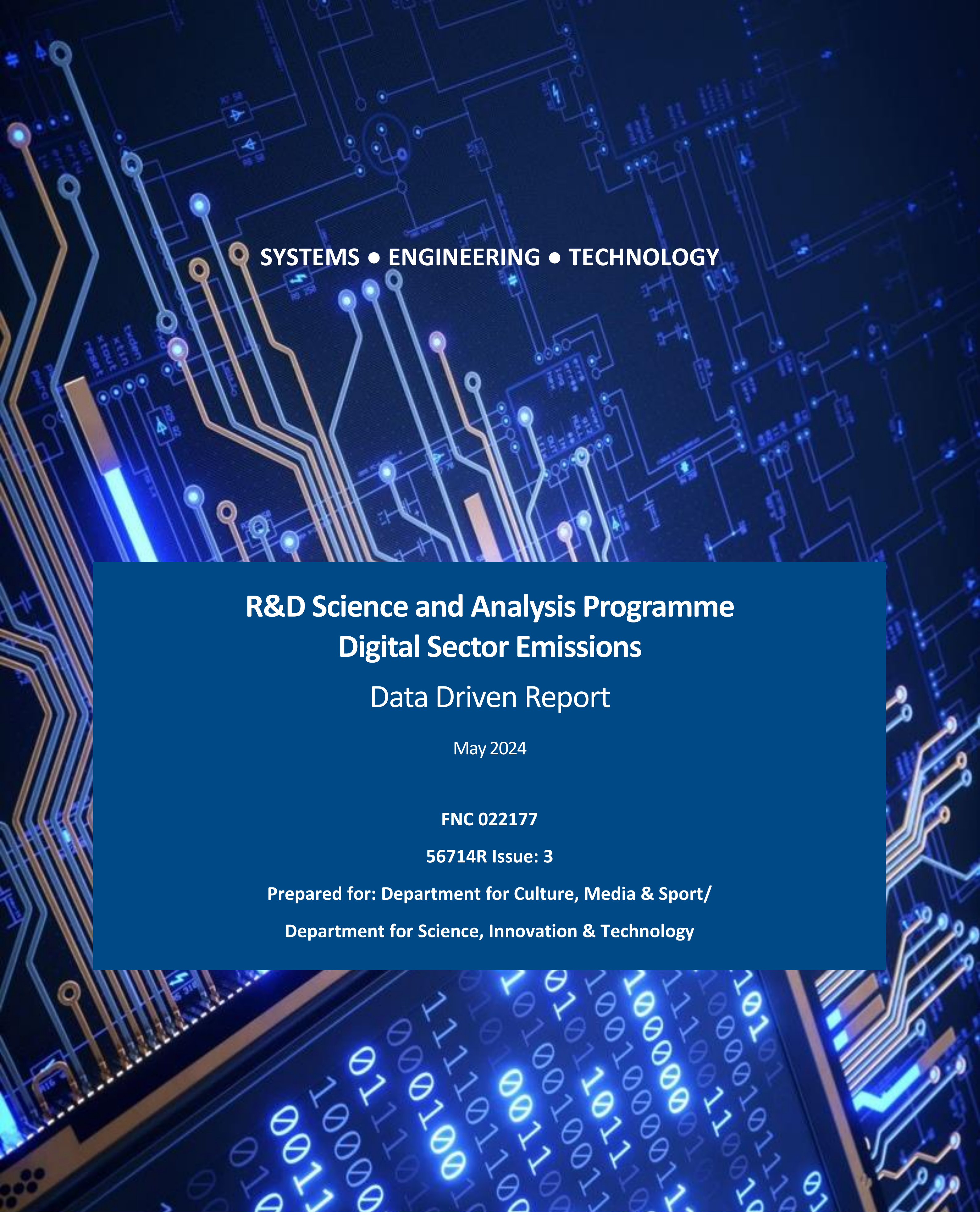

SYSTEMS ● ENGINEERING ● TECHNOLOGY

R&D Science and Analysis Programme
Digital Sector Emissions

Data Driven Report

May 2024

FNC 022177

56714R Issue: 3

Prepared for: Department for Culture, Media & Sport/

Department for Science, Innovation & Technology

UNIVERSITY OF CAMBRIDGE
Department of Public Health and Primary Care

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DISCLAIMERS

This research was supported by the Department for Science, Innovation & Technology and the R&D Science and Analysis Programme at the Department for Culture, Media & Sport. It was developed and produced according to the research team's hypotheses and methods. Any primary research, subsequent findings or recommendations do not represent Government views or policy.

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CONTRIBUTING ORGANISATIONS

	Frazer-Nash Consultancy Limited as the prime contractor was responsible for overall delivery of the Digital Sector Emissions research project. We set up a partnership consortium with the University of Cambridge and the University of Bristol. We provided project management oversight and led the overarching technical delivery of the project. We led the development and authorship of the Policy Driven Report, leading on the Digital Emissions Policy section, Conclusions and Executive Summary, and undertaking the literature review, and were the supporting author on the Data Driven Report.
	The University of Cambridge (Cambridge University Technical Services Limited) supported the project throughout and undertook the role of Data Technical Lead for the data analysis aspects of the project. This included researching related background literature and providing general technical expertise. They led the data analysis and were lead author for the Data Driven Report with technical support from Frazer-Nash.
	The University of Bristol supported the project throughout and undertook the role of Policy Technical Lead for the policy review aspects of the project. They were co-authors of the Policy Driven Report, leading on the Setting the Context and Mitigation Spotlight sections, and contributed to the literature review, providing technical expertise in relation to digital emissions. Thank you to the international experts who were involved in reviewing aspects of the reports and endorse the findings.

EXECUTIVE SUMMARY

The digital sector has been and continues to be a catalyst for new capabilities and efficiencies, transforming the way society operates and interacts. The environmental impacts of this sector, such as greenhouse gas (GHG) emissions and resources depletion, are significant and require careful consideration. The first essential step to inform future policy making is to quantify these impacts through a detailed inventory for the UK. This is something that had not been conducted before.

Commissioned by the Department for Culture, Media and Sport (DCMS) and the Department for Science, Innovation and Technology (DSIT), this report provides a robust analysis of the electricity consumption, GHG emissions and wider environmental impacts associated with the UK's digital sector. It also investigates future trends through case studies and scenario projections. The research was conducted in partnership with Frazer-Nash Consultancy, the University of Cambridge, and the University of Bristol.

Key Figures for the UK Digital Sector

- The digital sector contributes 19.28 Mt CO_2e to the UK's GHG emissions, 2.73% of the UK total GHG emissions (consumption footprint). This represents 29% of the yearly planetary boundary per capita (which represent the Earth's ecological limit).
- User devices are responsible for approximately half of these emissions, with data centres at 35% and networks at 13%.
- 63% of the digital sector's GHG emissions are due to embodied emissions (covering manufacturing, distribution, and end-of-life) and the remaining 37% result from usage.
- The sector's yearly electricity demand is estimated at 31.35 TWh, representing 9.77% of the UK's total electricity demand, with data centres accounting for 41% of this consumption and user devices 25%.
- Apart from GHG emissions, the digital sector's impact alone reaches over 35% of the planetary boundary per capita for abiotic resource depletion, which represent the maximum sustainable extraction level of minerals and metals. This is mostly due to user devices. Regarding freshwater eco-toxicity, the sector's impact covers 14% of the boundary.

Future Landscape of the Digital sector

The future landscape of the digital sector was explored through three qualitative scenario projections, which give an understanding of how the digital sector may evolve in the future:

- Scenario 1, No Change: Represents trends which mirror those seen in the present digital sector landscape.
- Scenario 2, Setting the Pace: Represents a UK proactively accelerating its reduction in emissions from digital technologies.
- Scenario 3, Lagging Behind: Represents a UK which experiences an accelerated growth in emissions arising from digital technologies, where little to no action is taken to reduce emissions.

Quantitative analysis of the targeted variables arising from the case studies below reflect the possible changes to the future landscape of the digital sectors from the scenario projections above:

- Case Study 1: Investigated the decarbonisation of the grid and its effects on the digital sector carbon emissions.
- Case Study 2: Investigated the carbon emissions associated with the rapid deployment of smartphones and computers mapped on to the grid decarbonisation projections.
- Case Study 3: Investigated the carbon emissions associated with the future demands for data centres mapped on to the grid decarbonisation projections.

Key Recommendations

1. **Collecting UK-specific data for the digital sector**. Several estimates presented in this report are based on studies undertaken outside the UK, which may not capture the specificities of the UK market, or the impact of UK policies. The data collection could be achieved by either commissioning surveys and primary data collection or through the expansion of compulsory reporting requirements.

2. **Collecting data on the number and size of UK data centres**. This is perhaps the biggest blind spot at this stage. With the growth of data centre-based services, AI among others, it is essential to have a better picture of the UK data centre landscape.

3. **Enhancing existing compulsory reporting of companies' electricity consumption and GHG emissions by requiring provision of more granular data (on locations, sectors and activities)**. Considering the broad activities conducted by large companies, the reporting of a single number covering all activities, different sectors and sometimes several countries is insufficient to have a clear picture of the sector. This step would involve requiring that companies release separately, numbers for the UK (instead of focusing on global figures only) and numbers for the different activities (e.g. mobile networks vs broadband, network infrastructure vs BAU).

4. **Further development of the scenarios is required to model the full GHG emissions and wider environmental impacts associated with the projections for both the use stage and embodied impacts.** The current case studies only model the use stage carbon emissions associated with a specific variable change (e.g. decarbonisation of the grid, rapid deployment of user devices). Further work will provide a more in-depth analysis to aid policy development.

5. **Further development of the scenarios is required to enhance the current projections to consider which digital technologies may be a part of the digital sector in the future and the effects they will have on the environment**. The scenario projections consider four core elements: user devices, networks, data centres and grid decarbonisation. The digital sector has multiple layers within its taxonomy and is ever evolving with new technologies such as AI, IOT, virtual reality becoming more predominant.

6. The scenarios and case studies only consider direct effects of the future landscape of the digital sector. **Further investigation into the enabling effects and system effects related to the changes to the digital sector** will provide a holistic understanding of the indirect environmental impacts.

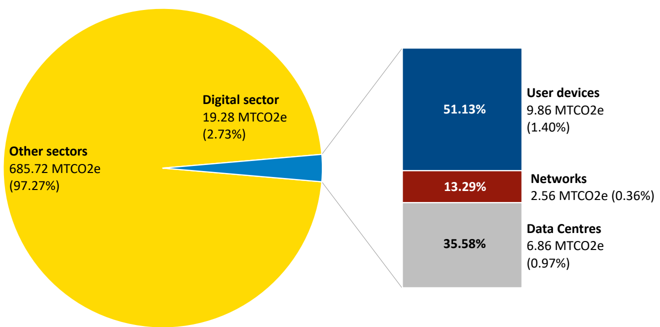
While the digital sector offers numerous benefits and opportunities for society, it is crucial to understand and mitigate its environmental impacts. This report provides policymakers with a quantitative resource to make subsequent informed decisions to leverage the benefits of digital technologies while minimising their environmental footprint.

This report also highlights the need for ongoing monitoring and evaluation of the sector's environmental impacts, which will be crucial in guiding the UK's journey towards Net Zero. The report is accompanied by a data spreadsheet to allow a deeper understanding of the different component of the UK digital sector, and future modelling for downstream case studies.

Digital Sector Environmental Impacts Summary

We estimated that the 2023 UK greenhouse gas (GHG) emissions from the digital sector were 19.28 million tonnes of CO_2 equivalent (Mt CO_2e). This equates to 2.73% of the 2021[1] UK GHG emissions (Figure A). The digital sector drew 31.35 TWh of electricity, equating to 9.77% of total 2022[1] UK electricity demand (Figure B). Approximately half of the 19.28 Mt CO_2e are attributed to user devices (51%), 36% to data centres and 13% to networks. Data centres dominate the electricity demand for the digital sector at 41%. Figure C show a breakdown of the different subcategories.

A



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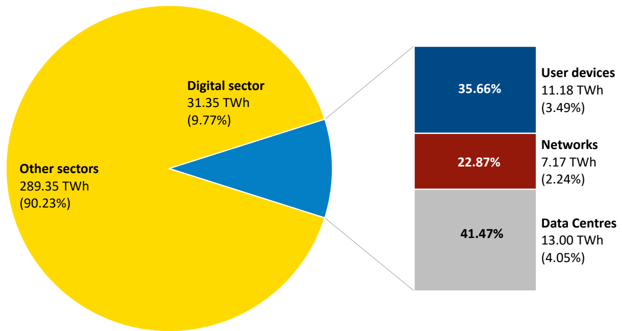

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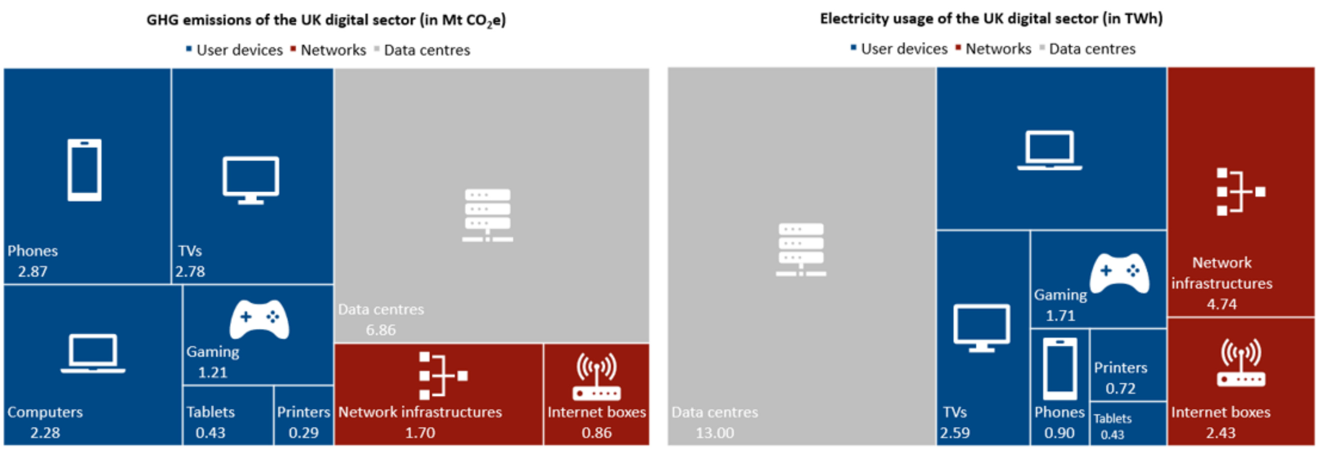
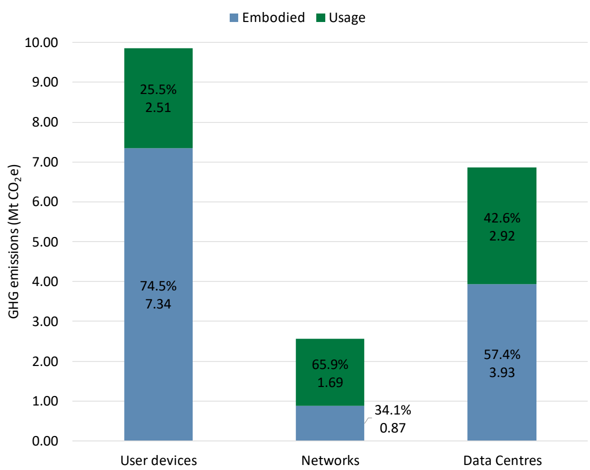


[1] Estimated electricity demand is compared to 2022 DESNZ statistics. Estimated GHG emissions are compared to 2021 ONS statistics. These are the latest published data at the time of writing.



Our analysis has shown that across the digital sector, 63% of GHG emissions are from embodied impacts (manufacturing, distribution, and end-of-life) while the remaining 37% are from usage. For user devices, embodied emissions outweigh use stage ones, while the opposite is true for networks, and the ratio embodied vs use stage is balanced for data centre.

CONTENTS

GLOSSARY

Term	Definition
Access Networks	A type of telecommunications network which connects subscribers to their immediate service provider.
Artificial Intelligence (AI)	The ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings.
Circular Economy	A model of production and consumption which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing products as long as possible to reduce waste.
Climate Change Mitigation	Interventions to reduce the release of greenhouse gas emissions into the atmosphere.
Cloud-based Applications	Software that users access primarily through the internet, meaning at least some of it is managed by a server and not users' local machines.
Cloud Computing	The practice of using a network of remote servers, hosted in providers data centres, to store, manage, and process data, rather than on a local server or personal computer.
Compute Equipment	Computer hardware includes the physical parts of a computer.
Content Delivery Networks	A network of interconnected servers that speeds up webpage loading for data-heavy applications.
Cryptocurrency	A digital currency designed to work as a medium of exchange through a computer network that is not reliant on any central authority, such as a government or bank, to uphold or maintain it.
DCMS	Department for Culture, Media, and Sport. Department of the UK Government.
Digital Economy	The economic activity that results from the online activity amongst people, businesses, devices, data, and processes.
Digital-Emissions Intersection	The development and deployment of innovative digital and data solutions can both contribute to, and support the reduction of, a country's greenhouse gas footprint. Interventions at the intersection i.e. impacting both emissions and digital growth/deployment, aim to increase the positive benefits and moderate the negative impacts.
Digital Taxonomy	The categorisation/ classification of digital technology.
DSIT	Department for Science, Innovation and Technology. Department of the UK Government.
Edge Networks (Computing)	Edge networks are a distributed computing paradigm that brings computation and data storage closer to the sources of data to improve response times, save bandwidth, and in some cases, also security. It is an architecture rather than a specific technology.
Future Compute Activities	Future computer systems where processing power, memory, data storage and network are assembled at scale to tackle computational tasks beyond the capabilities of everyday computers. 'Compute' is an umbrella term including, but not limited to, advanced compute, higher performance computing, large scale computing and supercomputing. Cloud computing does not entirely fall under this umbrella.

Term	Definition
Greenhouses Gas Emissions (GHG)	Emissions from natural or human activities that intensify the greenhouse effect (trapped heat in the atmosphere resulting in warming).
Greenwashing	The process of conveying a false impression or misleading information about environmental impacts, practices, or policies.
ICT	Information and Communications Technology.
Net Zero	A state where the release and removal of greenhouse gas emissions are in balance over a given period.
Offsetting	A trading mechanism that allows entities such as governments, individuals, or businesses to compensate for their GHG emissions by supporting projects that reduce, avoid, or remove emissions elsewhere.
Paris Agreement	The Paris Agreement, or Paris Climate Accords, is an international treaty on climate change. Adopted in 2015, the agreement covers climate change mitigation, adaptation, and finance. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."
Planetary Boundaries	The maximum sustained environmental intervention a natural system can withstand without experiencing negative changes in structure or functioning that are difficult or impossible to revert.
Policy Taxonomy	The categorisation/ classification of policy.
Product Environmental Footprint (PEF)	The impact of a person or company on the environment, expressed as the amount of land required to sustain their use of natural resources.
Science Based Targets initiative (SBTi)	The SBTi is a corporate climate action NGO. It develops standards for setting science-based targets for compass and financial institutions and also validates science-based targets to ensure their alignment with the Paris Agreement to limit global warming to 1.5C.
Scope 1 Emissions	Direct GHG emissions that occur from sources owned or controlled by the reporting organisation.
Scope 2 Emissions	A reporting organisations emissions associated with the generation of electricity, heating/cooling, or steam purchased for own consumption.
Scope 3 Emissions	Indirect emissions associated with the reporting organisations value chain. These can be either upstream or downstream from the organisation and are things that can be influenced but not directly control
Service Classes	A service class is a named group of work within a workload with similar performance goals, resource requirements, or business importance.

ABBREVIATIONS & ACRONYMS

Term	Definition
3G	3rd Generation Mobile Network
4G	4th Generation Mobile Network
5G	5th Generation Mobile Network
6G	6th Generation Mobile Network
ADPF	Abiotic Depletion Potential (Fossil Fuels)
ADSL	Asymmetric Digital Subscriber Line
ADSL	Asymmetric Digital Subscriber Line
AI	Artificial Intelligence
AP	Acidification Potential
AWS	Amazon Web Services
BT	British Telecoms
CCC	Climate Change Committee
CCUS	Carbon Capture, Usage and Storage
CDN	Content Delivery Network
CEP	Circular Electronics Partnership
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CPU	Central Processing Unit
DCMS	Department for Culture, Media, and Sport
DEFRA	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DSIT	Department for Science, Innovation and Technology
EU	European Union
FEP	Freshwater Eco Toxicity Potential
Frazer-Nash	Frazer-Nash Consultancy
FTTC	Fibre to the Cabinet
FTTP	Fibre to the Premises
GESI	Global Enablement Sustainability Initiative

doi.org/10.17863/CAM.114743

Term	Definition
GHG	Greenhouse Gas
Go Science	Government Office for Science
GPU	Graphics Processing Unit
GSMA	GSM Association
GWP	Global Warming Potential
ICT	Information Communication Technology
IoT	Internet of Things
IRA	Inflation Reduction Act
IR-HTP	Ionising Radiation Related to Human Health
ITU	International Telecommunication Union
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
MSP	Managed Service Provider
Mt	Megaton
OLED	Organic Light-emitting Diode
ONS	Office for National Statistics
PC	Personal Computer
PESTLE	Political, Economic, Social, Technological, Legal & Environmental
PMFP	Particulate Matter Formation Potential
POCP	Photochemical Ozone Formation
PSTN	Public Switched Telephone Network
SBTi	Science Based Targets initiative
SME	Small and Medium-sized Enterprises
Tbps	Terabits Per Second
TV	Television
TWh	Terawatt-hour
UK	United Kingdom
VR	Virtual Reality

doi.org/10.17863/CAM.114743

PREFACE

Frazer-Nash Consultancy teamed with the University of Cambridge and the University of Bristol to deliver a focussed investigation into the scale, drivers, effects and impacts of digital sector emissions. We have deep expertise in greenhouse gas emissions, expert knowledge of the digital technology landscape and experience of the latest international research and policy initiatives on this topic. We worked closely with government stakeholders, using an agile approach to research, which helped us continually refine and develop our focus to find and articulate insights at a policy level.

This important research is needed to identify reliable evidence on digital sector emissions to help overcome misconceptions. This will ensure that recommendations on policy interventions will deliver effective solutions to minimise digital sector emissions in the future.

Our research questions address the topic holistically, whilst encouraging derivation of the most useful information for UK policymakers:

1. Which countries, regions or industry practitioners are leading in decarbonisation of the digital sector?
2. What policies exist across the digital-emissions intersection? Have these been successful in driving decarbonisation?
3. What international standards exist that can be used to quantify digital emissions? Have these been demonstrated in practice?
4. What is the current quantity of GHG emissions from digital technologies in the UK?
5. What are the likely trajectories of greenhouse gas emissions from the use of digital technologies to 2035 in the UK?

Whilst addressing our chosen research questions, our journey through literature and analysis led us to uncover numerous additional observations and actionable insights. We have emphasised these insights throughout the report and synthesised them in our conclusion.

The value of this report is related to its timeliness. Calls to action to all sectors, to limit global warming must be answered with practical and tangible progress against goals and targets. The UK's Net Zero Strategy commits the UK to reaching Net Zero emissions by 2050 – initiatives to decarbonise the digital sector, used daily by billions of people globally, can have a real impact. We hope that the actionable insights delivered across our Policy and Data Driven Reports provide the analysis and evidence required for policy planning and decision-making.

1 INTRODUCTION

1.1 Background

Societies across the world have been shaped and advanced by digital technologies. Both the digital sector and wider industries have been able to develop new capabilities as a result of new technologies and the improved efficiency of existing ones. Data centres, networks, user devices, software and services run through systems which are changing the way society operates. This includes the way communities and wider societies interact with one another as well as creating new opportunities for connections socially, professionally, and economically. Research on this topic has informed the debate over the use of new digital technology as a means of meeting emissions reduction targets, as countries are looking towards reaching Net Zero in the coming decades, but also as a catalyst for increased emissions as the uptake of digital technology increases. As a result, the potential of the digital sector to impact global emissions substantially in both positive and negative directions has gained more attention globally.

The International Telecommunication Union (ITU), together with GSM Association (GSMA), Global Enablement Sustainability Initiative (GESI) and the Science-Based Targets initiative (SBTi) have published a normative 1.5°C trajectory for the decarbonisation of the digital sector. This calls for an emissions reduction of 45% between 2020 and 2030. We have therefore focussed our effort on qualitatively and quantitively analysing current environmental impacts of the digital sector in the United Kingdom (UK) and potential future trends based on future digital technology scenarios.

