UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

2024

Digital economy report

Shaping an environmentally sustainable and inclusive digital future

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United Nations
Geneva, 2024

United Nations Publications
405 East 42nd Street
New York, New York 10017
United States of America

Email: publications@un.org
Website: https://shop.un.org

This publication has been edited externally.

United Nations publication issued by the United Nations Conference
on Trade and Development

UNCTAD/DER/2024

ISBN: 978-92-1-003136-3
eISBN: 978-92-1-358977-9
EPUB ISBN : 978-92-1-358978-6
ISSN: 2664-2255
eISSN: 2664-2263
Sales No. E.24.II.D.12

Note

Within the UNCTAD Division on Technology and Logistics, the E-commerce and Digital Economy Branch carries out policy-oriented analytical work on the development implications of information and communications technologies (ICTs) and electronic commerce (e-commerce). The branch is responsible for the preparation of the *Digital Economy Report*, previously known as the *Information Economy Report*. The E-commerce and Digital Economy Branch promotes international dialogue on issues related to ICTs for development and contributes to building developing countries' capacities to measure e-commerce and the digital economy and to design and implement relevant policies and legal frameworks. The branch also manages the eTrade for all initiative.

In this report, the terms country/economy refer, as appropriate, to territories or areas. The designations of country groups are intended solely for statistical or analytical convenience, and do not necessarily express a judgement about the stage of development reached by a particular country or area in the development process. Unless otherwise indicated, the major country groupings used in this report follow the classification of the United Nations Statistics Division. These are:

Developed economies: member countries of the Organisation for Economic Co-operation and Development (OECD) (excluding Chile, Colombia, Costa Rica, Mexico and Türkiye), European Union member countries that are not OECD members (Bulgaria, Croatia, Cyprus, Lithuania, Malta and Romania), plus Albania, Andorra, Belarus, Bermuda, Bosnia and Herzegovina, Liechtenstein, Monaco, Montenegro, North Macedonia, the Republic of Moldova, the Russian Federation, San Marino, Serbia and Ukraine, plus the territories of Faroe Islands, Gibraltar, Greenland, Guernsey and Jersey.

Developing economies are all countries not specified above.

A file with the main country groupings used can be downloaded from UNCTADstat at http://unctadstat.unctad.org/EN/Classifications.html.

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The term "dollars" ($) refers to United States dollars, unless otherwise indicated.

The term "billion" signifies 1,000 million.

The following symbols may have been used in the tables:

Two dots (..) indicate that data are not available or are not separately reported.

A slash (/) between dates representing years, e.g. 1994/95, indicates a financial year.

Use of an en dash (–) between dates representing years, e.g. 1994–1995, signifies the full period involved, including the beginning and end years.

Annual rates of growth or change, unless otherwise stated, refer to annual compound rates.

Details and percentages in tables do not necessarily add up to the totals because of rounding.

Preface

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Digitalization continues to move at warp speed, transforming lives and livelihoods. At the same time, unregulated digitalization risks leaving people behind and exacerbating environmental and climate challenges.

The *Digital Economy Report 2024* highlights the direct environmental impact of our increased reliance on digital tools – from raw material depletion, water and energy use, air quality, pollution, and waste generation. These are accentuated by emerging technologies such as artificial intelligence and the Internet of things.

A just and sustainable digital economy requires just and sustainable policies.

Yet many developing countries continue to face obstacles in accessing digital technologies for their development needs, while bearing the brunt of environmental depletion, waste and climate change.

We cannot address digitalization and environmental sustainability in silos. This report calls for more comprehensive data on the environmental impact of digitalization, and digital policy frameworks that advance the Sustainable Development Goals and honour climate commitments.

As we prepare for the Summit of the Future and the Global Digital Compact, the United Nations offers a natural platform to bring together stakeholders from the digital and environmental communities.

Together, we can harness the benefits of digitalization while closing the digital divide and protecting our planet. This report is an important resource as we strive to build a just and sustainable digital future for all.

António Guterres
Secretary-General of the United Nations

Foreword

The digital economy, often praised for its virtual and intangible nature, has created the illusion of a world unburdened by material waste. However, this *Digital Economy Report 2024* starkly reveals the fallacy of this perception. The information and communications technology sector's carbon footprint in 2020, estimated at between 0.69 and 1.6 gigatons of carbon dioxide (CO_2) equivalent emissions, accounted for 1.5 to 3.2 per cent of global greenhouse gas emissions – at the upper range, slightly below the entire shipping industry's contribution to CO_2 emissions. The production of a single 2 kg computer requires the extraction of a staggering 800 kg of raw materials.

These figures are only set to rise, with the production of minerals essential for the digital transition, such as graphite, lithium and cobalt, projected to surge by 500 per cent by 2050 to meet the growing demand for digital and low-carbon technologies. Data centres, the backbone of the digital world, consumed an estimated 460 TWh of electricity in 2022, a figure projected to double by 2026. The number of semiconductor units quadrupled from 2001 to 2022 and continues to grow. Fifth-generation mobile broadband coverage is expected to increase from 25 per cent of the population in 2021 to 85 per cent by 2028, while the number of Internet of things devices is projected to grow from 16 billion in 2023 to 39 billion in 2029. This expansion, coupled with the growing popularity of e-commerce, which saw business sales rise from $17 trillion in 2016 to $27 trillion in 2022 in 43 countries, paints a complex picture of the digital economy's environmental impact.

This report serves as a wake-up call, urging us to confront the environmental consequences of our digital lifestyles.

The environmental impact of digitalization is a global issue, but its effects are not evenly distributed. Developing countries, often rich in the resources needed for digital technologies, bear a disproportionate burden of its costs while reaping limited benefits. For example, discarded smartphones, laptops, screens and other electronic devices grew by 30 per cent between 2010 and 2022, reaching 10.5 million tons globally. Developed countries generated an average of 3.25 kg of e-waste per person, compared to less than 1 kg in developing countries and 0.21 kg in least developed countries. Shockingly, only 24 per cent of this waste was formally collected globally in 2022, with a mere 7.5 per cent collected in developing countries.

Another point to consider is the impact of the extraction of minerals essential for digital technologies on environmental and social sustainability. Such extraction is often sourced through artisanal and small-scale mining, which is often associated with unsafe working conditions, environmental degradation and exploitation of vulnerable communities, including children. These circumstances highlight the urgent need for greater transparency and responsible sourcing practices within the digital supply chain, ensuring that the pursuit of technological progress does not come at the expense of vulnerable communities or the environment.

Yet, despite these challenges, digitalization also holds immense potential for environmental good. Digital technologies can drive energy efficiency, optimize resource use and enable innovative solutions for climate change mitigation and adaptation.

This report emphasizes the need for a balanced approach. We must harness the power of digitalization to advance inclusive and sustainable development, while mitigating its negative environmental impacts. This requires a shift towards a circular digital economy, characterized by responsible consumption and production, renewable energy use and comprehensive e-waste management.

As we navigate this complex landscape, international cooperation is paramount. We must strive for equitable distribution of the benefits and costs of digitalization, ensuring that no one is left behind in the digital age. We must work together to establish comprehensive global governance frameworks that promote sustainable digital practices and empower developing countries to participate fully in the digital economy.

The *Digital Economy Report 2024* draws attention to an important area. It underscores the urgent need for action at all levels – from Governments and businesses to international organizations and civil society. We must embrace a new mindset that considers sustainability at every stage of the digital life cycle.

I am confident that this report will provide valuable insights and recommendations for policymakers, industry leaders and all stakeholders committed to building a sustainable digital future. The choices we make today will determine the kind of world we leave for generations to come. Let us seize this opportunity to create a digital economy that thrives in harmony with our planet.

RebecaGrynspan

Rebeca Grynspan
Secretary-General of UNCTAD

Acknowledgements

The *Digital Economy Report 2024: Shaping an Environmentally Sustainable and Inclusive Digital Future* was prepared, under the overall guidance of Shamika N. Sirimanne, Director of the UNCTAD Division on Technology and Logistics, by a team comprising Torbjörn Fredriksson (team leader), Nadira Bayat, Laura Cyron, Daniel Ker, Smita Lakhe, Marcin Skrzypczyk, Thomas van Giffen and Wei Zhang.

The report benefited from major substantive inputs provided by Pablo Gámez Cersosimo, George Kamiya, David Souter, Alicia Valero and Kees Baldé on behalf of the United Nations Institute for Training and Research.

Valuable comments were received from experts who attended a brainstorming meeting in October 2022 and a peer review meeting in November 2023, both in Geneva. Participating experts included Jerry Ahadjie, Anastasia Akhigbe, Uma Rani Amara, Rachid Amui, Kees Baldé, Heleen Buldeo Rai, Helen Burdett, Bruno Casella, Francesca Cenni, Vlad C. Coroamă, Hana Daoudi, Papa Daouda Amad Diene, Lorraine de Montenay, Sofia Dominguez, Scarlett Fondeur Gil, Clovis Freire, Viridiana Garcia-Quiles, Pablo Gámez Cersosimo, Ebru Gokce-Dessemond, Carlos A. Hernandez S., Seok Geun In, Arnau Izaguerri Vila, David Jensen, George Kamiya, Paz Peña, Nicolas Mazzucchi, Gerry McGovern, Steven Gonzalez Monserrate, Graham Mott, Mireia Roura, Arantxa Sanchez, Deepali Sinha Khetriwal, David Souter, Alicia Valero, Zarja Vojta, Andrew Williamson and Anida Yupari Aguado. Written comments were also received from Ying Tung Chan, Honghui He, Guoyong Liang and Zongguo Wen.

UNCTAD greatly appreciates additional inputs from the Research Centre for Energy Resources and Consumption, the Economic Commission for Europe, the Economic Commission for Latin America and the Caribbean and the United Nations Institute for Training and Research.

The cover, graphics and layout were undertaken by Nadège Hadjémian and Gilles Maury. The 2024 report was edited by Romilly Golding. Diana Quiros provided administrative support.

Financial support from the core donors of the E-commerce and Digital Economy programme, namely Australia, Germany, the Kingdom of the Netherlands, Sweden and Switzerland, is gratefully acknowledged.

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Abbreviations

Ademe	Agence de la transition écologique
AfDB	African Development Bank
AI	artificial intelligence
ANRC	Africa Natural Resources Management and Investment Centre
Arcep	Autorité de régulation des communications électroniques, des postes et de la distribution de la presse
ASEAN	Association of Southeast Asian Nations
ASIC	application-specific integrated circuit
ASM	artisanal and small-scale mining
ASYCUDA	Automated System for Customs Data (UNCTAD)
ATM	automated teller machine
B2B	business-to-business
B2C	business-to-consumer
C2C	consumer-to-consumer
CAGR	compound annual growth rate
CO_2e	carbon dioxide equivalent
CODES	Coalition for Digital Environmental Sustainability
CRT	cathode ray tube
EACO	East Africa Communications Organization
EB	exabyte
ECE	Economic Commission for Europe
ECLAC	Economic Commission for Latin America and the Caribbean
EEE	electrical and electronic equipment
EPR	extended producer responsibility
FTA	free trade agreement
GB	gigabyte
GDP	gross domestic product
GHG	greenhouse gas
GNI	gross national income
GPS	Global Positioning System
GPT	generative pre-trained transformer
GSMA	Global System for Mobile Communications Association
GTIN	global trade item number
GW	gigawatt
GWh	gigawatt hour
ICC	International Chamber of Commerce
ICT	information and communications technology
IDC	International Data Corporation
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IGF	Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development
IISD	International Institute for Sustainable Development
ILO	International Labour Organization

IMF	International Monetary Fund
IoT	Internet of things
IP	Internet protocol
IPCC	International Panel on Climate Change
IRENA	International Renewable Energy Agency
IRP	International Resources Panel
ISA	International Seabed Authority
ISLP	International Senior Lawyers Project
ISO	International Organization for Standardization
IT	information technology
ITC	International Trade Centre
ITU	International Telecommunication Union
kW	kilowatt
LCA	life cycle assessment
LCD	liquid crystal display
LDC	least developed country
LED	light-emitting diode
LEO	low Earth orbit
Li-ion	lithium-ion
MSMEs	micro-, small and medium-sized enterprises
MSP	Mineral Security Partnership
Mt	megatons
MW	megawatt
NGO	non-governmental organization
OECD	Organisation for Economic Co-operation and Development
OHCHR	Office of the United Nations High Commissioner for Human Rights
OPEC	Organization of the Petroleum Exporting Countries
PACE	Platform for Accelerating the Circular Economy
PC	personal computer
PCB	printed circuit board
PPA	power purchase agreement
PUE	power usage effectiveness
RFID	radio frequency identification
SCSIT	screens, computers, small IT and telecommunications equipment
STEPS	stated policies scenario
TWh	terawatt hour
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
VAT	value added tax
WCO	World Customs Organization
WEEE	waste electrical and electronic equipment
WEF	World Economic Forum
WHO	World Health Organization
WSIS	World Summit on the Information Society
WTO	World Trade Organization

Overview

The *Digital Economy Report 2024: Shaping an Environmentally Sustainable and Inclusive Digital Future* highlights the urgent need for sustainable strategies throughout the life cycle of digitalization. From raw material extraction and usage of digital technologies to waste generation, the report explores the nature and scale of the sector's environmental footprint, which remains largely unassessed. What is apparent is that developing countries are suffering disproportionately from digitalization's negative environmental effects, as well as missing out on economic developmental opportunities due to digital divides. UNCTAD calls for global policies involving all stakeholders to enable a more circular digital economy and reduced environmental footprints from digitalization, while ensuring inclusive development outcomes.

Understanding the nexus of digitalization and environmental sustainability is increasingly important

Digitalization continues to transform the world economy and society, creating both opportunities and challenges for sustainable development.

Previous editions of the *Digital Economy Report* have largely focused on the implications of digitalization for inclusive development, the importance of bridging digital and data-related divides, enabling value creation and capture in developing countries and fostering better governance of data and digital platforms.

The *Digital Economy Report 2024* turns attention to the environmental footprint of digitalization. The topic is timely, not to say overdue. Digital transformation is taking place in parallel with growing concerns related to the depletion of raw materials, water stress, climate change, pollution and waste generation, which are all linked to planetary boundaries.

