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DEPARTMENT OF FOREIGN LANGUAGES

ÚSTAV JAZYKŮ

ICT AND CLIMATE CHANGE: ARE INFORMATION AND COMMUNICATION TECHNOLOGIES THE PROBLEM OR THE ANSWER?

ICT A ZMĚNA KLIMATU: JSOU INFORMAČNÍ TECHNOLOGIE PŘÍČINOU ČI ŘEŠENÍM?

BACHELOR'S THESIS

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AUTHOR Alsu Abrarova

AUTOR PRÁCE

SUPERVISOR Mgr. Magdalena Šedrlová

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ICT a změna klimatu: Jsou informační technologie příčinou či řešením?

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DOPORUČENÁ LITERATURA:

Anup, P. U., Arvind B. Climate Change Adaptation: Services and Role of Information Communication Technology (ICT) in India.
Fettweis, Gerhard, and Ernesto Zimmermann. ICT ENERGY CONSUMPTION – TRENDS AND CHALLENGES.
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doc. PhDr. Milena Krhutová, Ph.D.
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Abstract

The role of Information and Communication Technology (ICT) in addressing climate change is controversial. This thesis aims to identify if ICT is the cause or solution to climate change by analyzing its negative and positive environmental impacts. To begin with, the carbon and energy footprints of the main ICT components will be presented, as well as ways of minimizing the negative impacts. Furthermore, the potential of ICT to reduce carbon emissions in other sectors will be analyzed. Literature related to the latest technologies, climate change, and reports from companies whose main goal is a sustainable future were reviewed. The findings of this study show that ICT has both negative and positive environmental impacts. However, it has a major potential to tackle climate change by reducing the carbon footprint and increasing energy efficiency in other sectors, which outweighs ICT's negative impacts. It is done with the aid of new technologies, such as 5G, Internet of Things (IoT), and Artificial Intelligence (AI). Moreover, it is important to highlight the importance of further studies and collaboration of government, businesses, and consumers towards environmentally friendly ICT and a sustainable future with reduced climate change.

Keywords

ICT, climate change, carbon footprint, energy consumption, 5G, IoT, AI

Abstrakt

Úloha informačních a komunikačních technologií (IKT) při řešení změny klimatu je kontroverzní. Cílem této práce je zjistit, zda jsou ICT příčinou nebo řešením změny klimatu, a to na základě analýzy jejich negativních a pozitivních dopadů na životní prostředí. Na úvod bude představena uhlíková a energetická stopa hlavních komponent IKT a způsoby minimalizace negativních dopadů. Dále bude analyzován potenciál IKT ke snížení emisí uhlíku v jiných odvětvích. Byla přezkoumána literatura týkající se nejnovějších technologií, změny klimatu a zprávy společností, jejichž hlavním cílem je udržitelná budoucnost. Výsledky této bakalářské práce ukazují, že IKT mají jak negativní, tak pozitivní dopady na životní prostředí. Mají však velký potenciál pro řešení změny klimatu prostřednictvím snížení uhlíkové stopy a zvýšení energetické účinnosti v jiných odvětvích, což převažuje nad negativními dopady IKT. A to pomocí nových technologií, jako je 5G, internet věcí (IoT) a umělá inteligence (AI). Je důležité zdůraznit význam dalších studií a spolupráce vlády, podniků a spotřebitelů směrem k IKT šetrným k životnímu prostředí a k udržitelné budoucnosti se sníženou změnou klimatu.

Klíčová slova

ICT, změna klimatu, uhlíková stopa, spotřeba energie, 5G, IoT, AI

Rozšířený abstrakt

Informační a komunikační technologie (IKT) jsou základním nástrojem hospodářského rozvoje a hrají klíčovou roli v komunikaci, vzdělávání a v podstatě ve všech oblastech našeho života. Index rozvoje informačních a komunikačních technologií, který se používá ke sledování rozvoje IKT v jednotlivých zemích a k jejich porovnávání, ukazuje, že se informační a komunikační technologie ve světě rychle šíří a rozvíjejí ("Measuring the Information Society Report").

S rychlým rozvojem však přichází i zintenzivnění problémů souvisejících se změnou klimatu (Mahdavi a Sojoodi 2). Změna klimatu má katastrofické důsledky, jako jsou sucha, požáry, záplavy, zvyšování hladiny moří. V současné době je průměrná globální teplota o 1.15 °C vyšší než v předindustriálním období ("WMO Provisional State of the Global Climate 2022" 6). Dosažení globálního oteplení o 2 °C povede k ještě extrémnějším horkým dnům, suchům, silným dešťům a záplavám, chudobě ("IPCC Special Report on Global Warming of 1.5 °C"). Proto je zásadní identifikovat příčiny změny klimatu a předcházet jí.

Cílem této bakalářské práce je zjistit, zda jsou informační a komunikační technologie příčinou nebo řešením změny klimatu. K tomu je třeba analyzovat příslušnou literaturu, jako jsou výzkumné práce související se změnou klimatu a informačními a komunikačními technologiemi, zprávy společností, jejichž hlavním cílem je udržitelná budoucnost.

V této bakalářské práci byla použita metodologie rešerše odborné literatury, publikací organizací, které se zabývají implementací informačních a komunikačních

technologií pro řešení změny klimatu. Některé z těchto organizací a společnosti jsou Global e-Sustainability Initiative, Program OSN pro životní prostředí, Rámcová úmluva OSN o změně klimatu, Mezinárodní telekomunikační unie, Carbon Trust a Asociace světového systému pro mobilní komunikaci.

O vztahu mezi informačními a komunikačními technologiemi a změnou klimatu byla provedena řada studií. Studie provedená Malmodinem a Lundénem vychází z nejnovějších údajů ve srovnání s použitými údaji Andraeho a Edlera nebo Belkhira a Elmeligiho. Její rozsah navíc zahrnuje širší škálu zařízení informačních a komunikačních technologií a emisí z dodavatelského řetězce. Proto byla vybrána jako základ pro analýzu stopy IKT.

Hlavní nevýhodou IKT v souvislosti se změnou klimatu je jejich uhlíková stopa (celkové množství vyprodukovaných emisí skleníkových plynů), protože skleníkové plyny se uvolňují v průběhu všech fází jejich životního cyklu. Nejprve se uvolňují během získávání surovin, výrobního procesu a přepravy ke konečnému uživateli. Zadruhé se uvolňují při používání informačních a komunikačních technologií (spotřeba energie a údržba). Nakonec se emise opětovně uvolňují při likvidaci (Freitag et al. 1). Skleníkové plyny, jako je oxid uhličitý, metan, oxid dusný a ozon, přispívají ke skleníkovému efektu tím, že pohlcují sluneční záření. Spalování fosilních paliv ho zesiluje, což vede ke globálnímu oteplování. Další nevýhodou je energetická stopa, která je definována jako "provozní spotřeba elektřiny".

Zkoumání dopadů výrobků na životní prostředí během celého jejich životního cyklu (od získání surovin až po jejich likvidaci) se nazývá hodnocení životního cyklu (Life Cycle Assessment – dále jen LCA) (Pehnt 56). Tento přístup je běžně využíván vědci a podnikateli v různých studiích o vlivu sektoru IKT na změnu klimatu s cílem snížit negativní dopady.

Výzkum provedený Malmodinem a Lundénem v roce 2018 odhadl emise sektoru ICT na 730 Mt CO2e (megatun ekvivalentu oxidu uhličitého) v roce 2015, což představuje přibližně 1,4 % celosvětových emisí uhlíku. Největší podíl na tom měla uživatelská zařízení, jako jsou chytré telefony, pevné telefony, tablety a osobní počítače. Za nimi následovaly sítě ICT (PSTN, mobilní sítě, pevné sítě). A posledními byla datová centra a podnikové sítě. Pokud jde o energetickou stopu, celkový příspěvek odvětví ICT byl odhadnut na 805 TWh (terawatthodin), což představuje 3,6 % celosvětové spotřeby v roce 2015. Největším spotřebitelem elektrické energie byla uživatelská zařízení, dále datová centra a podnikové sítě, a nakonec sítě ICT. Další nevýhodou ICT je "elektronický odpad". S velkým množstvím elektronického odpadu vyprodukovaného v roce 2019 (44,3 mil. tun) bylo nakládáno mimo oficiální systém sběru, nikoliv ekologicky šetrným způsobem (Forti et al. 23). To znamená, že část elektronického odpadu skončila na skládkách, což má významný dopad na životní prostředí.

