unit/year.

Table 19: Allocation of desktops by type of desktop and personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| Desktops | 1,310,326 | 104,723 |
| Desktops mid range | 688,477 | - |
| Desktops gaming | 222,089 | - |

**Small Screens (IoT Displays)**
Small screens for smart IoT displays, are taken directly from CBS adoption rates on small IoT device adoption. This stock is calculated as 1,842,280 devices.

These small screens do not use large amounts of power, also because they spend long portions of time in idle mode. Their power draw is assumed to be similar to a landline phone at 0.6W, which total amounts to 5.2 kWh/unit/year given them being continuously on but in idle mode.

**Monitors**
Monitor stock is calculated with the assumption that each desktop has an additional 0.72 additional monitor screens in addition to 300000 extra monitors from averaging weighted waste data from the WEEE. The professional devices were derived from CBS, with monitors gaining popularity in the decline from desktops.

Assuming the average monitor is an energy label C monitor to cover the representation of range A to F as fairly as possible, the power consumption per device per year is taken as 18.6 kWh/unit/year, with the device being on for 4 hours per day. This value is doubled to 8 hours per day for work devices following the assumption that employees use these devices for their 8 hour work day [55].

**Speakers**
Speaker stock is estimated using Statista adoption rates. This found that 16.8% of the Dutch population own a speaker [56]. Given that waste reports based on weight share very different quantities, it it difficult to assume a fair value [57]. Averaging the two results and selecting a weight of 250 grams per speaker, the national stock was assumed to be 5,715,039 speakers.

Table 20: Allocation of monitors by personal versus professional devices and the differences in electricity use.

| | Personal devices | Professional devices |
|---|---|---|
| Monitors | 1,066,028 | 1,358,667 |
| Energy use per monitor (kWh) | 18.6 | 37.2 |

Assuming the average speaker draws approximately 8 W. Speakers are calculated to use an average of 5.05 kWh per unit per year based on 12 hours of use per week (one battery cycle).

**Printers**

Personal printer ownership is derived entirely from Statista's Dutch market adoption figures, yielding 414,611 printers [58]. The 2.3% adoption rate was multiplied with the population. This was also done for businesses over 20 employees, with an increased multiplication factors for every 100 employees. No distinction was made between the type of printer, but professional printers, presumably being larger, their environmental impact per printer was multiplied by 1.6 to account for this difference.

Depending of the type of printer, its lifespan can be from 3-5 years if its an inkjet printer or 5-7 years if it is a laser printer. Taking the average of these two results in a 5 year lifespan. Its power use can be calculated by its standby (2W) and active use (40W) averages. Assuming a printer is active for 15 minutes per week and in standby mode for the rest of the time, this equals to 17.08 kWh/unit/year [59].

Table 21: Allocation of printers by personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| Printers | 414,611 | 641,876 |

**Routers**

The total number of routers is calculated by equating them with households with fixed-line internet subscriptions, based on CBS data. This results in 8,206,916 routers, which was averaged with the values reported by ACM (8,370,000) to calculate a total of 8,288,458 routers. Professional routers were estimated for every company above 10 people which uses Wifi. This means that many professional routers also appear under personal due to companies with fewer employees working from home set-ups.

Vodafone and KPN typically report replacing equipment after 7 years, making the average lifespan 7 years for this equipment. The average power use of the equipment is around 6W. When multiplied by 24 hours in a day by 365 days in a year, this comes out to 52.56 kWh/unit/year [60].

**TV-boxes**

Table 22: Allocation of routers by personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| Routers | 8,288,458 | 38,120 |

ACM data on cable technologies reports total TV cable connections, which is assumed to be directly proportional to TV-box ownership, this equates to 6,880,000 units.

TV-boxes are comparable equipment to internet boxes with regards to lifespan. According to sources in 2020 which compared energy usage of TV-boxes per operator, these values could range between 20 and 260 kWh in a year. Although these devices have improved, Eneco stated in 2025 that this range is still on average between 30 and 130 kWh per year. Using the data from 2020 and comparing to the number of connections per operator, the found average per year is 96 kWh/unit. Adjusting this value for an improvement of 35% based on the improving technologies and lower range of Eneco's source finds a value of 62.4 kWh/unit/year [61] [62].

**TVs**

TVs were categorized into 4 different categories in this study. These are: non-smart TVs and three different size categories of smart TVs (small less that 28 inch, medium between 30 and 45 inch and large greater than 48 inch). Non-smart TVs are estimated by subtracting smart-TV adoption from total TV box numbers, producing 1,185,405 non-smart TVs. This assumes all smart-TV households use a cable TV box. Smart TVs are calculated by a 63% adoption rate and multiplied by 1.14 times the number of households for the number of TVs per households. They are categorized by size, which is taken from TNO survey data. In addition they each have different power draws depending on size. These are drawn from [63].

Table 23: Allocation of TVs by types of TV and personal versus professional devices.

| | Personal devices | Professional devices |
|---|---|---|
| non smart TVs | 1,185,405 | - |
| Small smart TVs | 797,243 | - |
| Medium smart TVs | 3,986,216 | 754,355 |
| Large smart TVs | 911,135 | 303,920 |

### Tier 2: Networks

With the prerequisite knowledge of the market dynamics, the following specific calculations were made per item of equipment.

**DSLAM**

A DSLAM, or Digital Subscriber Line Access Multiplexer, aggregates copper-based DSL subscriber lines and transfers the traffic to the access network. It is located in street cabinets, and assumed to be able to connect 800 users. This estimates the equipment count to be 2,320 units accounting for the number of subscribers to the xDSL network [20].

**Optical fiber (576-strands)**
A 576-strand optical fiber cable is used where large wavelength bundles are aggregated. The total estimated cable length is 16,125 km estimated from scaling the input of data from one of the major three network operators in The Netherlands according to their share of the fixed network.

**Optical fiber (12-strands)**
A 12-strand optical fiber cable is assumed to make up the majority of the network. The total estimated cable length is 1,433,800 km, which is accounting for cables used across all three types of fixed networks. This value was estimated from scaling the input of data from one of the major three network operators in The Netherlands according to their share of the fixed network.