1.2 Reporting Structure

Frazer-Nash Consultancy (Frazer-Nash), alongside academic partners at the University of Cambridge and the University of Bristol, led research focused on emissions associated with the digital sector. The presentation of research findings is delivered via two connected, but distinct reports:

- **Policy Driven Report**: focused on digital policy, strategy, and standards; and
- **Data Driven Report**: focussed on quantitative reporting (this report).

Policies, targets, and initiatives related to reducing the sectors Greenhouse Gas (GHG) impacts are discussed in the accompanying Policy Driven Report. This investigated the existing international policy landscape to better understand current practice and international experience. The Policy Driven Report provides policy analysis of 21 countries. The research involved in depth review of available literature, insights from academics working in the sector for many years and iterative feedback from stakeholders in DSIT, DCMS, Department of Environment, Food & Rural Affairs (DEFRA) and Department of Energy Security & Net Zero (DESNZ).

This document represents the 'Data Driven Report' which investigates the environmental impact of the digital sector within the UK and explores the future landscape. The Frazer-Nash team followed an agile approach to research and report delivery, with close involvement from DSIT and DCMS stakeholders throughout the process.

1.3 Structure of the Findings

This report starts by outlining the research approach, the taxonomy used and the scope of the project in Section 2 and 3. Section 4 provides contextual information by summarising the source of impacts, drivers of change and emission reporting standards identified through analysis in the Policy Driven report. Our methodology is presented in Section 5, along with a literature review of similar studies in other countries. This includes the methodology used, the results and a discussion of gaps and assumptions found, and made, during the data analysis. The data analysis is presented in Section 5.2. Following this is the future landscape section in Section 7, which is aligned to the same digital taxonomy introduced in Section 2. The methodology of our scenario development is discussed, results presented, and gaps in data availability highlighted. Further discussion on data gaps, and recommendation for future requirements is presented in the conclusion. In summary, the report presents:

doi.org/10.17863/CAM.114743

- The current environmental impacts of the digital sector, starting with an overview of the existing quantitative analyses conducted globally and for different countries. This overview is followed by a detailed analysis of the impacts of the UK digital sector in the 2023 calendar year.
- Analyses of future trends for the digital sector in the form of three future scenarios and three case studies. The design of the scenario projections, and an analysis of their impact on the digital sector's environmental impacts, has been explored.

The data driven report is composed of this written report and a full data spreadsheet (Appendix 1). While the main data sources and results are highlighted in this report, the full results are presented in the spreadsheet for further investigations. It also enables downstream case studies by changing some of the parameters.

1.4 Purpose and Research Aims

We live in an era of unprecedented connectivity. The implementation of adaptive and forward-thinking policies will be pivotal to ensure that the digital sector positively contributes to a resilient, decarbonised, and environmentally sustainable future. To achieve this, policy makers require an understanding of the GHG emissions associated with digital technologies, end user devices, and increased connectivity. This Data Driven Report aims to:

- Quantify the different environmental impacts of the digital sector in the UK in the 2023 calendar year;
- Blend qualitative and quantitative analysis to explore scenarios in digital technology adoption and emissions; and
- Understand the efficacy of policies influencing trends in digital technologies to fully exploit digital adoption whilst limiting/ reducing associated emissions.

This report will enable policymakers to identify key environmental impacts within the digital sector, aiding the prioritisation of hotspots that require attention and intervention. The quantification of impacts from the digital sector will be essential for tracking changes to the sector over time. The scenarios developed for this report provide policy makers with case studies of how mitigation efforts/ trends can be qualitatively and quantitatively evaluated to identify the effectiveness of potential emissions mitigation efforts.

doi.org/10.17863/CAM.114743

2 RESEARCH APPROACH

2.1 Identifying Relevant Literature

The Data Driven Report is built upon the literature review collated for the Policy Driven Report, which provided a strong base of information of the digital emissions landscape. This has been complemented by a comprehensive review of quantitative assessments of the environmental impacts of the digital sector, as well as subsequent data collection on emissions values for the technology comprised within the boundaries of this study (Section 3.3). The literature and data have been collated from a range of sources including, but not limited to governmental reports, company reports, academic literature, news articles, and research organisations. This range has allowed a wide variety of data on digital impacts to be collected, analysed, and down-selected to meet the aims of the report. An agile and collaborative approach has been used between Frazer-Nash, University of Cambridge, and University of Bristol to collate the literature and data into a central database, which has underpinned this report.

2.2 Digital Taxonomy

Our literature review findings suggested that although some international standards have been created around the information and communication technology (ICT) sector (by the ITU in particular), discrepancies remain between reviewed literature. The boundaries of the "digital sector" in particular are less well defined than the "ICT sector". To provide a framework for the research and data analysis, a digital taxonomy has been developed. This has been used in three ways to support this study:

- To guide and structure data collection;
- To guide the scenario-based analysis; and
- To identify further opportunities for data generation and analysis in the existing digital emissions landscape. The Digital Taxonomy also provides a uniform language and approach across the Data Driven Report (this document) and the Policy Driven Report.

Our research suggests that most studies consider the high-level categories outlined in Table 1 as key sources of digital emissions. These were used as a basis for our study. Section 3.3 further refines the taxonomy to set clear boundaries on what has been included within the quantitative assessment.

Table 1: The taxonomy of digital technologies

Infrastructure & Hardware Category	Examples
User Devices	▸ Computers, Laptops, Tablets, Smartphones ▸ Displays, Interaction Devices (e.g. VR headsets)
Networks	▸ Core Networks ▸ Edge Networks and Content Delivery Networks (CDN) ▸ Mobile Networks ▸ Access Networks (e.g. home and office networking equipment)
Data Centres	▸ Compute Equipment (e.g. servers, including specialist GPUs and ASICs) ▸ Network Storage

2.3 Data Matrix

Data for each subcategory of the digital sector boundaries (Section 3.3) was collated in a data matrix. Where several data sources were available for the same data point, the most appropriate source was down selected based on the following parameters:

- Reliability of the source;
- Representativity of the data;
- Robustness of data; and
- Consistency across the different categories.

To be selected, the ITU's three tests of data quality were applied: timeliness, accuracy, and accessibility. All the data used is publicly available. This data matrix is made available within Annex A.

2.4 Environmental Impact Calculation and Interpretation

For each category of equipment, a specific methodology was used to quantify electricity consumption and environmental impacts. The relevant academic literature and existing similar reports were used to guide the methodology. The different methodological decisions (choice of data sources and modelling assumptions), alongside their impacts on the results, are detailed in the methodology section (Section 5).

The different environmental impacts calculated within this study were contextualised by comparisons against published UK GHG emissions statistics and where appropriately compared to other country quantification results. Planetary boundaries and normalisation factors were also used where appropriate.

2.5 Scenario Development

We have utilised scenarios to gain an understanding of what the future landscape may look like in the digital sector. To construct the scenarios, we have assessed the current and future drivers and trends for our scenario-based analysis on digital emissions. We also have used key concepts from the Government Office for Science (GO-Science) Future Toolkit. The toolkit is a key resource that allows policy professionals to embed long-term strategic thinking in the policy and strategy process [1].

PESTLE analysis was conducted during our scenario development to further investigate potential drivers of change to digital emissions. The PESTLE framework is a popular tool used to explore political, economic, social, technological, legal, and environmental factors which may be present in the future. Examples of future drivers include, but are not limited to: tighter control on emerging services such as cryptocurrency, and increased technological literacy driving increased uptake. Our developed scenarios were further refined by assessing their relevance to the defined scope of the study, the availability of data on the topic and how they aligned with key trends that had been identified in wider literature. All scenarios have been developed with a time horizon of 2035.

3 RESEARCH SCOPE

The quantitative assessment of the current environmental impacts of the digital sector was conducted in line with the reference literature on the topic (further details is provided in the literature review, Section 5.1), mainly the 2022 ADEME report from France [2] and the 2024 study into the global ICT sector by Malmodin et al. [3]. These studies are both based on the methodology for the assessment of the environmental impact of the ICT sector (Recommendation L. 1450) produced by the ITU [4].

3.1 Temporal Remit

The temporal scope of this research was the most recent calendar year, 2023. The historical environmental impacts of the digital sector were out of scope of this research, but future trends are discussed in the second part of this report (Section 7).

3.2 Geographical Remit

The focus of data collection and analysis for current environmental impacts presented within this report was the UK. Where other countries have conducted similar analyses, they have been included within the literature review (Section 5.1). Certain equipment and infrastructures which are within the study taxonomy (Table 1) but located abroad were not included in the quantification. In particular, it means that certain equipment and infrastructures, such as data centres located abroad, contribute to the UK digital sector are out of scope of this study, primarily due to the absence of data on these.

3.3 Digital Sector Boundaries

The digital sector is described by the Office for National Statistics (ONS) as an extension of the ICT sector [5], but the ONS does not list the equipment included. The ICT sector boundaries are precisely defined by the ITU, and divided in three categories: user devices, network goods and data centres. Some user devices are not included in the ITU's ICT sector boundaries, but are relevant to the digital sector, and were therefore included in this report (similarly to [2]). This includes TVs, printers, and gaming devices. Both personal and professional usage were included. Table 2 lists the sector boundaries for this report.

The impact of ICT services (e.g. software development, ICT consultants), beyond those already included in the categories above, was out of scope for this study.

Table 2: Study boundaries

Infrastructure & Hardware Category	Included Boundaries
User Devices	▸ Computers (desktops and laptops) ▸ Computer peripherals (monitors and projectors) ▸ Consumer electronics for communication purposes (landline phones, mobile phones, smartphones, tablets) ▸ Printers ▸ Gaming (home and handheld consoles) ▸ Televisions
Networks	▸ Wireline and wireless access network goods ▸ Telecommunication core network goods and related telecommunication data centres ▸ Customers' internet access boxes
Data Centres	▸ All data centres (all sizes, from small servers to hyperscale) except telecommunication data centres (which are included in networks)

3.4 Life Cycle Stages

This study investigated the environmental impacts of multiple life cycle stages, including manufacturing, distribution, usage, and end-of-life. We have presented the results in the form of two types of impacts:

- **Embodied impacts**: include manufacturing, distribution, and end-of-life treatment; and
- **Use stage impacts**: includes the operation of digital infrastructure and hardware.

3.5 Environmental Impacts Considered

The ITU's recommendations [4], the relevant literature (e.g. Malmodin's studies [3], [6]), and most corporate reports only consider GHG emissions in their analyses, i.e. contribution to global warming measured in tonnes of carbon dioxide-equivalent (t CO_2e). GHG emissions are indeed the most commonly used metric to drive public policy, and for this reason are particularly highlighted when discussing the study results. Although GHG emissions are important, a number of other impacts need to also be considered to provide a more holistic view of the environmental impacts of the digital sector, provided the data is available. A standardised list of indicators has been compiled by the European Commission as part of the Product Environmental Footprint (PEF) project [7] with the view that it should be tailored to each situation by using a subset of this list. Eight indicators have previously been shown to be the most relevant to the digital sector [2] and are therefore included in this study (Table 3). The embodied environmental impacts for each type of equipment are assessed methodically as part of standardised life cycle assessments (LCA) following, for example, the standard ISO 14040:2006 [8]. Conducting an LCA in the digital sector is a challenge; some reviewed data is now available for embodied impacts from initiatives like NegaOctet [9], which have been aggregated in the ADEME report [2].

Table 3: Environmental impact indicators

Environmental Impact Indicator	**Description** (from [10])	**Standardised Unit**
Global Warming Potential (GWP)	Indicator of potential global warming due to emissions of GHG to the air. GHG emissions refers to the seven direct GHGs under the Kyoto Protocol (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride).	kg CO_2e
Particulate Matter Emissions (PMFP)	Indicator of the potential incidence of disease due to particulate matter emissions.	Disease incidence
Acidification Potential (AP)	Indicator of the potential acidification of soils and water due to the release of gases such as nitrogen oxides and sulphur oxides.	kg mol H^+
Ionising Radiation Related to Human Health (IR-HTP)	Damage to human health and ecosystems linked to the emissions of radionuclides.	kBq U-235
Photochemical Ozone Formation (POCP)	Indicators of emissions of gases that affect the creation of photochemical ozone in the lower atmosphere (smog) catalysed by sunlight.	kg NMVOC-eq
Depletion of Abiotic Resources (Minerals, Metals) (ADP)	Indicator of the depletion of natural non-fossil resources.	kg Sb-eq
Abiotic Depletion Potential (Fossil Fuels) (ADPF)	Indicator of the depletion of natural fossil fuel resources.	MJ
Freshwater Eco-Toxicity Potential (FEP)	Impact on freshwater organisms of toxic substances emitted to the environment.	CTUe

3.5.1 Contextualising Environmental Impacts

Other environmental impacts beyond GHG emissions are difficult to apprehend. Two different approaches can be used to contextualise these, planetary boundaries and normalisation.

Planetary boundaries are defined as limits within which humanity can safely develop and thrive or be environmentally sustainable compared to the Earth's ecological limits. More formally defined by Bjørn and Hauschild as "The maximum sustained environmental intervention a natural system can withstand without experiencing negative changes in structure or functioning that are difficult or impossible to revert" [11]. The nine planetary boundaries identified are climate change, change in biosphere integrity, stratospheric ozone depletion, ocean acidification, biogeochemical flows, land-system change, freshwater use, atmospheric aerosol loading and introduction of novel entities. These planetary boundaries have been mapped to the different environmental impacts considered by the EU PEF project by Sala et al. [12] to help contextualise these results. In the case of GHG emissions, the planetary boundary has been estimated at 0.985 tCO_2e/year/person.

With normalisation, the theoretical share per capita of each impact is calculated by dividing the global impacts in this category by the world's population. For example, for global warming, this would be the impact of each individual person on Earth if GHG emissions were evenly distributed around the globe. These factors are obtained from the European Platform on LCA (Environmental Footprint 3.0 [7]) and the ADEME report. In the case of global warming, global GHG emissions are estimated at 8.1 tCO_2e/year/person. Dividing the impacts estimated for the UK digital sector by these normalisation factors helps to contextualise these impacts.

doi.org/10.17863/CAM.114743

3.6 Direct vs Indirect Effects

Direct effects are those specifically connected with the production, deployment, use, and end-of-life of digital technology (those included in the top left box of Figure 1 below). Indirect effects arise from the enabling effects and systematic effects associated with the application of these digital technologies and the resulting behavioural and structural change arising from their life cycle.

Avoided emissions (and indirect emissions) from digital technology are relevant to the digital sector emissions footprint but are extremely difficult to reliably quantify and compare. The supplementary Policy Driven Report provides a focussed and thorough analysis for existing regional/ country policy, including some indirect sources – which will not be discussed in this Data Driven Report.

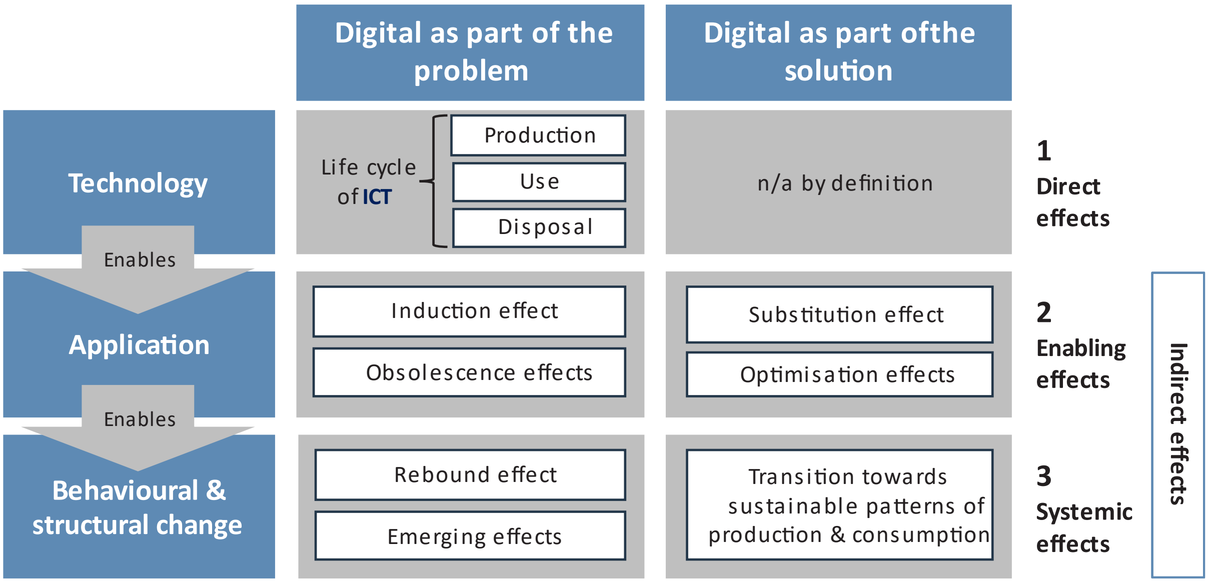


Figure 1: Modified from – Hilty and Aebischer (2015)

4 SETTING THE CONTEXT

4.1 Current Drivers and Trends

The growth and changes to digital technologies across the world will affect the total GHG emissions from the digital sector. These changes will be driven by the demand for technology along with technological advancements that can change the efficiency of devices. Future transformations may also use digital technology to address environmental challenges. The Policy Driven Report provides a detailed account of drivers and trends identified within the digital sector.

The drivers explored in the Policy Driven Report are described as abstract due to the strategic scale of digital sector emissions in which they are at play. Figure 2 illustrates a basic causal loop showing the interactions between the abstract drivers and how they may increase or reduce emissions within the digital sector. These drivers have provided key context around the scenarios that we have developed within Section 7.

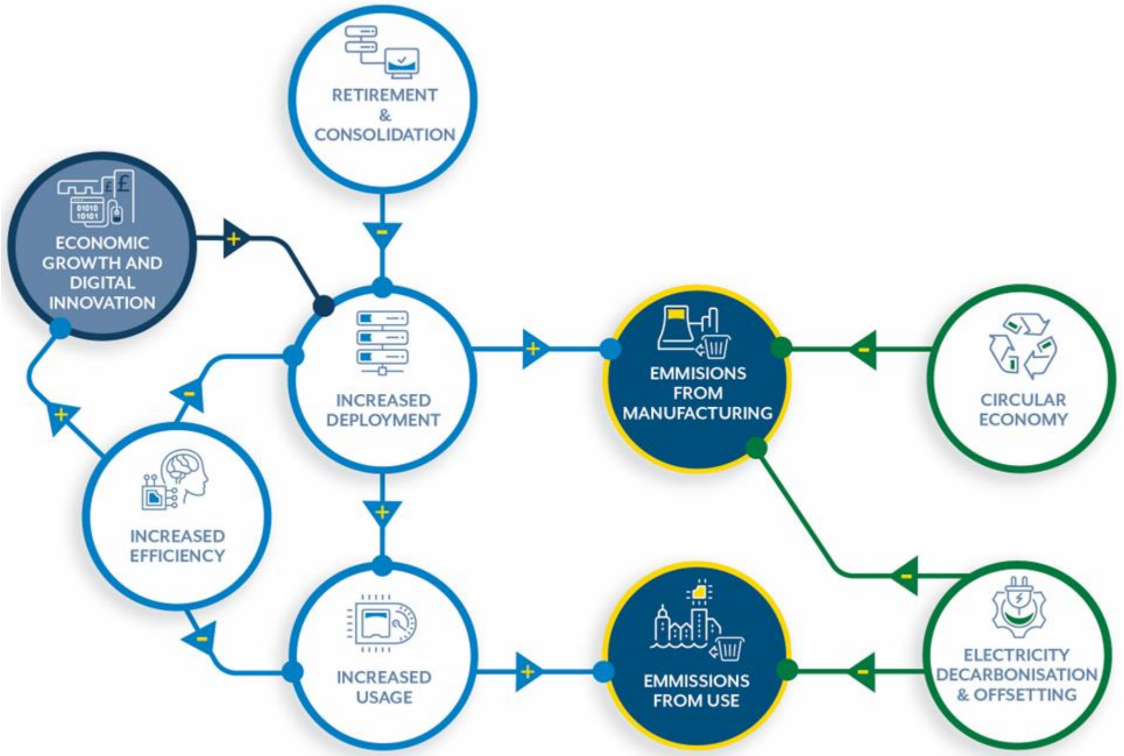


Figure 2: An example of a high-level causal loop showing the interactions between abstract drivers.

Our key conclusions on the drivers which are shaping trends in digital emissions are discussed below. A full discussion of specific drivers focussing on user devices, networks and data centres is presented in the Policy Driven Report.

- **Global digitalisation has led to an increase in absolute energy consumption and hence GHG emissions**, albeit at a much lower rate than the growth in the market size due to efficiency improvements. **Digital trends** have always been, and remain, **uncertain and can change quickly and unpredictively**.
- The **energy consumption by the hyperscale cloud operators** (AWS, Microsoft, Google) has **increased sharply** in the last couple of years [13]. This is **driven by increased global digitalisation, growth of existing cloud services and convergence with new, computationally intensive services, in particular AI**. Whether efficiency improvements in new technology will significantly mitigate increases in demand is yet to be supported with evidence; several competing views are expressed in the literature.

doi.org/10.17863/CAM.114743

- The demand for data transfer continues to grow in fixed and mobile networks. Fundamentally, there appears to be no limit to the demand. The majority of data travels through fixed networks (about 5 times as much as through mobile networks [14]). **While absolute data volume in mobile networks is smaller, the absolute energy consumption is significantly higher than fixed networks and continues to increase**.
- The deployment of additional networking equipment in response to 'peak demand' events results in a growth in energy consumption. For example, on 6th December 2023 the BT core network experienced a new peak of 30.1 Tbps [15], in response to several live-streamed football games co-occurring with a major update of the popular Call of Duty videogame. **Understanding the influence of demand on energy consumption more accurately, and effectiveness of demand shifting, could inform capacity decision-making**.
- **The energy consumption of a network is roughly the same irrespective of the level of use**. When network use significantly increased during the COVID pandemic, the result was almost no increase in energy consumption in networks across Europe [16].
- **There are windfall reductions in energy consumption from retirement of inefficient legacy equipment**, e.g. Public Switched Telephone Networks. For example, in the UK, the closure of 4,600 of the 5,600 Openreach exchanges over the next two decades will result in significant savings [17].
- **A major source of energy consumption is networking equipment in the home and office**. They are idle on average for 77% of the time, but still use over 80% of their maximum power consumption when idle. More than 90% of the population never turn home networking equipment off [18].
- While **global estimates of the overall environmental impact of end user devices are sparse and inconsistent**, there is **broad agreement that laptops and desktops dominate user device energy consumption** [19] (only eclipsed by home networking equipment which is considered an end user device in some studies). Globally, **when included, TVs and set-top boxes significantly dominate energy budgets**.
- **Globally, sales of new smartphones have currently plateaued/in slight decline** [20], most likely because of the **increase in popularity and quality of second-hand sales** [21]. Recently, **sales of refurbished devices have also increased**.
- The uptake of VR headsets is currently slow despite large-scale investment in hardware and associated software services. One early life cycle assessment estimates that the emissions associated with a VR headset are roughly 25-40% that of a smartphone, and mainly in the manufacture of the device [22]. **If VR headsets become widespread, there will be a significant increase in the overall impact of end user devices, particularly if features rapidly improve during the first years of mass market adoption, leading to high replacement rates**.

4.2 Additional Trends

Throughout the development of this report, data exploration and scenario development, additional trends were captured. This section summarises the key additional trends that have been identified. These have provided additional input into the development of the scenarios and case studies within Section 7.

4.2.1 User Devices

The digital sector, both in the UK and globally, is experiencing a significant surge in the use of user devices. In 2021, the number of mobile devices operating worldwide stood at almost 15 billion, up from just over 14 billion the previous year [23]. The number of mobile devices is expected to reach 18.22 billion by 2025, an increase of 4.2 billion devices compared to 2020 levels.

The escalating demand for user devices and peripherals, such as mobile phones, tablets, and laptops, will drive a significant demand for new and replacement technology. For example, the total number of connected devices in 2025 is predicted to be around 51.9 billion (up from 43 billion in 2020) [24].

Looking ahead, McKinsey (2022) estimates that by 2030, there could be between 2,000 and 5,000 operational quantum computers around the world [25]. Furthermore, the industrial PC market is on a growth trajectory, with predictions

doi.org/10.17863/CAM.114743

suggesting a compound annual growth rate of 5.7%. By 2035 the market value is expected to exceed USD $9 billion [26]. This growth reflects the increasing integration of technology across various industries and the continuous innovation within the digital sector.