Některým společnostem se podařilo snížit emise skleníkových plynů navzdory rostoucímu datovému provozu. Mezi opatření, která přijaly, patřilo používání recyklovaných materiálů a opětovně obnovitelných zdrojů energie v dodavatelském řetězci výrobků. Klíčové je také nakládat s elektronickým odpadem ekologicky šetrným způsobem, a to jeho recyklací a opětovným využitím, žádný odpad by neměl končit na skládkách. Přijetí těchto strategií společnostmi a širokou veřejností, kombinované a prováděné ve velkém měřítku, může minimalizovat negativní dopad IKT na změnu klimatu.

Co se týče pozitivních dopadů IKT, významnou studii provedly Asociace světového systému pro mobilní komunikaci a Carbon Trust, které zdůraznily úlohu a potenciál ICT při snižování emisí uhlíku v odvětvích, jako jsou budovy, doprava, výroba a energetika. Uvádí se také, že úroveň emisí, kterým se díky IKT podařilo zabránit v jiných odvětvích, je desetkrát vyšší než emise uhlíku ze samotných IKT ("The Enablement Effect" 11). Technologie jako 5G, umělá inteligence a internet věcí umožňují snižování emisí skleníkových plynů v zemědělství, energetice, dopravě, budovách, bydlení, práci a zdravotnictví. Snížení emisí uhlíku sítěmi 5G je umožněno efektivnějším využíváním energie pro přenášená data (Kuroki et al.). Technologie umělé inteligence přispívají ke snižování emisí uhlíku svými schopnostmi monitorování, řízení a předvídání (Herweijer et al.17). Snížení emisí pomocí internetu věcí je možné díky jeho schopnosti automatizovat systémy a zvyšovat jejich efektivitu. Kromě toho bylo podrobněji analyzováno snižování emisí uhlíku, které umožňují technologie 5G, M2M a IoT v odvětvích budov, dopravy, výroby, energetiky, inteligentního bydlení, práce, zdraví, a zemědělství. Dále byl uveden přínos informačních a komunikačních technologií k prevenci a účinné likvidaci následků katastrofálních změn klimatu. Systémy včasného varování, technologie dálkového průzkumu umožňují sledovat změny klimatu a předpovídat záplavy, vlny veder, propuknutí nemocí a zachraňovat lidské životy.

Z mých studií vyplývá, že využívání ICT může mít negativní dopady, jako je uhlíková a energetická stopa. Je však relativně malá ve srovnání s potenciálem ICT snížit emise uhlíku a zlepšit energetickou účinnost v jiných odvětvích.

Bibliografická citace

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Vedoucí práce: Mgr. Magdalena Šedrlová.

Prohlášení

Prohlašuji, že bakalářskou práci na téma *ICT a změna klimatu: Jsou informační technologie příčinou či řešením?* jsem vypracovala samostatně pod vedením vedoucí bakalářské práce a s použitím odborné literatury a dalších informačních zdrojů, které jsou všechny citovány v práci a uvedeny v seznamu literatury na konci práce.

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V Brně dne 30.05.2023 ....

Alsu Abrarova

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Introduction

Information and Communication Technologies (ICT) are spreading and developing rapidly around the world. However, with rapid digitalization comes the intensification of problems associated with climate change.

Human-induced climate change is defined as rapid warming due to greenhouse gas emissions, generated by burning fossil fuels. The frequency of such meteorological disasters as tropical cyclones, droughts, and floods is increasing. No measures taken means those numbers will increase as well as the frequency of natural disasters and fluctuation in temperature.

In 2022 the global mean temperature was 1.15 °C above the pre-industrial levels (relative to 1850-1900). Hoegh-Guldberg et al. highlight the necessity of limiting the average warming temperature to 1.5 °C, as reaching 2 °C of global warming might lead to extremely hot days in all land regions, increased heavy rainfall events and flooding, stronger melting of ice sheets and glaciers, and increased sea levels.

This thesis aims to analyze the negative and positive environmental impacts of ICT based on relevant sources and determine whether ICT is the cause of the intensification of climate change-related problems or an efficient tool to tackle it.

Methodologically, this study is based on the literature review, such as research papers on climate change and ICT, reports, and publications of sustainable organizations, like Global System of Mobile Communications, Carbon Trust, Intergovernmental Panel on Climate Change, and International Telecommunication Union.

This thesis is divided into five main chapters.

The first two chapters will introduce the reader to ICT and climate change definitions and basic terms used throughout the thesis, such as "carbon footprint", "energy footprint", "Life Cycle Assessment".

The third chapter presents the analyzis of the negative impacts of ICT, such as carbon and energy footrpints, e-waste. The components with the highest carbon footprints will be studied in more detail. Moreover, the ways of minimizing these effects will be stated.

The following chapter will introduce the reader to ICT as an effective tool to tackle climate change. The role of ICT in the adaptation and mitigation to climate change, new technologies, such as 5G, Artificial Intelligence (AI), Internet of Things

(IoT), and their contribution to carbon emissions abatement in buildings, transportation, energy, agricultural, living, working, and health sectors will be described in detail, including case studies from various companies implementing them. Furthermore, the contribution of the ICT sector to the prevention and effective recovery after the disastrous consequences of climate change will be stated.

Finally, the last chapter evaluates the degree of ICT efficiency nowadays.

1. Information and Communication Technology (ICT)

1.1 What is ICT?

Sarkar identifies ICT as “the varied collection of technological gear and resources which are made use of to communicate.” He also states that ICT systems are used to “generate, distribute, collect and administer information” (31). ICTs consist of Information and Communication Infrastructure (ICI), which is the physical telecommunications systems and services using them (television, Internet), and Information Technology (IT), which is the hardware and software used to collect, store, process, and transmit information (ibid. 32).

The main components of ICT, which are widely used in the analysis of its carbon and energy footprints, are user devices (laptop and desktop PCs, smartphones and other mobile phones, computer displays and peripherals, projectors, tablets, CPE (modems, gateways), surveillance cameras, payment terminals, wearables, smart meter connectivity), data centers, and ICT networks (PSTN, mobile networks, fixed networks) (Malmodin and Lundén 8).

1.2 The ICT role and development

The development and growth of communication, productivity, and research activities have all been significantly aided by ICT. High-tech products are becoming increasingly important, the use of information technology is expanding, and exports of goods and services in ICT are increasing (Özpolat 12833).

The Internet is a crucial part of ICT and a pivotal tool to communicate, share information and knowledge, provide educational access, and reduce geographic boundaries. Its invention has revolutionized the way we live and played a significant role in improving the comfort and convenience of our lives.

Fettweis and Zimmermann highlight the significant contribution of ICT systems to the economic growth of both developing and developed countries (ch. 1). According to Remeikiene et al., growth is affected at both macro (“productivity, effectiveness, innovation, and the efficiency of financial markets") and micro (accelerated communication, promoted business sustainability, facilitated emergence of new markets) levels. ICT technologies also contribute to the creation of "new jobs, new sources of income, business models" (10).

ICTs are spreading and developing rapidly around the world. The proof of that is the ICT Development Index (IDI) developed by ITU (International Telecommunication Union) in 2008 and published annually from 2009 to 2017. IDI is used to keep track of ICT developments in both developed and developing countries over time and compare them ("Measuring the Information Society Report" 25). The IDI results for 176 economies were presented in the years 2016 and 2017. Most of the economies' IDI values have risen compared to 2016 (ibid. 31). It means the ICTs are developing over time globally.

As we can see, ICT systems have experienced rapid expansion and development. Mahdavi and Sojoodi believe that the digitalization of the economy is likely to accelerate in the upcoming years. Moreover, they stress the demand for more research as with the rapid development comes the intensification of problems related to climate change (2). The aim of the thesis is to determine whether ICT is the cause of this intensification or an efficient tool to tackle it.

2. Climate change

For a deeper realization of how serious and catastrophic the consequences of climate change might be, the general meaning of climate change will be introduced, as well as the current situation and possible scenarios in case no measures are taken.

2.1 What is climate change?

As stated in the United Nations' *"Fast Facts: What is Climate Change?"* publication, climate change refers to fluctuations in temperature, rainfall, wind, and other elements. They might be either natural or caused by human activity. Human-induced climate change is identified as rapid warming due to burning fossil fuels that generate greenhouse gases, which "act like a blanket wrapped around the earth, trapping the sun's heat and raising temperatures" (par. 1, 2). Greenhouse gases, such as carbon dioxide, methane, nitrous oxide, and ozone, contribute to the greenhouse effect by absorbing solar radiation. The greenhouse effect is essential for sustaining life on Earth. However, burning fossil fuels has intensified it, leading to global warming ("Ericsson Energy and Carbon Report" 11). Due to Earth being a system where everything is interconnected, changes in one element cause changes in others. That is why temperature fluctuations cause droughts, fires, flooding, sea levels rising, ice melting, and other disastrous consequences ("Fast Facts: What is Climate Change?" par.5).