The rapid pace and expanding scope of digitalization make it increasingly important to understand the relationship between digitalization and environmental sustainability. How the world's ongoing digital transformation is managed will greatly influence the future of humanity and the health of the planet.

Environmental impacts are generated along the whole digitalization life cycle

Direct environmental impacts from digital devices and from information and communications technology (ICT) infrastructure occur along the life cycle, taking place during the production phase (raw material extraction and processing, manufacturing, distribution), the use phase and the end-of-life phase. The direct effects on natural resources, including on transition minerals, energy and water, as well as greenhouse gas (GHG) emissions and waste-related pollution, constitute the "environmental footprint" of the ICT sector.

There are also indirect environmental effects from the use of digital technologies and services in different sectors of the economy. These extend beyond digitalization's direct footprint and can be both positive and negative. For example, digital technologies can help to improve energy efficiency, reducing demand across all sectors. Digital technologies can be used to cut GHG emissions in the transportation, construction, agriculture and energy sectors. However, the potential gains may be reduced or counterbalanced by "rebound effects", in that digitalization may increase the consumption of goods and services, with negative effects on the environment as a result. Policies can greatly influence the net impact.

Digitalization is evolving rapidly, leaving a growing environmental footprint

In the past two decades, the world has experienced a digital shift few would have anticipated at the time of the World Summit on the Information Society in 2005, creating new opportunities for economic and social development, as well as new challenges. According to the International Telecommunication Union, the number of Internet users surged from 1 billion in 2005 to 5.4 billion in 2023. Between 2010 and 2023, estimates of annual shipments of smartphones more than doubled, from 500 million to about 1.2 billion.

From 2001 to 2022, the number of semiconductor units sold quadrupled, and these numbers keep expanding. Network infrastructure, including submarine cables and communications satellites, offers ever faster ways of connecting more people and machines. Fifth generation (5G) mobile broadband population coverage is expected by some market estimates to rise from 25 per cent in 2021 to 85 per cent in 2028.

Higher connection speeds enable more data to be generated, collected, stored and analysed, and this is central to emerging technologies such as big data analytics, artificial intelligence (AI) and the Internet of things (IoT). The number of Internet-connected objects is expected to rise from 13 billion in 2022 to 35 billion in 2028.

While digital technologies can be used to mitigate various environmental concerns, the growing numbers of end-user devices, investments in data transmission networks and data centres and more computationally intensive digital applications, such as AI and blockchain technology, are also translating into a growing environmental footprint. In the current highly linear digital economy production model – based on take/extract–make–use–waste – this leads to more demand for raw materials, water and energy, greater emissions of GHGs and more waste at the end-of-life phase.

It is difficult to assess the impact of digitalization on the environment

This report points to the need for building a stronger evidence base to allow for comprehensive assessments of the environmental effects of digitalization. There is a lack of timely, comparable and accessible data and there are few harmonized reporting standards. Analytical studies rely on a variety of sources that are quickly becoming outdated due to the speed of digital developments; for example, existing studies do not adequately capture the environmental impact of recent developments in AI or the shift to 5G mobile networks.

In some sectors, there is also limited disclosure of impacts. Results diverge considerably due to variations in methodologies, assumptions or the models used to estimate environmental impacts. For example, estimates of the ICT sector's life cycle GHG emissions for 2020 vary widely, from 0.69 gigatons to 1.6 gigatons of CO_2 equivalent (CO_2e) emissions, corresponding to 1.5–3.2 per cent of global GHG emissions in that year.

The impact of the ICT sector on water use is often overlooked, and there is a need for more transparent and reliable information on this. Water use at all stages of the digitalization life cycle can severely impact local biodiversity and livelihoods. Similarly, mining, an integral component of the production phase of digitalization, is highly water intensive. This can lead to competition for water resources between mining operations, agriculture and local households.

Likewise, semiconductor production requires large amounts of extremely pure water, and data centres consume a lot of water both indirectly, to generate electricity, and directly, to cool servers. Water pollution can result from the final phases of the digitalization life cycle when contaminants from electronic components leach into groundwater due to improper e-waste disposal and dumping. This type of pollution can adversely affect biodiversity and human health.

Digitalization's promise of dematerialization has not yet materialized

Available research suggests that the production phase of digitalization has the greatest combined negative impact on the environment. This is due to mineral and metal production, the volume of GHG emissions generated and water-related impacts. For example, in the case of smartphones, around 80 per cent of GHG emissions are attributed to the production phase.

Many consider the digital economy to be virtual, intangible or in the "cloud", but digitalization heavily relies on the physical world and raw materials. Digital devices, hardware and infrastructure are composed of plastics, glass and ceramics, as well as dozens of minerals and metals. It has been estimated that making a 2 kg computer involves extracting 800 kg of raw materials.

The key minerals and metals used for digitalization include aluminium, cobalt, copper, gold, lithium, manganese, natural graphite, nickel, rare earth elements and silicon metal, and these are almost identical to those required for the shift towards a low-carbon economy. The growing demand for these materials is greatly driven by the shift to low-carbon and digital technologies.

According to an assessment by the World Bank, production of minerals such as graphite, lithium and cobalt could see an increase of 500 per cent by 2050 to meet growing demand. The global energy and climate model of the International Energy Agency (IEA) revealed that consumption of platinum group minerals could be 120 times higher in 2050 than in 2022. Such trends risk meeting the limits of the availability of minerals on a planet with finite resources.

Geopolitical concerns could exacerbate digitalization's environmental footprint

The global minerals and metals market is highly concentrated geographically in terms of reserves, extraction and processing activities. For example, concerning extraction, in 2022, the Democratic Republic of the Congo produced 68 per cent of the world's cobalt. Australia and Chile produced 77 per cent of the world's lithium, and Gabon and South Africa produced 59 per cent of the world's manganese.

For China, shares of world production stood at 65 per cent for natural graphite, 78 per cent for silicon metal and 70 per cent for rare earth elements. China also plays a major role in terms of mineral processing, accounting for more than half of global mineral processing for aluminium, cobalt and lithium, about 90 per cent for manganese and rare earth elements, and close to 100 per cent for natural graphite.

Securing access to the supply of critical minerals has become a strategic priority, particularly for developed and developing countries that are important producers of goods needed for the transition towards a low-carbon and digital world. In some countries, efforts to secure mineral and metal supplies may inadvertently encourage hoarding and lead to overcapacity in production facilities. This may result in less efficient processes and an unnecessarily large environmental footprint for the digital economy.

Changing industrial policies reflect the strategic importance of critical minerals

The strategic importance of certain raw materials has triggered new policymaking.

As Asia, particularly China, emerged as the global electronics manufacturing hub, proximity to markets of intermediary products and components has bolstered burgeoning mineral processing activities. As China strives to improve its performance in strategic technology sectors, such as AI and low-carbon technology, there is an increased demand for minerals that are essential to these industries. Recent years have also seen a revival of industrial policies in some developed countries related to transition minerals and associated industries (including electronics). The focus in some global supply chains has shifted from “just in time” to “just in case” approaches.

In the United States of America, for example, the President has called for securing a made in America supply chain for critical minerals, and the 2022 Inflation Reduction Act in the country establishes percentages of critical minerals that must be mined, processed or recycled domestically.

The European Union, in its Critical Raw Materials Act of 2023, sets 2030 benchmarks for the strategic raw materials value chain and for diversifying its supplies. Both the United States and the European Union have also taken measures to support domestic production of semiconductors.

Resource-rich developing countries should benefit

If resource-rich developing countries can add more value to the minerals extracted, make effective use of proceeds from the raw materials and diversify into other parts of the value chain and other sectors, the increased demand for minerals and metals required for digitalization can be leveraged as an opportunity for development.

In this context, there is a fundamental need to reverse trade imbalances, wherein developing countries export raw minerals and import higher value added manufactures, which contributes to an ecologically unequal exchange.

It is also imperative to minimize negative environmental and social impacts, including human rights concerns. To achieve a more inclusive and environmentally sustainable digital economy, a balanced global policy response is needed that seeks to achieve responsible and sustainable consumption and production, and reflects the interests of both exporters and importers of raw materials.

Digital use is boosting energy and water consumption

As more people, businesses, Governments and organizations around the world make use of digital services, consumption of energy and water related to devices and ICT infrastructure has increased significantly.

When considering the life cycle of data transmission networks and data centres, the bulk of energy and GHG emissions stem from the use phase. For devices, on the other hand, the proportion of such emissions generated during the use phase is smaller, although this can vary depending on the device and the energy mix used. Emissions related to desktop computers and televisions occur largely during the use phase, while for smartphones, tablets and laptops, the production phase generates most of the emissions.

Data centres exert a significant environmental impact during the use phase. The expanding data-driven digital economy increasingly relies on data centres with huge storage and computing capacity, and these consume large amounts of both energy and water.

The estimated electricity consumption by 13 of the largest data centre operators more than doubled between 2018 and 2022; consumption was led by Amazon, Alphabet, Microsoft and Meta. And there is more to come. According to IEA, worldwide, electricity for data centres amounted to about 460 TWh in 2022, a figure that could more than double to 1,000 TWh by 2026. By way of comparison, total electricity consumption in France was about 459 TWh in 2022.

In some countries, growing data centre activity has put a strain on the local electricity grid. In Ireland, electricity use by data centres more than quadrupled between 2015 and 2022, representing 18 per cent of total electricity consumption in 2022. Projections indicate that this could reach 28 per cent by 2031.

In Singapore, where data centres were responsible for around 7 per cent of all electricity demand in 2020, the Government imposed a moratorium on new data centres and later replaced it with stricter conditions on the use by data centres of electricity, water and land.

Digital technologies have a significant water footprint which comprises a substantial part of their overall environmental impact. However, information on the impacts on water consumption is limited. Data centres not only have considerable electricity needs but also require water for cooling. Water usage and the impact of data centres on local water resources needs to be assessed in a location-specific context, as the choice of cooling technology is influenced by the local climate and resource availability; comparisons between regions with plentiful water supplies and those facing severe water shortages require vastly different considerations. While some cooling technologies can operate with less water, these technologies may consume more electricity instead. Therefore, water and electricity use by data centres should be considered holistically.

Energy consumption is accentuated by compute-intensive technologies

The environmental impacts of digitalization also vary depending on the activities and technologies involved. New digital services and their increasingly sophisticated technologies, such as blockchain, AI, 5G mobile networks and IoT, are poised to greatly increase the demand for data processing and storage and significantly affect the environmental footprint of the ICT sector. Some technologies, such as AI and blockchain, will primarily impact data centres. Others, such as 5G networks and IoT, will largely affect networks and devices. Managing and reducing the related environmental impacts will require concerted efforts from technology companies and policymakers.

Artificial intelligence and machine learning in particular require extensive computing resources and dedicated hardware. Understanding their energy and water use will become critical as mainstream applications, such as Gemini (formerly Bard), ChatGPT and Ernie, become more widely adopted.

For example, Meta's computing demand for machine-learning training and application has increased annually by more than 100 per cent in recent years. In the case of Microsoft, training of GPT-3 (a large language model on which ChatGPT is based) in its data centres in the United States has been estimated to have directly consumed 700,000 litres of potable water for cooling.

Cryptocurrency mining is another energy-intensive activity, especially when relying on a "proof-of-work" blockchain consensus mechanism, a process that requires significant computational power. According to the Cambridge Centre for Alternative Finance, the global energy consumption of bitcoin mining, the most prominent cryptocurrency, rose about 34 times between 2015 and 2023 to reach an estimated 121 TWh.

Understanding the energy and water footprints of AI and cryptocurrencies is crucial when assessing the environmental impacts of such technologies. Such operations should, to the greatest extent possible, be powered by low-carbon electricity. Operators also need to continue to improve the energy and water efficiency of data centres, while limiting the waste generated from frequent equipment replacements. At the same time, the scope for further efficiency improvements in these areas remains uncertain, partly due to the physical limits of transistors, which are fundamental building blocks of electronic devices.

Waste related to digitalization is expanding, with uneven regional implications

Waste from digitalization is a growing environmental concern. Between 2010 and 2022, the volume of waste from screens and monitors as well as small IT and telecommunications equipment expanded by 30 per cent globally, from 8.1 million to 10.5 million tons (not including waste from various IoT devices, batteries and communications satellites).

In 2022, the largest contributors of such waste were China, the United States and the European Union. In per capita terms, developed countries generated on average 3.25 kg of waste compared with less than 1 kg in developing countries and 0.21 kg in the least developed countries (LDCs). In the United States, an average citizen generated 25 times more waste than an average citizen in LDCs. These significant disparities reflect the digital divide between countries in terms of access, affordability and use of digital devices and equipment.

While it is important to address the considerable overconsumption in high-income countries and be mindful of the waste generated, it is also important to recognize that many developing countries still need to digitalize further in order to participate effectively in the global economy and society. This digitalization process will inevitably involve consumption, highlighting the complex balance between sustainability and economic development.

The growth in digitalization-related waste is due to several factors that include increased consumption of electronic devices and ICT equipment with shorter life spans; insufficient awareness among consumers about the waste implications of their devices; a linear model of production; and limited options for repairing or upgrading existing devices.

New models with higher performance quickly replace existing models or make them redundant. Planned obsolescence by producers, for example by making smartphones work more slowly over time or phasing out support for older versions of software, adds to the growing waste problem.

Encouragingly, concerns about planned obsolescence and limits to the right to repair have led to strong reactions from civil society. This is helping to raise awareness and spark calls for appropriate policy responses.

Digitalization-related waste collection needs to expand

Current rates of formal collection of digitalization-related waste remain low, especially in developing countries. While the global average for formal collection of digitalization-related waste amounted to 24 per cent of all waste in 2022, this figure dropped to just 7.5 per cent in developing countries. Even in developed countries, despite generally better formal collection systems, an average collection rate of 47 per cent is not high enough.

Waste management brings significant challenges. In developing countries, formal collection systems to manage digitalization-related waste in an environmentally sound manner are often lacking, and much of the waste is handled by the informal sector. Moreover, only one in four developing countries has adopted relevant legislation for managing waste from digitalization.

Available data and research indicate a pattern of unequal ecological exchange in the international trade of waste related to digitalization. This is due to the largely uncontrolled trade in used digital equipment, which typically moves from developed to developing economies.