4.2.2 Networks

Compared with today, network coverage and network types have the potential to be very different in 2035 both globally and in the UK. At the end of 2023, 5G coverage globally reached 45% [27]. There is a projected increase in 4G and 5G coverage to 95% and 85% respectively by 2029. 4G is also expected to be phased out between 2033 and 2035 as 5G increases coverage, with almost all 2G and 3G networks around the world to be shut down by 2030 [28]. We are expecting to see these patterns reflected across the UK, mainly driven by technology companies retiring increasingly redundant networks. In 2021, the UK Government agreed with mobile network operators to create a plan for the gradual phasing out of 2G and 3G services by 2033 [29].

A summary of this is as follows:

- EE (BT) has begun migrating customers to its 4G and 5G networks throughout 2023, in anticipation of its 3G network closing from January 2024. Its 2G network will be remaining until later this decade for voice calls and texts.
- Vodaphone began piloting its 3G switch-off plan in 2023 and plans to switch off the remainder of the UK by December 2023. It confirmed its 2G networks will remain in place for calls and texts.
- Three expects to have closed its 3G offering by end of 2024. Three do not have a 2G network.
- O2 (Virgin Media) has announced its 3G switch-off plan will happen in 2025 and is supportive of the Govts plans to switch off 2G by 2033.

These changes are expected to happen simultaneously to changes seen in fixed networks. The replacement of copper network connections with fibre optic cables has already been seen as a more carbon friendly option. In the UK Government's Future Telecoms Infrastructure Review [30] the Government set ambitious target for the availability of full fibre and 5G networks. They want to see 15 million premises connected to full fibre by 2025, with nationwide coverage by 2033.

The European Commission [31] studied different broadband technologies in Germany and found that fibre was the most energy efficient. The study noted that at 50 Mbps, fibre connections emitted 1.7 tonnes of CO_2 per year compared to copper which emitted 2.7 tonnes. The fibre networks consumed up to 36% less energy than copper broadband networks. Fibre can transmit data much longer distances than copper which also need amplifiers and, in turn require electrical power.

Fibre optic cables have a relatively low carbon footprint compared to copper cables, due to:

- Energy Efficiency: Fibre optic cables have a lower energy consumption requirement compared to copper cables.
- Smaller Physical Footprint: Fibre optic cables consist of a smaller footprint, resulting in fewer raw material requirements.
- Longer Lifespan: Fibre optic cables have a longer lifespan than copper cables.

Studies indicate that fibre networks are much more energy efficient than copper networks. Fibre networks were shown to use 12x less energy than copper by transmitting data using light sources of emissions. And deliver emissions reductions and energy improvements up to 80% compared to copper-based infrastructure (TalkTalk, 2021) [32]. Fibre optic networks have also been found to be more efficient than wireless alternatives. A study by the German Environment Agency [33] found that high-definition video streaming over the fibre optic connection generates 2 gCO_2 per hour of video streaming for the data centre and data transmission, whereas emissions over the 5G network are more than double at 5 gCO_2 per hour.

doi.org/10.17863/CAM.114743

4.2.3 Data Centres

In the digital sector, data centres and data transmission networks play a pivotal role both in the UK and globally. In 2020, these entities accounted for around 330 Mt CO_2e globally, including embodied emissions. This figure represents 0.9% of energy related GHG emissions or 0.6% of total GHG emissions [34].

Data centres are estimated to be responsible for up to 3% of global electricity consumption and are projected to reach 4% by 2030. To put this into perspective, an average hyperscale facility consumes 20-50MW annually, theoretically enough electricity to power up to 37,000 homes [35].

As digitalisation continues to advance, the reliance on data centres and data transmission networks will inevitably lead to increased energy use. Without the necessary improvements, emissions from data centres have the potential to escalate rapidly.

The International Energy Agency (IEA) continue to track data centres as part of their Tracking Clean Energy Progress 2023 Report and have given them the “More Efforts Needed” classification. This designation underscores how further improvements are needed to ensure data centres follow the IEA’s Net Zero emissions by 2050 scenario pathway [36].

The rapid growth in workloads handled by large data centres has resulted in a substantial increase in energy use in this sector over the past several years, growing by 20-40% annually, and this could continue. The combined energy use by four major technology companies – Amazon, Microsoft, Google, and Meta – more than doubled between 2017 and 2021. Even when potential new demands from cryptocurrency mining are excluded, overall data centre energy use appear likely to continue to grow moderately in the coming few years, but longer-term trends appear highly uncertain due to technology advancements [34].

4.2.4 Future Compute Activities

There is a theory that future compute activities [37] are not actually driving a growth in ICT emissions. Software and services such as AI may play a part in either reducing emissions through improving the efficiency of infrastructure, but also in analysing and processing emissions-related data. Although an encouraging theory, there is so far no clear evidence that it can be relied upon to reduce the environmental impacts of the sector as needed.

Data centre management software could get smarter, further optimising its own infrastructure. By integrating machine learning techniques with existing building management systems, operators will be able to understand potential inefficiencies in their systems, address them in real-time and predict future patterns [38]. This optimisation not only improves performance but also contributes to sustainability.

Developing AI services are also being used to increase the reliability of climate related information. ClimateBert, an AI neural language model, is already being deployed to effectively double check corporate reporting and disclosures related to emissions to root out ‘greenwashing’ [39]. Its goal is to correctly classify if an evidence statement is supported or refuted by a claim, effectively fact checking a company’s climate-related report. ClimateBert was pre-trained on over 2 million paragraphs of climate-related texts, gathered from various sources such as news, research articles and company climate reports. This means that claims made by companies can be judged to be supported or refuted and the robustness of evidence evaluated, which creates robust reporting.

4.2.5 Software and Services

A major growth in software and services driven by cryptocurrency, video streaming and generative AI will also drive new quantities of emissions. The cryptocurrency market is predicted to exceed USD $4,600 billion by 2030, reflecting an annual expansion rate of 7.1% from 2021 to 2030 [40]. The cryptocurrency mining electricity demand was estimated to be around 110 TWh in 2022, approximately 0.4% of annual global demand. Between 2015 and 2022, there has been a 2300%-3500% increase in cryptocurrency mining energy use [34].

Crypto-asset technologies will continue to require a considerable amount of electricity for asset generation, ownership, and exchange. Electricity use from these digital assets highly contributes to GHG emissions and local environmental impacts including pollution and disruption to the electrical grid [41]. This often disproportionately affects low-income neighbourhoods and communities of colour [42]. Furthermore, crypto-miners' intensive and irregular power consumption will also push up electricity prices for consumers and can increase risks for local electrical grids such as straining equipment and safety hazards.

This growth in crypto-asset technologies, contributing to GHG emissions and local environmental impacts, is leading to some changes in the crypto-mining processes. Historically, 'proof-of-work' mining has been the common method for validating crypto transactions which has a very large energy and hardware usage. Ethereum, which now uses a 'proof-of-stake' consensus mechanism, reduces the network's energy usage by over 99.9% [43]. A single transaction on Ethereum's 'proof-of-stake' network is now similar to the electrical usage of a Mastercard transaction. As of 2023, its yearly emissions were around 2,800 tCO_2e [44], around the same as five round-trip flights from London to New York.

Global electricity generation for the cryptocurrency assets with the largest market capitalisations resulted in a combined 140±30 Mt CO_2/year, or about 0.3% of global annual GHG emissions. Cryptocurrency activity in the US is estimated to result in approximately 25 to 50 Mt CO_2/y, which is 0.4% to 0.8% of total US GHG emissions [41]. This range of emissions is similar to emissions from diesel fuel used in railroads in the US. Due to the high server densities involved in cryptocurrency transactions, conventional data centres require additional electricity for the additional cooling needs [41].

4.2.6 Circular Economy

Circular economy initiatives that can contribute to emissions reductions (as an indirect beneficial effect) are spreading across the world, more rapidly than predicted in the past. The EU Right to Repair [45], adopted in March 2023, created additional rights to the consumers, which include (but not limited to):

- A right for consumers to claim repairs to products that are technically repairable under EU law to the producer;
- A producer's obligation to inform consumers about the products that they are obliged to repair themselves; and
- An online matchmaking repair platform to connect consumers with repairers and sellers of refurbished goods.

Another example is the EU Ecodesign requirements [46] (EU 2019/424). This policy covers servers and data storage products sold in the EU, including the computers and devices typically found in data centres and server rooms. The requirements include rules in energy efficiency, such as minimum server efficiency in active states, maximum server consumption in idle states, and information on the product operating temperature. They also take into account circular economy aspects such as extraction of critical raw materials for key components.

The European Commission carried out a study to analyse the environmental impact of servers and data storage products typically used for commercial purposes and calculated that switching to products that comply with the Ecodesign requirements will lead to savings of up to 9 TWh/year by 2030, approximately the yearly electricity of Estonia in 2014 [47]. Trends of circularity are also reaching the built environment which could lead to improvements in much of the infrastructure underpinning the digital sector. Data centres are a key example of this. The UK Green Building Council [48] (UKGBC) is a membership-led industry network aiming to transform the sustainability of the built environment. Some of the work by the UKGBC includes the retrofitting of commercial buildings to upgrade the energy performance, whilst also considering which retrofit measures are the most carbon and cost effective.

The UK is at the forefront, with the recent announcement that the UK will establish the world's first UN-backed International Centre of Excellence on Sustainable Resource Management in the Circular Economy. This one of a range of measures backed by UK government and the Maximising Resources, Minimising Waste programme launched in July 2023. Leaders in the electronic industry, such as Amazon, Dell, Google, HP, and Microsoft are also working with the

Circular Electronics Partnership (CEP) to drive an industry wide circular shift in key areas of the electronics value chain, focussing on design, material sourcing, manufacturing and recycling.

4.2.7 Grid Decarbonisation

Key policies announced in recent years, including REPowerEU in the EU, the Inflation Reduction Act (IRA) in the US and China's 14th Five-Year Plan for Renewable Energy, will lead to further support to accelerate low carbon electricity deployment in the coming years. These policies represent a global commitment to decarbonisation and a shift towards renewable energy sources.

The REPowerEU initiative aims to diversify the EU's energy supply and reduce dependency on imports, while the IRA in the US focuses on reducing inflation by promoting energy efficiency and renewable energy sources. Meanwhile, China's 14th Five-Year Plan outlines ambitious targets for the development and deployment of renewable energy technologies.

These policies not only promote the use of renewable energy but also encourage innovation in the energy sector. They are expected to stimulate investment in renewable energy infrastructure and drive technological advancements in the renewable energy sector. As a result, these initiatives will play a crucial role in the global transition towards a more sustainable and resilient energy grid.

There is a UK target for all electricity to come from 100% zero-carbon generation sources by 2035 [49]. The Climate Change Committee's (CCC) 6th Carbon Budget [50] projects that variable renewables will reach 60% of electricity generation by 2030, 70% by 2035 in the UK.

The National Grid [51] published their Future Energy Scenarios in 2023 which outlined different pathways for the future of the whole energy system out to 2050. Each pathway considers how much energy the UK might need and where it will come from, to build a picture of the ways in which Net Zero could be reached.

5 DATA GATHERING FOR QUANTIFICATION

5.1 Literature Review

The quantification methodology was designed, and data sources were gathered, based on a review of the relevant literature in this space. This section does not list all the literature, but rather highlights and summarises the most relevant reports and publications that are considered references in the field and/or used for this study.

The scope of most assessments in this space has been the GHG emissions of the ICT sector globally. One of the latest studies, and the reference in this space for global estimates, is a study by Malmodin and colleagues [3] which estimated the global 2020 use stage electricity consumption and life cycle GHG emissions. In this study, they extended the ICT sector to entertainment, media, and cryptocurrencies. This is an update on the 2015 estimates produced by the same team [6] which was the reference until then. This study included both embodied (mostly for user devices) and use stage impacts, but only considered GHG emissions.

A 2023 report by the World Bank [52] also aggregated data about the ICT sector, with a particular focus on telecommunications. The authors highlighted the 30 highest emitting countries for telecommunication and presented case studies about particular countries such as France and the UK. For the UK, this report commended the Streamlined Energy and Carbon Reporting Regulation introduced in 2019 as a way to improve transparency, but highlighted that companies commonly report carbon footprints with a significant lag and with different scopes.

Not all earlier studies about the carbon footprint of the ICT sector can be presented here, but a 2021 study by Freitag et al. reviewed previous estimates [19]. They discussed and summarised the difference in scopes. In particular, they highlighted the following issues: old data, lack of data interrogability, conflict of interest (for example when authors are employed by ICT companies, e.g. Malmodin working at Ericsson) and different boundaries for the ICT sector. They also highlighted the complex relationship between digital technology and GHG emissions in an interesting way: *“Historically we can be sure that four phenomena have gone hand in hand: ICT has become dramatically more efficient; ICT’s footprint has risen to account for a significant proportion of global emissions; ICT has delivered increasingly wide-ranging efficiency and productivity improvements to the global economy; and global emissions have risen inexorably despite this.”*. They also concluded that all previous studies agree that ICT is not on a path to reduce emissions in line with climate scientists’ recommendations (as well as the ITU’s) of a normative 1.5 °C trajectory for the decarbonisation of the digital sector unless additional steps are implemented by the sector or legislator.

The European Commission has commissioned several technical reports into the ICT sector, a number of them covering the period before 2020 and therefore still including the UK. The “ICT impact study” [53] retrieved commercial and energy consumption data for the main categories of the ICT sector and made available detailed statistics for user devices and networks. Other reports can provide useful data about European data centres and are mentioned in the methodology section below (Section 5.2.3), e.g. a report about energy-efficient cloud computing [54] and the EU Green Public Procurement criteria for data centres [55].

On a national level, France commissioned in 2020 an extensive study into the environmental impacts of the digital sector [56]. The first two chapters were released in 2022, presenting an inventory of the different environmental impacts. In particular, this study modelled 11 environmental indicators beyond just GHG gases (freshwater ecotoxicity, resource depletion, etc.). They considered both embodied and use stage impacts and made available granular data per device. Although the press release is available in English, the full detailed report is only available in French. This study also highlighted the same challenges as previous works: limited reliable data on the environmental impacts of infrastructures, the complex interdependence of user devices, networks and data centres and the diversity of stakeholders (business, consumers, governments etc.). The report has a comprehensive set of data used to calculate the environmental impacts of the digital sector. The reason for high data availability is due to France having a centralised framework where most data is reported to, or collected by, government agencies.

5.2 Estimation Methodology

Based on our literature review, and associated research, it was concluded that the preferred source of data for this report were official UK statistics produced by one of the Government departments. In the absence of such data, the ADEME report [2] commissioned by the French Government was used. For embodied impacts per unit, the ADEME report was used throughout for consistency, as it was the only source that conducted life cycle assessments for each subcategory in a consistent manner.

The temporal remit of this study was the most recent calendar year, 2023. When data for 2023 was not available, it was approximated by the most recent data available before that. This is considered a reasonable approximation since data such as installed base or yearly sales are quite stable year-on-year. The alternative would have been to focus the study on an older year for which most of the data was available, i.e. before 2020, with the compromise of not capturing the most recent data available.

The value used for the carbon intensity of electricity consumption was 224.994 gCO_2e/kWh, which is the average UK electricity consumption factor published by DESNZ for 2023 [57]. This is the sum of the electricity generation factor (207.074 gCO_2e/kWh) and the transport & distribution losses (17.92 gCO_2e).

Annex A provides a detailed summary of the sources of data used for user devices, networks and data centres, alongside a RAG assessment of data quality. Each section below also highlights the RAG assessment of the data sources used.

- Green: High confidence. Robust data available from reputable sources.
- Amber: Medium confidence. Data available from reputable sources but some extrapolation was needed to obtain the numbers of interest.
- Red: Low confidence. Limited data available and heavy reliance on assumptions.

5.2.1 User Devices

For user devices, data was collected on installed base, sales volume, and environmental impacts (embodied and use stage). In line with the ITU's recommendation, the embodied impacts of a device were fully attributed to the year of sale and the operational lifetime was not considered. Embodied impacts were therefore calculated by combining impact per unit (for each category of impact) with yearly sales. Embodied environmental impacts per unit were obtained from the ADEME report which conducted LCAs on representative devices and used NegaOctet 2021 data [9]. These cover manufacturing, distribution, and end-of-life. For the distribution phase, industry reports were used and simplifying assumptions were made in the ADEME report, assuming an average journey from Asia to Europe, when plausible, and local journeys when appropriate. The impact of distribution from the shop to the customer's home was not included. Use stage electricity consumption was obtained by combining yearly consumption per unit with the installed base. Use stage GHG emissions were obtained by multiplying electricity consumption with the average UK carbon intensity.

5.2.1.1 Laptops and desktop computers

Computers were divided in four subcategories: laptops (domestic and non-domestic usage) and desktop computers (domestic and non-domestic usage). Data for installed bases were obtained from the 2023 National Statistics on UK electrical products produced by the DESNZ [58]. For computers, the data is for 2022 (last year available). Yearly sales for laptops and desktop computers were obtained for 2023 from Statista Market Insights which aggregates primary data sources and market modelling [59]. Statista did not provide information on domestic vs non-domestic sales, so the figures were estimated by assuming that the distribution in sales is identical to the distribution in the installed base. Use stage electricity consumption per unit was obtained from the DESNZ National Statistics (2022 data).

doi.org/10.17863/CAM.114743

Table 4: Research confidence in data available for laptops and desktop computers

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Green	Green	Green	Green

5.2.1.2 Projectors

In the absence of better estimates, projectors installed base was obtained from aggregated EU numbers published in an ICT impact study commissioned by the European Commission (2019 data) [53], and assuming that the installed base per country is proportionate to population. A UK population of 66.7m people was used (UK population in 2019 from the Office of National Statistics). Yearly sales data were only available for projectors and monitors combined, and from Statista Market Insights (2023 data); it was assumed that the split between projectors and monitor sales was similar to the installed base. Use stage electricity consumption was obtained from the EU ICT report (2020 data), which contained figures for domestic and non-domestic usage separately; the two were combined in a weighted average, assuming the same distribution between the two as France.

Table 5: Research confidence in data available for projectors

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Red	Amber	Green	Amber

5.2.1.3 Monitors

Monitors installed base was obtained from the DESNZ national statistics (2022 data) and yearly sales inferred from the EU ICT report as described above. Use stage electricity consumption figures were also obtained from the DESNZ National Statistics; notably, these figures are around 3.5 times higher than the ADEME report.

Table 6: Research confidence in data available for monitors

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Green	Amber	Green	Green

5.2.1.4 Phones

Mobile phones were divided between smartphones and feature phones. For smartphones, the installed base and yearly sales were obtained from Statista Digital Market Insights (number of smartphone users and smartphone sales in 2023). The use stage electricity consumption was obtained from the ADEME report, based on data in the EU ICT report, which included energy loss due to phone chargers. For this, again, a weighted average between energy draw for domestic and non-domestic usage was calculate, assuming a similar distribution to France.

For feature phones, the installed base was estimated as the difference between the number of phone subscriptions (obtained from Ofcom's 2023 Market Update [60]) and the number of smartphone users described above. The yearly sales were obtained from Statista Market Insights (2023 data). The value used for the use stage electricity consumption was the same as the ADEME report, which is a rough estimate.

For landline phones, the installed base was obtained from the number of fixed line subscriptions reported by Ofcom (2023 data). The yearly sales were obtained from Statista Market Insights (2023 data). Use stage electricity consumption was obtained from the ADEME report, using a weighted average between domestic and non-domestic usage, assuming the same distribution between the two as France.

Table 7: Research confidence in data available for phones

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
(smartphone) Amber *(feature phones)* Green *(landline)* Green	Green	Green	Amber

5.2.1.5 Tablets

For tablets, installed base was obtained from Statista's own aggregated estimate of UK tablet users (2023 data), and yearly sales from Statista Market Insights (2023 data). Use stage electricity consumption was obtained from the ADEME report, using a weighted average between domestic and non-domestic usage, assuming the same distribution between the two as France.

Table 8: Research confidence in data available for tablets

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Green	Green	Green	Amber

5.2.1.6 Printers

For each type of printers, installed bases were obtained from aggregated EU numbers published in the EU ICT report (2020 data), and assuming that the installed base per country is proportionate to population. Yearly sales were estimated from Statista Market Insight aggregate number for printer sales, assuming that the distribution between printer types was similar to the installed base. For printers embodied impacts, a weighted average between domestic and non-domestic use had to be calculated. Printers' electricity usage was obtained from the EU ICT report.

Table 9: Research confidence in data available for printers

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Red	Red	Amber	Green

5.2.1.7 Gaming

Gaming devices were divided between handheld and home consoles. The installed base of home consoles was obtained from DESNZ National Statistics (2020 data), although it should be noted that there are diverging data for this. Yearly sales were obtained from Statista Market Insights (2023 data). Usage phase electricity consumption was obtained from DESNZ National Statistics (2020 data), but it should be noted that the number there was around 3 times bigger than the ADEME report.

Table 10: Research confidence in data available for home consoles

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Amber	Green	Green	Amber

Handheld consoles installed base was extrapolated from the DESNZ installed base of home consoles, and assuming the ratio handheld/home consoles was the same across Europe (ratio obtained from the ADEME report). Yearly sales were obtained from Statista Market Insights, merging handheld and hybrid segments (2023 data). Use stage electricity consumption was obtained from the ADEME report, which drew data from the EU ICT report among other sources.

Table 11: Research confidence in data available for handheld consoles

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Red	Green	Green	Green

5.2.1.8 TVs and Set Top Boxes

TVs were divided between LCD and OLED technology. The installed base for both was obtained from DESNZ national statistics (2022 data), combining primary and secondary displays. Yearly sales were obtained from Statista Market Insights (2023 data), which only reported total TV sales. The division in sales between LCD and OLED was assumed to be similar to the split in global sales. Use stage electricity consumption was obtained from DESNZ National Statistics (2022 data). For LCD screens, a weighted average between primary and secondary displays was calculated (weighted according to installed base). It is worth noting that the electricity usage for LCD screens is low compared to other sources (the ADEME report's number is 6 times higher).

For set top boxes, the installed base was obtained from DESNZ National Statistics (2022 numbers). The yearly sales were approximated by the sale number of "smart streaming devices" reported by Statista Market Insights (2023 data), which was coherent with a lifetime of about 6.5 years. Use stage electricity consumption numbers were obtained from DESNZ National Statistics (2022 numbers).

Table 12: Research confidence in data available for TVs and set top boxes

Installed base	Yearly sales	Embodied impacts	Use stage electricity consumption
Green	Amber	Green	Green

5.2.2 Networks

Networks were divided between customers' internet boxes and network infrastructures (fixed, i.e. broadband, and mobile).

5.2.2.1 Internet Boxes

For internet boxes, a bottom-up approach similar to the one used for user devices was used. Four types of boxes were considered: ADSL, cable, Fibre to the Cabinet (FTTC, when the fibre only goes as far as street cabinets) and Fibre to the Premises (FTTP, when the fibre goes all the way to the customer's home). Installed bases were estimated from the number of subscriptions for each type reported by Ofcom's Communications Market Report (2022 data) [61]. Embodied impact and yearly electricity usage per box were obtained from the ADEME report, assuming that the boxes were similar between France and the UK. Use stage GHG emissions were obtained by multiplying electricity consumption with the average UK carbon intensity.

Table 13: Research confidence in data available for internet boxes

Installed base	Embodied impacts	Use stage electricity consumption	Use stage GHG emissions
Green	Green	Green	Green

5.2.2.2 Network Infrastructures

Data on network infrastructures cannot be reliably estimated bottom-up from number of subscribers. Instead, annual electricity consumption and operational GHG emissions (Scope 1 and 2 unless specified otherwise) were obtained from operators' annual reports. It should be noted that these annual reports include more than the electricity usage of the network's core infrastructures, e.g. "Business As Usual" (BAU) operations, which can be significant and may lead to overestimates of the network's power usage. In some cases, non-IT operations can also be included. These reports remain for now the only source of data available. For operational GHG emissions, location-based estimates were used, as these are more realistic and not skewed by carbon mitigation measures. For fixed networks, the main operators were BT, Virgin Media and Sky [62]. For mobile network infrastructures, the main operators were Vodafone, EE (part of BT), O2 and Three [63]. Therefore, all these were included. This aligned with the 2023 report by The World Bank assessing the emissions and energy usage of telecom operators [52], which included BT, Virgin Media O2, Three and Vodafone in their study.