2.2 The present situation

The global mean temperature for 2017 was about 1 °C above pre-industrial levels (1850-1900). This is predominantly due to the increase of greenhouse gases in the atmosphere, which is caused by human activity. If the warming rate continues, the mean temperatures will reach 1.5 °C above the 1850-1900 average already in 2040, as shown in fig. 1 (Allen et al. 81).

As for now, it is stated in the "*WMO Provisional State of the Global Climate 2022"* publication that the global mean temperature in 2022 was 1.15 °C above the pre-industrial levels (6).

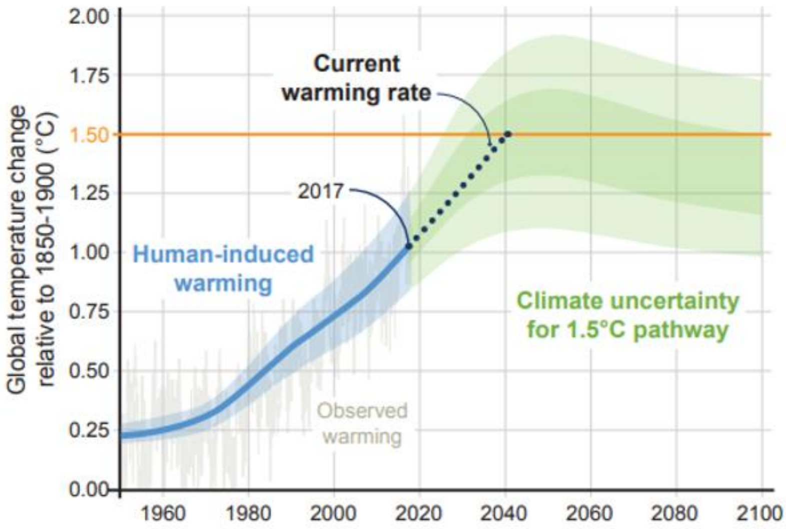

Fig. 1. How close are we to 1.5 °C?

Source: Allen, Myles, et al.

Approximately 90% of the heat, accumulated by greenhouse gases, is stored in the ocean. It is measured through ocean heat content, which was the highest in 2021 (ibid. 8). The global mean sea level has risen by 10 mm since January 2020 (ibid. 9). The marine heatwaves and marine cold spells, which are identified as periods of extreme heat and cold in seas and oceans, are also deviating. The marine heatwaves are becoming more frequent, while cold spells are becoming less frequent (ibid. 10). The glaciers, flowing ice, in the European Alps experienced mass loss in 2022. Their thickness changes of 3-4 meters were measured (ibid. 12). The Switzerland glaciers lost their volume from 77 km3 to 49 km3 between 2001 and 2022 (ibid. 13). Climate changes caused heatwaves and floods in South Asia, leading to a decline in crop yields, thousands of deaths, and diseases. Droughts in the Greater Horn of Africa resulted in crop failure and, consequently, food insecurity situations (ibid. 16, 17). These are only some of the disastrous consequences of climate change.

2.3 Climate change and human health

Apart from our planet, human health is also negatively affected by climate change. According to the article *"Climate Change and Health"* by the World Health Organization, frequent extreme weather events threaten key conditions of good health – clean air, water, nutritious food and a safe place to live in. Poor communities, people with disabilities, children and women, older population are affected the most. In 2030-2050 approximately 250 000 more deaths each year are expected to be caused by malaria, heat stress, and diarrhea. Siraj highlights that the cases of malaria disease were extended by increases in temperature to higher elevations in Colombia and Ethiopia's highland regions (1156).

As stated in the article *"Climate Effects on Health"* by National Center for Environmental Health, climate change also affects human health by increasing ozone and particle pollution, such as dirt and dust in the air. This, in turn, causes diminished lung function, increased hospital admissions and emergency room visits for asthma, and premature deaths (ch. Air Pollution).

2.4 What if no measures are taken?

Hoegh-Guldberg et al. highlight the necessity of limiting the average warming temperature to 1.5 °C. Reaching 2 °C of global warming might lead to extremely hot days in all land regions, increased heavy rainfall events and flooding, stronger melting of ice sheets and glaciers, and increased sea levels. The number of people living in poverty will increase, and poor people will become poorer, as climate change is a poverty multiplier. The 0.5 °C rise in temperature has already caused shifts in the distribution of plant and animal species, decreases in crop yields, and wildfires. With further rises in global temperature, similar events are expected. Limiting warming to 1.5 °C rather than 2 °C can help us avoid these risks (282).

As we can see, climate change has a catastrophic impact on our planet, threatens human health, and puts lives at risk. In the next chapter, the contribution of the ICT sector to the negative impacts of climate change will be analyzed.

3. Negative impacts of ICT

The main drawback of ICT related to climate change is its carbon footprint (total amount of greenhouse gas emissions produced) as greenhouse gases are emitted throughout its whole life cycle stages. Firstly, they are released during the raw material acquisition, manufacturing process, and transportation to an end-user. Secondly, they are emitted while using ICT (energy use and maintenance). Finally, emissions are released during the disposal (Freitag et al. 1).

The investigation of products or systems' environmental impacts throughout their whole life cycle (from raw material acquisition to disposal) is called a Life Cycle Assessment (LCA) (Pehnt 56). This approach is widely used by scientists and businesses in various studies of the ICT sector's impact on climate change in order to decrease negative effects and limit global mean temperature rises to 1.5 °C.

This chapter presents the negative environmental impacts of the ICT sector. An overview of the total carbon and energy footprints of ICT based on studies conducted by Malmodin and Lundén will be provided. Moreover, the greenhouse gas emissions of user devices, data centers, and ICT networks will be analyzed in detail. Finally, the possible ways of minimizing technologies' carbon emissions will be stated.

3.1 Total carbon and energy footprints of the ICT sector

There are several papers estimating the amount of greenhouse gases and electricity consumption of ICT. The study conducted by Malmodin and Lundén is based on the most recent data, compared to Andrae and Edler's or Belkhir and Elmeligi's used data. Moreover, its scope encompasses a wider range of ICT equipment and supply chain emissions. Therefore, it was chosen as a basis for the analysis of the ICT footprint.

The study conducted by Malmodin and Lundén in 2018 estimated the ICT sector's emissions to be 730 Mt CO2e (megatons carbon dioxide equivalent) in 2015 or about 1.4% of global carbon emissions. The user devices, such as smartphones, fixed phones, tablets, and PCs were the biggest contributors – 395 Mt CO2e. They were followed by ICT networks (PSTN, mobile networks, fixed networks), which resulted in a carbon footprint in the amount of 180 Mt CO2e. And the last ones were data centers and enterprise networks, which amounted to 160 Mt CO2e (28).

As for energy footprint, which is defined as “operational electricity consumption” or “use stage electricity consumption”, the total amount of the ICT sector’s contribution was estimated to be 805 TWh (terawatt hours), or 3.6% of global consumption in 2015. The largest electricity consumer was user devices (340 TWh), then data centers and enterprise networks (245 TWh), and, finally, ICT networks (220 TWh) (ibid. 3, 28).

Malmodin and Lundén compared the values of total carbon and energy footprints in 2015 with the values in 2007 and 2010 from previous studies conducted by Malmodin et al. (see table 1). As we can see, the ICT sector’s carbon emissions and electricity consumption in 2015 and 2010 do not vary much, which means they stopped growing significantly in 2010 with a possible peak in 2012/2013 (28).

Table 1

Carbon and energy footprints in years 2007, 2010, 2015 for the ICT sector

Year	**2007**	**2010**	**2015**
Carbon footprint [Mt CO2e]	620	720	730
Energy footprint [TWh]	710	800	805

Sources: Malmodin, Jens, et al., 2010, 2013. Malmodin, Jens, and Dag Lundén, 2018.

3.2 User devices

User devices encompass many types of electronics. Some of them are laptop and desktop PCs, smartphones, tablets, CPE (modems, gateways), surveillance cameras, and payment terminals. Malmodin and Lundén, using such data sources as ITU, Gartner, International Data Corporation, Information Handling Services, Future Source, Business Intelligence, and Pike Research, presented the total operational electricity consumption and carbon footprint of user devices. The largest emitters of greenhouse gases in 2015, including both the embodied and operational electricity consumption carbon footprints, were desktop PCs (94.2 Mt CO2e), smartphones (71.2 Mt CO2e), and CPE (57.8 Mt CO2e). The largest amount of energy in 2015 was consumed by desktop PCs (109.5 TWh), CPE (83.5 TWh), and laptop PCs (34 TWh). Wearables emitted the least amount of greenhouse gases and consumed less energy than other user devices (0.96 Mt CO_2e and 0.1 TWh) (8).

More detailed information will be provided on computers, laptops, smartphones, and CPE in subsequent subsections, as these user devices were defined as the ones with the highest carbon footprint.