In contrast, the higher-value parts of this waste for processing or treatment (such as printed circuit boards) are mostly exported from developing to developed countries. As a result, developing countries remain locked in the low value part of the waste value chain (e.g. uncontrolled trade in used electronic equipment), yet bear the burden of various related environmental and social costs.

E-commerce should become more environmentally sustainable

People and businesses are increasingly going online to buy goods and services. E-commerce represents an important application of digital technologies, with implications for both domestic and international trade.

Since the beginning of this century, the number of people shopping online has surged from less than 100 million to some 2.3 billion in 2021. The value of sales across the world's top 35 e-commerce platforms has boomed in recent years, from $2.6 trillion in 2019 to more than $4 trillion in 2021, led by Alibaba, Amazon, JD.com and Pinduoduo.

UNCTAD estimates that the total value of e-commerce sales by businesses, in the 43 developed and developing countries for which data are available, rose from $17 trillion in 2016 to $27 trillion in 2022. Most of these sales are domestic, but the share of international e-commerce is growing. At the same time, the shift to e-commerce has only just started in most developing countries, particularly in LDCs.

E-commerce is disrupting economic processes and consumption patterns, with positive and negative implications for environmental sustainability. While precise impact assessments of the environmental impact of e-commerce are hindered by limited data, the net effect depends on how businesses handle warehousing, storage, transportation, logistics, packaging and returns. Consumer behaviour plays a role, too.

E-commerce has boosted consumption due to enhanced accessibility and convenience, lower prices, greater product variety and wider reach of online marketing. More frequent purchases across different platforms and retailers – including more impulse buying – leads to overconsumption, causing increased transportation emissions and waste.

Making e-commerce more environmentally sustainable requires a greater emphasis on circular business models, ethical sourcing and production, energy-efficient logistics and adopting renewable energy and eco-friendly delivery solutions, as well as sustainable packaging and finding ways to promote sustainable consumption.

Policymakers can facilitate these changes through an appropriate mix of legislative, regulatory instruments and tax mechanisms to reduce CO_2 emissions in transportation and minimize waste from e-commerce. This will require a collaborative effort between Governments, businesses, platforms, logistics providers and consumers.

A new policy mindset is required

There is a need for new business models, policies and strategies that maximize the positive impact of digitalization on sustainability while minimizing the negative impacts.

Digital development should be assessed in light of several critical challenges: the need to reduce overall consumption and optimize the use of scarce resources without jeopardizing the prospects of future generations; the need to curtail carbon emissions and prevent catastrophic climate change; and the need to turn the accumulation of digitalization-related waste into an opportunity for recovery, recycling and reuse in a circular economy.

Achieving an inclusive and environmentally sustainable digital economy requires a shift towards circularity

According to the Circle Economy Foundation, the global economy is still only 7.2 per cent circular, showing a declining trend driven by rising material extraction and use.

A shift towards a more circular digital economy would optimize the economic and environmental impacts of digitalization, including supporting business opportunities and job creation. This means using renewable energy and adaptive and resilient infrastructure; reducing wasteful use of digital networks, products and services; increasing repair, reuse, refurbishment and recycling of devices; and significantly improving the recovery of material resources from digitalization-related waste.

Achieving greater circularity requires change at all stages of the digital life cycle: designing platforms, products and services in ways that foster sustainable consumption by default; encouraging sufficiency and frugality in the use of resources where overconsumption is currently prevalent; and facilitating the recovery and reuse of resources to maximize their value.

Many developing countries are in a double bind, experiencing limited benefits of digitalization and suffering high exposure to its negative environmental impacts

Currently, the distribution of benefits and costs from digitalization is skewed. Most of the value added in the digital economy is captured by developed and some digitally-advanced developing countries.

Countries at different levels of development are unevenly affected by environmental impacts related to the various stages of the digitalization life cycle. Many developing countries are providers of key raw materials, and some are the destination for significant digitalization-related waste. At the same time, developing regions are often at the tail end of global trade, where opportunities for value addition and economic growth are limited.

Moreover, developing countries tend to be more affected by climate change, which can limit their options for socioeconomic development. Finally, developing countries often lack the resources and capacity to use digital technologies for mitigating negative environmental impacts (box).

There are risks that LDCs in particular will fall further behind in terms of both digital development and environmental sustainability. Achieving environmentally sustainable digitalization that fosters inclusive development will require a reversal of the unequal ecological exchange and vulnerabilities faced by developing countries.

Against this backdrop, and in line with the principle of common but differentiated responsibilities, the extent and nature of responsibility for environmental protection varies according to each country's capabilities, historical responsibilities and level of development.

Economies that are more digitally developed have a particular responsibility to ensure a global transition towards an inclusive and sustainable digital future by devising and implementing policies to reduce digitalization's environmental footprint and to enhance the capacity of developing countries to benefit from digitalization.

Balancing climate needs with digital transformation in developing countries

Digital divides remain a significant barrier to socioeconomic development. While there is great potential for most developing countries to benefit from digital transformation, many countries have seen relatively limited benefits to date. A lack of financial and human resources often hampers the ability to harness digital infrastructure for sustainable development. At the same time, many countries struggle to use digital solutions for dealing with climate change and other environmental risks.

As historic responsibilities for environmental challenges lie predominantly with today's developed countries, which have also reaped the greatest gains from digitalization, tailored and nuanced solutions are needed to advance digital transformation in developing regions and balance environmental impacts. Policy responses should reflect the disproportionate role that developed countries have played in both technological progress and environmental degradation. Integrating policies on digitalization and environmental stewardship is essential. More international cooperation will be vital for low-income countries to participate in a global and environmentally sustainable digital transformation. Developed and digitally advanced countries can do more to support capacity-building for strengthening the digital readiness of countries trailing behind, as well as deploying digital solutions to mitigate climate change.

Source: UNCTAD.

Bold and resolute action at national and international levels is imperative

Policy efforts at the national level are more likely to prove successful if implemented as part of digital strategies developed with economic inclusion and environmental sustainability in mind. Similarly, government strategies to mitigate GHG emissions, conserve water resources and reduce waste generation should pay adequate attention to the environmental footprint of digitalization and to how digital technologies can offer solutions to environmental concerns.

Policies and strategies at the international level should acknowledge the needs and priorities of all countries and highlight opportunities for developing countries to benefit from the potential that digitalization offers. Development partners should offer adequate support to low-income countries to strengthen their capabilities for digitalization and environmental sustainability and to ensure that they can participate effectively in a more circular global digital economy. Several international developments provide opportunities for further advancement.

The World Summit on the Information Society (WSIS), which first established global goals for digital development in the early 2000s, will be reviewed by the United Nations General Assembly in 2025.

The 2030 Agenda for Sustainable Development, which was approved in 2015 and has sought to embed environmental sustainability at the heart of the international agenda, will be reviewed at the end of this decade.

Even before either of these reviews, the United Nations General Assembly will hold a Summit of the Future and agree on a pact for the future with parts emphasizing sustainable development and digital cooperation. The pact is expected to include a global digital compact, which is to set out principles, objectives and actions for digital development that support the Sustainable Development Goals.

More effective global governance is needed

There is currently no inclusive global governance framework in place to help galvanize collective action and facilitate knowledge-sharing among countries, build consensus, set global standards and encourage transparent reporting and monitoring of progress towards shared goals at the interface of digitalization and environmental sustainability. An inclusive and integrated approach is needed to enable policymakers to align their digital and environmental policies at all levels, thereby enhancing the global community’s ability to address complex and interdependent global challenges.

Multilateral and cross-sectoral dialogue between digital and low-carbon policy communities should be established at the heart of discussions on sustainable development and embedded in the work of international standard-setting bodies. Multi-stakeholder partnerships (such as the Coalition for Digital Environmental Sustainability) that can draw on the capabilities and strengths of international agencies, Governments, businesses and research organizations are likely to achieve better outcomes than Governments and multilateral agencies acting alone.

International processes and fora focusing on how to leverage digitalization for development, including the World Summit on the Information Society: 20-Year Review (WSIS+20), the Commission on Science and Technology for Development and the global digital compact, should give due attention to the environmental dimensions. There is an equal need for processes related to global environmental challenges – such as the International Resource Panel, the Intergovernmental Panel on Climate Change, the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services – to give more attention to the role of digitalization.

To protect the interests and well-being of all, including future generations, urgent and resolute actions have been called for to achieve systemic shifts in the areas of energy, food, mobility and the built environment. It is time to extend the calls for bold action to the entire life cycle of digitalization and to start systematically tracking the environmental footprint of the ICT sector.

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While digitalization is a means to an end, it will need to be as environmentally sustainable as possible

Chapter I

Digitalization and environmental sustainability

As the evolving digital economy continues to create both opportunities and challenges for trade and sustainable development, the *Digital Economy Report 2024,* for the first time, turns its attention to the environmental implications of digitalization.

Against a backdrop of multiple environmental crises and the digital solutions leveraged to tackle them, it is increasingly important to consider how to reduce the environmental footprint of digitalization itself.

This chapter outlines the importance of exploring the implications that arise at the nexus of digitalization and environmental sustainability, and stresses the need to consider the entire life cycle of digital products.

The chapter also notes that many developing countries face a particular challenge, as they are less equipped to harness digitalization to mitigate environmental risks while also being exposed to many of the potential environmental costs associated with digitalization.

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A. The digitalization and environmental sustainability nexus

1. An area in need of more attention

Sustainable development is a vital priority for the United Nations and the global community, articulated in successive United Nations summits and in the 2030 Agenda for Sustainable Development. Sustainable development implies economic and social development that is consistent with the protection of planetary boundaries – avoiding irreversible impacts on the environment – and with intergenerational equity, the idea that today's development should not jeopardize the opportunities of future generations (World Commission on Environment and Development, 1987).[1] In this context, three issues have become critical: the consumption of natural resources, the impact of climate change (especially resulting from fossil fuel consumption) and pollution. The cost of failure in these three areas threatens all aspects of sustainability and the future health of planet Earth.

The Rio Declaration from the first Earth Summit urged all stakeholders – Governments, businesses and civil society – to recognize that "environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it" (United Nations, 1993: Principle 4). Consequently, economic development that is not environmentally sustainable will also prove to be unsustainable economically.

Recent editions of the Digital Economy Report have looked in depth at the implications of the rapid growth of electronic commerce (e-commerce) and the digital economy on inclusive and sustainable development. They covered in particular the increasing significance of new digital technologies, platformization and digital data (UNCTAD, 2019a, 2021a). These reports highlighted the accelerated pace of digitalization, leading to a continuously changing nature of the digital economy, accompanied by widening digital and data divides and important environmental implications. They emphasized that bridging these divides and developing balanced frameworks for global governance of data and digital platforms are essential for ensuring inclusive and sustainable development outcomes.

Digital transformation of the world economy and society is taking place in parallel with growing concerns related to the depletion of raw materials, water use, air quality, pollution and waste generation, which are all linked to planetary boundaries, including climate change. Managing digital transformation will greatly influence the future of humanity and the health of the planet. This report explores the interconnectedness of rapid digitalization and the urgent need to foster environmental sustainability against a backdrop of growing inequality and vulnerabilities, such as increasing socioeconomic disparity, environmental degradation and geopolitical tensions. It explores ways to achieve economic prosperity that are compatible with planetary boundaries and intergenerational equity.

> Sustainable development implies economic and social development consistent with **planetary boundaries**

The topic is timely, not to say long overdue, as policy discussions on the environment and digitalization in the context of

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[1] The concept of planetary boundaries assesses human impact on nine dimensions of the planet relative to the time of pre-industrialization. This helps to determine the stability of the Earth system, which should support the well-being of people and the planet. Recent research has shown that globally, six out of nine boundaries have already been crossed (Richardson et al., 2023).

sustainable development have evolved separately for too long. Soon after the second Earth Summit in Rio de Janeiro in 2012, critical voices emerged, suggesting that the Summit had failed to recognize the relationship between information and communications technologies (ICTs), the Internet and sustainability, all of which are crucial elements of sustainable development policy (Souter and MacLean, 2012). The 2030 Agenda for Sustainable Development, which was adopted in 2015, did not take a cross-cutting view of the role attributed to digitalization. The word “digital” is in fact mentioned only in reference to the “digital divide”.

To date, shifts towards **low-carbon** and **digital technologies** were considered in parallel, yet they **are closely intertwined** within the broader economic transition

In the Paris Agreement, adopted in the same year as the 2030 Agenda, ICTs were primarily highlighted as a means to share information, knowledge and good practices among countries and stakeholders; to enable the development of low carbon energy technologies; to improve energy efficiency and support various adaptation efforts, such as early warning systems (United Nations Framework Convention on Climate Change (UNFCCC), 2016). Similarly, the 2023 outcome document of the twenty-eighth session of the Conference of the Parties to the United Nations Framework Convention on Climate Change recognizes the importance of digital transformation and increased access to technologies to achieve the goals set out in the Paris Agreement (UNFCCC, 2023) – without taking into consideration its direct environmental impact.

Digitalization has continued to evolve at a high speed and, from an environmental perspective, is offering new solutions but also obstacles to sustainability (box I.1). The relationship between digitalization and environmental sustainability in all its dimensions is starting to receive more attention in policy debates with a view to maximizing potential gains from digitalization, while mitigating environmental harms and facilitating sustainability. In the Bridgetown Covenant, the outcome document of the fifteenth session of the United Nations Conference on Trade and Development in 2021, member States included climate change, environmental degradation and the digital divide among the most important development questions (UNCTAD, 2021b). This evolution of the mandate is illustrative of the changing landscape of challenges faced by countries today, as well as their ever-increasing interconnectedness beyond trade, which requires a policy approach that breaks out of regulatory silos.

There are growing references to the “twin transitions”, alluding to the need to enable, on the one hand, the transition to a more digital economy and, on the other, the transition to a low-carbon economy (Muench et al., 2022; UNCTAD, 2023a). To date, shifts towards low-carbon and digital technologies have been considered as parallel processes. In reality, they are closely intertwined within the broader transition of the global economy. Moving towards more environmentally sustainable economic activities needs digital tools to become more efficient and resilient in the long term. At the same time, while digitalization is a means to an end, it will need to be as environmentally sustainable as possible to avoid adding to environmental risks. Moreover, the minerals and metal inputs needed for digitalization and the expansion of renewable energy sources are largely the same, creating competing demands and significantly influencing international trade and geopolitical dynamics.