Virgin Media O2 has only reported aggregate numbers since 2021, so the respective contribution of Virgin Media (broadband) and O2 (mobile) to the total numbers were not available for 2022 (latest data) and were assumed to be similar to 2020 (Virgin representing respectively 40% and 48% of electricity consumption and operational GHG emissions). The latest data released by Three was for 2021 and available in the World Bank report. In line with the World Bank's report, Scope 1, 2 and 3 were included for Three as this was more comparable to the other companies reporting (what is included in Scope 2 or 3 varied by company). The other operators with both broadband and mobile infrastructures (BT, Vodafone, Sky) did not communicate on the split in electricity consumption and GHG emissions between the two activities. They were therefore grouped as *mixed operators* in the results. Numbers for BT were pulled from their 2023 sustainability report, and numbers for Vodafone were from 2021 (World Bank report). Sky's data was only available for the UK and Ireland combined (2022 data), the figures for this operator are therefore likely to be slightly overestimated.

Embodied impacts were more difficult to assess, as no data was available about yearly equipment installation. Therefore, it was assumed that yearly embodied impacts were proportionate to electricity usage (as a function of equipment density), and similar between France and the UK. Embodied impacts per TWh in each category were calculated from the ADEME report and combined with the use stage electricity usage of each operator in the UK to estimate their total embodied impacts.

Table 14: Research confidence in data available for network infrastructures

Installed base	Embodied impacts	Use stage electricity consumption	Use stage GHG emissions
N/A	Red	Amber *(Virgin, O2, Sky)* Green *(Three, BT, Vodafone)*	Amber *(Virgin, O2, Sky)* Green *(Three, BT, Vodafone)*

5.2.3 Data Centres

Data centres were divided into three subcategories: enterprise, co-localisation, and Managed Service Provider (MSP) (Table 16). For each subcategory, embodied impact was assumed to be proportionate to white space, i.e. the area (in m^2) available for IT equipment. The embodied impacts per m^2 were obtained from the ADEME report, and the UK white space areas in the UK were obtained from a 2020 report commissioned by the EU Commission [55]. These estimates of white space did not include smaller server rooms without a dedicated building, or with an IT capacity lower than 25 kW. Use stage electricity usage was not available for each subcategory but the total electricity consumption of UK data centres in 2020 was obtained from a report produced by the EU Commission and the Borderstep Institute [54]. Use stage GWP was then calculated using average carbon intensity.

Table 15: Research confidence in data available for data centres

White space	Embodied impacts	Use stage electricity consumption
Red	Amber	Amber

Table 16: Definition of the three categories of data centres, quoted from [55].

Data Centre Category	Definitions
Enterprise Data Centre	A data centre which has the sole purpose of the delivery and management of services to its employees and customers and that is operated by an enterprise.
Co-location Data Centre	A data centre facility in which multiple customers locate their own network(s), servers, and storage equipment.
MSP Data Centre	A data centre offering server and data storage services where the customer pays for a service and the vendor provides and manages the required ICT hardware/software and data centre equipment. This management service includes the co-hosting of multiple customers, which may take the form of a cloud application environment.

6 QUANTIFICATION RESULTS

This section presents estimates for the annual environmental impacts of the digital sector in the UK, using the latest data available. As described in the methodology section, it is essential to address the multidimensionality of these impacts:

- **Diversity of impacts**: It goes beyond GHG emissions;
- **Diversity of systems**: Mostly categorised in three groups, user devices, networks, and data centres; and
- **Diversity of stages in the hardware's life cycle**: Manufacturing, distributing, usage, end-of-life.

The overall impacts were calculated by adding the impacts of the different categories (user devices, networks, data centres). Absolute digital sector impacts are reported, as well as relative impacts when appropriate. Contextual data (e.g. GHG emissions per person and per household) is provided wherever relevant.

Appendix 1 supplements this report, providing a detailed account of the data and calculation steps used to quantify environmental impacts of the digital sector. The Appendix is presented in the form of a Microsoft Excel Workbook.

6.1 Overall Results

6.1.1 GHG Emissions

The most recent yearly GHG emissions of the digital sector, as defined in this study, were estimated at 19.28 Mt CO_2e. This would represent 2.73% of the 2021 total UK GHG emissions (consumption footprint) estimated by the ONS (last available year). Of these 19.28 Mt CO_2e, 63% were due to yearly embodied emissions (12.15 Mt CO_2e) and 37% to use stage GHG emissions (7.13 Mt CO_2e). Approximately half of the digital sectors GHG emissions (embodied and use stage combined) were due to user devices (51%) with 36% due to data centres and 13% to networks. Figure 3 below summarises the total GHG emissions associated with the digital sector.

It is worth noting large differences between the embodied and use stage GHG emissions within each category (Figure 4). In the case of user devices, 75% of GHG emissions were due to embodied impacts, while for networks, this share was only 34%. For data centres, embodied impacts represented 57% of total GHG emissions.

To further contextualise the digital sector GHG emissions within the UK, the GHG emissions can be compared to functional units, here per person and per household within the UK. The yearly GHG emissions of the digital sector were estimated at 288 $kgCO_2e$ per person and 684 $kgCO_2e$ per household. This was based on the latest ONS census data from mid-2021 (67,026,300 people in the UK) and ONS estimates for 2022 (28.2m households in the UK).

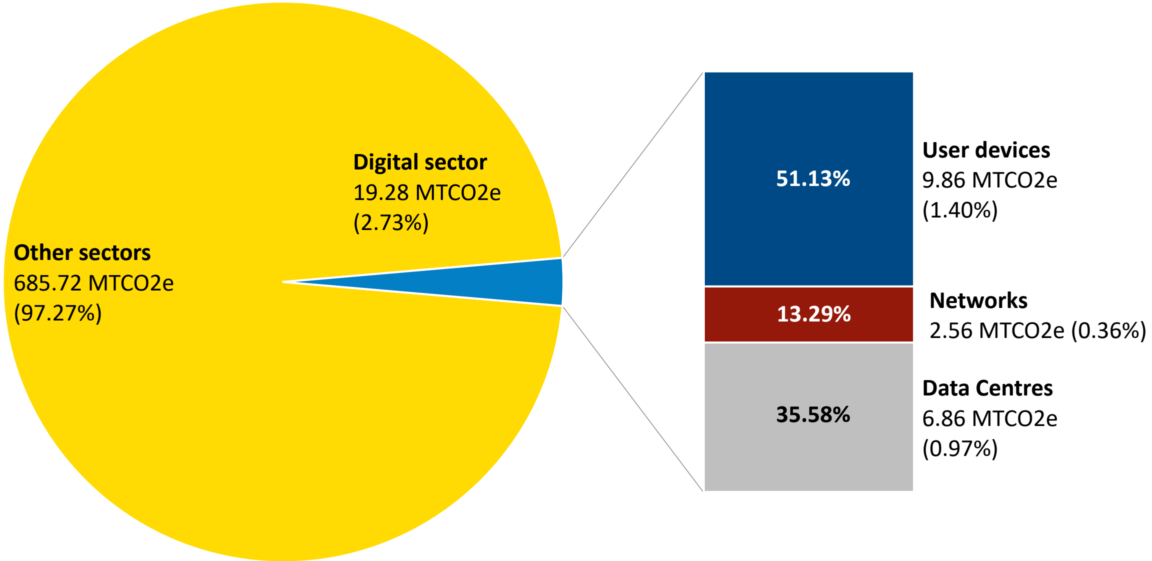


Figure 3: Yearly GHG emissions in the UK.

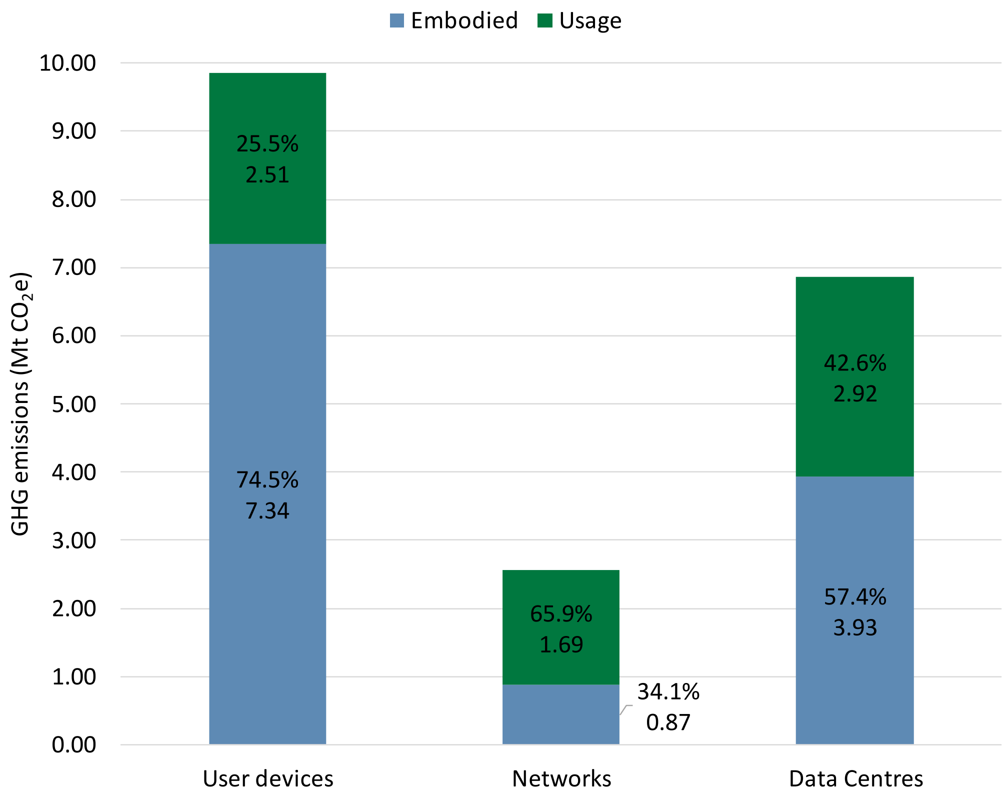


Figure 4: Embodied and use stage GHG emissions for each category.

6.1.2 Electricity Consumption

The yearly electricity usage of the digital sector was estimated to be 31.35 TWh, 9.77% of the total 2022 UK electricity demand. Of this, 42% of electricity demand came from data centres, 36% from user devices and 23% from networks (Figure 5).

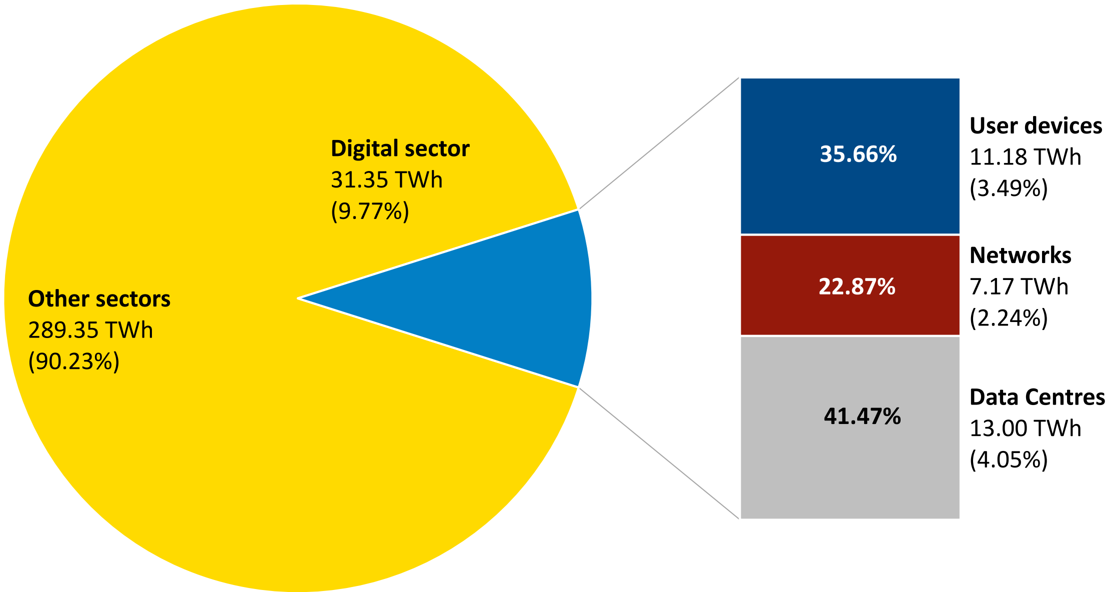


Figure 5: Yearly electricity consumption in the UK.

6.1.3 Other environmental impacts

Table 17 presents the raw results of environmental impacts for the UK digital sector, across the eight impact categories discussed in Section 3.5. These can be difficult to apprehend, and planetary boundaries (i.e. Earth's ecological limits) and normalisation (i.e. comparison to average world impact per capita) can be used for context (see Section 3.5 for more details on methodology).

In terms of planetary boundaries, the UK digital sector represented a significant share of the boundaries per capita (Figure 6). Regarding global warming potential, the UK digital sector alone was responsible for 29% of the planetary boundary in this category. It also represented 36% of depletion of abiotic resources (minerals, metals) and 21% of depletion of abiotic resources (fossil fuels). Interestingly, the responsibility lays with different parts of the sector depending on the impact considered: for minerals and metals depletion, 88% of the impact came from user devices, but for fossil fuels depletion, 55% was from data centres.

Regarding normalised impacts, Figure 7 and Figure 8 present the results as a number of individuals, and as a share of the UK's theoretical share of yearly environmental impacts. Figure 7 can be read as: *the UK digital sector's contribution to the depletion of abiotic resources (minerals, metals) was the same as the yearly average share of 11.9M people*. And Figure 8 can be read as: *the digital sector was responsible for 17.85% of the UK's total theoretical share of depletion of abiotic resources (minerals, metals)*.

Interestingly, planetary boundaries and normalisation do not highlight the same impacts. For example, GHG emissions (GWP) are more prominent when looking at planetary boundaries than normalisation. Ionising radiations, on the other hand, are most significant with normalisation and very marginal with planetary boundaries. It highlights the importance of considering a range of metrics for policy decisions, depending on the goal of the policy.

Table 17: Environmental impacts of the UK digital sector. Note that only GWP includes both embodied and use stage impacts, the other indicators only cover embodied impacts.

Environmental Impact Indicator	Value for the UK digital sector	Standardised Unit
Global Warming Potential (GWP)	1.93E+10	kg CO_2e
Particulate Matter Emissions (PMFP)	7.10E+02	Disease Incidence
Acidification Potential (AP)	7.08E+07	kg mol H^+
Ionising Radiation Related to Human Health (IR-HTP)	5.51E+10	kBq U-235
Photochemical Ozone Formation (POCP)	3.05E+07	kg NMVOC-eq
Depletion of Abiotic Resources (Minerals, Metals) (ADP)	7.58E+05	kg Sb-eq
Abiotic Depletion Potential (Fossil Fuels) (ADPF)	4.47E+11	MJ
Freshwater Eco-Toxicity Potential (FEP)	1.87E+11	CTUe

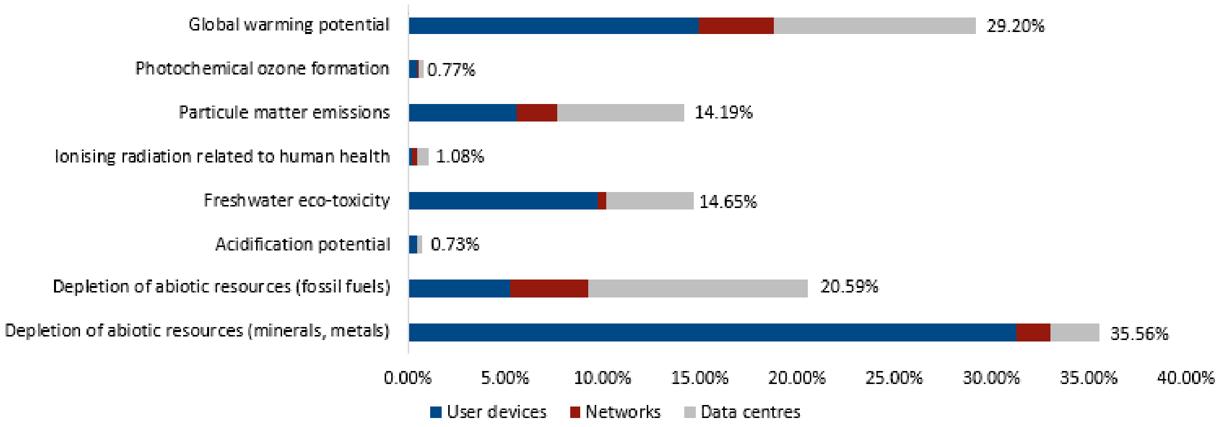


Figure 6: UK digital sectors' environmental impacts per capita compared to planetary boundaries.

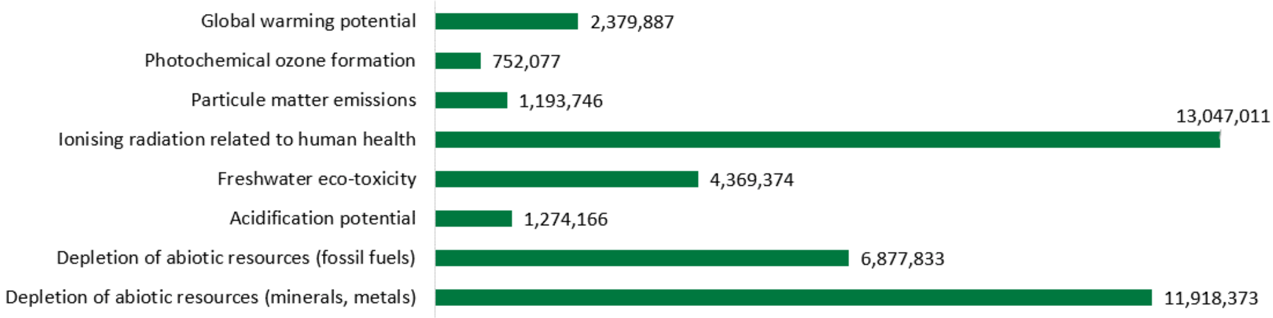


Figure 7: Normalised environmental impacts of the UK digital sector (in number of people)

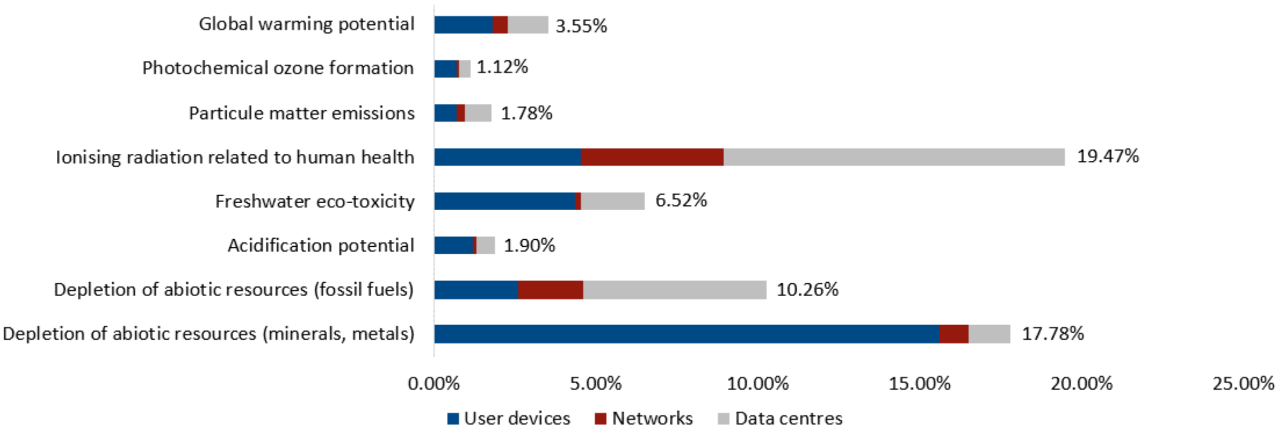


Figure 8: Normalised environmental impacts of the UK digital sector, per capita.

6.2 Breakdown per Taxonomy Category

Figure 9 provides an overview of how each taxonomy category is contributing to the GHG emissions as well as electricity consumption.

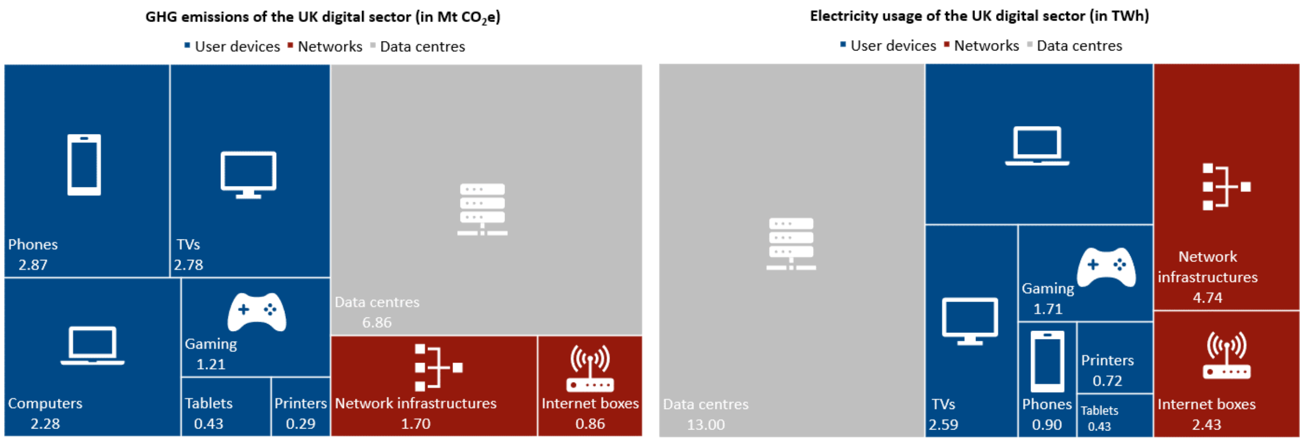


Figure 9: Overview of the different subcategories in terms of GHG emissions and electricity consumption.

6.2.1 User Devices

Our analysis has found that user devices were responsible for GHG emissions (embodied and use stage) of 9.86 Mt CO_2e. Phones were responsible for 29% of the GHG emissions attributable to user devices, followed by TVs at 28% and computers at 23% (Figure 10). Diving into subcategories, it appeared that smartphones were the biggest contributors to user devices' GHG emissions (27% and 2.65 Mt CO_2e) followed by LCD TVs (21% and 2.06 Mt CO_2e); OLED TVs, only 0.62%. Also worth noting, laptops were responsible for 13% of GHG emissions and home gaming consoles for 11%.

When comparing embodied and use stage GHG emissions, embodied impacts were responsible for 74% of user devices' results. Figure 11 presents a breakdown for each type of item. Particularly noteworthy, smartphones were 98% embodied impact and tablets 77% embodied. Laptops were 55% embodied and desktop computers only 40% embodied. Similarly, for projectors, over 71% of the GHG emissions were from usage and 57% use stage for printers. This shows that despite an overall strong contribution of embodied impacts, there are discrepancies between items.

Regarding electricity consumption, user devices used 11.18 TWh per year. Computers represented 43%, followed by TVs (23%) and gaming (15%) (Figure 10). Phones, which represented 29% of GHG emissions, only represented 8% of electricity usage. Looking into specific items, laptops represented 23% of electricity demand (2.6 TWh, 16% of domestic use, 7% for non-domestic), home gaming consoles 15%, LCD TVs 12% and set top boxes 10%.

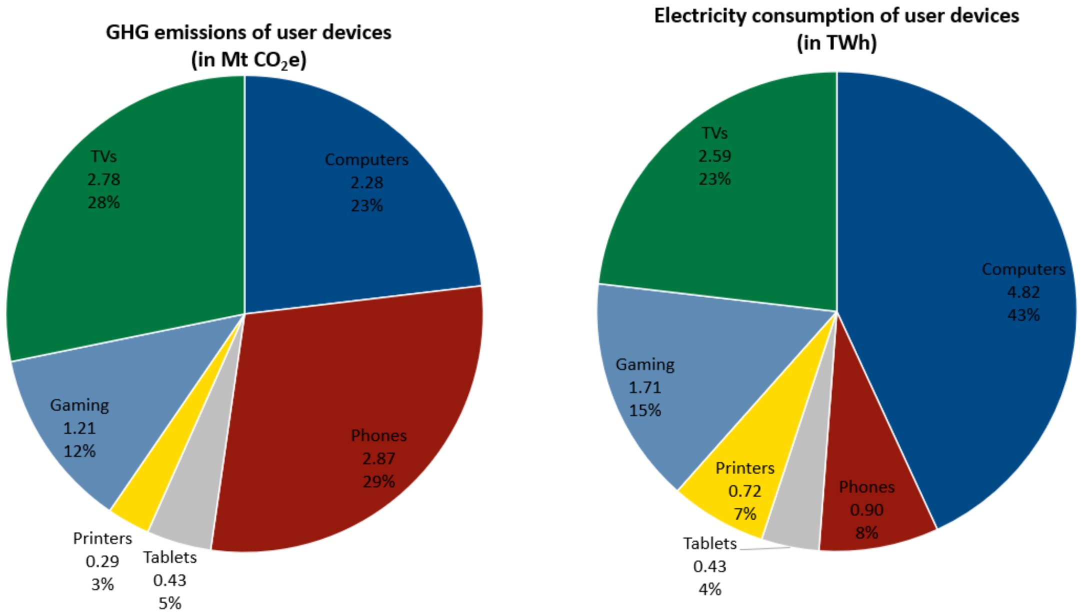


Figure 10: Contribution of different equipment to GHG emissions and electricity consumption for the user devices category.