**Collection router**
A collection router aggregates traffic from access devices (DSLAMs, OLTs) into higher transport layers and are positioned in metro aggregation nodes. The total estimated equipment count is 384 units, estimated from scaling the input of data from one of the major three network operators in The Netherlands according to their share of the fixed network.

**IAD**
An IAD, or Integrated Access Device with ONT/SFP capability, is a customer-premises device providing routing and optical termination at the end user's home or business. The total estimated equipment count is 8,288,458 units, one for every fixed network user.

**OLT**
An OLT, or Optical Line Termination, serves as the central office endpoint of the fiber optic fixed network. It resides in local exchanges sites. The total estimated equipment count is 3,600 units, this was determined from the public information avaliable from KPN and scaling according to their share of the fixed network [64].

**ONT**
An ONT, or Optical Network Termination, is the subscriber side equipment which connects user to the fiber optic network. The total estimated equipment count is 6,400,000 units, based on the aggregate of homes connected to fiber optics and COAX.

**Aggregation WDM**
An aggregation WDM (Wavelength Division Multiplexing) system multiplexes wavelengths at the metro layer, combining access flows onto backbone fibers. The total estimated equipment count is 224 units based on scaling the input of data from one of the major three network operators in The Netherlands according to their share of the fixed network. KPN also shares that they have approximately 100 of these metro later sites, further verifying this number without adapting it [64].

### Backbone WDM

A backbone WDM platform provides high-capacity multiplexing and transport within the metro core and backbone. The total estimated equipment count is 48 units based on scaling the input of data from one of the major three network operators in The Netherlands according to their share of the fixed network.

### P-PE router

A P-PE router, or Provider-Edge peering router, interconnects the ISP network with external networks and IXPs. It sits at the network edge and interconnect points. As a high up piece of equipment, the total estimated equipment count is 96 units based on

### Electricity consumption (fixed network)

Electricity consumption for active equipment across the fixed network is estimated by the reported values from all three of the major network operators. Here the total values are published in each of their year reports. Vodafone Ziggo provides a more detailed breakdown, attributing the percentages towards fixed and mobile. They reported 30% of their electricity consumption goes towards the fixed network and 35% towards the mobile network. Assuming this share shifts with the market % numbers in Table 4 the total consumption is 319,355 MWh.

### Passive multiband antenna

Moving onto the mobile network, the first major equipment piece is the antennas. An antenna is a radio access component which needs to be mounted high up on mobile towers or rooftop sites. It enables the entire mobile network and, through frequency bands determines the type of mobile network available at a point (2G–5G). The total estimated equipment count is 165,536 units based on the antenna register and the fact that each antenna point registered has three antennas. This is because one antenna only captures an angle of 120 degrees, requiring three to fully capture the area [65].

### BBU

A BBU, or Baseband Unit, handles radio baseband processing. It is co-located with the antenna system, making the total estimate equal to the amount of antenna sites. The total estimated equipment count is 55,179 units [65].

### Collection router (mobile network)

A mobile collection router aggregates traffic from antennas towards the mobile transport network. It is installed in mobile aggregation hubs and metro Points of presence. The total estimated equipment count is 4000 units, based on the scaled quantities reported from KPN (1200) [64].

### Aggregation router (mobile network)

Both router pieces have some overlap with those presented earlier in the fixed network equipment. This equipment is located in the backbone and therefore often does share overlap. An aggregation router in the mobile network handles intermediate transport between antennas and the core, deployed in metro transport nodes. The total estimated equipment count is 533 units based on publishing of KPN, scaled to the entire market share (160).

**Aggregation WDM (mobile network)**

A mobile aggregation Wavelength Division Multiplexing system multiplexes wavelengths for mobile backhaul and midhaul, located in metro and regional optical sites. The total estimated equipment count is 533 units based on publishing of KPN, scaled to the entire market share (160).

**Security gateway**

A mobile network security gateway provides encryption, tunneling, and authentication for mobile traffic and is located in datacenters. The total estimated equipment count is 191 units, for the number of Dutch datacenters.

**SP-GW / GGSN**

An SP-GW (Serving/PDN Gateway) or GGSN (legacy equivalent) anchors mobile packet data sessions. It is located centrally in the datacenters. The total estimated equipment count is 191 units, for the number of Dutch datacenters.

**MME / SGSN**

An MME/SGSN, or Mobility Management Entity / Serving GPRS Support Node, handles control of the plane mobility and session management within the mobile core. It is found in mobile core buildings. Using the KPN reported value of 160 as extrapolation for a total of 533 units [64].

**Backbone WDM (mobile network)**

A backbone WDM system for mobile transport provides multiplexing for long haul and regional connectivity. It is located in core transmission sites. No estimation could be made for the mobile network based on data. Therefore, it was assumed this value is equal to the fixed network with 48 units.

**P-PE router (mobile network)**

A mobile P-PE router connects the mobile core to external networks, content providers, and peering points. It resides in datacenters and interconnection facilities. The total estimated equipment count is 221 units, for the number of Dutch datacenters and assuming an additional extra 30 connections due to the equipment's function.

**Optical fiber**

A 12-strand optical fiber cable was used to model the supporting cable infrastructure and backbone connected to the mobile network. The total estimated cable length is 315,000 km based on scaling the input of data from one of the major three network operators in The Netherlands according to their share of the mobile network.

**Electricity consumption (mobile network)**

Electricity consumption for the mobile network was estimated for the entire Netherlands based on the VodafoneZiggo year report in 2024. Similar to the method used for the fixed network, the total reported values from the network operators were in their 2024 year reports.

Assuming this share shifts with the market % numbers in Table 4, the total consumption is 381,890 MWh for the mobile network.

### Tier 3: Data Centers

The context of datacenters to calculate these assumptions is found in the main body in section 3.

**Total Computer Floor Area**

The total computer floor area in Dutch data centers is calculated at 756,000 $\mathrm{m}^2$. This figure is derived from the Energy Efficiency Directive (EED) reports which accounted for 577,195 $\mathrm{m}^2$, and was calculated by Leitmotiv to account for missing to account for data centers that did not report their data. This total area serves as the foundational metric for estimating the quantities of infrastructure [22] [24].