It is important to work towards ensuring that no one is left behind as the world transitions towards a more digital and environmentally sustainable future. A just, low-carbon and digital technology transition requires an integrated approach to sustainable development, which brings together social progress, environmental protection and economic success into a framework of democratic governance. This extends to the human rights context.

Box I.1
The rapidly evolving nature of digitalization

When assessing the trade and development interface between digitalization and environmental sustainability, it is essential to acknowledge the dynamic nature of digital technologies and their applications (German Advisory Council on Global Change, 2019; UNCTAD, 2019a; Global Enabling Sustainability Initiative and Deloitte, 2019). Continuing digitalization creates many new opportunities for harnessing data and digital technologies to foster trade and development and mitigate adverse development and environmental impacts. At the same time, the importance of ensuring that the digital ecosystem is as environmentally sustainable as possible increases further.

Higher speed. The increased use of the Internet and online services partly reflects the recent accelerated progress in high-speed online transmissions. This opens up opportunities for developing new digital applications, such as digital government and financial services, social media and online purchases. The digital delivery of services, both domestically and internationally, relies on greater bandwidth to support high-quality video calls or streaming. The extent to which different parts of the world can seize such opportunities still varies greatly.

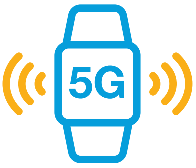
Shift to the cloud. Cloud computing is a key element of the evolving digital landscape (UNCTAD, 2013). It enables users to access scalable and flexible data storage and computing resources as well as to stream video and music. The imagery of the intangible “cloud” can be misleading; cloud computing is well anchored on the ground through hardware, networks, storage and services needed to deliver computing as a service. A defining feature of cloud storage is the transfer of large volumes of data to third party-owned data centres, often controlled by a small number of very large companies (UNCTAD, 2021a).

Platformization. Digital platforms, acting as intermediaries and infrastructure of the digital economy, are uniquely placed to capture and extract extensive data from online actions and interactions on the platforms. The expansion of digital platforms is directly linked to their capacity to collect, analyse and monetize digital data, with businesses ranging from Internet search and social media to cloud storage and e-commerce (UNCTAD, 2019a). The growing role of platforms has led to strong market concentration, dominated by a small number of global digital platforms from the United States and China (UNCTAD, 2021a). Platforms increasingly control all parts of the global data value chain, including data collection, data transmission (installing and owning cables and satellites), data storage (cloud and hyperscale data centres) and data analysis (machine learning and artificial intelligence (AI)). This pivotal role in the digital economy requires high levels of responsibility and better platform governance.

Exponential data growth and real-time sensing. The surge in Internet use, improved cloud infrastructure and the growth of global platforms have significantly boosted interconnectedness among people, machines and the planet. Data generated in real time from improved interconnectedness can help to address various development challenges, including in agriculture, energy, health, home appliances and transportation by analysing (near) real-time data. For instance, the “Internet of things” (IoT), through sensing, automation and cloud computing, is expected to expand from 13 billion connections in 2022 to over 35 billion by 2028, particularly in Asia and the Pacific, and will employ various devices (sensors, meters, etc.) to collect and transmit timely data (Global System for Mobile Communications Association (GSMA), 2023a). At the same time, this increasing connectivity spurs the demand for digital devices, digital networks and services that support the IoT. This translates into more demand for natural resources, more use of water and energy, more greenhouse gas emissions from the production and use of the devices, and more waste to handle at the end of life.

Cognitive changes. The exponential increase in data generation is amplifying the importance of big data analytics, machine learning and AI. Global corporate investment in AI (including private investment, mergers and acquisitions, public offerings, and minority stakes) surged from an estimated $15 billion in 2013 to $189 billion in 2023.[a] Concerns are mounting that powerful AI systems may be evolving too fast and too far, as labs compete to develop ever more sophisticated

Internet of things connections to grow to **35 billion** by 2028, mainly in Asia-Pacific



solutions, with unknown consequences and limited regulation.[b] New generative AI solutions – such as Bing, ChatGPT, Dall-e, Ernie, Gemini (formerly Bard), Gigachat, Midjourney, SenseChat and Tongyi Qianwen – have been met with strong interest, although long-term user numbers remain uncertain.[c] While offering new experiences and value to users, AI applications are computationally costly, energy- and equipment-intensive and generate large quantities of waste (Strubell et al., 2019).

Towards virtuality. Another new feature driven by digitalization, higher computing power and speed is increased "virtuality", seen in the growing use of augmented reality and virtual reality. Virtual reality offers a three-dimensional online environment that can be entered by using a dedicated headset connected to a computer or game console. Augmented reality shows the real world enhanced by computer-generated items, such as graphics, enhancing the real world by superimposing computer-generated information (Shen and Shirmohammadi, 2008). Such technologies can enable users to access objects and experiences regardless of their physical location. Increased adoption of virtual reality may have both positive and negative environmental impacts, depending on the inputs required and whether it replaces or complements existing polluting behaviour.

Distributed ledger technology. Blockchain and other distributed ledger technologies allow multiple parties to engage in secure transactions without any intermediary. The technology underpins cryptocurrencies and holds potential for many domains relevant to developing countries, such as digital identification, securing property rights and disbursing aid.[d] Blockchain technology, specifically cryptocurrencies that rely on proof-of-work as their mechanism to validate transactions, demands significant resources, notably electricity and processing power. The International Energy Agency (IEA) estimates blockchain energy demand to increase by nearly 50 per cent between 2022 and 2026 (IEA, 2024). How growth in adoption of distributed ledger technology is handled will have environmental implications in the future, and will depend on adoption rates and efficiency improvements.

Source: UNCTAD.

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[a] See https://aiindex.stanford.edu/report/.

[b] See https://futureoflife.org/open-letter/pause-giant-ai-experiments/.

[c] See https://www.washingtonpost.com/technology/2023/07/07/chatgpt-users-decline-future-ai-openai/.

[d] See UNCTAD (2021c) for blockchain applications in support of the Sustainable Development Goals.

United Nations General Assembly resolution 76/300, on the human right to a clean, healthy and sustainable environment, adopted in July 2022, recognizes that this right is "related to other rights and existing international law" (paragraph 2) and affirms that its promotion "requires the full implementation of the multilateral environmental agreements under the principles of international environmental law" (paragraph 3).

The digitalization and environmental sustainability nexus is to some extent reflected in the report by the United Nations Secretary-General, *Our Common Agenda*, and its proposal for a global digital compact and the Inter-Agency Task Team for the Global Accelerator on Jobs and Social Protection for Just Transitions (United Nations, 2021a). All this is expected to feature prominently in the Summit for the Future in September 2024.[2] As part of these broader efforts, new initiatives have been launched. In particular, in 2022, the Coalition for Digital Environmental Sustainability (CODES) developed an "Action Plan for a Sustainable Planet in the Digital Age" at the Stockholm+50 Conference (CODES, 2022). Nonetheless, considerably more attention

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[2] See https://www.un.org/en/common-agenda/summit-of-the-future.

needs to be given to the intersection between the rapidly evolving digital economy and environmental sustainability, and its implications for trade and development. The processes involved are all complex and difficult to regulate.

2. Comprehensive life cycle assessments

The relationship between digitalization and environmental sustainability is multifaceted and can be explored from various perspectives. There is a need to consider the extent to which digitalization complies with the "planetary guardrails" (Haum and Loose, 2015), related to the climate, nature, soils and oceans. Key environmental impacts are linked to energy use and greenhouse gas (GHG) emissions, protecting habitats, soil and water resources and reducing air pollution and waste. All of these are closely linked to the concept of the Anthropocene age which reflects how human activity has a long-lasting impact on the environment (*The Economist*, 2023).

Digital solutions are often seen as key for achieving Sustainable Development Goal 12 which relates to sustainable consumption and production. For example, they can reduce the environmental impacts of consumption and economic development through the use of smart devices and by enhancing production efficiency (World Economic Forum (WEF) and PwC, 2020; Technopolis and Institut für ökologische Wirtschaftsforschung, 2024). This raises a critical question of how to better leverage digitalization to achieve sustainability, for which improved data and measuring approaches are needed. Hence, the main focus of this report is how to make digitalization and activities related to the ICT sector more sustainable. Unless adequately addressed, their negative impacts are likely to increase as digitalization expands across all sectors.

Discussions of sustainable consumption and production have increasingly focused on the desirability of a more circular economy to reduce environmental impacts. Most goods today are produced in an essentially linear model that begins with the extraction of raw materials and passes from processing, design, manufacturing, distribution and use to disposal. As will be discussed later in this report, the digital economy still remains highly linear. A more circular digital economy would seek to reduce, reuse and recycle digital devices and infrastructure, including by extending their lifespan. This can be achieved through sharing, rental or donation; maintenance and repair; resale and redistribution; as well as remanufacturing and refurbishing. These activities can help reduce emissions caused by mineral extraction and processing, manufacturing or final disposal. Ideally, transitioning to a more circular digital economy would help achieve at least equivalent levels of economic growth and business profitability to those in the linear economy but with greater environmental sustainability.

The ability to identify significant environmental opportunities and risks arising from digitalization is hampered by a lack of agreement on what specifically constitutes the ICT sector (typically, end-user devices, network infrastructure and data centres; figure I.1) and associated services and what needs to be included when measuring environmental impact. This together with a lack of relevant data makes it challenging to develop targeted policy responses to minimize the environmental impacts of digitalization.

Digital solutions are often seen as key for achieving **Sustainable Development Goal 12** on sustainable consumption and production

To better understand these impacts, researchers use life-cycle assessments (LCAs) to evaluate the environmental impacts of a product or a service throughout its entire life span.[3] International standardization for LCA methodology, particularly ISO 14040 and ISO 14044, has laid the foundation for a formalized, robust and reliable approach to measuring environmental impacts. LCA is not limited

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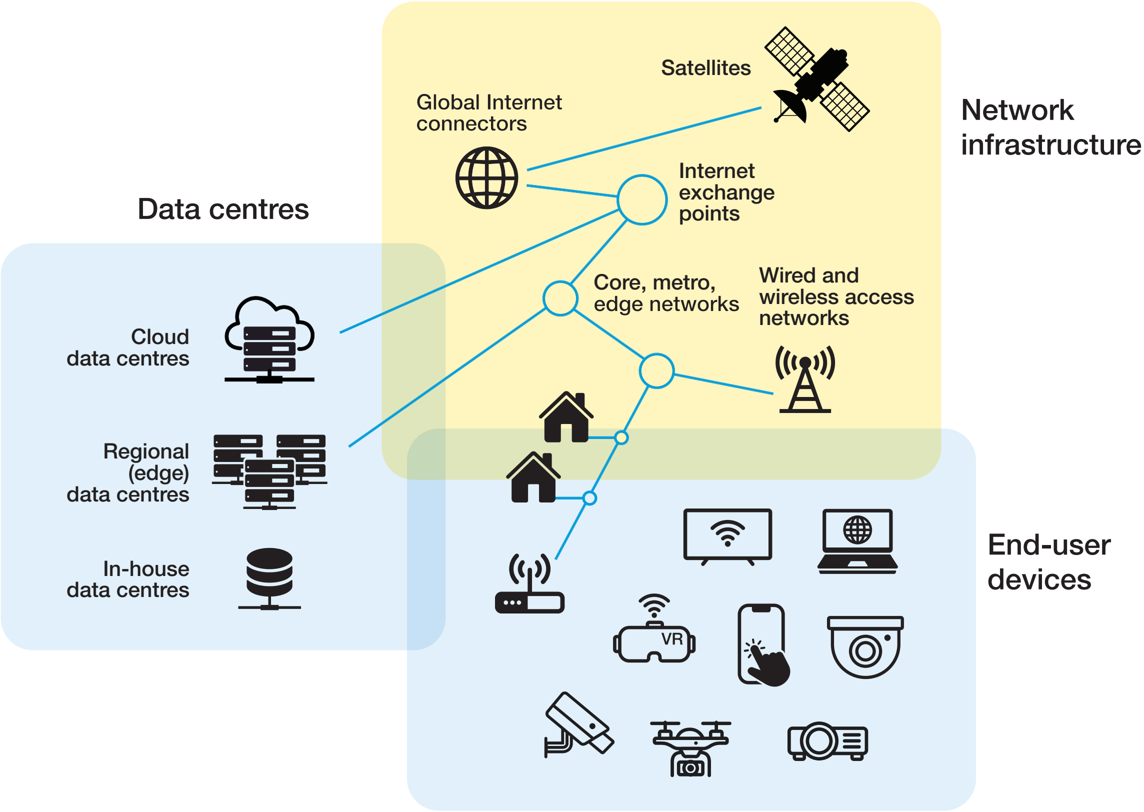
[3] LCA can be applied in different areas and sectors. Recent UNCTAD work has investigated the trade impact from manufacturing (UNCTAD, 2021d) and of plastic substitutes on the environment (UNCTAD, 2023b).

to any single environmental indicator, such as GHG emissions, but can encompass multiple criteria. For instance, the LCA-based product environmental footprint methodology developed by the Joint Research Centre of the European Union identifies 16 environmental impacts that can be assessed through LCA, with a strong link to various Sustainable Development Goals and to planetary boundaries (Joint Research Centre, European Commission et al., 2019).[4]

For digital transformation, LCA can help to identify stages with important environmental impact from end-user devices and ICT infrastructure (networks and data centres), highlight potential environmental trade-offs and assess the sustainability potential of substituting digital for non-digital technologies (Hilty and Aebischer, 2015; Itten et al., 2020).

Given data availability, LCAs in the digital economy typically focus on GHG emissions. However, this focus has limitations. Such partial analysis can lead to production processes that are environmentally suboptimal, potentially leading to

Figure I.1
The ICT sector is made up of three parts: Networks, data centres and end-user devices



Source: UNCTAD, based on Pohl and Hinterholzer (2023).