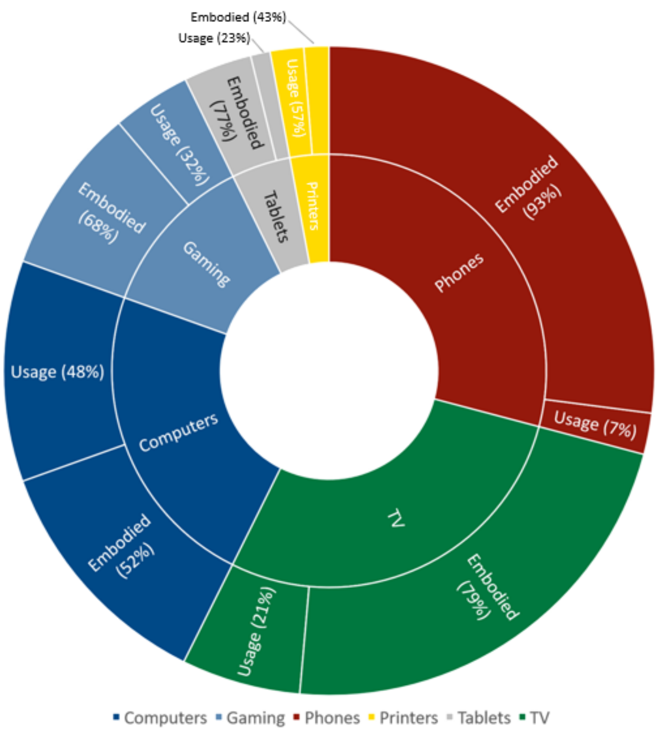


Figure 11: Contribution of embodied and use stage GHG emissions to each equipment's emissions.

6.2.2 Networks

The total GHG emissions of networks were estimated at 2.56 Mt CO_2e, with 66% due to usage, a proportion stable across all subcategories of networks. 66% of all GHG emissions were due to infrastructures and 34% to internet boxes. The main contributors were BT (35% of the network category, 52% of network infrastructure GHG emissions), and FTTC internet boxes (19% of the network category, 57% of network infrastructure GHG emissions) (Figure 12).

The total electricity usage of networks was estimated at 7.17 TWh, 66% going to network infrastructure and 34% to subscribers' internet boxes. The main contributors were the same as for GHG emissions, due to the estimation methodology (both embodied and use stage GHG emissions are mostly correlated to electricity consumption) (Figure 12).

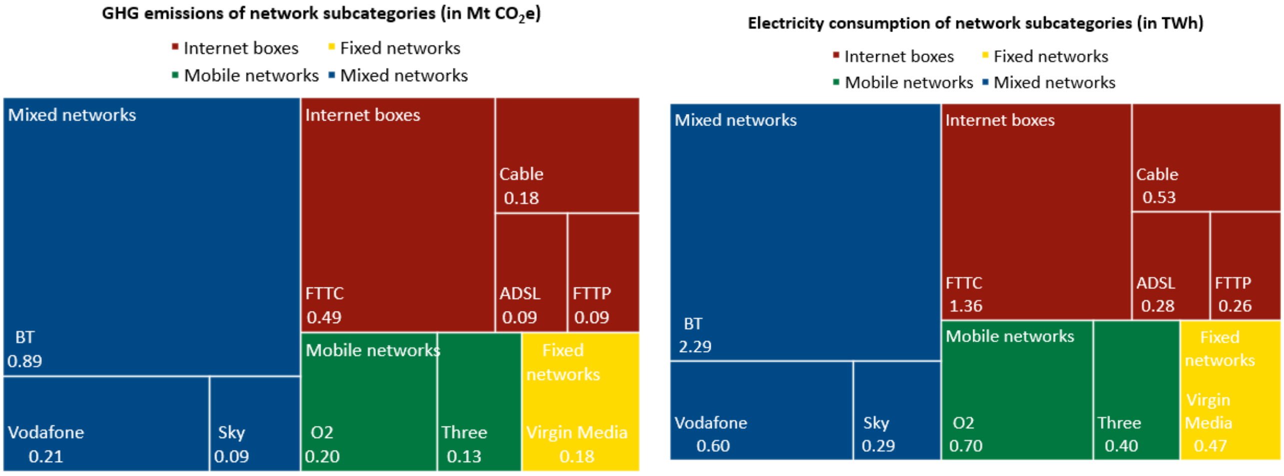


Figure 12: GHG emissions and electricity consumptions of different network subcategories.

6.2.3 Data Centres

The total GHG emissions from data centres were estimated at 6.86 Mt CO_2e, with 57% due to embodied emissions and 43% due to usage. The embodied impacts are dominated by enterprise and co-location data centres (55% and 43% respectively). Use stage GHG emissions were only available for the whole category. The total electricity usage from data centres in the UK was estimated at 13 TWh.

6.3 Comparison to Other Countries and Other Studies

Here we present some comparison to other studies and other countries, bearing in mind discrepancies in scope and data sources.

In the 2024 study by Malmodin and colleagues [3], the global GHG emissions of the sector were estimated at 764 Mt CO_2e and the electricity usage at 916 TWh. This would put the UK digital sector's contribution to the global digital sector at around 2.5% of GHG emissions and 3.4% of electricity usage. It is worth noting that the split between use stage and embodied emissions highlighted by Malmodin et al. is the opposite of the results obtained through this UK-focussed research and analysis (64% usage in Malmodin et al. vs 37% here). It can be explained by the relatively low-carbon electricity available in the UK compared to the world average, and the limited inclusion of embodied emissions outside user devices in the Malmodin study. The distribution between the three main taxonomy categories is similar to what was found in this research: 57% for user devices (vs 51% in the UK) and 24% for networks (vs 13% in the UK).

Previous estimates, aggregated by Freitag and colleagues, argued that the contribution of the ICT sector to global GHG emissions was between 2.1% and 3.9% (the latest Malmodin study estimated 1.4%); it was 2.73% in the UK. The authors showed a wide range of distributions between user devices, networks, and data centres: from 32% to 57% for user devices (51% in the UK).

The ADEME report had a similar scope to this study, although included a wider range of user devices. The overall GHG emissions estimated (embodied and use stage) was similar to the UK, at 16.9 Mt CO_2e (19.28 Mt CO_2e in the UK) and represent a similar share of France's emissions (2.5% vs 2.73% in the UK). These also represented a similar impact per capita, at 0.25 tCO_2e (0.29 tCO_2e in the UK). Electricity consumption was about 50% higher, at 48 TWh, this was in line with overall electricity demand in France: in both countries, digital sector consumption represented about 10% of overall demand. The ADEME reported a higher contribution of user devices to overall carbon footprint: 78.7% of total GHG emissions (51% here).

6.4 Limitations

Throughout the quantification modelling, various data from multiple sources was used. This section highlights the main limitations identified through modelling.

Data availability (UK): One of the main limitations of this study derives from data availability. In several instances, UK-specific data was not available, and assumptions had to be made, e.g. that the number of devices per person was stable across Europe, or that the UK market was similar to the French market in some respect.

Data availability (2023): The year data was available for was also an issue. Although this study aimed at assessing the most recent impacts of the digital sector, for some categories data was only available for 2020 or earlier. For example, companies have a one to two years lag in releasing annual reports. The Department for Energy Security & Net Zero (DESNZ) published their 2022 UK GHG Emissions report on the 6th February 2024, demonstrating that it is a government and industry wide struggle for data collection. More specific limitations due to data availability were discussed in the methodology section (Section 5).

Conflicting figures: In some cases, diverging data was available about electricity consumption or impacts. Most significantly, DESNZ's estimates of TVs electricity usage was 6 times lower than the number used in France from the ADEME report. Using the French value would increase the GHG emissions of the sector by 1.8 Mt CO_2e and the electricity consumption by 8 TWh. For these items with a particularly large impact, further UK-specific surveys may be warranted. DESNZ's publication also recognise the limitations and uncertainties relating to emissions estimates, and the warnings included are relevant to this study as well:

> *It is impractical to directly measure emissions from every exhaust, chimney, and acre of land in the UK, so greenhouse gas emission estimates are based on a series of models that estimate emissions from different sources. The source data and methods used to derive UK greenhouse gas emission estimates have been developed to be consistent with methods defined within international guidance. The approach used is largely defined by the availability of data and the significance of the emission source in the overall UK inventory. Estimates of greenhouse gas emissions have an inherent uncertainty due to uncertainty in the underlying data used to calculate the emissions, and due to uncertainty in the applicability, completeness, and application of that data.*

Data about data centres were particularly difficult to come by, and conflicting figures can be found. This study used 13 TWh as the total electricity consumption of the UK data centres, but a 2022 note by National Grid ESO suggested a range between 4 and 10 TWh [64].

Lack of granularity: Network providers including BT, Vodafone and Sky provided aggregated numbers which included fixed and mobile network types. For this study we have kept these numbers aggregated to reduce the assumptions used to break it down, but a better understanding of mobile vs fixes network infrastructures would require disentangling them. Operators also tend to aggregate electricity usage from daily operations (BAU) with IT and non-IT usage. Reporting disentangled figured would greatly facilitate the monitoring of networks' energy usage.

Statista internal modelling: A number of data points are obtained from Statista Market Insights, which provide market data that can't be obtained elsewhere. These are derived internally by Statista's modelling team and there is a lack of transparency about what exactly feeds into each number.

Modelling choices: When modelling embodied impacts, for each device these impacts were fully allocated to the year of sales. This may distort the estimate in fast changing markets, or when supply chain is disrupted for example. Another example is carbon intensity. Use stage GHG emissions were estimating by using the yearly average carbon intensity of electricity for the UK. This ignores the (sometimes large) discrepancies between different parts of the country: according to the National Grid ESO, at the time of writing, it is 4 gCO_2/kWh in North Scotland and 383 gCO_2e/kWh in South-West England, 95 times higher. It also doesn't account for the daily variability of the share of renewable in the UK's energy mix, which may skew results for processes that are happening at particular times of year.

7 FUTURE LANDSCAPE OF THE DIGITAL SECTOR

This section is shaped around discussion and analysis of the possible UK future digital landscape. We explore three potential scenarios backed by UK and worldwide data. The scenarios provide a high-level view of how the digital sector may evolve in the future to 2035. An in-depth study would be required to model the full effects of the many variables involved on GHG emissions. This activity does not fall within the scope of our study; however, it could be conducted as part of a detailed modelling study in the future to provide further insight into how future projections will affect the digital sector. We developed case studies to demonstrate how specific variables within each scenario may affect the sector's carbon emissions[1]. Our scenario projections and case studies were developed using the principles and methods described within the GO Science Futures Toolkits. The drivers and trends for the digital sector summarised in Section 4 were used to guide the direction of the scenarios as well as development of the case studies. The scenarios and case studies have been developed to aid policy makers understanding of how the modelling produced as part of the quantification section (section 6) can aid the development of future policy and to understand the effects to GHG emissions. The current analysis produced for the future landscape of the digital sector assumes current climate predictions; more rapid climate change could lead to more severe impacts.

7.1 Aim of Scenario Analysis

To aid policy makers visualise plausible future of the digital sector, we have developed three scenarios. These have been designed to help:

- **Understanding Uncertainty:** Scenarios aid the understanding of the uncertainty of the future. They are not predictions, but rather a set of plausible futures that may occur. The scenarios aid exploration of a range of possibilities and should be taken into consideration as equally possible to occur.
- **Strategic Decision Making:** Scenarios can inform strategy by highlighting potential opportunities and threats. They can guide decision-making and resource allocation, helping policy makers to be prepared for different possible futures.
- **Testing Plans:** Scenarios are also useful for testing strategic plans against a variety of different future states to ensure they are robust.
- **Stimulating Innovation:** By considering a range of futures, we can also stimulate innovation. Scenarios can help policy makers to think outside of the usual assumptions and consider different perspectives.
- **Communication Tool:** Scenarios can also be a powerful communication tool. They can help to demonstrate the potential implications of current decisions and bring to life abstract concepts.

Scenario projection can significantly aid policy development in several ways:

- **Informed Policy Making:** By considering a range of possible futures, policy makers can develop flexible policies that are robust to different outcomes. This can lead to more resilient and effective policies.
- **Risk Management:** Scenarios can help identify potential risks and challenges that may arise in the future. This can allow for the development of contingency plans and risk mitigation strategies.
- **Stakeholder Engagement:** Scenarios can be used to engage stakeholders in the policy development process. They can help to illustrate the potential impacts of different policy options and facilitate discussion and consensus building.
- **Long-term Planning:** Scenarios encourage long-term thinking, which is often necessary for policy development. They can help to ensure that policies are not just reactive but are also proactive and strategic.

[1] The case studies did not explore the full GHG emissions impacts and wider the environmental impacts explored within Section 5.2.

doi.org/10.17863/CAM.114743

- **Policy Evaluation:** Scenarios can also be used to evaluate the potential impacts of policies. By testing policies against different scenarios, policy makers can assess their likely effectiveness and make adjustments as necessary.

The key to effective scenario planning in policy development is to use the scenarios as a tool for learning and exploration, rather than prediction. It's about understanding the range of possibilities, not about trying to predict the future with certainty. This approach can lead to more robust and resilient policies that are better able to navigate the uncertainties of the future.

7.2 Scenario Selection

7.2.1 Introduction

Debate over how digital sector emissions will impact global emissions in the future is multifaceted. A contributing factor is the uncertainty surrounding technology uptake and development. As new innovations emerge (e.g. AI, 5G and Internet of Things (IoT)), their likely projected energy consumption and GHG emissions are unclear. This ambiguity is due to multiple factors including energy efficiencies, production techniques and user behaviours.

As well as technological developments, political, social, and economic factors also have the ability to drive significant variations in emissions from digital technologies. Government policies, corporate practices and societal behaviour all play a role. For instance, regulations promoting renewable energy sources may drive down emissions, while consumer demand for energy-intensive devices may have the opposite effect. Additionally, economic incentives and market dynamics impact investment in sustainable technologies.

7.2.1 Axis of Uncertainty

Axes of uncertainty for the future of the digital sector were established (Figure 13) to enable core framing of our scenarios. The two axes align with the core goals of the UK digital sector, the ability to be a global leader in digital technology and to achieve Net Zero ambitions. The axis of uncertainty formed the basis of our PESTLE analysis.

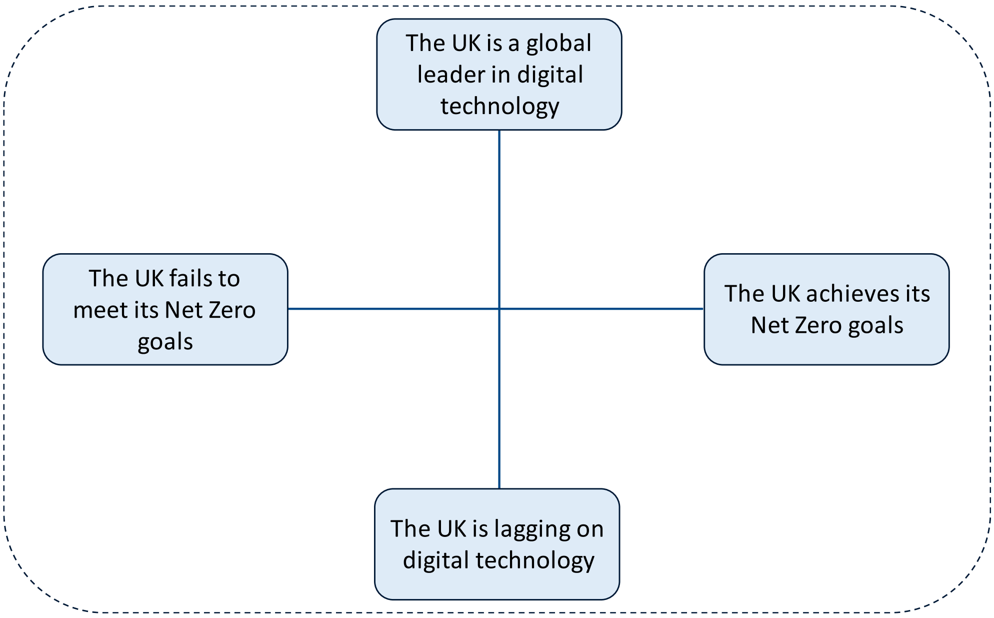


Figure 13: Axis of uncertainty for the digital sector.

7.2.2 PESTLE Analysis

A PESTLE framework assesses the political, economic, social, technological, legal, and environmental factors which will drive future change. The analysis has been undertaken through the lens of the axis of uncertainty to ensure a digital sector perspective is maintained. The PESTLE framework is useful for policy makers in that it forces a holistic perspective of the external environment, enabling resultant strategic decisions to align with the prevailing conditions and anticipate future changes. In the case of our analysis, the future scenarios have been constructed for the UK in 2035.

The key factors that have been used to develop the potential future scenarios are summarised below:

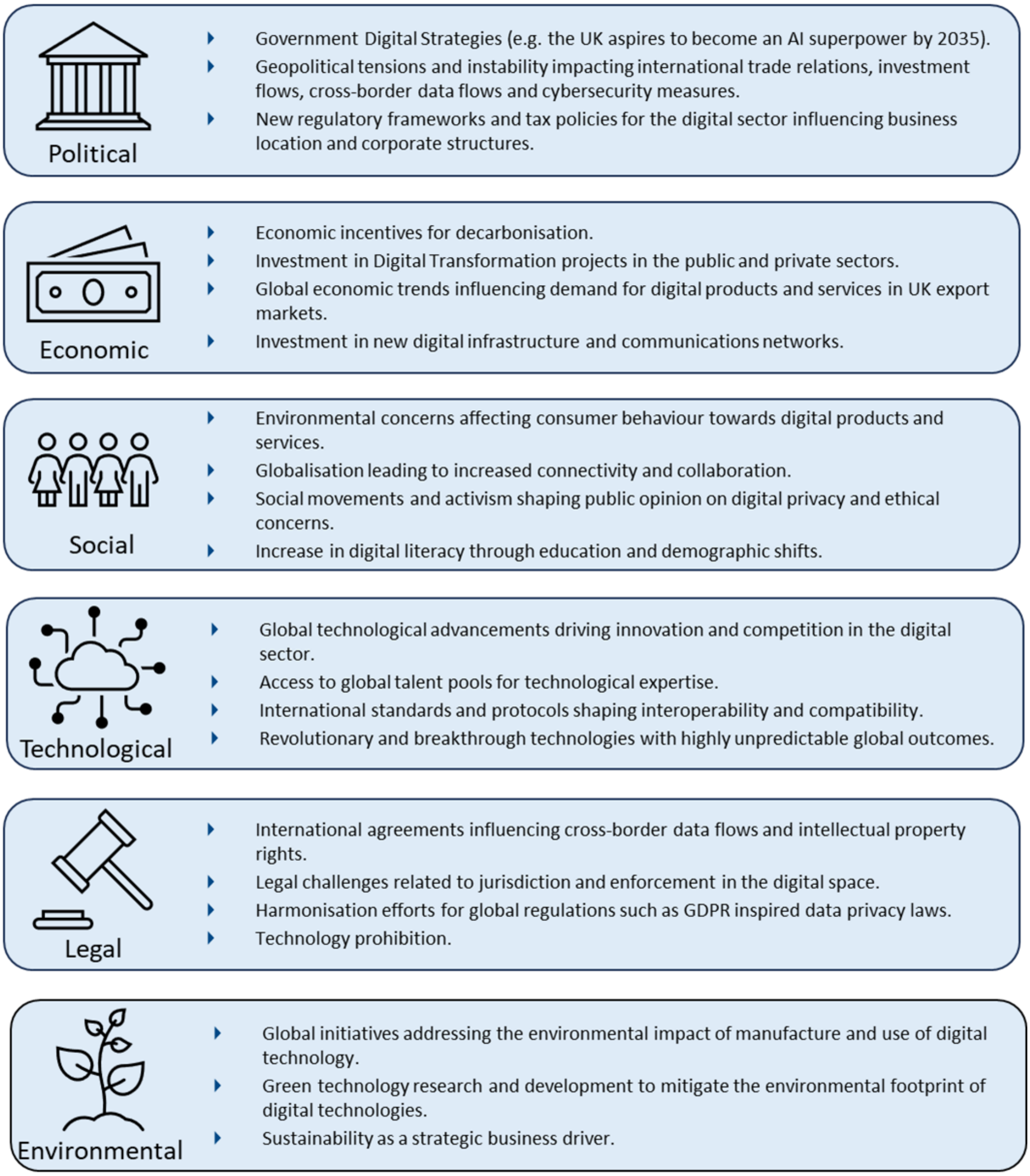


Figure 14: PESTLE analysis

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7.3 Potential Future Scenarios for the Digital Sector

The scenarios provide a high-level picture of what existing literature and our analysis suggests is likely to be driving the UK digital sector in 2035. The three scenarios (as highlighted in Figure 15) have been developed to describe the possible future landscape of the digital sector within the UK. The trends discussed within the scenarios are related to the three taxonomy categories discussed within this report which have been developed through data gathered in Section 4[2]. Indirect effects of the projections are out of the boundaries for this study. Annex C provides a summary of the critical assumptions of each scenario projection.

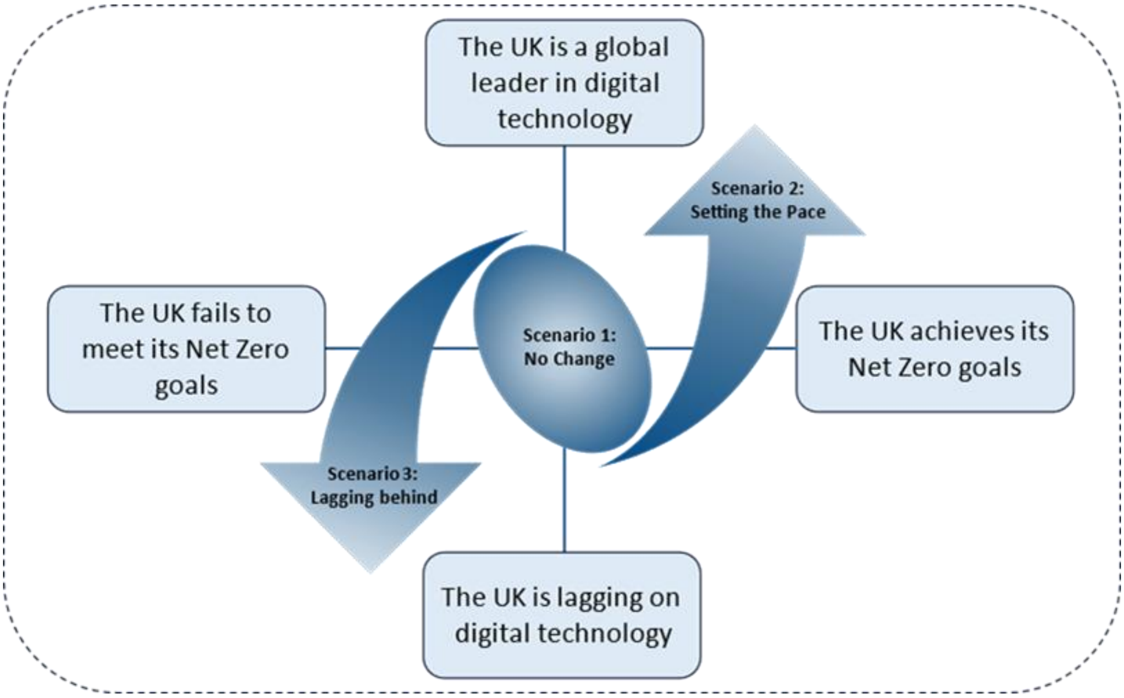

Figure 15: Scenarios developed to describe the possible future landscape.