**Servers**

The quantity of servers is essential for quantifying the ICT footprint of datacenters. This is also because there is little publicly available information shared about servers. Hyperscalers only share their PUE. Colocation datacenters on the other hand have no knowledge of their server quantities, since majority of these arrangements are left to the clients. Enterprise datacenters often are so small that they do not need to publicly share any information on their datacenters [22].

The area of datacenter space serves as a good basis for estimating the server count. A simplified equation for this calculation is as follows:

$$\text{Number of servers} = A_{\text{DC}} \times \frac{\text{load rate}}{S_{\text{rack}}} \times \frac{U_{\text{rack}}}{U_{\text{server}}} \tag{13}$$

This equation calculates based on the area of a data center ($A_{DC}$), the loading rate of a full rack (load rate), the surface area of one rack ($S_{\text{rack}}$), the number of units in one rack ($U_{\text{rack}}$) and the average units one server takes up in a rack ($U_{\text{server}}$). This estimate was calculated using a load rate of 80%, the surface area of a rack being $4m^2$, the standard rack size of 42U and the average space per server to be 5U (accounting also for empty space the server takes to cool). These estimates come from the SDIA and Resilio [66]. Combined with the scaled calculation for area being 756,000 $\mathrm{m}^2$, the calculated number of servers is found to be 1,270,080.

Server configuration is highly important in combination with the server count. The key server components are SSDs (Solid State Drives) and HDDs (Hard Disk Drives) which are data storage devices for servers. Storage servers therefore have a higher volumne of these. Next, the amount of RAM which can be handled. In addition, the number of central processing units (CPU) and their processing power reflected in the number of cores are also included. Finally, AI servers also contain a Graphics processing unit (GPU) [24]. Different configurations were constructed based on the shared data by ODC Noord and other undisclosed datacenters. These are shown in Table 24 with their number from the LCI. The total amounts to 1,270,080 servers. The split in AI was done with the publication from the DDA which stated that in 2024, 2% of Dutch servers were dedicated to AI [9]. These were divided into rack and blade servers. A blade server is a slim, modular server that shares power, cooling, and networking within a larger chassis, making it more space efficient. They are more modern but also less common than the rack server and therefore make up a smaller share. A rack server is a self contained unit mounted in a standard rack, offering more flexibility and independence, hence typically found in colocation datacenters.

Table 24: The selected server configurations based on the categorization of server types.

| **Server type** | **Servers** | **Server configuration** |
|---|---|---|
| low range server | 245,740 | 1 CPU, 8 cores, 2 RAM x 16 GB and 1 SSD, 1024 GB |
| mid range server | 414,700 | 1 CPU, 16 cores, 24 RAM x 16 GB and 4 SSD, 2048 GB |
| high range server | 85,500 | 2 CPU, 16 cores, 24 RAM x 16 GB and 4 SSD, 2048 GB |
| AI server | 23,400 | 2 CPU, 8 GPU, 16 cores, 24 RAM x 16 GB and 4 SSD, 2048 GB |
| low blade server | 61,450 | 1 CPU, 8 cores, 2 RAM x 16 GB and 1 SSD, 1024 GB |
| medium blade server | 136,600 | 1 CPU, 16 cores, 24 RAM x 16 GB and 4 SSD, 2048 GB |
| high/AI blade server | 33,600 | 2 CPU, 16 cores, 24 RAM x 16 GB and 4 SSD, 2048 GB |
| storage server | 158,700 | 1 CPU, 16 cores, 12 RAM x 16 GB and 10 SSD, 7680 GB |

### Network Switches

The total number of switches is estimated at 94,853 units, derived from numbers shared by two first hand datacenter datasets and scaling these values assuming a standard ratio of Top of Rack switches to server racks.

### Core Routers

The quantity of core routers is estimated at 4,260 units, derived from numbers shared by two first hand datacenter datasets and scaling these values based on size knowledge.

### Cooling Infrastructure

The cooling equipment was calculated through a split between adiabatic cooling and free cooling units. This followed the methodology in [67] where the equipment of cooling was allocated on a per watt basis. This derives 1716 units in The Netherlands.

### UPS (Uninterruptible Power Supply)

The total number of UPS units is estimated at 39,000. This calculation assumes that one commercial UPS unit is required for every 15 kW of IT load, this serves the higher end power redundancy requirements of the sector, based on the EED datasets [22].

### Backup Generators

The inventory includes 1,262 backup generators with capacity of 206 kW and 820 backup generators with 2 MW capacity, this was estimated based on the average redundancy tiers being N+1 at the generator level, which was reported in the EED datasets [22]. Redundancy represents how many times there is a backup in case of failure. The level of redundancy accounts for the number of backup equipment a datacenter has. It is assumed a generator accounts for 2 MW at a large scale datacenter and a smaller datacenter uses one of 206 kW to align with available LCIA data. A split was made between large and small datacenter power allocation based on the DDA reporting shown in Table 5. This concluded that approximately 1300 MW could be allocated to large datacenters making use of 2 MW generators, and the other 203 MW was assumed to be using 206 kW generators. Dividing by the power per generator and multiplying by 1.3 to account for the level of redundancy of N+1, the values of 1262 and 820 backup generators were obtained.

These generators do not run as they are only backup. They only need to remain warm continuously in case they are needed, but this is done via electric heating. This electricity is accounted for in the PUE non-IT number.

**Electricity usage**

The total electricity supplied to Dutch data centers is recorded as 5.093 TWh based on CBS data from 2024 [7]. This data is taken directly from the connection to the electric grid. No significant additions were made through assumptions about enterprise data which was missing. It was therefore, not included.

**Water usage**

The sector consumes 2.53 million $m^3$ of water annually, this number was calculated through the extrapolation of the EED reporting by the SDIA [66]. According to the DDA report, 88% of this is potable water, the other 12% is comprised of waste water from industry [9].

## 8.2 Appendix B: Sensitivity Analysis

Because of the lack of LCI, no Monte Carlo analysis could be carried out to test the sensitivities of inputs with each other. The five key parameters tested for their sensitivity were: Device kWh per year, average lifespan of devices, professional to personal split of devices, the impact of ADPe from using the CODDE database, assumed average PUE and server configuration. These focus on tiers 1 and 3 as they are the biggest contributors. Given that PUE does not influence the total results, it was not included in Table 25.