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[4] The Joint Research Centre suggests the following impact categories for a comprehensive environmental footprint of consumption in relation to Sustainable Development Goals: Goal 3 (good health and well-being): human toxicity, cancer; human toxicity, non-cancer; particulate matter; photochemical ozone formation; ionizing radiation; Goal 6 (clean water and sanitation): impacts due to water use, ecotoxicity, eutrophication; Goal 13 (climate action): climate change; impact due to resource use; Goal 14 (life below water): eutrophication marine and freshwater; ecotoxicity; Goal 15 (life on land): impact due to land use; eutrophication terrestrial; acidification; impact due to mineral and metal resource use; ozone depletion (Joint Research Centre, European Commission et al., 2019).

"greenwashing". For instance, electricity use by data centres can be reduced by upgrading servers more frequently, yet this leads to more electronic waste.

This report examines the three phases of the life cycle of end-user devices and ICT infrastructure and seeks to assess the environmental footprint of digitalization in view of the interconnected global challenges of digitalization, climate change, trade and development. Typically, within such an assessment:

- The *production phase* covers the extraction of raw materials, including minerals and metals, and their complex refining process; the assembly of different components of devices and ICT infrastructure; and their subsequent transportation for global distribution. This phase is discussed in chapter II, with a particular focus on the intensity of mineral and metals use, as well as geopolitical, trade and development considerations of their value chain.
- The *use phase* considers environmental effects generated by operating and using end-user devices, transmission networks and data centres. Particular attention is given to energy use, GHG emissions and water consumption. This is the focus of chapter III. Chapter V looks at a specific use case, namely the environmental impact of e-commerce.
- The *end-of-life phase* at the treatment of digital technologies after use, and the importance of moving towards a more circular economy, is discussed in chapter IV.

3. Direct and indirect effects

The three phases of the life cycle of digitalization have different environmental impacts. In order to assess the overall possible effects, it is important to distinguish between direct and indirect effects.[5]

a. Direct effects

Direct (or first order) effects result from digital devices and ICT infrastructure throughout their life cycle, spanning raw material extraction and processing, manufacturing, transportation for distribution, use and the end-of-life phase (ITU, 2014). The direct effects on resource use, energy use, GHG emissions and water and soil pollution constitute their "environmental footprint" (Hilty and Aebischer, 2015).

As noted above, it is important to consider other direct environmental impacts beyond GHG emissions (Mewes, 2023). For example, extraction of raw materials and handling of waste during production and end-of-life phases can have significant environmental impacts, such as soil contamination and dangers to biodiversity (table I.1). Additionally, in extraction, production and cooling of digital devices and infrastructure significant amounts of water are used throughout the life cycle (Olivié-Paul, 2022).

GHG and water footprints, while interconnected, raise different issues. In one sense they go together: the more ICT devices are built and deployed, the more energy is used, the more GHGs are emitted, and the more water is consumed. There can also be a negative correlation. For example, there is often a trade-off between the energy and the water used for cooling. Moreover, while GHG emissions are particularly relevant for climate change, the water footprint relates to freshwater scarcity (increasingly a consequence of climate change) and possible impacts on biodiversity. Unlike the global impact of GHG emissions, which can be offset in various places, negative impacts on water supply are highly location-specific. Saving water in one area cannot compensate for the local impact in another.

> Focusing only on GHG emissions can result in environmentally **suboptimal production processes,** potentially leading to "greenwashing"

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[5] For more details, see Berkhout and Hertin (2001); Bieser and Hilty (2018); Bremer et al. (2023); Coroamă et al. (2020); Hilty and Aebischer (2015); Horner et al. (2016); Pohl et al. (2019); Williams (2011).

Table I.1
Direct environmental effects of digital devices and infrastructure

Life cycle phase	Type of environmental impact	Digital device example: Smartphone
Production ▲	**Raw materials extraction.** Impacts on GHG emissions and the local environment from extracting and processing raw materials to make digital devices and infrastructure.	Materials, fossil fuels and water needed for transport and processing of raw materials for smartphone production.
	Production and transportation. Impacts on GHG emissions and water use from manufacturing and transporting digital devices and infrastructure.	Energy and water to produce and ship a smartphone to market.
Use ▲	Impacts on GHG emissions and water use from operating digital devices and infrastructure.	Energy needed to use a phone; energy and water needed to power the underlying digital infrastructure such as data centres, mobile or fixed broadband.
End-of-life ▲▼	Impacts on GHG emissions, pollution of water and soil from reuse, recycling and end-of-life treatment of digital devices and infrastructure.	*Negative:* Energy to dispose of the smartphone; impacts on water and soil from recycling and disposal of components. *Positive:* Proper reuse and recycling of devices and components reduces future negative impacts from raw material extraction.

Source: UNCTAD, adapted from Bremer et al. (2023); Pohl et al. (2019); Horner et al. (2016).

Notes: A red upward pointing arrow indicates a negative effect (increasing environmental impact); a green downward pointing arrow indicates a beneficial effect (avoided impact). A red upward pointing arrow next to a green downward pointing arrow means that the net effect can be either positive or negative.

b. Indirect and rebound effects

Indirect (or second and higher order) effects describe other environmental impacts from the use of digital technologies and services in different sectors of the economy, thus going beyond the direct footprint of the ICT sector. These can be both environmentally beneficial and harmful. Positive indirect effects that decrease emissions or other environmental harms are sometimes referred to as “enabling effects”, “abatement” or “avoided emissions” (Bremer et al., 2023).

Data-driven digital technologies can be powerful tools to mitigate negative environmental footprints from economic activities. For instance, they can enable real-time monitoring and adaptation in resource use (“optimization effect”). Substituting physical goods and travel with digital alternatives can enable decarbonization and dematerialization within some production and consumption patterns (“substitution effect”). Various studies highlight the potential for significant GHG emissions reduction through the effective use of digital technologies in different industries (box I.2).

The International Panel of Climate Change (IPCC) acknowledges the potential role of digital technologies, including sensors, IoT and AI to mitigate climate change, improve energy management, boost energy efficiency and promote the adoption of low-emission technologies while creating economic opportunities (IPCC, 2022a). Despite this, take-up of digitally enabled production processes remains limited. Industry estimates suggest that effective use of digital technologies could significantly reduce global GHG emissions (Global Enabling Sustainability Initiative and Deloitte, 2019). The same study optimistically concluded that digitally induced reductions of emissions could be nearly seven times the size of the growth in total carbon emissions from the ICT sector over the same period. Researchers also recognize the potential of supply chain and business model innovations to reduce the environmental impact of the economy (Blanco et al., 2022; Parida et al., 2019; Wang, 2017). Furthermore, machine learning offers mitigation potential by improving monitoring, energy use and optimizing transport and construction (Rolnick et al., 2023).

To date, various studies have been unable to confirm the potential for environmental gains from digitalization through anticipated

Box I.2
Opportunities for digital technologies to mitigate carbon emissions

Digital technologies can be applied across sectors with a view to reducing negative environmental effects. This box provides examples of potential opportunities including in global value chains, transportation, construction, agriculture and energy. However, in most areas, empirical evidence on actual gains realized remains limited.

Digital technologies can be used to make global value chains more environmentally sustainable by enhancing productivity, reducing environmental impacts of current production and consumption modes, introducing new, more environmentally friendly technologies and eco products, and enhancing the diffusion of business models based on circular economies (UNCTAD, 2023c). The use of advanced robotics, three-dimensional printing, sensors and wireless technologies can enable automation and the decentralization of tasks to potentially reduce emissions from transport. Digitalization can also help to better monitor environmental standards, optimize logistics, boost operational efficiency and thereby reduce carbon emissions and energy consumption. Data processing technologies, such as big data analytics, cloud computing and AI, further contribute to environmentally sustainable production processes.

The transport sector accounts for about one-quarter of global energy-related GHG emissions; varying from below 3 per cent in some least developed countries (LDCs) to more than 30 per cent in high-income countries, although growth rates in transport-related emissions have been larger in developing regions in recent years.[a] Smartphone applications can help to optimize routes and vehicle efficiency (GSMA, 2019). However, the effect of circular and shared economy initiatives as well as other aspects of digitalization is uncertain (IPCC, 2022a). Dematerialization could reduce demand for transport services, while an increase in e-commerce with priority delivery may raise demand for freight transport.

Another major contributor to emissions is the buildings and construction sector. In 2021, this sector accounted for 37 per cent of energy and process-related CO_2 emissions.[b] Digital technologies may be leveraged to reap benefits from optimizing energy use through automation in smart buildings and cities (Global Enabling Sustainability Initiative and Deloitte, 2019).

The agricultural sector accounts for 10–12 per cent of global anthropogenic (human-generated) GHG emissions. Precision agriculture, improved weather prediction and the IoT in smart water infrastructure can notably reduce CO_2 emissions and improve irrigation efficiency (Global Enabling Sustainability Initiative and Deloitte, 2019; Technopolis and Institut für ökologische Wirtschaftsforschung, 2024). At the same time, precision farming has been found to only slightly reduce pesticide use (Bovensiepen et al., 2016).

According to the IPCC (2022a), improvements in energy efficiency from digital technologies can help to reduce energy demand in all end-use sectors. This includes material input savings and increased coordination. For example, smart appliances and energy management can effectively reduce energy demand and associated GHG emissions without reducing service levels; similarly, district heat systems can use waste heat from nearby data centres.

Source: UNCTAD, based on cited sources.

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[a] See IPCC (2014, 2022a).

[b] See https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector.

Empirical evidence on actual environmental gains from digitalization **remains limited**

efficiency and substitution gains from ICT (Clausen et al., 2022; Schultze et al., 2016). In fact, one review found no significant shift towards sustainable energy consumption levels in any sector after introducing digital tools (Lange et al., 2020). Similarly, the IPCC (2022a) stresses that potential gains may be reduced or counterbalanced by "rebound effects", leading to increased demand for and use of goods and services.

Rebound effects in digitalization, where initial positive impacts are offset by increased demand and use, can undermine the benefits of more efficient goods and services (Vickery, 2012; Coroamă and Mattern, 2019; Technopolis and Institut für ökologische Wirtschaftsforschung, 2024). Rebound effects can occur for the same good or service because the efficiency gains made it cheaper or more convenient to consume more of it. The money or time saved through digitally induced efficiency, however, can also lead to the increased consumption of other goods and services, two phenomena often referred to as "income effect" (Coroamă and Mattern, 2019) and "time rebound" (Binswanger, 2001), respectively.

Indirect environmental effects could be significantly greater than the direct environmental footprint from digital technologies

Digitalization is also decreasing the skill thresholds needed to perform various activities, thus likely increasing their use ("induction effect") – a phenomenon that may be particularly visible for autonomous vehicles (Coroamă and Pargman, 2020) and the use of data analysis through large language AI models, such as ChatGPT, which previously required specialized training. Additionally, an "obsolescence effect" may arise as certain unconnected products become less useful because they are not connected to newer generations of technology (Hilty and Aebischer, 2015). Even if it is possible to achieve efficiency improvements and substitute physical goods with digital services,[6] behavioural changes due to rebound effects and increased overall consumption may mitigate anticipated beneficial environmental effects (Digitalization for Sustainability, 2022).

In the case of e-commerce, for example, buying a product online can be more energy efficient under certain conditions than driving to a physical store to buy the same product, thereby reducing GHG emissions. But if the convenience of online shopping encourages increased purchasing frequency, volume and returns that are not always resold, any initial emission reductions may be diminished or counterbalanced.

Higher order indirect effects, or societal effects, stem from behavioural changes triggered by the interaction of direct and indirect effects, including rebound effects, as digital technologies are widely adopted, leading to changes in lifestyles and value systems (Hilty and Aebischer, 2015; Horner et al., 2016; Pohl et al., 2019; Williams, 2011). For example, digitally enabled teleworking reduces transport-related energy use but increases energy use in the places in which the telework is performed. It may induce secondary changes such as living locations (for instance, relocating further away from urban centres into larger houses), communication methods (more remote communication through social media) and purchasing habits (online rather than offline) (table I.2).

Challenges in measuring indirect effects often lead to these being excluded when assessing the true environmental impact of digitalization. This underlines the importance of developing better standardized frameworks to more adequately account for indirect and rebound effects to ensure that efficiencies are correctly estimated in the future (Widdicks et al., 2023).

c. Combined effects of digitalization are uncertain

Understanding the cumulative environmental effects is crucial for policymakers, researchers, the private sector and consumers to determine the net impact of

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[6] While this substitution from physical goods to digital services may appear to reduce the need for materials, this is not necessarily the case, as any digital service is enabled by devices, transmission networks and data centres.

digital technologies. The cumulative effect depends on whether ICT is considered part of the problem or solution for environmental sustainability (figure I.2): In terms of direct effects, negative impacts arise from the production, use and end-of-life phases of digital devices and infrastructure. Applying digitalization in other sectors, however, can have both positive indirect effects, limiting environmental impacts through optimization and substitution, or negative impacts by inducing more consumption or making existing devices obsolete. Furthermore, more systemic indirect effects due to behavioural or structural changes can either reduce or increase the impact on the environment.[7]

Indirect environmental effects could be significantly greater than the direct environmental footprint from using digital

Table I.2
Indirect environmental effects from the use of digital devices and infrastructure

Type of indirect effect	Potential environmental impact	Digital device example: Use of maps on a smartphone
Substitution ▲▼	Products are replaced by their digital equivalents (with lower or higher environmental impacts).	Replacement of paper-based maps and dedicated GPS-only devices.
Optimization ▼	Adoption of digital technologies leads to efficiency improvements.	Enhanced traffic and energy efficiency through real-time routing, reducing travel due to optimized routes.
Rebound ▲▼	Time and income effects. Optimization gains from digital technologies enable cost reductions (in terms of money or time), boosting the consumption of the good or service or of other goods or services.	***Same good or service:*** additional use of device compared to traditional paper-based maps, increased data consumption. ***Other good or service:*** energy consumed during time/with resources saved by more efficient travel.
Induced consumption ▲	Digital technologies induce an increase in the consumption or use of a product, process or service.	Increased travel as smartphone-enabled routing eases and aids driving in unfamiliar areas.
Transformational (societal) rebound ▲▼	Introduction of digital technologies causes macroeconomic adjustments across sectors.	Growth in location-based services and advertising; GPS technology in smartphones boosts autonomous vehicles and expands intelligent transportation system manufacturing.
Sustainable lifestyle and practices ▼	Digital technologies enable or encourage more sustainable lifestyles and practices.	Smartphone maps and routing promote sustainable travel methods, such as walking or biking in unfamiliar areas.
Systemic transformation and structural economic change ▲▼	Digital technologies generate systemic society-wide transformations.	Digital maps change transportation consumption boosting demand for car-sharing and ride-sharing such as Uber; long-term, GPS-enabled autonomous vehicles shift living and working location choices. Improved navigation efficiency may enable more private vehicle use over public transportation, and delay structural changes needed to reduce carbon emissions and traffic congestion.