7.3.1 Scenario 1: No Change

Our first scenario represents trends which mirror those seen in the present digital sector landscape. General trends of technology uptake continue at an expected rate and the corporate self-regulation and policy landscape is unchanged. Despite this, sustainability will be seen as an important business driver for companies and organisations to maintain their reputations with the public. As a result, it can be expected that levels of emission from the digital sector will follow current predictions. Figure 16 summaries the key elements of Scenario 1.

[2] These scenarios project a simplified version of the digital sectors landscape. It should be noted that the digital sector is ever evolving and consists of multiple elements.

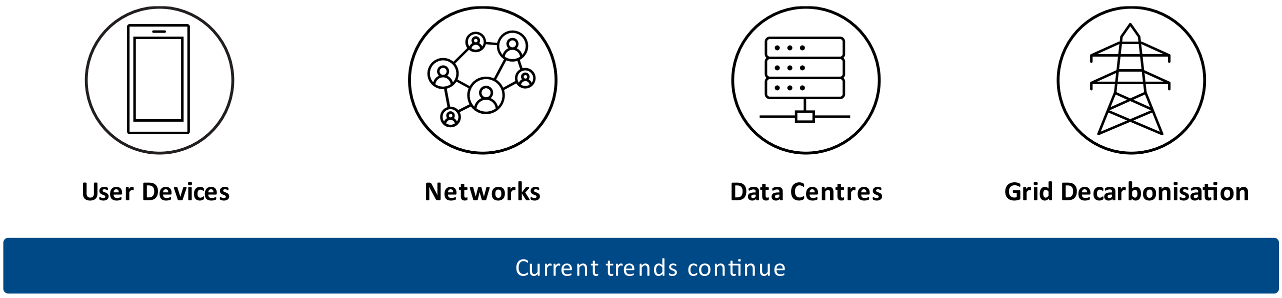

Figure 16: Scenario 1 summary.

User Devices

Laptops and desktops, once the primary consumers of energy, are now sharing the stage with home networking equipment, which could potentially surpass them in energy usage. TVs and set-top boxes are making their mark on energy budgets.

The smartphone market is witnessing a unique trend. New smartphone sales are plateauing, perhaps even declining slightly, as the appeal of second-hand sales grows. The quality and popularity of these pre-owned devices are reshaping consumer preferences. The market for refurbished devices is growing. As environmental consciousness rises and the impact of electronic waste becomes more evident, consumers are gravitating towards these cost-effective and eco-friendly alternatives. This confluence of trends is setting the stage for a future where sustainability and efficiency become integral to the narrative of user devices.

Networks

The deployment of additional networking equipment to meet peak demand events is driving an increase in energy consumption. This trend underscores the importance of understanding the influence of demand on energy consumption to inform capacity decision-making. The energy consumption of a network remains approximately the same, irrespective of the level of use. This suggests that typical interventions, such as sustainable website design, may not contribute significantly to reducing energy consumption in networks.

The retirement of inefficient legacy equipment, such as Public Switched Telephone Networks, is leading to windfall reductions in energy consumption. This trend is expected to continue as more legacy equipment including copper cables, 2G and 3G is phased out.

A significant source of energy consumption is networking equipment in homes and offices. These devices, which use over 80% of their maximum power consumption when idle, present a significant opportunity for energy savings if turned off when not in use. This paints a picture of a future where strategic decisions and practices could significantly impact the energy efficiency of networks.

Data Centres

The demand for data transfer is surging in both fixed and mobile networks. Despite the higher energy consumption, mobile networks are ready for a significant increase in data volume. This surge is mirrored in the energy consumption of hyperscale cloud operators such as AWS, Microsoft, and Google, which has seen a sharp increase in recent years. This rise is driven by digitalisation, the growth of existing cloud services, and the convergence with new, computationally intensive services, particularly AI. While there are hopes that new technology will bring efficiency improvements to mitigate this demand, evidence remains abstract.

Data centres are grappling with rapidly growing workloads, leading to a substantial increase in energy use in this sector, a trend that shows no sign of decline. This is demonstrated by the combined energy use of major tech companies - Amazon, Microsoft, Google, and Meta - which more than doubled between 2017 and 2021, indicating that their data centres' energy consumption is set to continue its upward trajectory.

Even when potential new demands from cryptocurrency mining are excluded, the overall energy use of data centres appears set for moderate growth in the coming years, although longer-term trends remain uncertain. This paints a picture of a future where balancing energy consumption with the relentless demand for data will be a critical challenge.

Grid Decarbonisation

As part of this scenario, we are expecting that the share of renewables in UK energy production will follow the path projected in the CCC 6th Carbon Budget [50]. Under the 'Balance Pathway' it is shown that there will be a 50% increase in energy demand by 2035. This pathway suggests that renewable technologies reach 70% of generation by 2035 for the UK. Offshore wind is expected to become the backbone of the system, providing a significant proportion of the generation in 2035.

7.3.2 Scenario 2: Setting the Pace

Our 'Setting the Pace' scenario represents a UK which is accelerating the reduction in emissions from digital technologies. This scenario sees far more enhancement of self-regulation by companies and organisations, major efficiency improvements in digital technologies and new policies in place to drive emissions reductions. "Sustainability" will become a critical business driver as a result of new policies, laws and standards. Figure 17 summaries the key elements of Scenario 2.

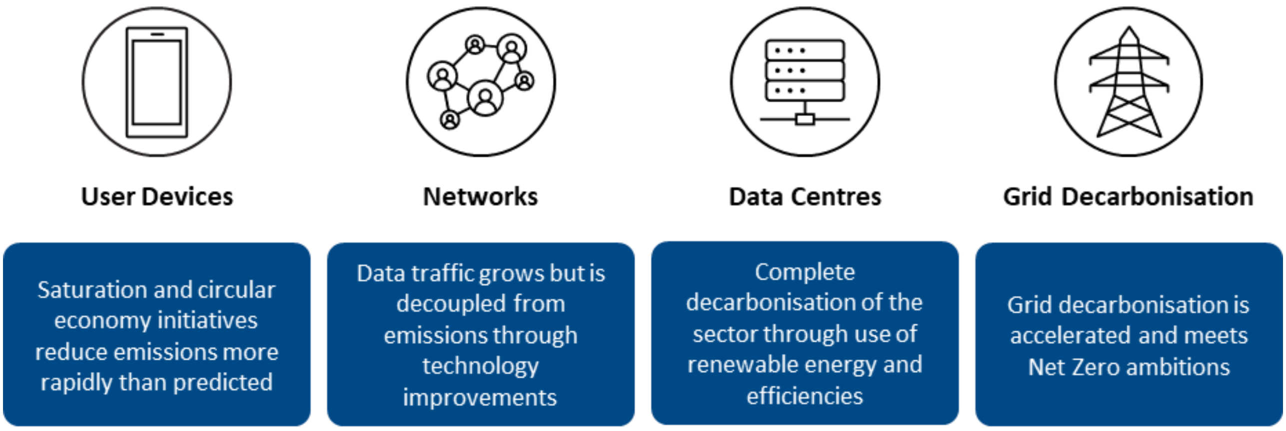

Figure 17: Scenario 2 summary.

User Devices

The digital sector may witness a significant surge in the use of user devices followed by saturation within the market. In this evolving landscape, the UK is at the forefront, with multiple initiatives and policies being announced including sustainable resource management to increase circular economic behaviours. This will aim to maximise resources as well as minimise waste. Industry will also be working in CEPs to drive an industry-wide circular shift in key areas of the electronics value chain, focusing on design, material sourcing, manufacturing and recycling. This paints a picture of a future where sustainability and efficiency become integral to the narrative of user devices.

Networks

The UK will witness significant growth in data traffic. This surge, however, is not leading to a proportional increase in emissions, due to advancements in technology. The evolution of mobile networks is a testament to this, with the landscape being reshaped by the rise of 4G and 5G technologies. As these networks expand their reach, older, less efficient networks are being phased out.

The retirement of these redundant networks is not just a technological shift, but also an environmental consideration. The UK Government, in its Future Telecoms Infrastructure Review, has acknowledged this and set ambitious targets for the availability of full fibre and 5G networks. This move signifies a commitment to not only advancing the nation's digital infrastructure but also mitigating the environmental impacts of these developments. Therefore, the narrative of data traffic growth is intertwined with the narrative of technological progress and environmental responsibility.

Data Centres

In the era of rapid digitalisation, the UK is increasingly reliant on data centres and data transmission networks. This reliance, while necessary for progress, inevitably leads to increased energy use. The sector is making strides towards complete decarbonisation, harnessing renewable energy sources, and improving efficiencies to mitigate the environmental impact.

Data centre management software is evolving, integrating machine learning techniques with existing building management systems. This allows operators to identify and address inefficiencies in real-time, and even predict future patterns. Meanwhile, the demand for data transfer is surging in both fixed and mobile networks. Despite the higher energy consumption, these networks are poised for a significant increase in data volume. Data centres, grappling with rapidly growing workloads, are also seeing a substantial increase in energy use. Through smart optimisation and a commitment to sustainability, they are contributing to the sector's journey towards decarbonisation.

Grid Decarbonisation

As part of this scenario, we are expecting an accelerated pace to the complete decarbonisation of grid. As a result, decarbonisation of the digital sector's energy consumption by renewable energy uptake will enable the UK to achieve the reduction of emissions from digital technologies. For this scenario we have assumed that whilst the digital sector continues to grow, the UK electricity mix becomes increasingly dominated by low-carbon sources.

The British Energy Security Strategy [65] claims "by 2030, 95% of British electricity could be low-carbon; and by 2035 we will have decarbonised our electricity system, subject to security of supply", with a target for all electricity to come from 100% zero-carbon generation by 2035.

This scenario for grid decarbonisation, follows the strategy and scenarios set out by the National Grid's Future Energy Scenarios, which presents three pathways under which the UK will meet Net Zero by 2050. The three decarbonisation pathways are described as;

- **Leading the Way:** The UK achieves net zero by 2046 through rapid decarbonisation, significant investment in advanced technologies, and consumer engagement in energy management. Energy demand decreases due to efficiency improvements and home retrofits. Hydrogen, produced via renewable-powered electrolysis, decarbonises challenging industrial processes.
- **Consumer Transformation:** The net zero target is achieved by 2050, driven by consumer engagement and extensive home energy efficiency improvements. Electricity demand is smartly managed, and typical homes use electric heat pumps and EVs. Higher peak electricity demands are managed with flexible technologies like energy storage and Demand Side Response.
- **System Transformation:** The net zero target is achieved by 2050, with significant changes on the energy supply side. Typical consumers use hydrogen boilers, EVs or fuel cell vehicles, with fewer home energy efficiency improvements. Hydrogen demand is high, primarily produced from natural gas with CCUS.

7.3.3 Scenario 3: Lagging Behind

Our 'Lagging Behind' scenario represents a UK which experiences an accelerated growth in emissions arising from digital technologies, and little to no action is taken to reduce emissions. In this scenario, regulation is ineffective and inefficiently deployed to restrict emissions production. This scenario assumes that sustainability is no longer a key business driver for the private sector. Improvements in the efficiency of digital technology plateaus, not matching the rate of uptake and deployment, resulting in increased energy demand by the sector. Figure 18 summaries the key elements of Scenario 3.

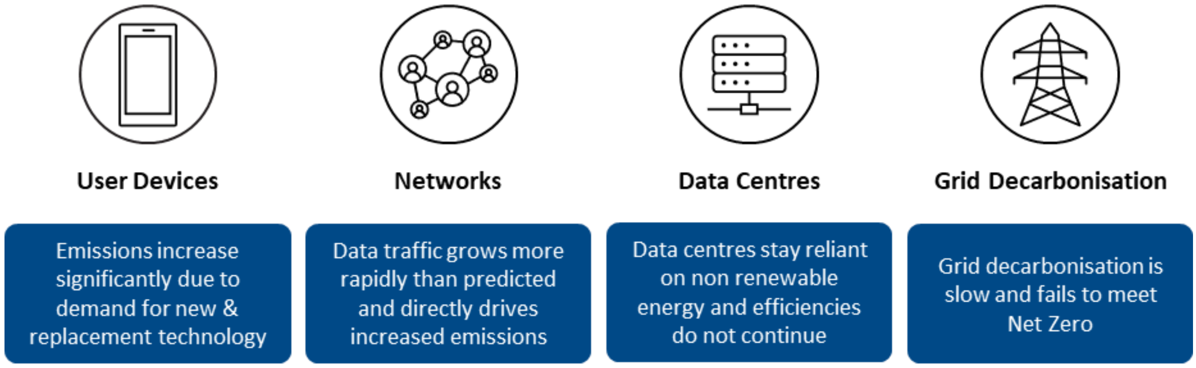

Figure 18: Scenario 3 summary.

User Devices

Significant surge with the uptake of user devices may be seen. This increasing demand for devices and peripherals, such as mobile phones, tablets, and laptops, is driving a substantial need for new and replacement technology. However, this growth comes with a cost. Emissions are increasing significantly due to this demand, further increasing the digital sector’s environmental footprint.

The UK does not pursue new policies or regulations that enable resource management, circular economy, and sustainability. This absence of regulatory action does not promote sustainable practices and responsible growth.

Networks

Data traffic is growing at a pace that surpasses predictions. This rapid growth is directly driving an increase in emissions. The evolution of mobile networks has been slower than anticipated. The older 2G and 3G networks are still present within the system, and the uptake of the more efficient 5G technology has been slow-moving.

The deployment of fibre has also been slow. Copper cables, despite their limitations, remain the primary mechanism for fixed networks. This slow transition to more efficient technologies underscores the challenges faced by the digital sector in balancing progress with sustainability.

Data Centres

Data centres stand as pivotal entities. These centres continue to rely heavily on non-renewable energy sources, resulting in increased environmental footprint. Efficiencies in these centres do not seem to make significant progress.

Simultaneously, data centres are grappling with rapidly growing workloads. This growth is leading to a substantial increase in energy use in the sector, further intensifying the environmental impact. Data centres are at the heart of digital progress, yet their continued reliance on non-renewable energy and lack of efficiency improvements poses significant challenges to the goal of sustainability.

Grid Decarbonisation

As part of this scenario, we are expecting grid decarbonisation at a slow pace and fails to meet Net Zero targets. This scenario for grid decarbonisation, follows the strategy and scenarios set out by the National Grid’s Future Energy Scenarios, which presents the ‘Falling Short’ scenario outlining how under such a pathway the UK will not meet Net Zero by 2050. Despite some progress on decarbonisation compared to today, the reliance on fossil fuels is still high.

7.4 Targeted Case Studies

The scenarios describe the potential future landscapes of the UK digital sectors and are built up using multiple variables. This makes modelling and analysis of the scenarios for all the variables difficult to conduct without increasing the number of assumptions and uncertainties of the model produced in Section 5. For this reason, three case studies have been produced which alter a targeted variable within the scenario. The case studies have been developed based on key

doi.org/10.17863/CAM.114743

drivers and trends summarised within Section 4 and identified in the Policy Driven Report. Each case study targets a specific aspect of Figure 2, taking into consideration where data was available for modelling.

Quantitative analysis has been conducted using the Appendix 1 Workbook as a basis. We have then implemented adjustments to the variable values in the model, as outlined within the case studies. This aims to demonstrate how potential future trends may affect the carbon emissions of the digital sector in the UK. Additionally allowing policy makers to gain an understanding of how potential policy scenarios can be tested and analysed. Annex D provides a summary of the data and variable changes used to develop the case studies. The case studies that have been explored include:

1. Case Study 1: Decarbonisation of the grid;
2. Case Study 2: Rapid deployment of user devices; and
3. Case Study 3: Data centre transformation.

7.4.1 Case Study Limitations

The case studies focus on the carbon emissions arising from the digital sector rather than exploring the impact of all GHGs. This is due to grid projections only reporting carbon emissions intensities. Further work to develop an understanding of the full GHG emissions and wider environmental impacts is required to enable a more detailed understanding of the effects of different digital sector trends.

The case studies use grid carbon intensity projections from the CCC and National Grid ESO. Some ‘Setting the Pace’ scenario projections (*Consumer Transformation* and *System Transformation*) look less ambitions than the ‘No change’ scenario projection (CCC 6th Budget) within the short term (up to 2030) with the ‘No Change’ scenario achieving a greater rate of decarbonisation. Each grid decarbonisation projection has been modelled independently by the CCC and National Grid ESO and is recognised as projections based on certain variables. The variables used to model these projections include but not limited to technology, societal, behavioural levers which change the rate of decarbonisation. For this reason, within the case studies, the ‘No Change’ scenario sees a faster reduction in emissions within the short term, however then slows down, resulting in the ‘Setting the Pace’ scenarios to decarbonise further in the long term. Further development of a consolidated projection for grid decarbonisation would allow for a more consistent approach. For further details regarding the methodology and results of the grid projections produced by CCC and National grid please review [50] and [51] respectively.

The case studies also only dive into the use stage emissions associated with the digital sector and the targeted technologies. The embodied emissions are out of scope for the emissions modelling of the case studies. Embodied carbon intensities are calculated using a life cycle approach which takes into consideration the full value chain. As the grid decarbonises in the UK, the electricity grids of other countries including the United States or China where some of the hardware originates from may have a different trajectory. For this reason, it is not feasible here to calculate the variation of embodied carbon intensities for future UK scenarios due to multiple geographical uncertainties. Further research is required on the global supply chain and the embodied carbon digital emissions associated with them.

7.4.2 Case Study 1: Decarbonisation of the Grid

7.4.2.1 Approach

In 2035, the UK may have an energy mix which is dominated by renewable and low-carbon sources. In line with the UK’s Net Zero ambitions and reduction in emissions in line with the Paris Agreement, it is recognised that there is a requirement to limit the production of GHGs related to energy generation. This case study explores the variation of carbon emissions produced by the digital sector as a result of different rates of grid decarbonisation. The case study assumes that the digital sector will continue to grow at a constant rate, but the electricity mix could become increasingly dominated by low-carbon sources. This could mean that whilst energy usage within the digital sector might increase, the carbon intensity could decrease due to a cleaner energy mix.

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Each scenario has been modelled using the grid decarbonisation projections outlined within Section 7.3. Table 18 summarises the carbon intensity factors used.

Table 18: Electricity intensity values

Scenario	Projection Source	Carbon Intensity (gCO_2/kWh)	
		2030	2035
Scenario 1: No Change	CCC Balanced Pathway	50	10
Scenario 2: Setting the Pace	National Grid ESO Leading the Way	38	-7
	National Grid ESO Consumer Transformation	66	-14
	National Grid ESO System Transformation	68	0
Scenario 3: Lagging Behind	National Grid ESO Falling Short	104	50

The National Gris ESO *Leading the Way* and *Consumer Transformation* projections result in negative emissions intensities by 2035, due to the deployment of negative emissions technologies. These negative emissions are attached to a fixed predicted electricity demand and may lead to undesirable edge cases if used in scenarios modelling (e.g. suggesting that the more electricity is used, the less CO_2 is in the atmosphere). To avoid these, we used a carbon intensity of 0 gCO2e/kWh for these scenarios.

7.4.2.2 Results

The different decarbonisation scenarios have been modelled for each taxonomy category. Figure 19 highlights the affects the various decarbonisation scenarios will have on the digital sectors carbon emission. For our modelling, we have assumed that the installed base (i.e. number of smartphones in use) and the electricity usage is kept constant throughout. This case study also only explores the use stage carbon emissions related to the digital sector.

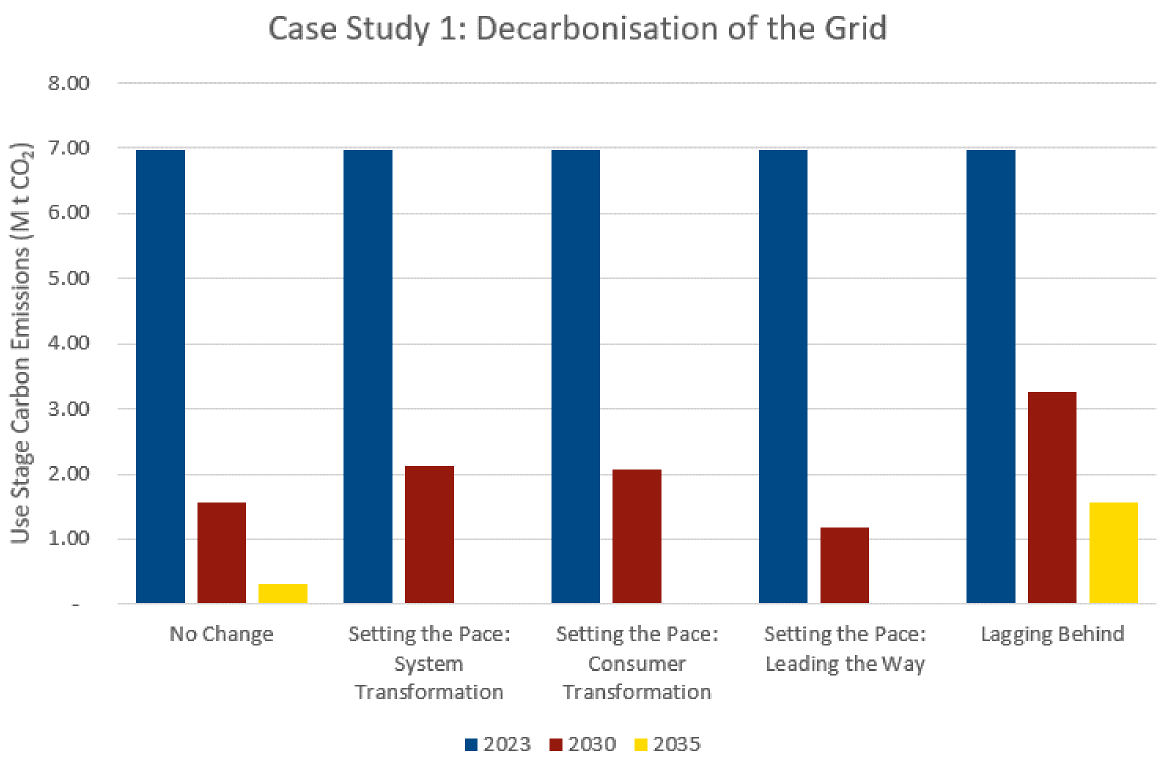

Figure 19: Impact of the grid decarbonisation on UK digital sector carbon emissions.

The five scenarios shown in Figure 19 all show a considerable difference in total carbon emissions in comparison to the 2023 footprint we calculated in Section 5.2. The greatest impact is seen in the 'Setting the Pace' scenarios where decarbonisation of the grid is supplemented with widespread public engagement and system transformations to increase energy efficiency. Under these scenarios, we estimate that in 2035, the carbon emissions from electricity consumption by digital technologies will be 0.00 Mt CO_2. In contrast, the 'Lagging Behind' scenario would lead to a footprint of 1.57 Mt CO_2 in 2035.

Decarbonising the grid will impact almost all aspects of the digital sector. Data centres, user devices and networks all rely on the grid to function and therefore the use stage emissions of all such technologies can reduce if the carbon intensity of electricity is also reduced.

7.4.3 Case Study 2: Rapid Deployment of User Devices

7.4.3.1 Approach

Trends indicate that user devices deployment is rapidly increasing year-on-year. This has the potential to significantly increase the carbon emissions associated with the use of user devices, but could also indirectly affect network and data centre requirement, further increasing power consumption and carbon emissions. This case study explores the effects of the rapid deployment of user devices, specifically through smartphones and computers in the UK in 2035.

When looking at the UK specifically, the number of smartphone users has been forecast to continuously increase between 2024 and 2029 by a total of 2.6 million users (+4.34%) [66]. After continually increasing for 9 years, the smartphone user base is estimated to reach 62.53 million users and therefore a new peak in users in 2029 [67].

Personal computing is another element of hardware that is expected to become more prolific in our 2035 UK scenarios. The number of households with a computer in the UK has been forecast to continuously increase between 2024 and 2029 by 1.1 million households (+4.1%) [68]. After continually increasing for 12 years, the number of computer households in the UK is estimated to reach 27.87 million households and therefore another new peak in 2029 [68].

There are no exact projections for the number of connected devices that will be operation in the UK in 2035. As a result of this, we have extrapolated the above trends between 2024-2029 to model case study 2. We also have modelled the grid decarbonisation scenarios from Case Study 1 to project varying pathways for emissions arising from smartphones and computers out to 2035.