Table 25: Percentage difference from baseline across all sensitivities.

| Sensitivity | GWP(%) | PM(%) | LU(%) | ADPf(%) | ADPe(%) | WU(%) |
|---|---|---|---|---|---|---|
| Device electricity+25% | 3.59 | 7.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| Device electricity-25% | -3.59 | -7.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| Device lifespan+0.5yrs | 4.81 | 5.44 | 7.39 | 3.32 | 7.19 | 6.22 |
| Device lifespan-0.5yrs | -4.20 | -4.71 | -6.87 | -3.28 | -6.48 | -6.11 |
| Pers/prof split +40% | 2.92 | 3.33 | 5.00 | 2.41 | 5.61 | 3.77 |
| Pers/prof split -25% | -1.83 | -2.08 | -3.13 | -1.50 | -3.51 | -2.35 |
| CODDE database | -0.91 | 0.06 | -9.90 | -0.90 | 9.54 | -0.13 |
| Server impacts +25% | 2.51 | 2.57 | 9.81 | 2.57 | 1.41 | 1.77 |
| Server impacts -25% | -2.51 | -2.57 | -9.81 | -2.57 | -1.41 | -1.77 |

The effects on the individual life cycle stage splits are shown on the following pages.

## Extension of lifespan of devices

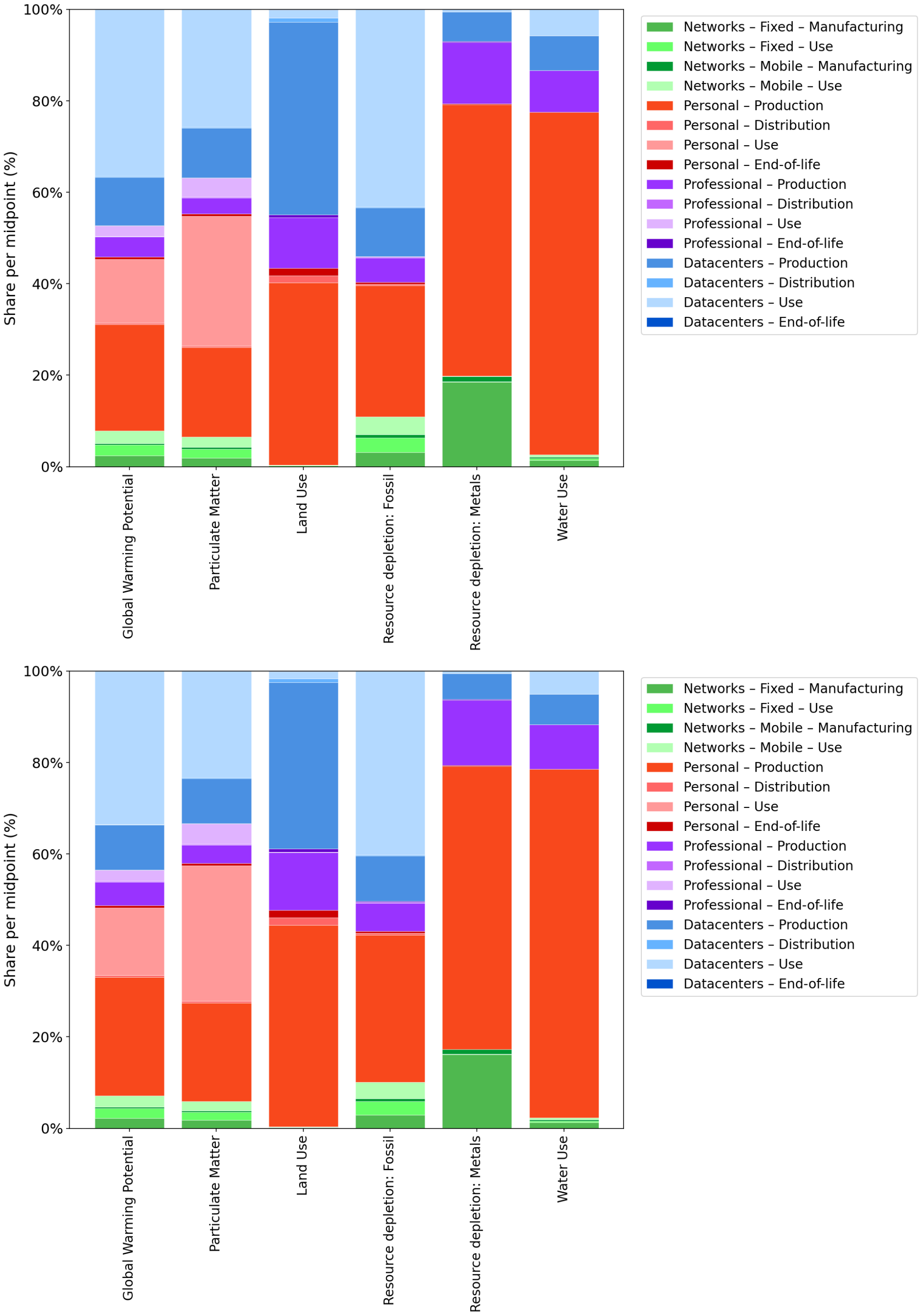


Figure 33: Modeling a half of a year longer lifespan per device (top) and a half of a year shorter per device (bottom).