Source: UNCTAD, adapted from Bremer et al. (2023); Pohl et al. (2019); Horner et al. (2016).

Notes: A red upward pointing arrow indicates a negative effect (increasing environmental impact); a green downward pointing arrow indicates a beneficial effect (avoided impact). A red upward pointing arrow next to a green downward pointing one means that the net effect can be either positive or negative.

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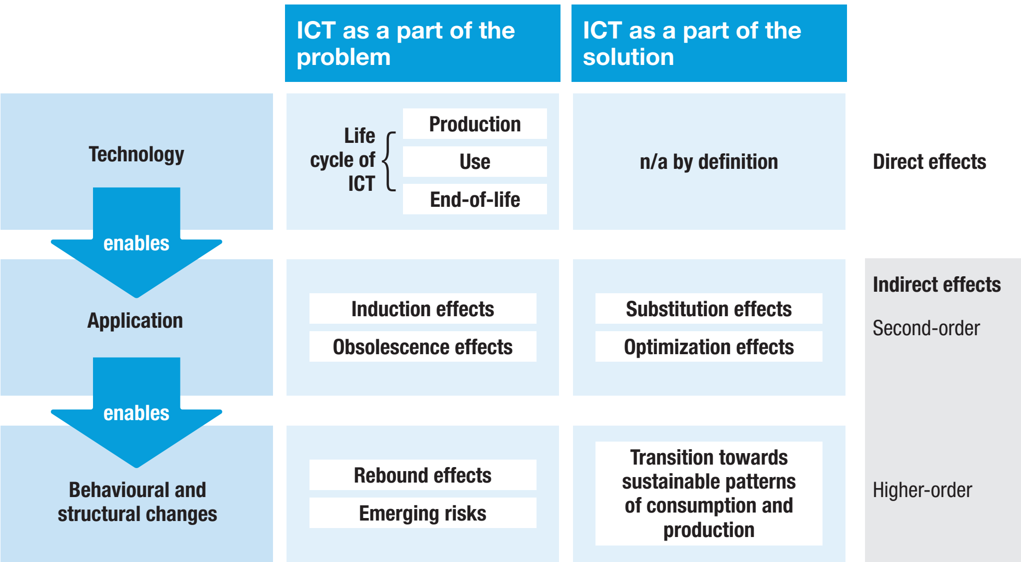
[7] For more information, see IEA (2017); Bergmark et al. (2020); Coroamă et al. (2020); Global Enabling Sustainability Initiative (2020); The Royal Society (2020); Bieser et al. (2023); Bremer et al. (2023); Kaack et al. (2022); Technopolis and Institut für ökologische Wirtschaftsforschung (2024).

technologies.[8] For example, direct life cycle GHG emissions ("ICT footprint" in the figure) from teleworking using a computer, data transmission networks and data centres are likely to be less than 0.4 kg carbon dioxide equivalent emissions (CO_2e)[9] when a global average electricity grid mix is used.[10] This is roughly one tenth of the emissions arising from a 20 kilometre commute to work by car.[11] Hence, using digital technologies can lead to a positive indirect effect of avoiding a commute equivalent to 4 kg of CO_2e emissions ("applications of digital technology" in the figure). Longer-term behavioural and lifestyle changes ("structural effects and economic changes" and "systemic and societal-level effects and transformation" in the figure) can have larger, albeit uncertain, positive or negative indirect impacts, depending on how policy, technology and behaviour interact and evolve. However, to date, options to comprehensively measure indirect effects remain limited, though the International Telecommunication Union (ITU, 2022) has put forward a first recommendation (L.1480) on assessing the impact of ICT on GHG emissions in other sectors.

This report thus focuses primarily on the direct environmental effects of digital devices and infrastructure, encompassing the entire life cycle. Chapter V is an exception as it looks at a specific use case of digitalization,

Figure I.2
Digitalization as a problem or a solution for promoting environmental sustainability



	ICT as a part of the problem	ICT as a part of the solution	
Technology	Life cycle of ICT: Production Use End-of-life	n/a by definition	Direct effects
Application	Induction effects Obsolescence effects	Substitution effects Optimization effects	Indirect effects Second-order
Behavioural and structural changes	Rebound effects Emerging risks	Transition towards sustainable patterns of consumption and production	Higher-order

Source: UNCTAD, based on Hilty and Aebischer (2015).

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[8] Indirect effects are also considered when categorizing scope 1, scope 2 and scope 3 emissions. Scope 1 covers direct GHG emissions owned or controlled by a producing entity; scope 2 covers indirect GHG emissions from electricity, heating or cooling used; and scope 3 are indirect emissions linked to all other indirect effects, e.g., from mining, production, inputs, transportation and end-of-life treatment (Allwood et al., 2014). Scope 3 is understood to have the largest emissions impact, and is the most complex to measure.

[9] CO_2 equivalent emissions serve as a proxy measure that allows emissions from various GHGs to be compared in terms of their potential for global warming. For this, an amount of a GHG is converted to an amount of CO_2 which has the same global warming potential as the original GHG (Eurostat, 2023; IPCC, 2023).

[10] Based on an eight-hour workday using a laptop (30W), 24-inch LED monitor (30W), 50 per cent allocation of a router (5W), fixed access and core networks (<5W), data centre services (<2W) and associated embodied emissions.

[11] Based on the life cycle GHG emissions for an average new vehicle in 2017 including raw material extraction, production, use (fuels included), based on IEA (2019).

namely e-commerce. E-commerce has both positive and negative direct and potential indirect environmental impacts, and these can be influenced by policymaking.

Regardless of indirect environmental impacts of digitalization, including societal effects, minimizing the direct footprint of the digital economy remains essential.

B. Assessing the overall direct environmental footprint of digitalization

Comprehensive assessments of the environmental footprint of digitalization **are scarce**

As noted above, accurately assessing the direct environmental impacts of the ICT sector is difficult. Rapid technological and economic changes further complicate measurement, with numerous factors affecting environmental impacts, such as resource depletion, GHG emissions, water consumption, biodiversity and noise. Taking a broad, multicriteria perspective on the environmental footprint, available research suggests that the production phase has the greatest impact. This is due to mineral and metal depletion, the volume of GHG emissions generated and water-related impacts (Duporte et al., 2022). During the use phase, GHG emissions and water consumption are the main concerns (Agence de la transition écologique (Ademe) and Autorité de régulation des communications électroniques, des postes et de la distribution de la presse (Arcep), 2022; Bordage, 2019; Freitag et al., 2021).

1. Measurement challenges

Comprehensive assessments of the environmental footprint of digitalization are scarce, due to five factors. First, there is a lack of timely, comparable and accessible data regarding the energy and environmental impacts of the ICT sector, with no harmonized reporting standards. Additionally, there is often limited disclosure of impacts such as the effect on local watersheds (Koomey and Masanet, 2021; Pasek et al., 2023). Data scarcity leads to analytical studies having to rely on hugely varying and potentially outdated data sources, given the speed of change in the digital economy (Freitag et al., 2021). There is also no standardized approach for converting ICT energy use in kilowatts per hour (kW/h) into tons of GHGs emitted, as these depend on the technologies and source of energy used. Consequently, estimates vary significantly between countries and sectors (Chiarella et al., 2022). Nevertheless, as energy use and GHG emissions data are still the most frequently available, much research has focused on these areas.

Second, the scope of the ICT sector varies between studies. For instance, televisions and consumer electronics are included as part of the sector in some studies (Andrae and Edler, 2015; Malmodin and Lundén, 2018), but not in others (Belkhir and Elmeligi, 2018). More importantly, new applications, such as AI, blockchain and the IoT, are often not yet considered, likely underestimating the overall sectoral impact (Freitag et al., 2021). The increasing integration of digital technologies into other sectors further complicates the ability to set clear boundaries when assessing the sector's environmental footprint.

Third, studies also vary in the definition of the life-cycle stages of the ICT sector. ITU has introduced standards on conducting life-cycle analyses of the ICT sector (such as the ITU-T L.1410 and L.1450), but they have not been consistently followed by researchers, with some exceptions (ITU, 2020; Malmodin and Lundén, 2018; Malmodin et al., 2024).

Fourth, even those studies that look at similar life-cycle stages have reached different conclusions due to varying assumptions and models adopted to estimate the environmental impact. For example, variations include anticipated growth of the ICT sector, its correlation with energy consumption (reflecting assumptions on efficiency gains in computing power) and the extent to which ICT will contribute to emissions reductions in other sectors (Freitag et al., 2021).

Moreover, existing literature mainly looks at the global environmental impact, overlooking location-specific effects.[12] As such, studies neglect consequences that are highly region- or country-specific, such as mining for raw materials, which primarily affects developing countries, and water use, both of which have profound environmental implications that extend beyond the generalized impact of global GHG emissions.

The need to improve availability of quality data and common measurement methodologies must not be an excuse for policy inaction

Such methodological challenges have led to considerable variation in estimates of the ICT sector's environmental impact (Koomey and Masanet, 2021) and of its subsectors. For example, to calculate network energy intensity (i.e. the energy needed per amount of data sent across the Internet), existing estimates differed by a factor of 20,000 a decade ago (Coroamă and Hilty, 2014). Disagreement also persists on whether overall impact is overestimated – due to outdated data, excessive growth assumptions and projections that extrapolate too far into the future (Koomey and Masanet, 2021) – or underestimated, because these estimates exclude relevant technologies and trends (Freitag et al., 2021). As it is vital to estimate and analyse impacts to inform policy actions, the need to improve the availability of quality data must not be an excuse for inaction. However, more work is needed to develop commonly accepted measurement methodologies that can help in policymaking.

2. Estimates of the carbon footprint of the ICT sector

As noted, energy use and GHG emissions are the most researched aspects of the ICT sector's environmental footprint. The energy use of devices, data centres and networks has been estimated to account for approximately 6 to 12 per cent of global electricity use (about 1 to 2 per cent of global energy use), depending on use patterns, number of devices and associated energy consumption (IPCC, 2022a). Still, since 2015, studies assessing total GHG emissions of the ICT sector have arrived at vastly different results (table I.3). Estimates of life cycle emissions for 2015 range from 0.73 to 1.1 metric gigatons of CO_2 equivalent ($GtCO_2e$) emissions (1.4–2.2 per cent of global GHG emissions), and for 2020 from 0.69 to 1.6 $GtCO_2e$ emissions (1.5–3.2 per cent of global GHG emissions). Differences are even greater if the most optimistic and most pessimistic estimates are also considered.

These differences become more pronounced in longer-term projections. For example, Andrae and Edler (2015) estimate in their "best case" scenario that the ICT sector (excluding televisions and associated devices) could emit 1.3 $GtCO_2e$ in 2030 but as much as 19 $GtCO_2e$ in the "worst case" scenario – representing a 15-fold difference.

Many of the studies in table I.3 are widely cited, but this does not mean they are necessarily robust to changes in model assumptions and underlying data. For example, Andrae and Edler (2015) and Belkhir and Elmeligi (2018) largely rely on relatively simplistic extrapolations.[13] More

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[12] A recent study by ITU and the World Bank provides estimates in country case studies, highlighting the variation in data collection approaches for climate data in the ICT sector (Ayers et al., 2023).

[13] The latter study extrapolates GHG emissions from data centres using a study from 2009–2010 (Vereecken et al., 2010), applying an assumed compound annual growth rate from an industry report, implicitly disregarding underlying drivers of data centre demand growth and efficiency improvements.

recently, Andrae (2019a, 2020) significantly revised downwards earlier estimates from Andrae and Edler (2015) – in some cases by more than half for 2020 – indicating the limited usefulness of extrapolations beyond a few years.[14] The rapidly evolving nature of digital technologies makes long-term projections highly uncertain and further complicates defining the scope of the ICT sector's footprint as more objects become connected to the Internet.[15]

The methodological approach of Malmodin and Lundén (2018) involves a more comprehensive combination of bottom-up data (e.g. shipment data of devices, servers, other hardware), detailed life-cycle analyses, reported operator data and benchmarking with other high-quality studies that have focused on specific ICT subsectors (e.g. data centres). However, their methodology has also been criticized in Freitag et al. (2021) for lacking transparency and replicability. ITU (2020), largely based on Malmodin and Lundén (2018), and Malmodin et al. (2024) provide greater transparency regarding the methodologies and assumptions applied.

In the case of energy use and associated GHG emissions, different studies have estimated that 56–80 per cent of the ICT sector's total life cycle emissions come from the use phase (Andrae, 2020; Bordage, 2019; Malmodin and Lundén, 2018; Malmodin et al., 2024; Masanet et al., 2013; Whitehead et al., 2015). However, the relative shares of each phase differ greatly between data centres, data transmission networks and connected devices. The production phase is the most important for devices, especially for highly energy-efficient battery-powered devices (such as smartphones and tablets). Around 80 per cent of the GHG impacts of a smartphone's life cycle can be attributed to the production phase (Ercan et al., 2016; Lhotellier et al., 2018; Clément et al., 2020; Ademe and Arcep, 2022). Meanwhile, the use phase dominates the GHG impact of life cycles of data centres and networks due to their high energy intensity and constant operation (Andrae, 2020; Bordage, 2019; Malmodin and Lundén, 2018; Malmodin et al., 2024; Masanet et al., 2013; Whitehead et al., 2015).

3. Environmental footprint beyond emissions and energy

Direct environmental impacts of digital technologies also concern, among other impacts, raw material depletion, water consumption and quality, local air quality, soil, biodiversity and waste. The importance of these impacts differs across ICT products and the different life cycle stages. For example, material use, water and air quality and biodiversity impacts are particularly important in the production phase, while waste generation is most important, but not exclusively, in the end-of-life phase. In studies applying comprehensive, multicriteria analyses, the production phase emerges as the life-cycle stage that has the most adverse effects on the environment (Ademe and Arcep, 2022; Bordage, 2019).