The case study only investigates the use stage carbon emissions associated with user devices. This is considered a major limitation when considering user devices due to the embodied emissions contribution to smartphones and computers account for 98% and 52% respectively. Embodied emissions need to be further investigated to give a more holistic view of the impacts of the rapid deployment of user devices.

7.4.3.2 Results

Figure 20 shows that despite the projected increase in the number of smartphones, carbon emissions under all scenarios decrease to varying levels. Our 'Lagging Behind' scenario shows the smallest decrease in carbon emissions compared to 2023 levels. We have calculated that in 2023 the use stage carbon emissions of smartphones will be 0.049 Mt CO_2, whereas under 'Lagging Behind' this will fall to 0.012 Mt CO_2 in 2035. Under both *Consumer Transformation* and *System Transformation* carbon emissions reduce at a slower rate to our 'No change' scenario. This could be explained by these transformation scenarios reflecting technology changes such as CCUS taking time to be instigated, increasing use of electric vehicles creating more demand on the grid and the lag between mass consumer engagement and behavioural change. As a result, there is a delicate balance between efficiency improvements in digital technologies and external demands on the grid that will impact the levels of carbon emissions arising from smartphone use.

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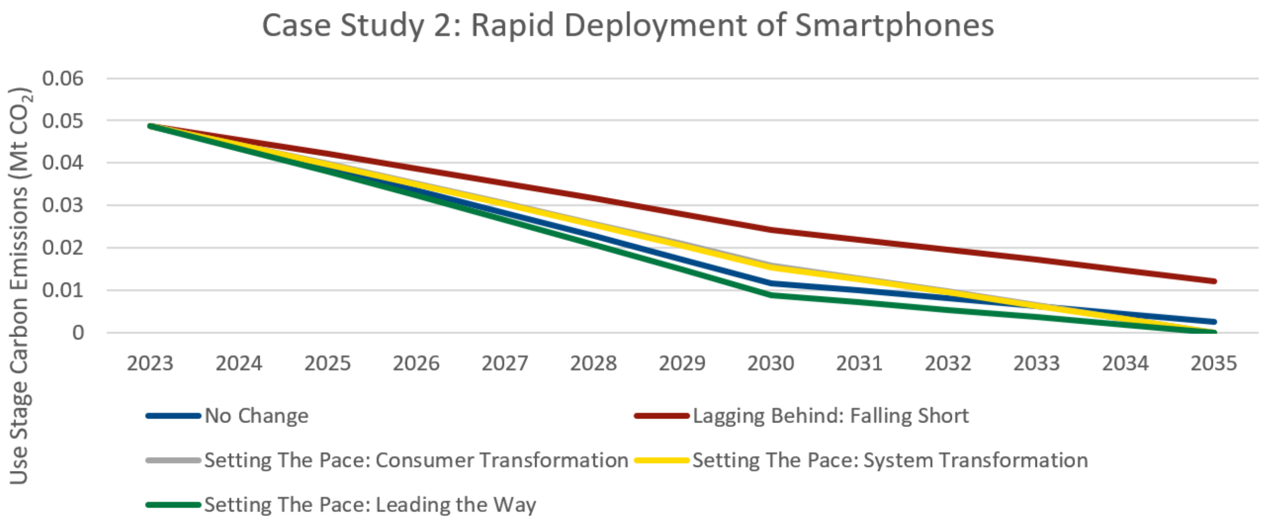

Figure 20: Carbon emissions impact of the rapid deployment of user devices.

Similarly to Figure 20, Figure 21 reflects a trend where 'Lagging Behind' scenario sees the smallest reduction in carbon emissions, falling from 1.30 Mt CO_2 in 2023 to 0.57 Mt CO_2 in 2035 for computers. The 'No Change' scenario will lead to a reduced level of reduction at 0.11 Mt CO_2 in 2035. The set of 'Setting the Pace' scenarios shows the greatest reduction in carbon emissions, reducing to 0.00 Mt CO_2 in 2035 reflecting both the high level of decarbonisation of energy production and widespread public engagement on energy efficiency strategies. The *Consumer Transformation* scenario sees peak electricity demands being managed with flexible technologies including smart energy management. These smart digital solutions will enable easier consumer participation in the delivery of a Net Zero whole energy system. Actions including mandating technology manufacturers to include smart capability in their products could be key to the delivery of smart and efficient homes in digitised world. Despite this, the extent to which consumers are willing and able to change their behaviour and lifestyle to follow a pathway of this sort still has a high level of uncertainty.

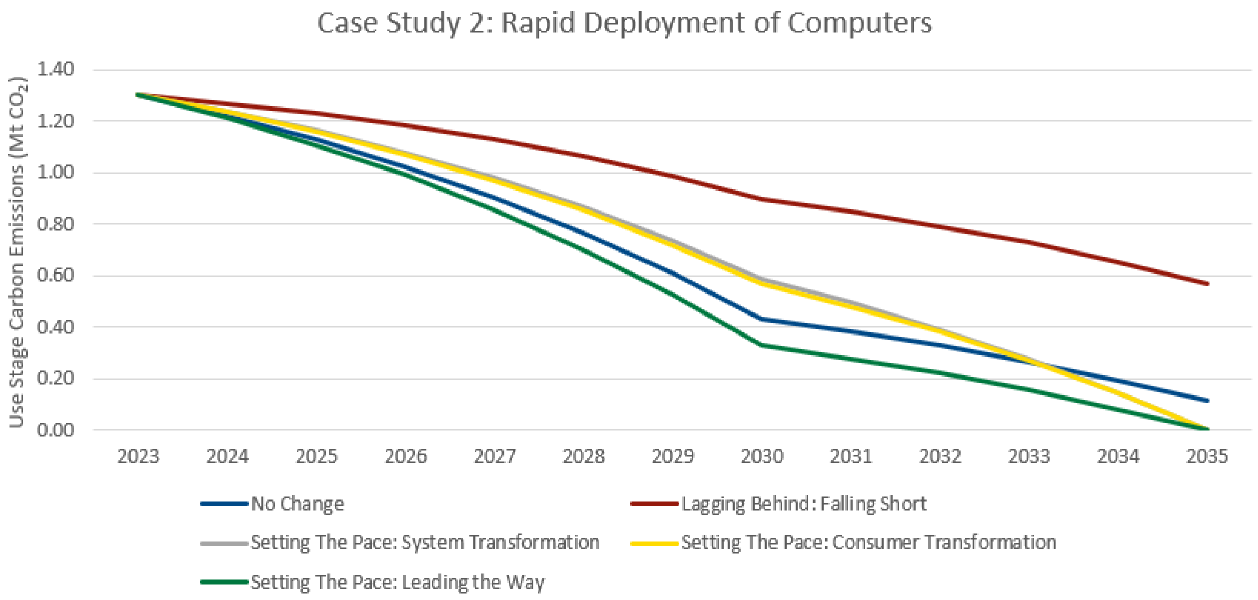

Figure 21: Carbon emissions impact on the rapid deployment of computers.

7.4.4 Case Study 3: Data Centre Transformation

7.4.4.1 Approach

Our third case study assessed how the carbon emissions from the use of data centres may vary between now and 2035. Data centre energy demand is expected to increase significantly, but there is a high level of uncertainty about how much it will increase by. As data centres have a significant impact on electricity consumption, and as the populations demand for data processing continues to increase, electricity consumption can be assumed to increase. This increase in demand will need to be matched by sufficient low carbon energy supply in the coming years. Despite the uncertainties, the overall trends point to one of growth for data centres in Britain over the coming decades. Recent announcements and plans to build from data centre operators, in addition to market trends, have produced estimates of an almost doubling in colocation facility average power consumption between 2021-2030 and a more than ten-fold increase in hyperscale.

The National Grid [69] has reflected this level of uncertainty in its projection of GB data centre electricity demand between 2023 and 2035 as shown in Table 19.

Table 19: National Grid ESO data centre electricity demand projections.

Projection	Annual Electricity Demand (TWh)			
	2023	2025	2030	2035
Upper Boundary	11.1	15.0	22.0	25.3
Lower Boundary	4.2	4.8	5.4	7.3

We have used the National Grid's projections in Table 19 along with the annual average carbon intensity factors for the Grid electricity in Table 18 that have been used for the previous case studies.

7.4.4.2 Results

The results of the analysis for Case Study 3 are presented in the figures below. Figure 22 shows the projected changes to carbon emissions from the use stage of data centres under our 'No Change' scenario. In 2035 the upper boundary is projected to be 0.25 Mt CO_2 and the lower boundary 0.07 Mt CO_2.

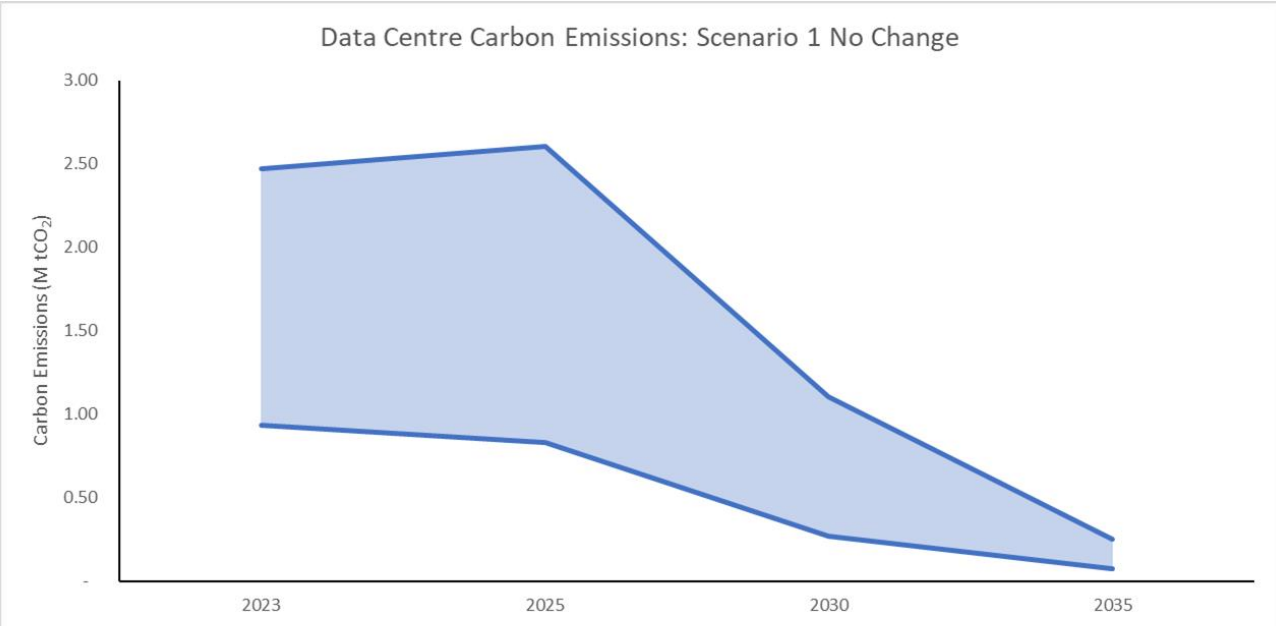

Figure 22: Carbon Emissions impact from projected data centre demands under the 'No Change' Scenario.

Our three 'Setting the Pace' scenarios have projected that in 2035 carbon emissions will fall to 0 Mt CO_2 regardless of whether the electricity demand from data centres lies towards the upper or lower boundary. Figure 23 shows that the *Leading the Way* scenario created a more rapid reduction in carbon emissions between 2025 and 2030 than the *System Transformation* scenario in Figure 24. There is very little difference between the *System Transformation* and *Consumer Transformation* which reflects the patterns seen in the earlier case studies.

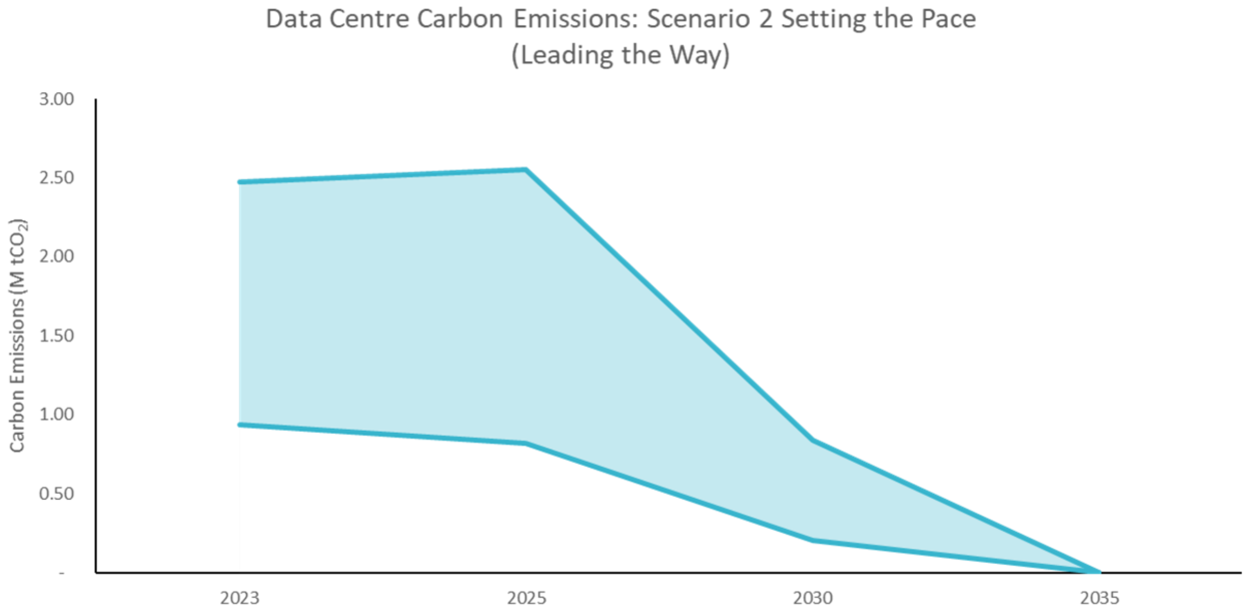

Figure 23: Carbon Emissions impact from projected data centre demands under the 'Setting the Pace' (Leading the Way) Scenario.

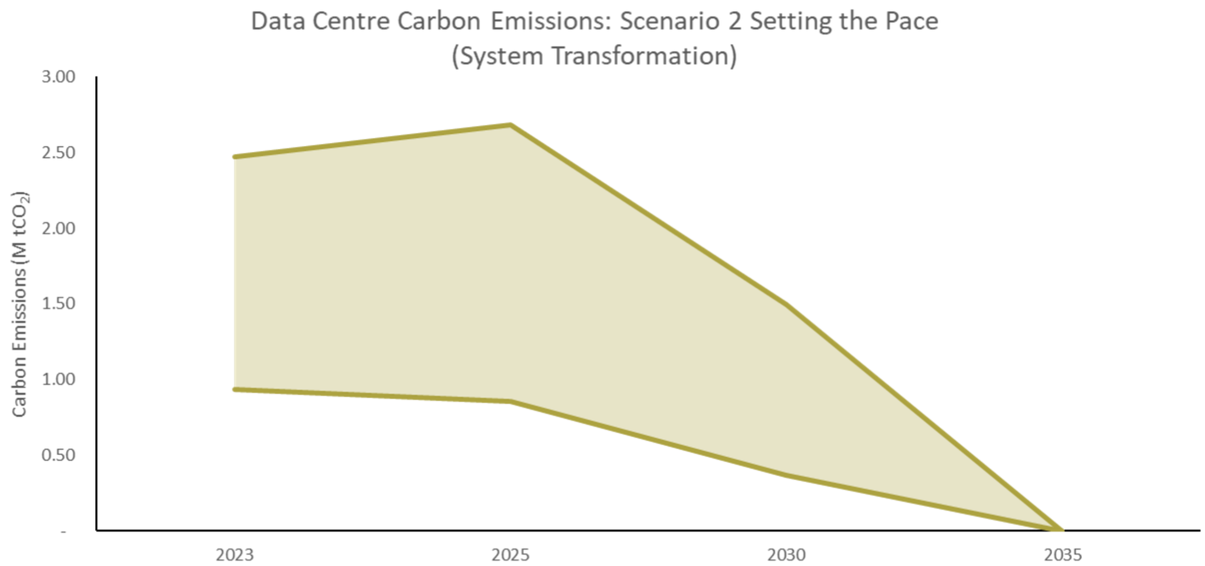

Figure 24: Carbon Emissions impact from projected data centre demands under the 'Setting the Pace' (System Transformation) Scenario.

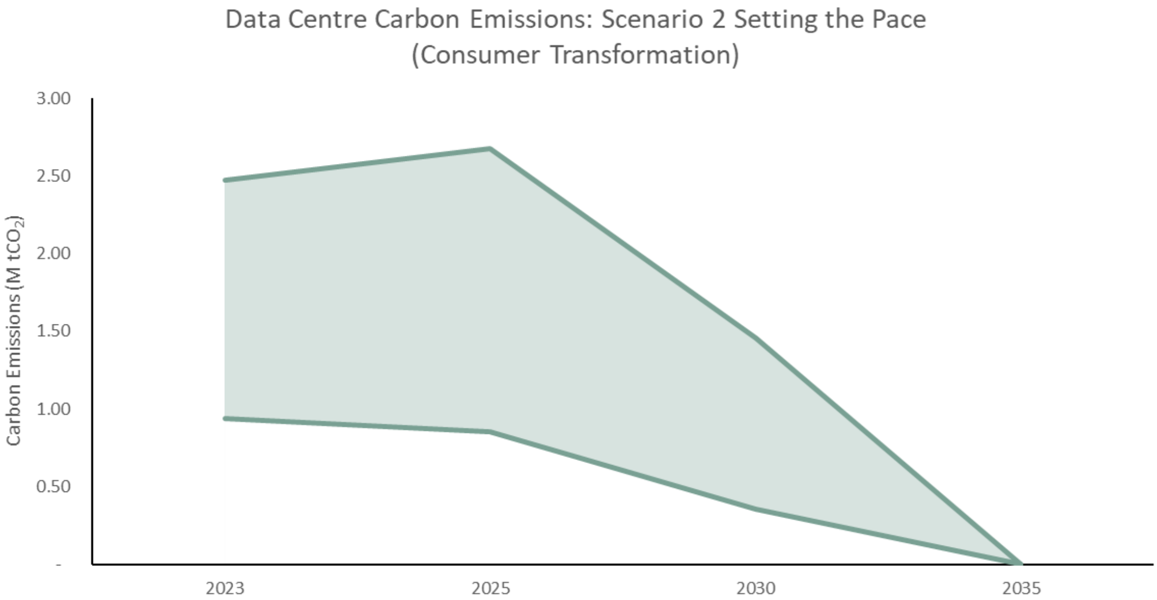

Figure 25: Carbon Emissions impact from projected data centre demands under the 'Setting the Pace' (Consumer Transformation) Scenario.

Figure 26 shows the projected changes under the ‘Lagging Behind’ scenario. This scenario shows the lowest reduction in carbon emissions, with the upper boundary in 2035 remaining at 1.26 Mt CO_2. The increasing demand for electricity from data centres along with the continued use of inefficient fossil fuels means the reduction in carbon emissions is not as significant as projected in the National Grid’s *Falling Short* grid scenario.

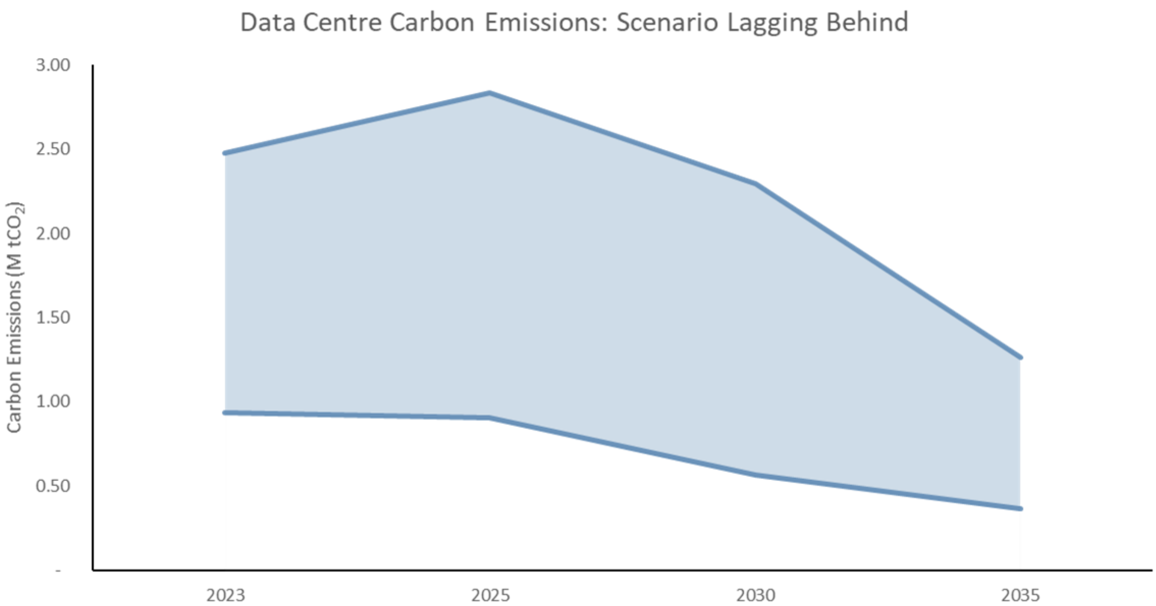

Figure 26: Carbon Emissions impact from projected data centre demands under the 'Lagging Behind' Scenario.

8 CONCLUSION

The digital sector has been a catalyst for new capabilities and efficiencies, transforming the way society operates and interacts. At the same time, the environmental impacts of this sector, e.g. in terms of GHG emissions, are significant and require careful consideration.

This Data Driven Report aimed to quantify the environmental impacts associated with the digital sector within the UK. In order to do this, data has been collected from various sources to craft a picture of the sector. This is the first time the entire digital sector has been quantitatively assessed for its environmental impacts within the UK. The calculations produced will provide the UK Government with baseline numbers that can be used for policy decisions, and a framework that can be updated as more data becomes available.

The three main categories assessed by the research team included user devices, networks, and data centres. The analysis considered a range of life cycle stages (manufacturing, distribution, usage, and end-of-life), providing a comprehensive and granular understanding of these impacts. Electricity consumption and GHG emissions are discussed in detail, alongside a broader range of relevant environmental impacts, such as depletion of abiotic resources and freshwater ecotoxicity. In addition to this report, a quantification model has been produced, making it easy to update the results for future years and incorporate data updates.

The most recent yearly GHG emissions of the digital sector are estimated at 19.28 Mt CO_2e, equivalent to 2.73% of the 2021 UK emissions. User devices are responsible for approximately half of these emissions, with data centres at 35% and networks at 13%. 63% of the digital sector's GHG emissions are due to embodied emissions (covering manufacturing, distribution, and end-of-life) and the remaining 37% result from use stage.

The sector's yearly electricity demand is estimated at 31.35 TWh, representing 9.77% of the UK's total electricity demand, with data centres accounting for 41% of this consumption and user devices 25%.

The digital sector's impact reaches over 35% of the planetary boundary per capita for abiotic resource depletion (minerals and metals, mostly due to user devices), 29% of the boundary for GHG emissions and 14% of the boundary for freshwater ecotoxicity. Adding in the rest of the economy would undoubtedly exceed greatly these planetary boundaries (e.g. the UK total GHG emission per capita of ~6 tCO_2e represents 6 times the planetary boundary).

Through the exploration of scenarios and case studies, the report provides insights into the potential impact of policy decisions influencing trends in digital technologies. This can be used as a template for future uses of the data for new targeted case studies. Policymakers can use this information to identify key environmental impacts within the digital sector and prioritise areas that require attention and intervention.