## Personal to Professional split in devices

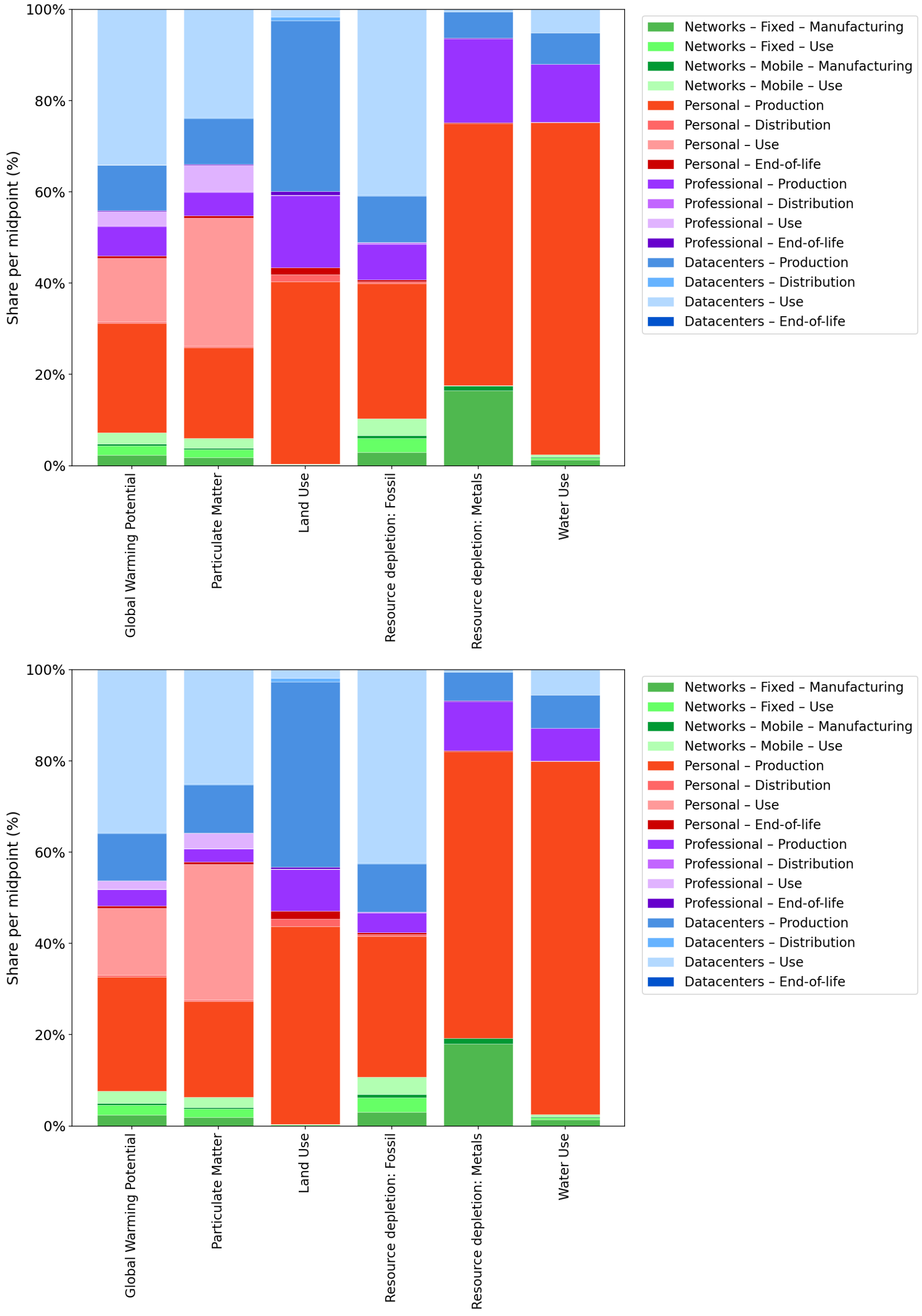
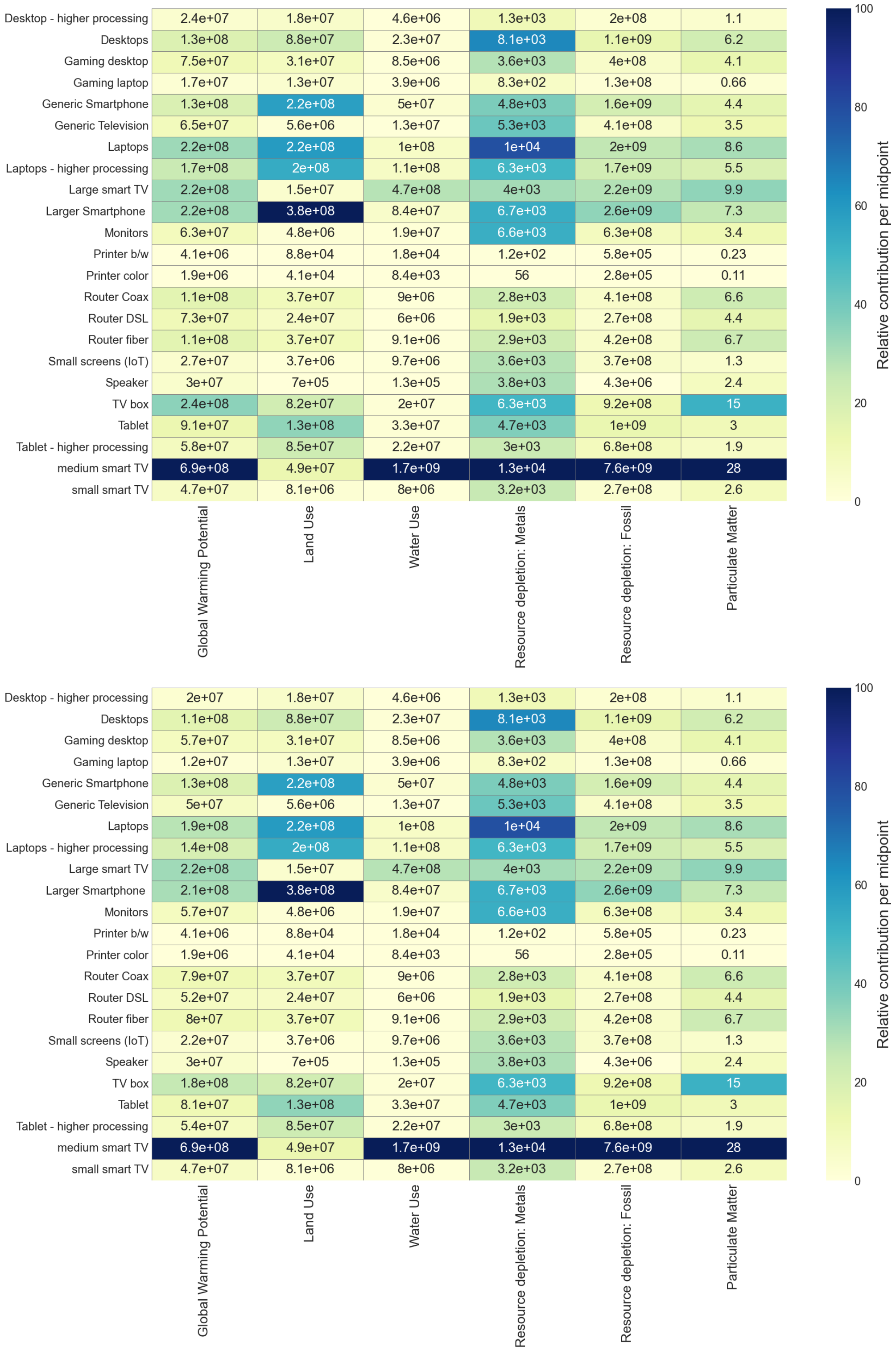