3.2.1 Computers, laptops

LCA of a personal computer Pentium IV was analyzed by Byung-Chul et al. in 2006. As a result, the pre-manufacturing stage was the largest contributor to global warming, ecotoxicity (124, 125). During this stage, materials such as iron, aluminum, gold, plastics, and copper are extracted from the earth, transported, and processed. These activities lead to high energy consumption and the production of greenhouse gases, deforestation, and pollution ("Basic Information about Electronics Stewardship"). The manufacturing of printed circuit boards and small electrical parts such as resistors and connectors was a significant contributor to global warming (Byung-Chul et al. 125). The next stages, manufacturing (assembly and packaging) and transportation, did not have a great environmental impact. The use stage was the second greatest contributor to global warming after the pre-manufacturing stage due to the electricity produced by fossil fuels. The disposal stage which includes "collection, disassembly, refinery processes for recycling, and incineration or landfill" also had a great environmental impact, especially due to the leakage of metals from landfill sites and "consumption of several chemicals during the refinery process" (ibid. 126).

However, modern companies are taking steps to incorporate renewable sources into the entire supply chain. A notable example is Apple Inc., a multinational company that designs, manufactures, and sells user devices. Its goal is to become carbon neutral for products' entire life cycle by 2030. This would be done by transitioning its supply chain to 100% renewable electricity ("Supplier Clean Energy 2022 Program Update" 1). In the fiscal year 2021, Apple Inc. managed to avoid 13.9 million metric tons of carbon emissions in its supply chain (ibid. 1). Fig. 3 shows the life cycle carbon emissions of a 14-inch MacBook Pro, which carbon footprint is 271 kg CO_2e ("Product Environmental Report" 2). It is free of harmful substances (such as beryllium, arsenic, and mercury). Moreover, recycled aluminum is used for the notebook's enclosure, so the same strength and durability are delivered without mining new aluminum ore. The company is transitioning from fossil-fuel-based plastics to ones made from renewable/recycled sources. Additionally, recycled tin is used in the main logic board, as well as recycled rare earth elements are used in all magnets (ibid. 3). As contrary to Pentium IV personal computer, MacBook Pro is designed with energy-efficient components, using recycled material, and no waste generated by supplier sites is sent to landfill (ibid. 4).

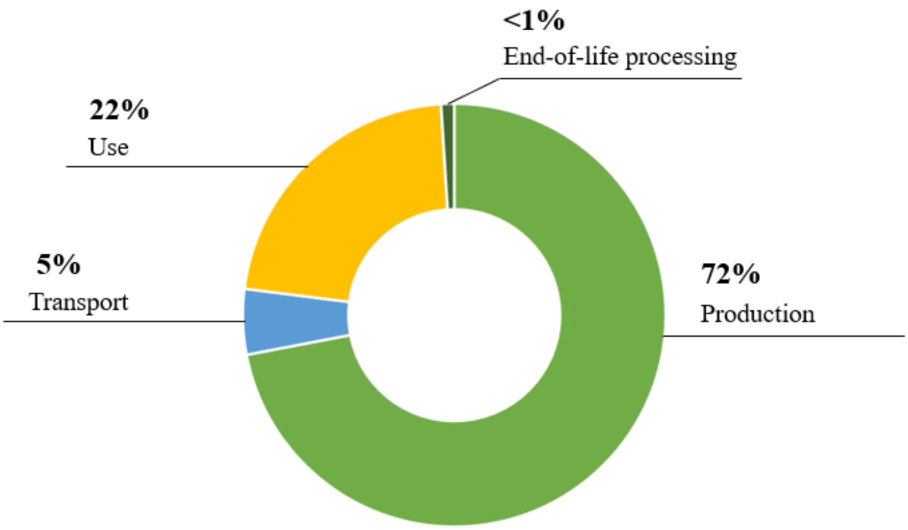

Fig. 2. 14-inch MacBook Pro life cycle carbon emissions

Source: "Product Environmental Report"

The IT Services of the University of Oxford conducted some measurements of power consumption of several staff desktops and laptops to identify the environmental impact of IT and reduce it. As a result, the standard desktop PC and screen produced around 778 kg CO2e annually (85% from manufacture and shipping, 15% from electricity consumption). PC, which was active continuously, produced around 73 kg CO2e (excluding the impact of manufacturing). This amount was reduced by 49% using default power-saving features. Shutting down the PC when not in use reduced it by 76%. And finally, turning the desktop off at the wall socket reduced carbon emissions by 80%. As for laptops, their environmental impact is even greater due to users' desire to replace them more frequently. The manufacture of laptops itself produces more carbon emissions than the desktops manufacture ("Environmental Impact of IT: Desktops, Laptops and Screens" ch. Impact).

3.2.2 Smartphones

Smartphones are the most popular user devices. The carbon footprint of smartphones is substantial as a result of their high sales volumes (Malmodin and Lundén 22). In 2022 around 121 million tons of CO2 were predicted to be produced during the smartphones manufacturing process, shipping, and the first year of usage. Another 16 million tons of CO2 were expected to be emitted during the usage stage and the rest from end-of-life processes and refurbishing (International Data Corporation qtd. in Lee et al.).

In order to determine which components of the Sony XperiaTM smartphone have the greatest environmental impact, the LCA study was conducted by Ercan. It included smartphone usage, its accessories (such as the charger, headset, cable, manual, and packaging box), and network usage. As a result, the smartphone itself was estimated to produce 51 kg CO2e for an average global user over a 3-year life cycle period. The distribution of carbon emissions is shown in fig. 2 (18, 51).

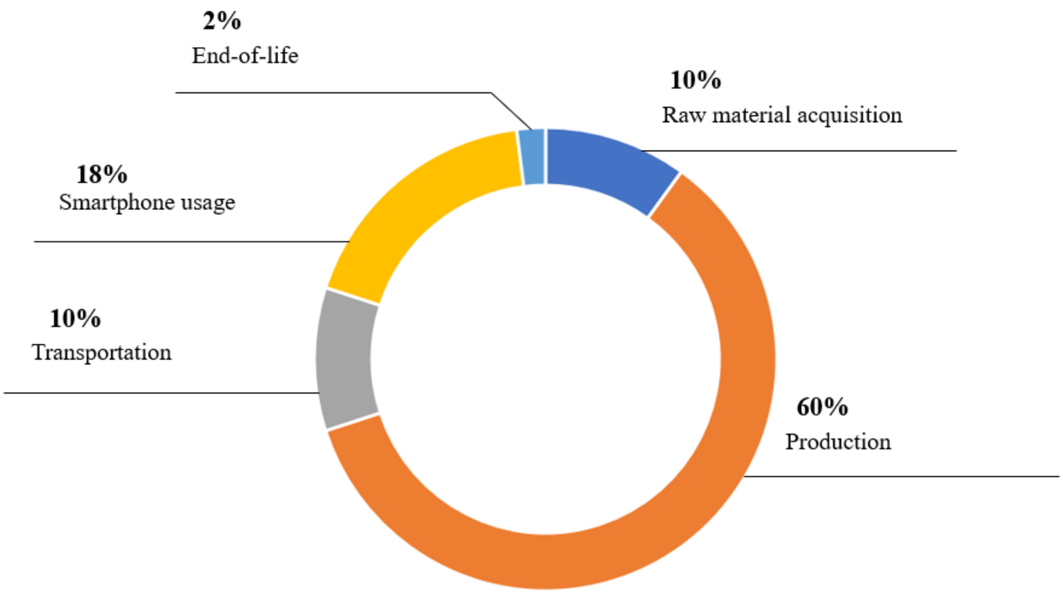

Fig. 3. Sony XperiaTM smartphone life cycle carbon emissions

Source: Ercan, Elif Mine.

The total carbon footprint, encompassing both the accessories and network usage, resulted in 117 kg CO_2 for an average global user over a 3-year life cycle period (ibid. 72). The production stage of the device had the greatest impact on climate change, particularly the production of integrated circuits. (ibid. 47). In the raw material acquisition stage, the shell of the smartphone had the largest environmental impact (ibid. 44). In the transportation stage, the distribution of the final phone kit to resellers and operators with the aid of air and road means of transportation accounted for most of the climate change impact (ibid. 49).

3.2.3 Customer Premises Equipment (CPE)

Customer Premises Equipment (CPE) is defined as the telecommunications equipment which is placed at the customer's location (home or business). It is utilized for internet access, networking, and telecommunications applications. Some types of CPE devices are modems, gateways, switches, and Wireless Access Points ("What is Customer Premise Equipment (CPE)?").

In 2015 the CPE had one of the highest carbon footprints between the user devices after desktop PCs and smartphones, resulting in 57.8 Mt CO_2e. The operational carbon footprint of the use stage was significantly higher than manufacturing due to CPE being always active (Malmodin and Lundén 16).