While the digital sector offers numerous benefits and opportunities, it is crucial to understand and mitigate its environmental impacts. This report provides a quantitative resource for policymakers, enabling informed decision-making to fully exploit the benefits of digital technology while minimising its environmental footprint. The findings underscore the importance of ongoing monitoring and evaluation of the digital sector's environmental impacts, informing future policy and practice. The digital sector has a pivotal role to play in the UK's journey towards Net Zero, and this report and the Policy Driven Report contributes to the critical discourse on how to navigate this path sustainably.

doi.org/10.17863/CAM.114743

9 RECOMMENDATIONS

This report has been focussed on a quantitative assessment of the environmental impacts of the UK digital sector, rather than on the policy recommendations derived from it (this is the focus of a parallel Policy Driven Report). Through our analysis we have been able to draw some general conclusions for further consideration:

1. The GHG emissions associated with the use stage equates to 37% of the digital sector's total GHG. This impact comes from the consumption of electricity by digital technologies and can be reduced by decarbonising the UK energy grid. The decarbonisation of the electric grid will be decisive in achieving a Net Zero digital sector in the coming years and should be prioritised to ensure the sector continues to decarbonise.
2. Data centres are estimated to already represent 41% of the electricity consumption of the digital sector. This should be accounted for in policies encouraging rapid expansion of high-performance data centres across the UK to ensure that this category's electricity usage doesn't grow uncontrollably [70].
3. The embodied emissions of user devices are responsible for 7.3 Mt CO_2e per year, 38% of the digital sector's emissions. The GHG emissions associated with smartphones are 98% from embodied impacts and only 2% from use stage. It is therefore crucial to identify options that could limit the number of devices manufactured and disposed of each year. For example, by ensuring that devices can be kept for longer, repaired, and suitably recycled. This is likely to require cultural and legislative changes.
4. Broader environmental impacts beyond GHG emissions are essential to gaining a full picture of the complex impact of the digital sector, and their inclusion in assessments should become more common. In the case of the digital sector, these highlight that the digital sector is consuming a significant part of the planetary boundaries per capita in some of categories of impacts and should be further investigated.

This report presented the first comprehensive assessment of the environmental impacts of the UK digital sector. It will hopefully not be the last and can be built upon in future years when more data becomes available and technologies change. While a number of significant policy decisions can be made based on this assessment, there is also a deeper need, and an opportunity, for better data collection to improve future studies. The more pressing needs for data collection include:

1. **Collecting UK-specific data for the digital sector**. Several estimates presented in this report are based on studies undertaken outside the UK, which may not capture the specificities of the UK market, or the impact of UK policies. The data collection could be achieved by either commissioning surveys and primary data collection or through the expansion of compulsory reporting requirements.
2. **Collecting data on the number and size of UK data centres**. This is perhaps the biggest blind spot at this stage. With the growth of data centre-based services, AI among others, it is essential to have a better picture of the UK data centre landscape.
3. **Enhancing existing compulsory reporting of companies' electricity consumption and GHG emissions by requiring provision of more granular data (on locations, sectors and activities)**. Considering the broad activities conducted by large companies, the reporting of a single number covering all activities, different sectors and sometimes several countries is insufficient to have a clear picture of the sector. This step would involve requiring that companies release separately numbers for the UK (instead of focusing on global figures only) and numbers for the different activities (e.g. mobile networks vs broadband, network infrastructure vs BAU).

The scenarios projections can be used to develop an understanding of the future landscape of the digital sector. While these projections provide a baseline, further refinement and development is needed. It can be used as a tool to understand how policies may affect the carbon emissions of the future digital sector. The more pressing recommendations that have been identified regarding the scenario projections and case studies include:

1. **Further development of the scenarios is required to model the full GHG emissions and wider environmental impacts associated with the projections for both the use stage and embodied impacts.** The current case studies only model the use stage carbon emissions associated with a specific variable change (e.g. decarbonisation of the grid, rapid deployment of user devices). Further work will provide a more in-depth analysis to aid policy development.
2. **Further development of the scenarios is required to enhance the current projections to consider which digital technologies may be a part of the digital sector in the future and the effects they will have on the environment**. The scenario projections consider four core elements: user devices, networks, data centres and grid decarbonisation. The digital sector has multiple layers within its taxonomy and is ever evolving with new technologies such as AI, IOT, virtual reality becoming more predominant.
3. The scenarios and case studies only consider direct effects of the future landscape of the digital sector. **Further investigation into the enabling effects and system effects related to the changes to the digital sector** will provide a holistic understanding of the indirect environmental impacts.

A more in-depth account of specific recommendations to improve the different estimates is highlighted within Annex E.

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ANNEX A – Data Source Summary

Annex A provides a summary of data sources used to calculate the emissions of the digital sector within the UK.
A RAG assessment has been conducted for each data source.

- Green: High confidence. Robust data available from reputable sources.
- Amber: Medium confidence. Data available from reputable sources but some extrapolation was needed to obtain the numbers of interest.
- Red: Low confidence. Limited data available and heavy reliance on assumptions.

User Devices

<table>
<tr><th></th><th></th><th colspan="4">Data sources summary</th></tr>
<tr><th></th><th></th><th>Installed base</th><th>Yearly sales</th><th>Embodied impact</th><th>Use stage electricity consumption</th></tr>
<tr><td rowspan="6">Computers</td><td>Laptops (domestic)</td><td rowspan="4">DESNZ national stats 2022</td><td rowspan="4">Statista 2023 (assuming domestic/non-domestic distribution identical to installed base) (from Statista Market Insight)</td><td rowspan="6">ADEME report 2020</td><td rowspan="4">DESNZ national stats 2022</td></tr>
<tr><td>Laptops (non-domestic)</td></tr>
<tr><td>Desktop computers (domestic)</td></tr>
<tr><td>Desktop computers (non-domestic)</td></tr>
<tr><td>Projectors</td><td>Estimated from EU numbers (same as ADEME report): 35m projectors in 2019 in EU28 from EU ICT report, proportionate to UK population that year (66.7m people from ONS)</td><td rowspan="2">Based on combined sales of monitors and projectors from Statista 2023 (Market Insight), assuming same distribution between the two as in France.</td><td>From EU ICT report 2020, weighted average assuming same domestic/non-domestic distribution as France.</td></tr>
<tr><td>Monitors</td><td>DESNZ national stats 2022</td><td>DESNZ national stats 2022 (lower than other sources,</td></tr>
</table>

					e.g. 3.5x higher in ADEME report)

		Data sources summary			
		Installed base	**Yearly sales**	**Embodied impact**	**Use stage electricity consumption**
Phones	Mobile phones (feature phones)	Estimated as number of subscriptions (from Ofcom 2023) minus number of smartphones in the UK (from Statista 2023)			ADEME report 2020 (rough estimate)
	Mobile phones (smartphones)	Statista 2023 (number of smartphone users) (digital market insights)	Statista 2023 (Market Insights)	ADEME report 2020	ADEME report 2020 (based on EU ICT report), including loss due to phone charger (weighted average between domestic and non-domestic, assuming similar distribution as France)
	Landline phones	Ofcom fixed line subscriptions 2023			ADEME report 2020 (based on EU ICT report) (weighted average between domestic and non-domestic, assuming similar distribution as France)
Tablets	Tablets	Statista 2023 (tablet users) (aggregated estimation)	Statista 2023 (Market Insights)	ADEME report 2020	ADEME report 2020 (based on EU ICT report) (weighted average between domestic and non-domestic, assuming similar distribution as France)

<table>
<tr><th colspan="2"></th><th colspan="4">Data sources summary</th></tr>
<tr><th colspan="2"></th><th>Installed base</th><th>Yearly sales</th><th>Embodied impact</th><th>Use stage electricity consumption</th></tr>
<tr><td rowspan="11">Printers</td><td>Mono laser printer</td><td rowspan="11">Extrapolated from EU 2020 numbers (from EU ICT report), assuming installed base is proportionate to population across the EU.</td><td rowspan="11">Using Statista 2023 (Market insights) overall sales and assuming same distribution as the installed base.</td><td rowspan="11">ADEME report 2020, weighted average between domestic and non domestic</td><td rowspan="11">From EU ICT report</td></tr>
<tr><td>Colour laser printer</td></tr>
<tr><td>Inkjet MFD</td></tr>
<tr><td>Inkjet printer</td></tr>
<tr><td>Mono laser MFD</td></tr>
<tr><td>Colour laser MFD</td></tr>
<tr><td>Mono laser copier</td></tr>
<tr><td>Colour laser copier</td></tr>
<tr><td>Professional printer/ MFD</td></tr>
<tr><td>Scanner</td></tr>
<tr><td>Fax machine</td></tr>
</table>

doi.org/10.17863/CAM.114743

		Data sources summary			
		Installed base	**Yearly sales**	**Embodied impact**	**Use stage electricity consumption**
Gaming	Gaming consoles (handheld)	Extrapolated from DESNZ national stats 2020 for home consoles, assuming the ratio handheld/home is the same across Europe (ratio obtained from ADEME/VGCHartZ)	Statista 2023 (merging handheld with hybrid) (Market Insights)	ADEME report 2020	ADEME 2020 (from EU ICT and others)
	Gaming consoles (home)	DESNZ national stats 2020 (diverging data on this)	Statista 2023 (Market Insights)		DESNZ national stats 2020 (diverging data on this, DESNZ data higher than other sources, e.g. 3x ADEME report)
TV	Domestic TV (LCD)	DESNZ national stats 2022 (primary and secondary TVs)	Statista 2023 (Market Insights), assuming LCD/OLED UK distribution is similar to global sales distribution.	ADEME report 2020	DESNZ national stats 2022, weighted average of primary and secondary display, weighted by installed base (this is low compared to other sources (e.g. ADEME is 6x higher)
	Domestic TV (OLED)	DESNZ national stats 2022			DESNZ national stats 2022
	Set top box	DESNZ national stats 2022	Statista 2023 (Market Insights), approximated by the number of "smart streaming device" in the absence of other data. This is coherent with a lifetime of 6.5 years (44/6.7).		DESNZ national stats 2022

Networks

<table>
<tr><th colspan="3"></th><th colspan="4">Data source summary</th></tr>
<tr><th colspan="3"></th><th>Installed base</th><th>Embodied impacts</th><th>Use stage electricity consumption</th><th>Use stage GHG emissions</th></tr>
<tr><td colspan="2" rowspan="4">Internet boxes</td><td>ADSL</td><td rowspan="4">Estimated from the number of subscriptions for each type reported by Ofcom (2022)</td><td rowspan="4">From ADEME report, estimating the yearly embodied cost per installed box from the French market</td><td rowspan="4">From ADEME report</td><td rowspan="4">Derived from electricity consumption using UK average carbon intensity</td></tr>
<tr><td>Cable</td></tr>
<tr><td>FTTC</td></tr>
<tr><td>FTTP</td></tr>
<tr><td rowspan="3">Network infrastructures</td><td>Fixed</td><td>Virgin Media</td><td rowspan="3">N/A</td><td rowspan="3">From ADEME report, estimating the impacts per TWh in the French market, and using the same values for the UK market, combined with the UK-specific usage electricity consumption.</td><td rowspan="2">Obtained from Virgin Media O2's 2022 annual report. Estimating the Virgin/O2 split by assuming the same electricity usage distribution as 2020 (from World Bank's report), which was the last time Virgin and O2 reported separately (40% Virgin).</td><td rowspan="2">Obtained from Virgin Media O2's 2022 annual report (scope 1+2 location-based). Estimating the Virgin/O2 split by assuming the same carbon footprint distribution as 2020 (from World Bank's report), which was the last time Virgin and O2 reported separately (48% Virgin).</td></tr>
<tr><td rowspan="2">Mobile</td><td>O2</td></tr>
<tr><td>Three</td><td>From the World Bank's report (obtained from company's 2021 report)</td><td>From the World Bank's report which aligns with Hutch 3g's scope 1, 2 and 3 in 2022. Including scope 3 like the World bank report as it doesn't include customers but does include a lot of operations. Seems more comparable to other companies.</td></tr>
</table>

			Data source summary			
			Installed base	Embodied impacts	Use stage electricity consumption	Use stage GHG emissions
Network infrastructures	**Mixed**	BT	N/A	From ADEME report, estimating the impacts per TWh in the French market, and using the same values for the UK market, combined with the UK-specific usage electricity consumption.	BT's 2023 sustainability report, scope 2 electricity consumption.	BT's 2023 sustainability report, scope 1 and 2 location-based GHG emissions.
		Vodafone			2021 data from World Bank's report.	2021 data from World Bank's report.
		Sky			2022 Sky group's impact report for UK + Ireland	2022 Sky group's impact report for UK + Ireland

Data Centres

	Data source summary		
	White space	Embodied impacts	Use stage electricity consumption
Enterprise data centres	From 2020 EU commission report for England only.	Embodied: from enterprise DC in the ADEME report.	EU Borderstep 2020 report, 2020 estimates (conflicting numbers, probably high estimate. This is the higher bound of National Grid estimates)
Co-location data centres		Embodied: from co-localised DC in the ADEME report.	
MSP data centres		Embodied: from overall average DC in the ADEME report	

ANNEX B – Results Summary

Annex B provides a summary of the results gained by the quantification of emissions of the digital sector for the UK. For further analysis and information please view the supporting Appendix 1 Excel workbook.

Yearly Embodied Impacts

User Devices

Embodied Environmental Impact		Depletion of Abiotic Resources (Minerals, Metals) (ADP)	Abiotic Depletion Potential (Fossil Fuels) (ADPF)	Acidification Potential (AP)	Freshwater Eco-Toxicity Potential (FEP)	Ionising Radiation Related to Human Health (IR-HTP)	Particulate Matter Emissions (PMFP)	Photochemical Ozone Formation (POCP)	Global Warming Potential (GWP)
		kg Sb-eq	MJ	kg mol H+	CTUe	kBq U-235	Disease incidence	kg NMVOC-eq	Mt CO_2e
User devices	Computers	1.02E+05	1.84E+10	7.37E+06	2.33E+10	1.53E+09	6.13E+01	3.06E+06	1.19E+00
	Phones	8.26E+04	3.58E+10	1.58E+07	4.39E+10	5.77E+08	8.83E+01	7.04E+06	2.67E+00
	Tablets	1.38E+04	4.42E+09	2.00E+06	6.02E+09	1.09E+08	1.12E+01	9.55E+05	3.34E-01
	Printers	2.59E+02	2.48E+09	7.65E+05	2.80E+09	1.84E+08	4.95E+00	3.66E+05	1.23E-01
	Gaming	9.75E+04	1.16E+10	4.97E+06	1.48E+10	4.15E+09	2.95E+01	2.05E+06	8.21E-01
	TV	3.70E+05	4.14E+10	1.37E+07	3.39E+10	6.33E+09	8.18E+01	5.97E+06	2.20E+00
Total User Devices		**6.66E+05**	**1.14E+11**	**4.46E+07**	**1.25E+11**	**1.29E+10**	**2.77E+02**	**1.94E+07**	**7.34E+00**

Networks

Embodied Environmental Impact		Depletion of Abiotic Resources (Minerals, Metals) (ADP)	Abiotic Depletion Potential (Fossil Fuels) (ADPF)	Acidification Potential (AP)	Freshwater Eco-Toxicity Potential (FEP)	Ionising Radiation Related to Human Health (IR-HTP)	Particulate Matter Emissions (PMFP)	Photochemical Ozone Formation (POCP)	Global Warming Potential (GWP)
		kg Sb-eq	MJ	kg mol H+	CTUe	kBq U-235	Disease incidence	kg NMVOC-eq	Mt CO_2e
Networks	Internet boxes	7.41E+03	1.87E+10	1.69E+06	3.03E+09	4.39E+09	3.12E+01	6.58E+05	3.12E-01
	Infrastructures	2.99E+04	6.77E+10	2.80E+06	1.62E+09	8.07E+09	7.54E+01	1.36E+06	5.62E-01
Total Networks		**3.73E+04**	**8.65E+10**	**4.49E+06**	**4.65E+09**	**1.25E+10**	**1.07E+02**	**2.02E+06**	**8.74E-01**

Data Centres

Embodied Environmental Impact	Depletion of Abiotic Resources (Minerals, Metals) (ADP)	Abiotic Depletion Potential (Fossil Fuels) (ADPF)	Acidification Potential (AP)	Freshwater Eco-Toxicity Potential (FEP)	Ionising Radiation Related to Human Health (IR-HTP)	Particulate Matter Emissions (PMFP)	Photochemical Ozone Formation (POCP)	Global Warming Potential (GWP)
	kg Sb-eq	MJ	kg mol H+	CTUe	kBq U-235	Disease incidence	kg NMVOC-eq	Mt CO_2e
Data Centres	5.50E+04	2.47E+11	2.17E+07	5.72E+10	2.97E+10	3.27E+02	9.07E+06	3.93E+00
Total Data Centres	**5.50E+04**	**2.47E+11**	**2.17E+07**	**5.72E+10**	**2.97E+10**	**3.27E+02**	**9.07E+06**	**3.93E+00**

Embodied Environmental Impact Summary

Embodied Environmental Impact	Depletion of Abiotic Resources (Minerals, Metals) (ADP)	Abiotic Depletion Potential (Fossil Fuels) (ADPF)	Acidification Potential (AP)	Freshwater Eco-Toxicity Potential (FEP)	Ionising Radiation Related to Human Health (IR-HTP)	Particulate Matter Emissions (PMFP)	Photochemical Ozone Formation (POCP)	Global Warming Potential (GWP)
	kg Sb-eq	MJ	kg mol H+	CTUe	kBq U-235	Disease incidence	kg NMVOC-eq	Mt CO_2e
User Devices	6.66E+05	1.14E+11	4.46E+07	1.25E+11	1.29E+10	2.77E+02	1.94E+07	7.34E+00
Networks	3.73E+04	8.65E+10	4.49E+06	4.65E+09	1.25E+10	1.07E+02	2.02E+06	8.74E-01
Data Centres	5.50E+04	2.47E+11	2.17E+07	5.72E+10	2.97E+10	3.27E+02	9.07E+06	3.93E+00
Total Digital Sector	**7.58E+05**	**4.48E+11**	**7.08E+07**	**1.87E+11**	**5.51E+10**	**7.11E+02**	**3.05E+07**	**1.21E+01**

doi.org/10.17863/CAM.114743

Yearly Usage GHG Emissions

Usage GHG Emissions		Electricity Consumption	Global Warming Potential (GWP)
		TWh	Mt CO_2e
User devices	Computers	4.82	1.08
	Phones	0.90	0.20
	Tablets	0.43	0.10
	Printers	0.72	0.16
	Gaming	1.71	0.38
	TV	2.59	0.58
	Total User Devices	**11.18**	**2.51**
Networks	Internet boxes	2.43	0.55
	Infrastructures	4.74	1.14
	Total Networks	**7.17**	**1.69**
Data Centres		13.00	2.92
	Total Data Centres	**13.00**	**2.92**
	Total Digital Sector	**31.35**	**7.13**

doi.org/10.17863/CAM.114743

ANNEX C – Scenario Projections Critical Assumptions

	Scenario 1: No Change	Scenario 2: Setting the Pace	Scenario 3: Lagging Behind
Digital Technology Demand			
User Devices	Demand will Plateau	Increased demand until market becomes saturated	Increased demand
Networks	Increased demand	Increased demand	Increased demand
Data Centres	Rapid growth in demand	Rapid growth in demand	Growth in demand
Digital Technology Emissions			
User Devices	Plateau followed by slow reduction	Accelerated reduction	Increase
Networks	Steady reduction	Accelerated reduction	Increase
Data Centres	Steady reduction	Accelerated reduction	Increase
Digital Technology Improvement			
User Devices	Steady advancements in technology	Accelerated advancement in technology	Steady advancements in technology
Networks	Advancement in technology coupled with the retirement of legacy equipment	Major technology improvements coupled with the retirement of legacy equipment	Slow advancements in technology
Data Centres	Efficiencies yet to be realised	Efficiencies realised	No efficiency improvements
Other Factors			
Grid Decarbonisation	Decarbonisation at a steady rate	Decarbonisation at an accelerated rate	Decarbonisation at a steady rate
Corporate Self-Regulation	Unchanged	Enhancement in self-regulation	Unchanged
Policy & legislation	Unchanged	New policies put in place	Inefficient and ineffective policies
Sustainability as a Business Driver	Important business driver	Critical business driver	Not a business driver
Circular Economy Initiatives	No initiatives	Roll out and uptake of initiatives	No initiatives
Meet Net Zero Ambition	Ambition met	Ambition met	Ambition not met

doi.org/10.17863/CAM.114743

ANNEX D – Case Study Data Summary

Annex C provides a summary of the data and variables used to develop the case studies seen in Section 7.4.

Case Study 1: Decarbonisation of the Grid

1. Case Study Description

This case study investigates how different grid decarbonisation projections will affect the use stage carbon emissions of the digital sector.

2. Controlled Variable

- User devices: installed base
- Networks:
    - Network boxes: install base
    - Fixed and Mobile: energy demand
- Data centred: energy demand

3. Independent Variable

Grid electricity carbon emissions intensity.

4. Dependant Variable

Carbon emissions associated with the use stage of the digital sector.

5. Data

Data Source	**RAG Status**
Committee on Climate Change Sixth Carbon Budget	
National Grid ESO Future Energy Scenario	
DESNZ GHG reporting conversion factors	

6. Key Assumptions

The National Gris ESO Leading the Way and Consumer Transformation projections result in negative emissions intensities by 2035, due to the deployment of negative emissions technologies. These negative emissions are attached to a fixed predicted electricity demand and may lead to undesirable edge cases if used in scenarios modelling (e.g. suggesting that the more electricity is used, the less CO_2 is in the atmosphere). To avoid these, we used a carbon intensity of 0 gCO_2e/kWh for these scenarios.

Case Study 2: Rapid Deployment of User Devices

1. Case Study Description

This case study investigates how the deployment of smart phones and computers affect the use stage carbon emissions of the digital sector mapped on to the different grid decarbonisation projections.

2. Controlled Variable

3. Independent Variable

- Grid electricity carbon emissions intensity
- Instal base of smartphones
- Instal base of computers

4. Dependant Variable

Carbon emissions associated with the use stage of the smartphones and computers.

5. Data

Data Source	**RAG Status**
Committee on Climate Change Sixth Carbon Budget	
National Grid ESO Future Energy Scenario	
DESNZ GHG reporting conversion factors	
Smartphone Statista Projections	
Number of households with a computer Statista Projections	

Case Study 2: Rapid Deployment of User Devices
6. Key Assumptions
The National Gris ESO Leading the Way and Consumer Transformation projections result in negative emissions intensities by 2035, due to the deployment of negative emissions technologies. These negative emissions are attached to a fixed predicted electricity demand and may lead to undesirable edge cases if used in scenarios modelling (e.g. suggesting that the more electricity is used, the less CO_2 is in the atmosphere). To avoid these, we used a carbon intensity of 0 gCO_2e/kWh for these scenarios. Smartphone and computer projected growth has been equally distributed each year.

Case Study 3: Data Centre Transformation	
1. Case Study Description	
This case study investigates how different grid decarbonisation projections will affect the use stage carbon emissions of data centres based on their future energy demand projections.	
2. Controlled Variable	
3. Independent Variable	
• Grid electricity carbon emissions intensity • Data centre annual electricity demand projections	
4. Dependant Variable	
Carbon emissions associated with the use stage of the data centres.	
5. Data	
Data Source	**RAG Status**
Committee on Climate Change Sixth Carbon Budget	Green
National Grid ESO Future Energy Scenario	Amber
National Grid ESO Data Centres	Green
DESNZ GHG reporting conversion factors	Green
6. Key Assumptions	
The National Gris ESO Leading the Way and Consumer Transformation projections result in negative emissions intensities by 2035, due to the deployment of negative emissions technologies. These negative emissions are attached to a fixed predicted electricity demand and may lead to undesirable edge cases if used in scenarios modelling (e.g. suggesting that the more electricity is used, the less CO_2 is in the atmosphere). To avoid these, we used a carbon intensity of 0 gCO_2e/kWh for these scenarios.	

ANNEX E – Account of Specific Recommendations

ANNEX E provides a more in-depth account of specific recommendations to improve the quantification of the digital sectors results.

Infrastructure & Hardware Category	**Recommendations**
User Devices	• Improved data on installed bases for the different categories within user devices. • The digital sector is ever evolving and futureproofing is required. This could include starting to collect data on emerging markets whose share is predicted to increase (IoT, VR, OLED screens etc.). • Identifying and collecting more data regarding domestic vs non-domestic installed bases, as these are targeted by different policies. • The embodied impact estimates rely on GHG intensity factors based on the life cycle of each device. UK specific life cycle assessments should be conducted to gain an understanding of embodied emissions specific to user devices within the UK.
Networks	• Require separate reporting of mobile and fixed network electricity usage and environmental impacts, as well as distinguish between the different activities of the company. • Require UK statistics to be reported annually, in addition to global activities. • Limit the delay allowed for the publication of these results, as some companies take 2 or 3 years to publish these. • Gain an understanding of the network infrastructures installed every year to estimate embodied impacts. • Clarify the scope of Scope 1,2 and 3 for network providers.
Data Centres	• Inventory of data centre (white) space in the UK. • Require reporting of data centres' electricity usage in the UK, and submit cloud providers to the same reporting expectations as networks providers (UK specific figures provided annually).

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doi.org/10.17863/CAM.114743