Figure 34: Modeling a greater (top) average split of 40% more professional devices in personal to professional devices and a smaller (bottom) average split of 25% less.

## Electricity use by devices per year



| | Global Warming Potential | Land Use | Water Use | Resource depletion: Metals | Resource depletion: Fossil | Particulate Matter |
|---|---|---|---|---|---|---|
| Desktop - higher processing | 2.4e+07 | 1.8e+07 | 4.6e+06 | 1.3e+03 | 2e+08 | 1.1 |
| Desktops | 1.3e+08 | 8.8e+07 | 2.3e+07 | 8.1e+03 | 1.1e+09 | 6.2 |
| Gaming desktop | 7.5e+07 | 3.1e+07 | 8.5e+06 | 3.6e+03 | 4e+08 | 4.1 |
| Gaming laptop | 1.7e+07 | 1.3e+07 | 3.9e+06 | 8.3e+02 | 1.3e+08 | 0.66 |
| Generic Smartphone | 1.3e+08 | 2.2e+08 | 5e+07 | 4.8e+03 | 1.6e+09 | 4.4 |
| Generic Television | 6.5e+07 | 5.6e+06 | 1.3e+07 | 5.3e+03 | 4.1e+08 | 3.5 |
| Laptops | 2.2e+08 | 2.2e+08 | 1e+08 | 1e+04 | 2e+09 | 8.6 |
| Laptops - higher processing | 1.7e+08 | 2e+08 | 1.1e+08 | 6.3e+03 | 1.7e+09 | 5.5 |
| Large smart TV | 2.2e+08 | 1.5e+07 | 4.7e+08 | 4e+03 | 2.2e+09 | 9.9 |
| Larger Smartphone | 2.2e+08 | 3.8e+08 | 8.4e+07 | 6.7e+03 | 2.6e+09 | 7.3 |
| Monitors | 6.3e+07 | 4.8e+06 | 1.9e+07 | 6.6e+03 | 6.3e+08 | 3.4 |
| Printer b/w | 4.1e+06 | 8.8e+04 | 1.8e+04 | 1.2e+02 | 5.8e+05 | 0.23 |
| Printer color | 1.9e+06 | 4.1e+04 | 8.4e+03 | 56 | 2.8e+05 | 0.11 |
| Router Coax | 1.1e+08 | 3.7e+07 | 9e+06 | 2.8e+03 | 4.1e+08 | 6.6 |
| Router DSL | 7.3e+07 | 2.4e+07 | 6e+06 | 1.9e+03 | 2.7e+08 | 4.4 |
| Router fiber | 1.1e+08 | 3.7e+07 | 9.1e+06 | 2.9e+03 | 4.2e+08 | 6.7 |
| Small screens (IoT) | 2.7e+07 | 3.7e+06 | 9.7e+06 | 3.6e+03 | 3.7e+08 | 1.3 |
| Speaker | 3e+07 | 7e+05 | 1.3e+05 | 3.8e+03 | 4.3e+06 | 2.4 |
| TV box | 2.4e+08 | 8.2e+07 | 2e+07 | 6.3e+03 | 9.2e+08 | 15 |
| Tablet | 9.1e+07 | 1.3e+08 | 3.3e+07 | 4.7e+03 | 1e+09 | 3 |
| Tablet - higher processing | 5.8e+07 | 8.5e+07 | 2.2e+07 | 3e+03 | 6.8e+08 | 1.9 |
| medium smart TV | 6.9e+08 | 4.9e+07 | 1.7e+09 | 1.3e+04 | 7.6e+09 | 28 |
| small smart TV | 4.7e+07 | 8.1e+06 | 8e+06 | 3.2e+03 | 2.7e+08 | 2.6 |