In conclusion to this section, the user devices emit greenhouse gas emissions throughout all life cycle stages. The production stage of both smartphones and computers had the greatest contribution to climate change. However, the negative impact can be reduced by using renewable energy sources and recycled materials in the products supply chain, and proper disposal. Moreover, shutting down the PC and turning the desktop off at the wall socket when not in use also reduces carbon emissions.

3.3 ICT networks

As stated in the *"Mobile Net Zero: State of the Industry on Climate Action 2022 Report"* by GSMA (Global System of Mobile Communications), one of the most common methodologies to measure greenhouse gas emissions from operators is the use of scopes, which represent categories of emissions. The first scope covers direct emissions produced by operators themselves, including activities like running a fleet for network maintenance. The second scope refers to indirect emissions that result from purchased energy, heating, and cooling for own use. The third scope encompasses indirect yet related to the supply chain emissions. It is the largest contributor to greenhouse gas emissions and the hardest to measure (19). In 2021 the first scope resulted in 2 % of the total amount of carbon emissions. The second scope accounted for 26 % of emissions. Finally, the third scope was responsible for 72 % of the total, which is the highest amount (CDP, GSMA Intelligence qtd. in "Mobile Net Zero: State of the Industry on Climate Action 2022 Report" 21).

Despite the challenges in measuring indirect emissions from the supply chain, the approximate amount of greenhouse gases emitted by operators was introduced by GSMA Intelligence, which resulted in 490 MtCO2e (million tonnes of carbon dioxide equivalent) in 2021 (1% of global carbon emissions) (IEA qtd. in "Mobile Net Zero: State of the Industry on Climate Action 2022 Report" 21).

Nevertheless, the statistics are not as disappointing as they might have been. Some operators succeeded in controlling their emissions, while some of them even managed to reduce their carbon footprint despite growing data traffic. For instance, AT&T, Telenor, and Verizon managed to reduce their carbon emissions between 2020 and 2021. That is possible thanks to energy-efficient networks, such as 5G, and operators' investments in renewable energy ("Mobile Net Zero: State of the Industry on Climate Action 2022 Report" 20).

3.4 Data centers

Data centers are identified as "closed spatial units such as server cabinets, server rooms, parts of buildings or entire buildings", where IT components are installed. Small IT installations, used for computing and storage, are also data centers (Hintemann and Hinterholzer).

3.4.1 Growth of cloud data centers

According to research by Eurostat, the use of cloud services in Germany has grown significantly. The number of companies using them doubled between 2018 and 2021. The growth in demand for cloud services leads to the increasing number of data centers. In such Scandinavian countries as Sweden, Finland, Denmark, and Norway the share of cloud-using companies is higher, 64-75%. It is also high in the Netherlands (65%) and Italy (60%) (qtd. in Hintemann and Hinterholzer).

3.4.2 Data centers’ carbon footprint

As stated in *“SMART 2020: Enabling the Low Carbon Economy in the Information Age”*, the data centers’ global carbon footprint was 76 Mt CO2e in 2002. In 2020 it was expected to reach a 3 times higher value, which is 259 Mt CO2e. That makes the data centers the fastest-growing contributors to the ICT’s carbon footprint. The carbon footprint of some data centers’ infrastructure was expected to grow significantly: volume servers (from 27 to 136 Mt CO2e), cooling systems (from 24 to 70 Mt CO2e), and power systems (from 13 to 62 Mt CO2e). Mid-range servers were expected to decrease their carbon emissions from 5 to 2 Mt CO2e. Storage systems’ emissions were likely to be around 2 times higher in 2020 and high-end servers were not expected to show significant changes (ch. 2).

According to International Energy Agency, in 2020 the data centers and transmission networks resulted in approximately 300 MtCO2e (Kamiya ch. CO2 emissions). It means that carbon emissions even exceeded the expectations stated in “SMART 2020: Enabling the Low Carbon Economy in the Information Age” report.

3.4.3 Data centers’ energy consumption

There is no precise information on the amount of energy consumption of data centers. Andrae, Belkhir and Elmeligi, Petit et al. argue that there is a significant increase, while other researchers, Masanet et al., Shehabi et al., believe that energy consumption remained constant throughout recent years (gtd. in Hintemann and Hinterholzer). In 2015 Malmodin and Lundén estimated the total energy footprint of data centers and enterprise networks to be 245 TWh (28). According to a study conducted by Borderstep Institute, the total energy consumption in Germany in 2021 was estimated to be 17 billion kWh, which is 6.5% higher than in 2020. 11 kWh are consumed by such IT components as servers, storage, and network. The energy consumption of data centers’ infrastructure (cooling, uninterruptible power supply) increased from 4.6 to 6.1 billion kWh between 2010 and 2021. The main reason for the increase in consumption is the power demand for the performance of data centers (qtd. in Hintemann and Hinterholzer).

3.5 E-waste

The term e-waste is an abbreviation of “electronic waste”. According to “Solving the E-waste Problem (Step) White Paper”, it refers to electrical and electronic equipment (EEE) which is considered by the owner as a useless item to get rid of (4, 5). According to Forti et al., 53.6 Mt (metric tonnes) of e-waste were produced in 2019, with a growth of 9.2 Mt since 2014 (23). Small IT and telecommunication equipment resulted in 4.7 Mt produced. Screens and monitors have shown a 1% decrease and resulted in 6.7 Mt thanks to lighter flat panel displays. The largest amount of e-waste was generated by small equipment (e.g., toasters, calculators, radio sets, video cameras, small electric and electronic devices) – 17.4 Mt and large equipment (e.g., large printing machines, washing machines) – 13.1 Mt (ibid. 24).

A large amount of e-waste generated in 2019 (44.3 Mt) was managed outside of the official collection system, not in an environmentally friendly way (ibid. 23). It means that some of the electronic waste ended up in landfills, which has a significant environmental impact due to the release of methane, a powerful greenhouse gas. Moreover, e-waste consists of various components, some of which contain hazardous metals. For instance, mercury is used in sensors, data transmission, telecommunication, and mobile phones. Cadmium is present in printed circuit boards and batteries (Khaliq et al. 156). “Improper e-waste management can cause air pollution and lead to the contamination of soil, surface water, and groundwater” (Barrero et al. 7). This directly contributes to climate change.

3.6 Minimizing the negative impact

As we have seen, some companies managed to reduce their greenhouse gas emissions despite growing data traffic. Some of the measures they took were the use of recycled materials and renewable energy sources in the products’ supply chain. “The ICT sector’s carbon footprint could be reduced by over 80 percent if all electricity consumed came from renewable energy sources” (“A quick guide to your digital carbon footprint”

7). Operators can also avoid emissions by the use of energy-efficient networks, such as 5G.

Green technologies or green computing is an approach to designing, manufacturing, using, and disposing of technologies with minimal environmental impact and greater efficiency (Murugesan 26). For instance, green computer design means the adoption of new techniques and nontoxic materials, and less electrical power consumption while still being economically viable and effective (ibid. 30, 31). Green data center means the use of environmentally friendly design, improved airflow management, and new energy-efficient equipment (ibid. 28).

It is also crucial to manage e-waste in an eco-friendly way by recycling and repurposing it. For instance, Apple launched Apple Trade In which allows customers to return their old devices. These devices are further reused or recycled ("Product Environmental Report" 7). Moreover, no e-waste should end up in landfills.

The adoption of those strategies by companies and the general public, combined and implemented on a large scale, can minimize the negative impact of the ICT sector on climate change.

4. Positive impacts of ICT

As such negative impacts of the ICT sector as carbon footprint and energy consumption were analyzed and ways of minimizing them had been presented, the attention can be drawn to the positive impacts, which are the focus of this chapter. The role of ICT in climate change adaptation and mitigation, and its potential to reduce emissions in other sectors will be examined.

4.1 Climate change adaptation and mitigation

To begin with, ICT is a valuable tool for climate change adaptation and mitigation. Adaptation is defined by Fankhauser as a "process of adjustment to climate effects, in order to moderate the negative and/or enhance the positive impacts of climate change" (Imam et al. 2). It is a great way to minimize the influence of climate change in the present time, while mitigation is a long-term strategy (Anup and Arvind 71).

ICT can play direct and indirect roles in the adaptation process. The direct role means the use of ICT for database development, which can be then employed to observe and measure climate change and assess its consequences. Whereas the indirect role means that ICT can support public outreach and build awareness of climate change impacts (ibid. 72).

As for climate change mitigation, Öhlander identifies it as measures taken to decrease greenhouse gas emissions and slow down the rate of increasing temperature globally. Moreover, she states that ICT services are able to reduce greenhouse gases by 15 % by 2030. Even more reductions are possible thanks to new technologies like 5G, AI, and IoT.