The production phase emerges as the stage with **the most adverse environmental effects**

Biodiversity and livelihoods can be severely affected by the water use of digital technologies and infrastructure,[16]

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[14] The Shift Project's 2019 report, largely based on modelling by Andrae and Edler (2015), has been widely cited despite similar methodological issues. A review of data centre energy estimates by Mytton and Ashtine (2022) also noted its methodological problems.

[15] Some studies, such as Andrae and Edler (2015), used exponential growth rates to arrive at alarming figures that have been widely quoted in the media (Koomey and Masanet, 2021). They projected that the ICT sector could end up using half of the world's electricity consumption by 2030, while accounting for nearly one quarter of global GHG emissions. This, however, is an improbable scenario given the time required to build ICT and energy infrastructure and the high costs of energy.

[16] Low-income countries have recently experienced a loss in their biodiversity likely linked to important land degradation from activities such as mining of critical raw materials in resource-rich countries, while other countries have gained in per capita terms through accelerated conservation efforts (IPBES, 2019; Balvanera et al., 2019).

Table I.3

Overview of selected recent assessments of global greenhouse gas emissions

Institution and studies	Approach	Strengths	Limitations	Greenhouse gas emissions estimates (Per year)
Ericsson; Telia (Malmodin et al., 2024; Malmodin and Lundén, 2018)	Hybrid approach combining bottom-up data (e.g. shipments of devices, servers, other hardware), previous life cycle analyses, top-down reported data from data centre operators, network operators, and major equipment manufacturers, and benchmarking to other studies such IEA (2017).	Strives to follow the ITU-T L.1450 standard. The analysis is based on rich and recent sources of bottom-up data, use of reported operator data, and benchmarking to established studies implies high degree of analytical quality.	Main limitation is the lack of transparency regarding some datasets (e.g., operator energy consumption). However, some of this data can be accessed through companies' sustainability reports or other disclosures. The 2023 study frequently refers to supplementary material that is not easily accessible.	0.73 GtCO$_2$e in 2015 0.76 GtCO$_2$e in 2020 1.4% of global emissions
GreenIT.fr (Bordage, 2019)	For data centres, based on estimated number of servers in operation and LCA of three data centres from previous studies. For networks, based on data traffic and access types. For devices, bottom-up estimates, based on sales figures and average lifespans.	Reports environmental impacts across multiple impact areas, including energy consumption, GHG emissions, water consumption and abiotic resource depletion.	While the scope appears to be comprehensive, the lack of detail regarding assumptions and data sources makes it difficult to evaluate its quality. The scope of the study includes televisions and peripherals and is limited to manufacturing and use.	1.4 GtCO$_2$e in 2019 3.8% of global emissions (56% from use, 44% from manufacturing)
Huawei (Andrae, 2019a, 2019b, 2020, 2017; Andrae and Edler, 2015)	Data centres and networks estimated based on Internet Protocol traffic estimates from Cisco with varying assumptions for energy intensity per unit of Internet Protocol traffic (for data centres, fixed access networks, and mobile access networks). Devices estimated based on bottom-up data combining number of devices per year, expected electricity use, and expected lifespans. Projects three scenarios (best, expected, worst) to 2030 with differing assumptions for electricity use, pace of energy efficiency improvements, device lifespans, and share of embodied emissions.	High degree of transparency, with a supplementary model disclosing assumptions and detailed results.	Assumptions are transparent but lack sources or explanations, making some appear arbitrary, such as energy intensity assumptions, efficiency improvement factors and assumed lifespan of devices. The 2015 study's long-term projections, especially the "worst case" scenario, have been widely cited, suggesting that the ICT sector would consume half of the world's electricity and generate a quarter of global GHG emissions. These implausible long-term projections have created confusion regarding the actual climate impacts of digital technologies and have since been amended.	Andrae (2020) "Expected" scenario: 0.66 GtCO$_2$e in 2015 0.69 GtCO$_2$e in 2020 0.71 GtCO$_2$e in 2025 1.3 GtCO$_2$e in 2030 Andrae and Edler (2015) "Expected" scenario: 0.94 GtCO$_2$e in 2015 1.3 GtCO$_2$e in 2020 2.1 GtCO$_2$e in 2025 4.4 GtCO$_2$e in 2030
International Telecommunication Union (ITU, 2020)	Similar approach and data sources as Malmodin and Lundén (2018) aligned with ITU-T L.1450 and linked to the 1.5°C objective of the Paris Agreement.	Similar to Malmodin and Lundén (2018), strives to follow the ITU-T L.1450 standard. Provides significant methodological detail in an annex.	Projections aim to align ICT sector emissions with the 1.5°C objective which adds additional uncertainty to the estimations, as outlined in the section "Risks".	0.74 GtCO$_2$e in 2015 0.69 GtCO$_2$e in 2020 0.53 GtCO$_2$e in 2025 0.39 GtCO$_2$e in 2030
ITU; World Bank (Ayers et al., 2023)	Bottom-up extrapolation based on environmental, social and governance reports from the largest telecommunications operators, data centre operators, equipment manufacturing and use.	Clear on which life cycle stages are included and which are not (no transport, end-of-life). Takes into account variations in electricity mix into its global aggregates.	Due to data limitations, estimates of data centres are limited to relatively efficient co-location data centres, cloud computing and social media storage, leading to a lower bound estimation of the impact from this section of the ICT sector. Not all life-cycle phases included.	0.57 GtCO$_2$e in 2022 1.7% of global emissions (Telecom operators: 0.133 GtCO$_2$e Co-location data centres: 0.042 GtCO$_2$e Cloud and content data centres: 0.032 GtCO$_2$e PC manufacturing: 0.065 GtCO$_2$e; PC use: 0.187 GtCO$_2$e Smartphone manufacturing: 0.057 GtCO$_2$e; their use: 0.018 GtCO$_2$e; Network manufacturing: 0.033 GtCO$_2$e)

Institution and studies	Approach	Strengths	Limitations	Greenhouse gas emissions estimates (Per year)
Lancaster University (Freitag et al., 2021)	Detailed review of recent studies estimating the global GHG footprint of the ICT sector, focusing on Malmodin and Lundén (2018), Andrae and Edler (2015) and Belkhir and Elmeligi (2018).	Provides a useful comparative review of the three major global ICT GHG studies published since 2015, comparing scopes, methods, and assumptions.	Includes televisions and related peripherals in top-level results, contrary to the ITU recommendation to categorize them under the entertainment and media sector. Lacks critical assessment of the reviewed studies, implying equal validity of all three studies despite varying levels of quality.	1.2–2.2 $GtCO_2e$ in 2020 (including televisions) 2.1–3.9% of global emissions 0.8–1.7 $GtCO_2e$ in 2020 (excluding televisions)
McMaster University (Belkhir and Elmeligi, 2018)	Data centres and networks are extrapolations of trends from previous studies and industry reports on demand growth (e.g. Vereecken et al. (2010) for data centres and Van Heddeghem et al. (2014), Lambert et al. (2012) and Pickavet et al. (2008) for networks). Devices are estimated using a bottom-up approach based on published academic and industry estimates for units and life cycle impacts. Projections are based on linear extrapolation of carbon emissions for data centres and networks based on trends from around 2008 to 2012.	The main strength of this analysis is the bottom-up analysis of devices.	Emissions from data centres and networks ignore their embodied carbon (emissions from materials and manufacturing). The linear extrapolation of GHG emission trends for data centres and networks to 2040 does not take account of potential efficiency improvements and underlying drivers of demand growth, and likely overestimates future emissions if the historical trend is taken from a period of rapid growth. Three years after publication, the author notes in Freitag et al. (2021) that: “regarding data centres, Belkhir himself noted that his projection of 495 $MtCO_2e$ for data centres in 2020 is overestimated”.	0.87 $GtCO_2e$ in 2015 1.1–1.3 $GtCO_2e$ in 2020 1.4–1.8 $GtCO_2e$ in 2025 7 $GtCO_2e$ in 2040
Schneider Electric Sustainability Research Institute (Petit et al., 2021)	Bottom-up estimation of number of devices and infrastructure. Given varying estimates of the existing stock of devices, the study focuses on growth rates rather than quantities.	As a post-COVID-19 study, this takes into account recent changes in the development of the ICT sector.	Study is not peer-reviewed. No information on distribution of emissions from manufacturing and embodied emissions, limited information on definition of embodied emissions. Does not consider end-of-life and transportation. Projections for 2030 are based on the sector’s aim to reduce emissions by 50 per cent by that point.	0.96 $GtCO_2e$ in 2020 2.8% of global emissions; (27% from manufacturing) 0.89–1.2 $GtCO_2e$ in 2030 Or 2.6–3.4% of global emissions (with manufacturing accounting for 32% of 0.89 and 24% of 1.2 $GtCO_2e$)
The Shift Project (The Shift Project, 2019a, 2021)	Uses model from Andrae and Edler (2015) (same scope of technologies and life-cycle stages) with the institution’s assumptions on data traffic and number of devices and introduces new scenarios. Projects four scenarios: expected updated; sobriety; higher growth higher energy efficiency; superior growth peaked energy efficiency.	Given that this analysis is based on the model developed by Andrae and Edler (2015), the same strengths outlined in Huawei also apply here.	Given that this analysis is based on the model developed by Andrae and Edler (2015), the same weaknesses outlined in Huawei also apply here.	1.8 $GtCO_2e$ in 2015 2019 study, “Expected updated”: 1.6 $GtCO_2e$ in 2020 2.7 $GtCO_2e$ in 2025 2021 study “Expected updated”: 1.4 $GtCO_2e$ in 2020 1.8 $GtCO_2e$ in 2025

Source: UNCTAD, based on Andrae (2017, 2019a, 2019b, 2020); Andrae and Edler (2015); Belkhir and Elmeligi (2018); Bordage (2019); Freitag et al. (2021); ITU (2020); Malmodin et al. (2024); Malmodin and Lundén (2018); Petit et al. (2021); The Shift Project (2019a, 2021).

Notes: Refer to Freitag et al. (2021) for a detailed review and critique of most of the studies presented in this table. All GHG estimates are for the ICT sector only and exclude televisions unless specified. Emissions excluding televisions in Freitag et al. (2021) were estimated by UNCTAD based on the primary data from the three studies reviewed by Freitag et al. GHG estimates for Andrae and The Shift Project have been recalculated using their publicly available spreadsheet models to exclude televisions and associated peripherals (set-top boxes, DVD players, etc.). The Shift Project did not publish their 2021 model, so those figures are estimated based on the relative share of televisions from their 2018 model (2019 study). ITU (2020) projections for 2020–2030 are based on decarbonization efforts of the electricity supply in line with the 1.5°C trajectory.

potentially threatening the balance of ecosystems (Mewes, 2023). Estimates of how much water is required to produce digital devices vary widely. For instance, for smartphones, estimates range from 100 to 13,000 litres of water per device depending on the underlying assumptions and modelling approaches (Friends of the Earth, 2015; Leahy, 2014; Merchant, 2017).

Beyond production, which includes mining, using ICTs requires large amounts of water for data centre cooling, with very limited water being reused (Monserrate, 2022). This effect is aggravated by the fact that many production hubs and data centres are located in areas under water stress (Jones, 2018; Farfan and Lohrmann, 2023; *The Guardian*, 2023).[17] Similarly, the end-of-life phase is linked to significant impacts on the water supply in some locations. Groundwater contamination from leaching, dumping and digitalization-related processing activities can adversely affect biodiversity and human health.

Adverse effects of device production and digitalization-related waste often **impact regions far from where the devices are mainly used**

Mining for digital technologies comes with a significant environmental footprint. The specific impact depends on the local ecosystem as well as on the mining technology used. As the overwhelming majority of earth and rock removed in mining is eventually discarded, this can lead to high levels of toxicity from mining by-products and soil damage (Dwivedi et al., 2022; The Shift Project, 2019a). Moreover, mining can be very water-intensive, often leading to competition for water between mining operations, agriculture and direct consumption (UNCTAD, 2020).

Most studies position themselves as global analyses. However, the environmental impacts can have varying effects at local, regional and global levels. For example, air pollutants have adverse impacts on local air quality and human health, whereas the impacts of climate change from GHG emissions are global.

Moreover, digital technologies can also affect other dimensions of sustainability, notably gender equity and human rights. It is important to ensure that the human rights impacts and the unique challenges confronting women and girls, youth, indigenous peoples and other groups at risk of being left behind, are not overlooked. For instance, nearly 12.9 million women and many children work in the informal sector managing waste from digitalization, which makes them significantly more likely to be exposed to potential negative consequences for their health (Parvez et al., 2021; World Health Organization (WHO), 2021a).

From an equity perspective and in view of today's highly complex global supply chains, it is important to recognize that adverse impacts associated with device production and waste generation at end-of-life often affect regions located far away from where the devices are predominately used. While developed countries remain the primary users of many aspects of the ICT sector, considerable harm may accrue in regions that currently use and benefit less from digitalization. However, to date, research specific to the environmental impact of the digital economy on developing countries remains scarce.[18] This results in policy discussions being skewed towards the concerns of high-income countries that are better positioned to harness the benefits of digital technologies.

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[17] Overall, the share of global population affected by water stress is rising. In 2018, about 10 per cent of the global population – more than 733 million people – lived in countries with high water stress (Food and Agriculture Organization (FAO) and United Nations Water, 2021), with projections predicting a 40 per cent shortfall of freshwater by 2030 (Global Commission on the Economics of Water, 2023), triggered by human activity (Yao et al., 2023) and leading to increasing tensions within and between countries and the displacement of affected populations.

[18] This mirrors the scarcity in environmental research, especially on climate impacts, for low-income countries. In these countries, 23 per cent of the population live in areas that remain uncovered by research on local climate impacts, compared to only 3 per cent in high-income countries (Callaghan et al., 2021). This is also the case in dimensions such as water access.

4. Environmental sustainability in the context of digital and development divides

In the digitalization and environmental sustainability nexus, the distribution of environmental impact is linked to countries' geographical location and socioeconomic status. The disparities in income, wealth, digital access and use, and development have been further exacerbated by the COVID-19 pandemic and recent geopolitical tensions. This underscores the need for nuanced policy responses to address these divides.