| | Global Warming Potential | Land Use | Water Use | Resource depletion: Metals | Resource depletion: Fossil | Particulate Matter |
|---|---|---|---|---|---|---|
| Desktop - higher processing | 2e+07 | 1.8e+07 | 4.6e+06 | 1.3e+03 | 2e+08 | 1.1 |
| Desktops | 1.1e+08 | 8.8e+07 | 2.3e+07 | 8.1e+03 | 1.1e+09 | 6.2 |
| Gaming desktop | 5.7e+07 | 3.1e+07 | 8.5e+06 | 3.6e+03 | 4e+08 | 4.1 |
| Gaming laptop | 1.2e+07 | 1.3e+07 | 3.9e+06 | 8.3e+02 | 1.3e+08 | 0.66 |
| Generic Smartphone | 1.3e+08 | 2.2e+08 | 5e+07 | 4.8e+03 | 1.6e+09 | 4.4 |
| Generic Television | 5e+07 | 5.6e+06 | 1.3e+07 | 5.3e+03 | 4.1e+08 | 3.5 |
| Laptops | 1.9e+08 | 2.2e+08 | 1e+08 | 1e+04 | 2e+09 | 8.6 |
| Laptops - higher processing | 1.4e+08 | 2e+08 | 1.1e+08 | 6.3e+03 | 1.7e+09 | 5.5 |
| Large smart TV | 2.2e+08 | 1.5e+07 | 4.7e+08 | 4e+03 | 2.2e+09 | 9.9 |
| Larger Smartphone | 2.1e+08 | 3.8e+08 | 8.4e+07 | 6.7e+03 | 2.6e+09 | 7.3 |
| Monitors | 5.7e+07 | 4.8e+06 | 1.9e+07 | 6.6e+03 | 6.3e+08 | 3.4 |
| Printer b/w | 4.1e+06 | 8.8e+04 | 1.8e+04 | 1.2e+02 | 5.8e+05 | 0.23 |
| Printer color | 1.9e+06 | 4.1e+04 | 8.4e+03 | 56 | 2.8e+05 | 0.11 |
| Router Coax | 7.9e+07 | 3.7e+07 | 9e+06 | 2.8e+03 | 4.1e+08 | 6.6 |
| Router DSL | 5.2e+07 | 2.4e+07 | 6e+06 | 1.9e+03 | 2.7e+08 | 4.4 |
| Router fiber | 8e+07 | 3.7e+07 | 9.1e+06 | 2.9e+03 | 4.2e+08 | 6.7 |
| Small screens (IoT) | 2.2e+07 | 3.7e+06 | 9.7e+06 | 3.6e+03 | 3.7e+08 | 1.3 |
| Speaker | 3e+07 | 7e+05 | 1.3e+05 | 3.8e+03 | 4.3e+06 | 2.4 |
| TV box | 1.8e+08 | 8.2e+07 | 2e+07 | 6.3e+03 | 9.2e+08 | 15 |
| Tablet | 8.1e+07 | 1.3e+08 | 3.3e+07 | 4.7e+03 | 1e+09 | 3 |
| Tablet - higher processing | 5.4e+07 | 8.5e+07 | 2.2e+07 | 3e+03 | 6.8e+08 | 1.9 |
| medium smart TV | 6.9e+08 | 4.9e+07 | 1.7e+09 | 1.3e+04 | 7.6e+09 | 28 |
| small smart TV | 4.7e+07 | 8.1e+06 | 8e+06 | 3.2e+03 | 2.7e+08 | 2.6 |

Figure 35: Increasing the electricity use of devices by 25% (top) and decreasing by 25% (bottom) effects on the heatmap of Tier 1: end-user devices.

### Using the data from CODDE

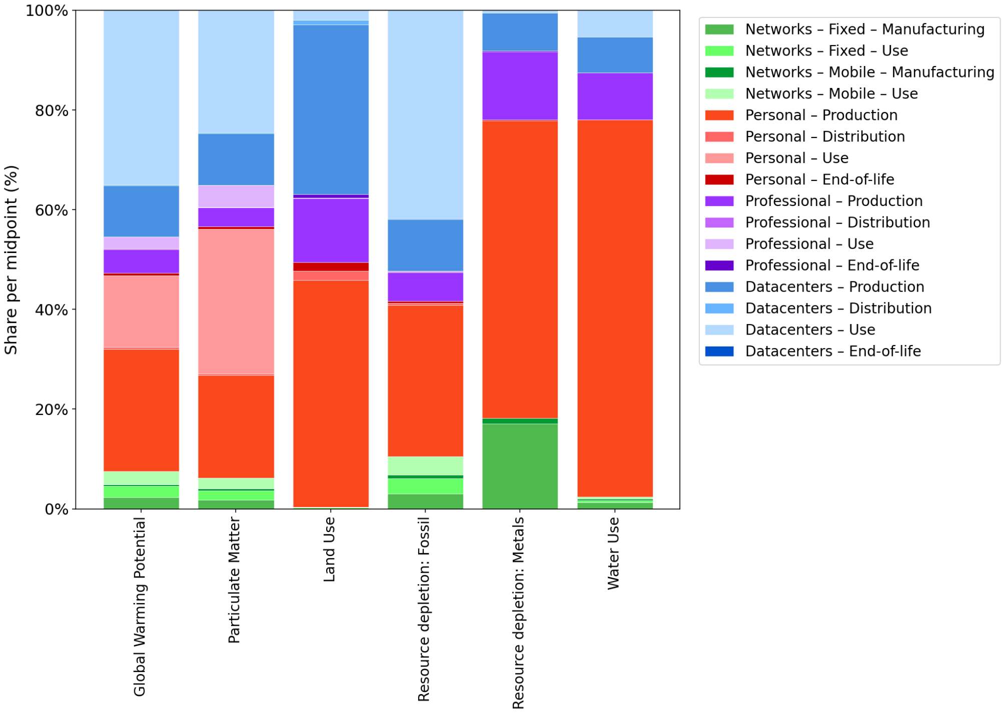
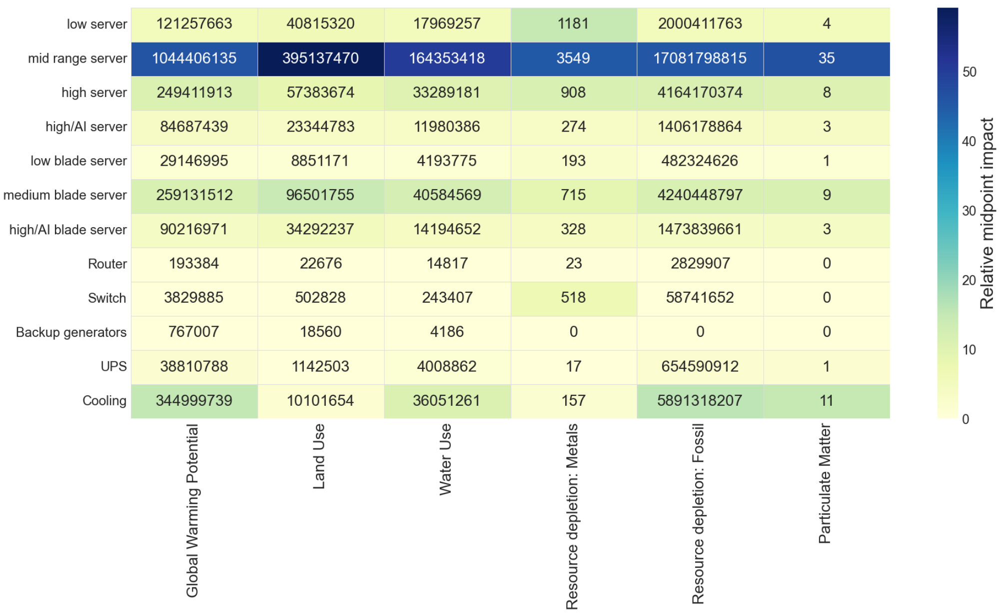


Figure 36: Using the CODDE database for plotting the results of server production phase impacts, this results in a shift in both the ADPe and Land Use midpoints.