4.2 Digital technologies to tackle climate change

This sub-chapter examines 5G, IoT, and AI technologies. Their definitions and implementations to decrease the negative impact of climate change will be analyzed.

4.2.1 Fifth generation wireless technology (5G)

5G is the fifth generation of cellular networks. It serves as a platform that facilitates communication among various emerging technologies. In comparison to 4G networks, 5G offers up to 100 times higher bandwidth, which means that larger amounts of data can be transmitted with higher speed and efficiency. It is also more reliable and able to support a greater number of connected devices (Kuroki et al. 14).

The reduction of carbon emissions by 5G networks is enabled by the more efficient use of energy for data transmitted. Energy reduction is possible thanks to these technologies: beamforming (allows the focused transmission of wireless signals to a particular location, so no energy is wasted on broadcasting in areas where no devices are operating), Massive Multiple-Input, Multiple-Output (allows the transmission of more data using the same amount of energy), Millimeter Wave Spectrum (contributes to an increased amount of data transmitted within a signal while decreasing energy consumption), Smart-Sleep Mode Technology (radio infrastructure can "sleep" when there is no traffic, decreasing energy consumption), and Virtualized Radio Access Networks (energy is reduced by dynamic programming and centralization of computing resources) (ibid. 16).

Kuroki et al. created a model to determine the specific impact of 5G technology on reducing carbon emissions. According to the analysis, 5G could result in annual carbon emissions abatement of up to 330.8 MMtCO2e (million metric tons of carbon dioxide equivalents) by 2025 in the United States. The study focused on five industries: transportation and cities, manufacturing, energy and buildings, agriculture, and working, living, and health (19). As a result, the highest 5G-enabled reduction of carbon emissions is estimated to be in the transportation (86.5 MMt CO2e), working, living and health (81.1 MMt CO2e), manufacturing (67.4 MMt CO2e), and energy and buildings (67.9 MMt CO2e) sectors. The reduction in the agricultural sector can result in 27.8 MMt CO2e (ibid. 4).

4.2.2 Artificial Intelligence (AI)

According to Herweijer et al., Artificial Intelligence is "a collective term for technologies that can sense their environment, think, learn, and take action in response to what they're sensing and their objectives" (13). AI adoption in agriculture, water, energy, and transport sectors globally can reduce worldwide greenhouse gas emissions by up to 4 % in 2030 (ibid. 14).

In the agricultural sector, the AI-enabled reduction of emissions is possible by better monitoring and managing environmental conditions, and crop yields (ibid. 17).

In the energy sector, AI has the potential to enhance efficiency with the aid of intelligent grid systems. These systems utilize advanced predictive capabilities to effectively manage the energy demand and supply and optimize the integration of renewable energy solutions (ibid. 17).

In the transportation sector, the reduction of emissions is enabled by more accurate traffic prediction, real-time planning of journeys, and advancing autonomous vehicle technologies (ibid. 17).

The utilization of AI in the prediction, management, and monitoring of water resources has the potential to mitigate environmental impacts (ibid. 17).

4.2.3 Internet of Things (IoT)

According to Lakhwani et al., the term Internet of Things (IoT) can be defined as a huge network of interconnected devices, which collect, assemble, and transmit data with the aid of various sensors. The data of the surrounding environment and the working condition of the connected devices are constantly processed by the sensors. The common language or an intermediate translator is used for communication between interconnected devices. The information gathered is then utilized for the system's automation and efficiency improvement (ch. 1).

The Internet of Things is utilized in various fields. Some of them are transportation, buildings, agriculture, and energy sectors (ibid. ch. 1). There are even more sectors, however, these are the ones where IoT is widely used for the reduction of carbon emissions and energy consumption.

As for the transportation sector, one of the IoT's applications is smart parking and traffic handling. The data is analyzed from traffic cameras, smartphones, and road sensors to manage road congestion (ibid. ch.1). Moreover, ensuring precise data on available parking spots also improves traffic efficiency. Consequently, traffic jams and carbon emissions can be reduced (Agrawal and Vieira 85).

In buildings, actuators and sensors can be installed in devices like heaters, air conditioners, and lights. This way the heating, cooling, and flow of light can be controlled automatically, depending on the surrounding conditions, so the energy is utilized efficiently (ibid. 87).

In agriculture, the sensors are capable of effectively monitoring weather conditions, soil composition, humidity levels, and crop growth. An example is the GreenIQ application, which enables remote control of irrigation (thanks to embedded sprinklers controller) and lighting (Lakhwani et al. ch.1). The use of the Internet of Things in agriculture allows efficient use of land, a decreased amount of used fertilizer, and reduced wastewater from irrigation ("The Enablement Effect" 29). Consequently, the negative impact on climate change is reduced.

As for the energy sector, the utilization of M2M ("smart technologies connecting one machine to another", a subset of IoT) in smart grids enables easier monitoring and regulation of energy demand. This increases the resilience and stability of the system and improves the distribution efficiency, while decreasing the environmental impact (ibid. 11, 18).

Additionally, remote sensing plays a crucial role in disaster early warning and prevention. It allows quick data collection from the area of disaster. The information gathered is further used in disaster management and prevention. The same areas can be viewed for a long time, allowing the monitoring of environmental changes and human impact (Dash and Sharma 276).

Overall, technologies like 5G, AI, and IoT play crucial roles in transforming transportation, manufacturing, buildings, agriculture, and energy sectors to be more efficient and environmentally friendly, thereby reducing carbon emissions.

4.3 Carbon emissions abatement

The GSMA together with Carbon Trust (organization helping other businesses decarbonize) studied how mobile network-enabled technologies are helping to reduce emissions. 14 countries in 6 regions were chosen as a representative global sample and 6000 smartphone users were examined ("The Enablement Effect" 10, 11). The authors of the report claim that the level of emissions abatement enabled by mobile communication technologies is 10 times greater than the carbon footprint of the mobile networks themselves. In 2018 the decrease in 1.44 billion MWh of electricity and gas and 521 billion liters of fuel was enabled with the aid of mobile technologies (ibid. 9).

Most of the avoided emissions from M2M technologies are in buildings, transport, manufacturing, and energy sectors (ibid. 11). These industries are some of the biggest emitters nowadays.

4.3.1 Smart buildings

Smart buildings refer to buildings with fully automated systems and advanced management of electricity, air conditioning, and access control. These buildings are connected to the network with the aid of the Internet of Things and 5G network. Their design is energy-efficient, incorporating systems that optimize energy usage and prioritize sustainability. Moreover, they are built with eco-friendly materials, thus reducing carbon emissions and waste ("What is a smart house?").

The reduction of carbon emissions in buildings is enabled by smart meters, HVAC (heating, ventilation, and air conditioning) control, and building management systems. The greatest reduction of emissions is enabled by M2M automated monitoring and HVAC systems, which resulted in the reduction of 103 MtCO2e in 2018 ("The Enablement Effect" 16).

Smart meters provide a convenient monitoring system for tracking energy and water consumption, thereby raising awareness and encouraging changes in behavior, stimulating the reduction of carbon emissions. Furthermore, users are able to remotely operate appliances, heating, and cooling systems thanks to smart home control, which is integrated into smartphone apps (ibid. 17).

An example of the implementation of technologies into buildings is Telefónica company which provided end-to-end solutions to a top-level hotel, where connected meters and submeters were installed to get information on energy consumption. The company received all generated data to its centralized platform. As a result of the data processing, the cooling and lightning circuits ended up having the highest energy consumption. Therefore, the automated equipment to control those circuits was placed in the hotel. The client reported energy savings of up to 12 % ("Take Things Further: Smart Energy Case Study").

These technologies are crucial for facilitating the transition to carbon-neutral buildings and decarbonization. Their implementation in more buildings would result in a significant reduction of the building's carbon footprint.

4.3.2 Transportation

As stated before, carbon emissions of the transportation sector can be reduced with the aid of traffic handling and smart parking. Smart monitoring and management of traffic congestion are enabled by integrating M2M technology into urban infrastructure. With the aid of mobile communications technology, the redirection of traffic is possible for further avoidance of congestion and route optimization. Traffic flow can also be improved by traffic lights' communication enabled by smart monitoring ("The Enablement Effect" 25). Real-time camera data is collected and fed into a traffic management platform. This data is further used to dynamically control signal timings based on the current demand for the traffic flow (Keskinian et al. 24). This way drivers are able to maintain a more consistent speed, reduce fuel consumption, and carbon emissions ("The Enablement Effect" 25).

Smart parking helps drivers to find free parking spots, without the need to circle around. Futile attempts of searching the parking spaces create congestion and cause air pollution. Smart parking services address this problem by guiding the driver directly to a parking spot. For instance, China Mobile deployed two smart parking pilots powered by NB-IoT (Narrowband Internet of Things) to showcase its capabilities. The installation of smart parking sensors across 4000 spaces was involved in the first pilot. The second pilot involved 6 sets of entrance and exit systems together with a parking management system with more than 300 parking bays. The parking system utilized sensors in each parking bay to detect occupancy. This information was further sent to parking attendants via the NB-IoT network. As soon as the spot was occupied, the charging was commenced, and data was sent to inform other drivers of remaining parking spaces. As a result, China Mobile smart parking service brought significant benefits, such as reduced congestion and pollution. Thanks to integrated mobile payments, the amount of time spent to enter and exit car parks was also reduced ("China Mobile Smart Parking – Internet of Things Case Study").

Environmental impact from the transportation sector can also be reduced by changing driving habits with the aid of services like Telia Eco-Driving (Telia is a multinational telecommunications company). It operates on the Telia IoT platform and is connected via Telia IoT Edge, the company's powerful processor and gateway. By collecting and analyzing data on driving habits and fuel consumption in real-time, Telia Eco-Driving provides immediate feedback to drivers while they are on the road, enabling them to keep track of their driving behavior and its impact on fuel consumption ("Eco-Driving: Minimize Your Fuel Costs and Environmental Impact"). This empowers drivers to make adjustments to their driving habits to lower fuel consumption and reduce carbon emissions.

Another tool to tackle climate change is Vehicle Climate Management, a service provided by Telia company as well. The service utilizes Telia IoT Edge, which collects data from temperature sensors installed in the vehicle. The heating process can be monitored in real-time, the history can be viewed. By controlling and automating the vehicle's heating system, unnecessary heating can be eliminated, optimizing energy consumption and reducing the environmental impact ("Vehicle Climate Management: Reduce Both Your Heating Costs and Environmental Impact").

Additionally, transportation emissions can be reduced significantly through the increase in the usability of ride-sharing, bike-sharing, and public transport. The widespread adoption and effectiveness of such car-sharing applications can be enabled by 5G technology, which allows the successful integration of Internet of Things systems within the physical infrastructure (Kuroki et al. 29). Furthermore, 5G technology plays a crucial role in expanding the use of public transport. It can be done by providing real-time updates on the precise location of buses and trains, up-to-the-minute schedules, and availability of seats (ibid. 33). This way people can rely on public transportation and use it more frequently, reducing the number of vehicles on the road, and their carbon footprint.

The bike-sharing company Mobike launched in Shanghai has transformed the way people commute with the aid of ICT tools, promoting eco-friendly transportation. The ICT enables real-time monitoring of bikes, allowing the company's staff to efficiently distribute bikes to areas with high demand, optimizing their availability across the city. The data from 8 million bikes across 200 cities globally is collected and processed by Mobike's data platform in order to predict the demand for bikes and distribute them more effectively. Mobike has also implemented several environmentally friendly strategies to reduce material usage and enhance sustainability. The collection of damaged bikes for their further repair, remanufacturing, or recycling is practiced. The damaged bikes are located and retrieved with the aid of GPS tracking. In 2016 Mobike users cycled over 5.6 billion kilometers in total, which resulted in estimated 1.2 million tonnes of reduced carbon emissions. It is estimated that the adoption of Mobike-like services in 500 cities could lead to a reduction of 30-60 million tonnes of carbon emissions ("Bike Sharing with Chinese characteristics").

4.3.3 Manufacturing

Mobile technologies also contribute to reduction of emissions in the manufacturing sector with the aid of inventory management systems, which decrease the demand for more storage space at the warehouses. Consequently, less energy for lighting and cooling is needed, which lead to 240 Mt CO2e of avoided emissions in 2018 ("The Enablement Effect" 34).

Furthermore, IoT enables a carbon-saving solution for shipping pallets. According to *"AT&T 10x Case Study: Unlocking the Potential of Connected, Reusable Pallets"*, wooden pallets present some challenges, such as financial and environmental costs of disposal and replacement. However, reusable and connected pallets, made from composite materials, address those challenges (1). The Internet of Things is embedded into reusable pallets. The connected pallets allow users to reduce fuel consumption and decrease wood waste and the amount of raw materials required for the production of replacement pallets. Users can track them moving from one location to another in the supply chain, reducing risks of loss, the cost, and time of locating and replacing pallets (ibid. 2,3). If 1 million wooden pallet trips were replaced with reusable, connected pallets, then 640 metric tons of CO2 could be reduced, resulting in a 21 % reduction in carbon emissions (ibid. 4).

Additionally, ICT contributes to carbon emissions abatement in the manufacturing sector by providing detailed real-time data on electricity usage and temperature levels in warehouses. It was done for Lineage, leading food cold storage company. As cold storage facilities consume a substantial amount of energy, Lineage aimed to lower their energy consumption and carbon footprint. To reach this goal, it collaborated with ndustrial.io (an energy optimization company) and AT&T (a telecommunications company). Smart meters and sensors were installed across the warehouses ("AT&T 10x Case Study: Energy Efficient Frozen Food" 3, 4). The cloud-based system provided by ndustrial.io utilized AT&T Internet of Things connectivity to collect temperature and humidity data. This information helped determine the ideal temperatures for specific areas. With the aid of this information, the system could control chillers (refrigeration systems), turning them on/off as needed to maintain the required temperatures. As a result, Lineage witnessed an 8 % decrease in annual energy cost (ibid. 5). Annual carbon savings resulted in 1400 tCO_2 per cold storage facility (calculated as an average for 2015, 2016, and 2017) (ibid. 11). Lineage company managed to reduce its energy usage and greenhouse gas emissions by real-time temperature monitoring, analysis, and control.

4.3.4 Energy sector

In the energy sector, 5G-enabled smart grids can significantly contribute to carbon emissions abatement. Two-way communication, real-time monitoring and the millisecond-level response time enabled by 5G technology help match supply and demand for energy, reducing excess generation and peak consumer demands. Moreover, the grid issues can be detected and addressed promptly. Overall, smart grids can significantly improve energy efficiency while reducing energy consumption and environmental impact with the aid of enhanced monitoring, analysis, and control enabled by ICT technologies (Keskinian et al. 31).

4.3.5 Smart living, working, and health

Online services such as mobile banking, shopping, and video-calling let people perform activities remotely, with no need to travel. This resulted in 302 Mt CO_2 of avoided emissions in 2018. Mobile communication technologies also enable "sharing" apps, which provide a platform for selling, renting, or giving away goods such as clothes, and electronics. These activities facilitate waste reduction. Additionally, ICTs enable the sharing of services, such as accommodation and bike sharing. Accommodation sharing alone resulted in 10% of the total avoided emissions calculated in "The Enablement Effect" in 2018. Moreover, the use of apps such as Airbnb resulted in higher avoidance of emissions compared to living in hotels (20).

The utilization of audio conferencing and collaborative software platforms enabled by mobile communications technology allow companies to conduct their business remotely. Therefore, there is no need for employees working from home to travel to offices, which leads to the avoidance of emissions. Further reduction of emissions is enabled by decreased energy consumption in office buildings. While working from home also requires energy use, the overall carbon savings of avoided commuting generally outweigh this (ibid. 20). Telecommuting, which refers to remote work, has been widely promoted to reduce companies' carbon footprint. In 2012 Dell company launched its telecommuting "2020 Legacy of Good Plan". In 2015 about 20000 employees worked from home, resulting in the reduction of greenhouse gases by 6700 metric tonnes (Sutton).

As for the healthcare sector, emissions can be reduced by avoiding the need for a patient to travel to the hospital. This is done with the aid of virtual wards, which utilize the hospitals' systems and staff, allowing the patients to receive necessary care in places they live, without the need to travel. Similar to a traditional hospital ward, the virtual ward has a set number of available virtual "beds" (Hakim). For instance, patients in virtual wards using the Telehealth service are given "devices to record their oxygen levels, heart rate, respiratory rate, blood pressure, ECG, step count, and temperature". Patience are being monitored daily, and the results are sent to the Telehealth service system ("Telehealth – Health Technology Service").

4.4 ICT in agriculture

To explore the potentials of ICT usage in agriculture, the study by Imam et al. was conducted in four villages of Sirajganj District in Bangladesh, which are highly vulnerable to climate hazards like flood, riverbank erosion, fog, the erratic behavior of temperature, rainfall, and seasonal pattern. As a result, the most significant adaptation strategies were flood early warning, improved cropping patterns, and occupational migration. People get the flood early warning through mobile voice SMS every day during the rainy season. They also go to the UDCs (Universal Data Collection) and the CDCs (Centers for Disease Control) to know the weather forecast, so plantation and cultivation of crops can be planned. Visual guidance to any agriculture-related problem can be found by farmers thanks to the agricultural UDC's software (mobile application). Moreover, they get information on the amount of pesticide or fertilizer which has to be applied (96, 100, 101).