## Altering the average PUE value



| | Global Warming Potential | Land Use | Water Use | Resource depletion: Metals | Resource depletion: Fossil | Particulate Matter |
|---|---|---|---|---|---|---|
| low server | 121257663 | 40815320 | 17969257 | 1181 | 2000411763 | 4 |
| mid range server | 1044406135 | 395137470 | 164353418 | 3549 | 17081798815 | 35 |
| high server | 249411913 | 57383674 | 33289181 | 908 | 4164170374 | 8 |
| high/AI server | 84687439 | 23344783 | 11980386 | 274 | 1406178864 | 3 |
| low blade server | 29146995 | 8851171 | 4193775 | 193 | 482324626 | 1 |
| medium blade server | 259131512 | 96501755 | 40584569 | 715 | 4240448797 | 9 |
| high/AI blade server | 90216971 | 34292237 | 14194652 | 328 | 1473839661 | 3 |
| Router | 193384 | 22676 | 14817 | 23 | 2829907 | 0 |
| Switch | 3829885 | 502828 | 243407 | 518 | 58741652 | 0 |
| Backup generators | 767007 | 18560 | 4186 | 0 | 0 | 0 |
| UPS | 38810788 | 1142503 | 4008862 | 17 | 654590912 | 1 |
| Cooling | 344999739 | 10101654 | 36051261 | 157 | 5891318207 | 11 |

Figure 37: The PUE change is not visible in the total graph because the value of electricity itself did not change. Instead it is altered as being lowered to 1.245 to match an appropriate kWh average rather than an average from the number of datacenters.

## Server configuration

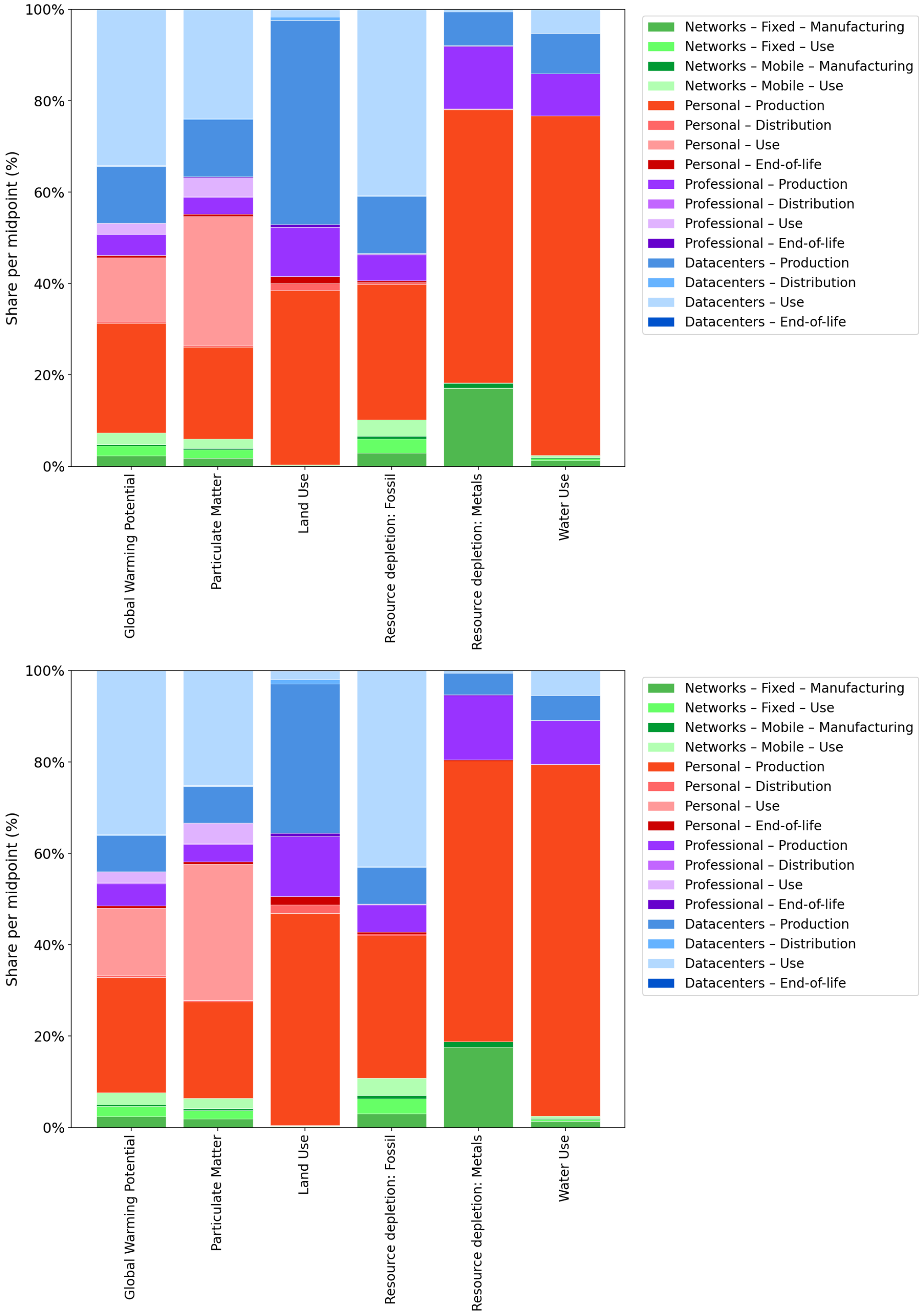


Figure 38: Server configuration uncertainty measured through changing the impacts of production, distribution and end-of-life impacts by 25% (top) and negative 25% (bottom).