The ICT services, such as mobile phones and Internet use through UDC and CDC are both playing a significant role in the adaptation process.

4.5 Remote sensing technologies

Satellite remote sensing is an important tool for climate system observation. It uses sensors onboard satellite to gather information about Earth's surface, subsurface, and atmosphere (Yang et al. 875). The data gathered from satellite remote sensing allows the monitoring of snow extent, ice covers dynamics, and sea surface temperature worldwide and reveals an uneven warming pattern (ibid. 875, 876).

Remote sensing technologies are also widely used for vulnerability mapping for a better understanding of present and possible future risks related to climate change (Campbell-Lendrum et al. 733). As an example, sensor technologies can be used to map surface temperatures and urban heat island levels, showing where city greening and urban cooling measures should be taken or alerting to the risks of heat waves (Luber and McGeehin 433).

Moreover, the data from remote sensing technologies then can be used for disease modeling. For instance, modeling of Lyme disease in Portugal showed that its transmission risk is higher in the center and northern parts of the country (Casimiro et al.).

Remote sensing technology plays a crucial role in adaptation to climate change. It allows the monitoring of the environment and a better understanding of changes happening in it. The information gathered can be used by policymakers to take the right measures to tackle climate change.

4.6 Early warning systems for health protection

With the intensification of heatwave events, which are associated with climate change, many countries have developed a heatwave early warning system to reduce negative human health consequences through timely alerting vulnerable populations. It forecasts weather conditions, predicts potential health outcomes and communicates risks (Lowe et al.).

Hii et al. highlight the role of early warning systems in pre-epidemic preparedness and disease control. For instance, they managed to develop a dengue (rapidly spreading viral infection) forecasting model in Singapore that provides early warning of a dengue outbreak up to 16 weeks ahead. This time allows local authorities to mitigate coming outbreaks effectively (ch. Discussion).

4.7 ICT and disaster management

Due to climate change, natural disasters are happening more frequently, causing damage, poverty, and loss of lives. The goal of disaster management and disaster risk reduction is the mitigation of potential losses, appropriate assistance to victims, and effective recovery from climate change impacts. For effective disaster management ICTs like the Internet for emergency websites, cell phones, and GIS (Geographic Information System) are used. GIS consists of hardware and software utilized for storing, retrieving, crisis mapping, and analyzing geographic data. GIS visually displays the centralized critical information, such as the area affected by the disaster, possible routes to reach this location and evacuation routes, the evaluation of damage, logistical planning to provide supplies, and the nearest location of fire stations (Dash and Sharma 273, 276). This way ICT technologies play a significant role in climate change-related disaster prevention, mitigation, and recovery.

In conclusion to this chapter, the role of ICT as a valuable tool for climate change adaptation, which refers to measures to tackle climate change taken in the present time, and mitigation, a long-term strategy, was analyzed. The direct role of technologies in the adaptation process encompasses the utilization of ICT for database development, which can be then employed to observe and measure climate change and assess its consequences. The indirect role refers to the use of ICT to support public outreach and build awareness of climate change impacts (Anup and Arvind 71, 72). Technologies like 5G, AI, and IoT enable the reduction of greenhouse gas emissions in the agricultural, energy, transportation, buildings, living, working, and health sectors. The reduction of carbon emissions by 5G networks is enabled by the more efficient use of energy for data transmission. AI technology contributes to carbon emissions abatement by its monitoring, managing, and predicting capabilities. The IoT-enabled reductions are possible thanks to its ability to automate systems and improve their efficiency. The carbon emissions abatement enabled by 5G, M2M, IoT technologies in buildings, transportation, manufacturing, energy, smart living, working, and health, and agriculture sectors were analyzed in more detail. Finally, the contribution of ICT to prevention and effective recovery after the disastrous consequences of climate change was stated.

5. How efficient are we today?

The global operators' electricity consumption increased by 5% between 2020 and 2021, while global data traffic increased by 31% over the same period. That is a significant efficiency improvement ("Mobile Net Zero: State of the Industry on Climate Action 2022 Report" 30). According to the report from the official website of Ericsson company *"A quick guide to your digital carbon footprint"*, carbon and energy footprints do not follow the same development trends as data traffic, which increased tenfold in 2015 since 2010. Moreover, it is likely that data traffic will continue increasing, but not the ICT's footprints, due to efficiency development, smartphones replacing larger devices (ibid. 6). Besides, more companies are investing in renewable energy like solar and wind power (ibid. 7). The production of "energy-smart digital devices", the adoption of open communication protocols are being developed and realized by governments and manufacturers for intelligent efficiency ("Energy Efficiency 2021" report 95).

Nevertheless, there is still room to grow. The wider adoption of renewable sources, recycled materials, proper disposal management in the products's supply chain, greener technologies with environmentally friendly design, the implementation of AI, IoT, 5G technologies in various sectors would result in higher efficiency and less carbon emissions.

Conclusion

To bring this thesis to a close, Information and Communication Technologies have both positive and negative impacts on climate change.

The main drawback of the ICT sector is its carbon footprint, as emissions are released during all the life cycle stages of ICT, starting from the raw material acquisition and ending with the disposal. An overview of the total carbon and energy footprints of ICT in 2015 based on a study conducted by Malmodin and Lundén was provided, resulting in 1.4% and 3.6 % of global footprints respectively. The largest emitters of greenhouse gases were desktop PCs, smartphones, and CPE. The LCA of Pentium IV and modern 14-inch MacBook Pro were compared. As a result, the MacBook was designed with more energy-efficient components, using recycled material, and no waste generated by supplier sites was sent to landfill. The adoption of such strategies as the use of renewable energy sources and recycled materials in the supply chain, proper disposal of e-waste, and the use of green technologies by companies and the general public, combined and implemented on a large scale, can minimize the negative impact of the ICT sector on climate change significantly.

As for the positive effects, new technologies such as 5G, IoT, and AI enable carbon emissions abatement in sectors with the highest carbon footprint: buildings, transportation, manufacturing, and energy. The reduction of carbon emissions by 5G networks is enabled by the more efficient use of energy for data transmission. AI technology contributes to carbon emissions abatement through its monitoring, managing, and predicting capabilities. The IoT-enabled reductions are possible thanks to its ability to automate systems and improve their efficiency.

The reduction of carbon emissions in buildings is enabled by smart meters, HVAC control, and building management systems. A convenient monitoring system for tracking energy and water consumption provided by smart meters raises awareness and encourages changes in behavior, stimulating the reduction of carbon emissions.

Carbon emissions in the transportation sector can be reduced with the aid of traffic handling, smart parking, and changing driving habits. The collection and analyzing data on driving habits and fuel consumption in real-time empowers drivers to adjust their driving habits to lower fuel consumption and reduce carbon emissions. The heating process can be monitored in real-time, thereby, unnecessary heating can be eliminated, optimizing energy consumption and reducing the environmental impact. Additionally, transportation emissions can be reduced significantly through the increase in the usability of ride-sharing, bike-sharing, and public transport, as the reduction in the number of vehicles on the road leads to a reduction in carbon footprint.

Mobile technologies also contribute to the reduction of emissions in the manufacturing sector with the aid of inventory management systems, connected and reusable shipping pallets, and by providing detailed real-time data on electricity usage and temperature levels in warehouses.

5G-enabled smart grids can significantly contribute to carbon emissions abatement with the aid of enhanced monitoring, analysis, and control.

Online services such as banking, shopping, sharing and mobile-accessed health platforms reduce the need for traveling, enabling the reduction of millions of tonnes of carbon emissions globally.

Moreover, ICT is intensively utilized in adaptation strategies for monitoring and measuring climate change effects and spreading awareness of them, as well as in agriculture for plantation and cultivation planning and other agro-related information. Early warning systems are able to predict coming outbreaks of diseases, floods and heatwaves, helping to minimize the disastrous consequences of climate change and save people's lives.

The potential of ICT to be a solution to the problem of climate change is major. It is a great tool for decarbonization in other sectors. In order to minimize its negative impacts and reach the full potential of ICT to tackle climate change, governments, businesses and consumers must work together. Technologies must be used as a tool for sustainability, so a bright and carbon-free future can be created for all.

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List of abbreviations

Abbreviation:	Definition:
BIP	Basis point
BRICS	Brazil, Russia, India, China, South Africa
CDC	Centers for Disease Control
CO2	Carbon Dioxide
CPE	Customer Premise Equipment
GSMA	Global System of Mobile Communications
IDC	International Data Corporation
IDI	ICT Development Index
IHS	Information Handling Services
IPCC	Intergovernmental Panel on Climate Change
ITU	International Telecommunication Union
LCA	Life Cycle Assessment
OLED	Organic Light-Emitting Diode
PSTN	Public Switched Telephone Network
UDC	Universal Data Collection