Developed countries have generated the bulk of emissions while propelling their economic development, with Europe and North America responsible for approximately 40 per cent of anthropogenic CO_2 emissions since 1850 (Chancel et al., 2023; Diffenbaugh and Burke, 2019; IPCC, 2023). The Paris Agreement of 2015 (UNFCCC, 2016) acknowledged this historical fact and placed a greater responsibility on these countries for future GHG reduction efforts.

However, the inequality in emissions transcends national borders, reflecting a stark divide in consumption patterns across different income groups. The wealthiest 10 per cent of the population in every region emit significantly more than the global average (Chancel et al., 2023), associated with overconsumption by wealthy individuals.

While global Internet use surged from 35 to 67 per cent between 2013 and 2023, the digital divide remains a significant barrier to socioeconomic development in an increasingly digitalized world.[19] Despite advances in ICT infrastructure, disparities in access and use persist, particularly between high-income and low-income countries, including LDCs. These divides encompass not just the number of devices and Internet connections per capita, but also the affordability of digital services, the quality of infrastructure and the digital literacy of individuals and businesses. The disparities in Internet use intensity – the data divide – are driven by varying levels of development and highlight missed chances for leveraging digitalization for the Sustainable Development Goals (UNCTAD, 2021a). Particularly pronounced in LDCs and remote Small Island Developing States, the digital divide is exacerbated by factors such as socioeconomic status, location, age and gender.

Overall, the divides in terms of development, environment and digitalization are interrelated, emphasizing the need to address them holistically. Developing regions are primary providers of many of the raw materials required for digitalization, with extractive processes that can lead to land degradation. Furthermore, developing countries contribute to the part of global value chains where value addition is relatively small and therefore have limited scope for accelerated economic growth. At the end of the life cycle of digital technologies, developing countries are the destination for an important share of waste from global digitalization, which opens up another dimension of the digital divide. As noted above, these countries are also more affected by climate change, which directly impacts their options for socioeconomic development. Moreover, low-income countries are less able to afford and harness digital tools to mitigate various environmental impacts. Thus, the opportunities for technologies to address these environmental concerns in the short term are possibly overstated.

Divides in development, environmental responsibility and impact, and digitalization are interrelated and need to be addressed holistically

By contrast, consumption patterns in developed countries and of wealthy individuals everywhere are increasingly marked by overconsumption. This is both in terms of digitalization, for instance measured by the number of devices per person, and the environment, measured in terms of the multiples of CO_2 emissions per capita. Additionally, this group causes

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[19] ITU (2023). Key ICT indicators, available at https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx.

environmental externalities in developing countries due to the production of devices used in developed countries.

These factors point to the need for developed countries and digitally advanced economies to assume particular responsibility for ensuring a transition towards a more environmentally sustainable digital economy that can generate inclusive development. At the same time, efforts are needed to strengthen the ability of many developing countries to better harness opportunities from digitalization in an environmentally sustainable manner.

C. Conclusions and roadmap for the rest of the report

Amid environmental crises and digitalization, **developing countries face a double bind…**

…they are **most vulnerable** to digitalization's negative impacts **yet least equipped to use digital tools for mitigation**

This chapter has highlighted the need to give more attention to the interlinkages between the rapidly evolving digital economy and environmental sustainability, and how they relate to trade and development. The expanding scale and changing nature of digitalization have environmental implications at all three stages of the life cycle of digital devices and infrastructure. Depending on their positioning, countries will encounter different opportunities and challenges at each stage. There is a need to improve the understanding of how countries at different levels of development are affected and how this affects global trade dynamics.

The relationship between digitalization and sustainability is bidirectional. Against a backdrop of multiple environmental crises and the importance of leveraging digital solutions for economic development and to tackle these challenges, it is increasingly important to consider how to reduce the environmental footprint of digitalization. However, this comes with a double bind for developing countries, in particular LDCs. On the one hand, they are often the most vulnerable to potential negative environmental and social effects arising from digitalization, relating to raw material extraction, carbon emissions, water consumption and waste from digitalization. On the other hand, they are less equipped to harness digital technologies to mitigate risks from climate change and other environmental crises.

Trade and technological change are integral parts of the significant transformation process that the world is undergoing. This is underscored by the urgent need to reduce carbon emissions, address widening economic inequalities and enable economic diversification and structural transformation. In the context of the interrelated nature of the Sustainable Development Goals, this requires policy integration and coherence at the national, regional and international levels. Against this background, this report seeks to contribute to a better understanding of the environmental impact of the production, use and end-of-life phases of digital devices and ICT infrastructure with a view to informing policy debates on digitalization, trade and environmentally sustainable and inclusive development.

While digital tools and solutions can be used to reduce the global environmental impact of various sectors and bring the 2030 Agenda for Sustainable Development back on track, positive outcomes cannot be taken for granted. As shown in this chapter, the overall environmental footprint of the digital economy is hard to assess and remains largely unknown. Identifying opportunities and risks from digitalization is hampered by a lack of agreement on what constitutes the ICT sector and its associated services, what criteria to include in an environmental impact assessment, a lack of broadly agreed methodologies to measure impact, and a lack of data.

The remainder of this report explores the direct environmental impacts along the three main stages of the ICT sector life cycle. Chapter II focuses on the environmental impacts of the production phase, from raw materials extraction and processing, as well as manufacturing of ICT devices and infrastructure. Chapter III turns to the use phase, giving special attention to the environmental impacts related to data centres and emerging technological applications. Chapter IV focuses on the end-of-life phase and the potential for fostering more circularity related to digital devices and infrastructure. Chapter V explores a case of indirect and rebound effects from ICT use, notably in the context of e-commerce. Finally, chapter VI discusses actions and policies to facilitate a more environmentally sustainable digital economy which is conducive to inclusive development.

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Addressing the surging demand for transition minerals will require rethinking models of consumption and production

Chapter II

Digitalization trends and the material footprint

The first phase of the life cycle of digitalization is the production of digital devices and ICT infrastructure. This phase covers the extraction and processing of materials, manufacturing and distribution of the digital products, accounting for the largest share of digitalization's environmental footprint.

There is growing demand for minerals and metals needed for the shift to low-carbon and digital technologies, which is part of a broad transformation in the world economy.

This can provide opportunities for many developing countries, provided they are able to add more value to their raw materials. In addition, the environmental and social implications of this production need to be managed. There is a need to reverse structural trade imbalances, wherein developing countries export raw minerals and import higher value-added manufactures, which contributes to an ecologically unequal exchange.

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A. Introduction

The digitalization life cycle starts with the production phase, which includes raw material extraction and refining, from which components are produced for the manufacturing of digital hardware and building of ICT infrastructure. The production stage mainly concerns the core digital sector (IT/ICT) included in the overall definition of the "digital economy" (UNCTAD, 2019a: figure I.1).

Within the digitalization life cycle, it is the production phase that has the largest overall environmental footprint (see chapter I). Most studies focus on the environmental footprint in terms of carbon emissions or energy impact. The material footprint of digitalization, which is the focus of this chapter, has received much less attention.[1]

Digitalization was expected to contribute to the dematerialization of the world economy. So far, that promise has not materialized (Creutzig et al., 2022; Dedryver, 2020; Hynes, 2022). Indeed, the increased global material footprint, which has quadrupled since 1970, is a growing concern (Lenzen et al., 2021). The 2024 Global Resources Outlook by the International Resources Panel (UNEP and IRP, 2024) warns that material resource extraction could increase by almost 60 per cent between 2020 and 2060, unless urgent and concerted action is taken to change the way resources are used. This projected increase would far exceed resources required to meet essential human needs, in line with the Sustainable Development Goals.

Moreover, the material footprint is highly unequal. In 2020, it was estimated that high-income countries had the highest material footprint per capita (24 tons), which was close to five times that of lower middle-income countries (5 tons) and six times the amount of low-income countries (4 tons) (UNEP and IRP, 2024).

Further, in assessing nations' cumulative material use in excess of equitable and sustainable boundaries, Hickel et al. (2022: e342) find that "high-income nations are responsible for 74 per cent of global excess material use, driven primarily by the United States (27 per cent) and the European Union 28 high-income countries (25 per cent). China is responsible for 15 per cent of global excess material use, and the rest of the Global South (i.e., the low-income and middle-income countries of Latin America and the Caribbean, Africa, the Middle East, and Asia) is responsible for only 8 per cent. Overshoot in higher-income nations is driven disproportionately by the use of abiotic materials, whereas in lower-income nations it is driven disproportionately by the use of biomass".

Material resources extraction and processing affect all aspects of the triple planetary crisis. They account for 60 per cent of GHG emissions, over 90 per cent of biodiversity impact and 40 per cent of pollution-related health impacts. This is likely to continue due to unchecked resource use and affluent lifestyles in high-income countries, while a significant share of the world's population cannot meet basic human needs (UNEP and IRP, 2024).

However, this exponential surge in demand is raising concerns that it will collide with the limits of finite resources. Increasing costs and efforts for extraction, as discoveries of deposits and mineral ores decline, are resulting in a growing interest in exploring mineral resources in uncharted areas such as in the ocean bed and in outer space. Mineral depletion will require a rethinking of the use of resources and a move

> The promise of the dematerialization of the world economy following digitalization has not materialized

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[1] Material footprint is defined as the total amount of raw materials extracted to meet final consumption demands. See https://unstats.un.org/sdgs/report/2019/goal-12/.

towards more responsible and sustainable modes of consumption and production.

A transition to low-carbon technologies can only be successful with the support of digital tools, and digitalization needs to be environmentally sustainable

Given this context, this chapter focuses on the material footprint of digitalization, with a particular emphasis on the dynamics of minerals and metals use, and the implications for trade and development. It emphasizes the need to consider the shift to a low-carbon and digital economy as part of a (single) transition, which requires vast amounts of minerals and metals. A transition to low-carbon technologies can only be successful with the support of digital tools, and digitalization needs to be environmentally sustainable. The analysis in this report uses the term "transition minerals and metals", or "transition minerals" for short.

Section B analyses the material footprint of digitalization. Section C reflects on demand projections and possible supply responses related to transition minerals. Section D discusses international minerals markets, which are strongly influenced by geopolitics. Opportunities for developing countries for inclusive and sustainable development outcomes from increased minerals demand are highlighted in section E. Negative environmental and social impacts that mining generates, including on human rights, are presented in Section F. Section G provides conclusions.

B. The expanding material footprint of digitalization

The generalized idea that digitalization, by moving activities from the analogue, physical world to the digital, virtual world will lead to dematerialization, is not matched by reality. The digital society and economy are commonly associated with concepts such as "virtual", "intangibles" or the "cloud", which imply an ethereal world, yet these are far from being dematerialized. Indeed, digitalization is relatively material-intensive, as it involves the use of significant amounts of physical materials, particularly to produce digital hardware or to build ICT infrastructure, not to mention its high energy demands during the use stage (see chapter III).

Estimations of the materials used for digitalization do not abound.[2] This section discusses the material composition of digital devices and ICT infrastructure, focusing on minerals and metals, and presents trends in digitalization that are leading to increased demand for resources that are also needed for low-carbon technologies.

1. The material composition of digital hardware and ICT infrastructure

Digitalization strongly relies on the physical world and involves large amounts of material consumption (UNEP, 2021a), particularly to produce digital devices, including the batteries powering them, and to build digital infrastructure such as transmission networks and data centres (CODES, 2022).

While the digital world is based on data, which are intangible, these data need physical supports. First, the interface between humans and the digital world is enabled through physical devices such as mobile phones or smartphones, personal

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[2] For example, Ademe and Arcep (2023) estimates that, on average, a person living in France generates 949 kg/year of resources through ICT use and the production of devices, and 301 kg/year of waste (including electronics and linked to the extraction of raw materials).

computers, tablets, smart televisions and wearable devices;[3] this is how people connect with the digital world in their daily lives. Second, communications and data transmissions pass through infrastructures such as mobile transmission networks, fibre optics, submarine cables or satellites. Finally, the storage of data and cloud services takes place in data centres, which are heavy users of hardware and IT equipment. Some of the largest data centres may contain tens of thousands of servers (Lehdonvirta, 2023).

Digital devices, hardware and digital infrastructure are composed of plastics, glass and ceramics, as well as several dozens of minerals and metals; for instance, Bookhagen et al. (2020) estimate that for a smartphone, metals represent 45 per cent of the total composition, with the display or glass accounting for 32 per cent, plastics, 17 per cent, and other materials, 6 per cent. Moreover, most of the metal value (72 per cent) comes from gold.[4] In economic terms, an analysis of the composition of an iPhone 6 (16 GB) smartphone suggests that the price of the mineral content was about $1 (Valero et al., 2021; Merchant, 2017). However, it is necessary to go beyond economic value and factor in social and environmental externalities.

The analysis in this chapter focuses on the minerals and metals composition of devices and ICT infrastructure, as these raw materials primarily contribute to essential digital, electronic and electric functionalities. Properties of minerals and metals contribute to conductivity, durability and energy density and increase the capacity for energy storage and enable devices to be lightweight. Minerals and metals also have electronic, magnetic, mechanical or optical properties, depending on the mineral or metal used. These materials are of particular importance for developing countries, which are often major producers and exporters of these resources. Other components also have a significant environmental impact, particularly plastics, although they are not as integral to the digitalization process as minerals and metals. Plastics are generally used in overall production processes and used in all countries.[5]

In recent years, minerals have received increased attention, as they have become essential for the functioning of modern societies, particularly for advancing both low-carbon and digital technologies, and especially in the context of mitigating climate change. While there has been much discussion of “critical” and “strategic” minerals (or metals, materials and raw materials) as well as “energy transition minerals”, including battery minerals (UNCTAD, 2020), far less attention has been paid to their role in the context of digitalization.

While there has been much discussion of “critical” and “strategic” minerals and metals, far less attention has been paid to their role in digitalization

Many countries are adopting the term “critical minerals” and are establishing lists of such minerals or raw materials. However, there is no standard definition of “criticality”; it varies over time and depends on individual country objectives. Criticality generally refers to economic importance and strategic interest, import dependence and vulnerability of the mining supply chain (Hendriwardani and Ramdoo, 2022). These lists mostly focus on the energy aspect of the transition. However, as illustrated in figure II.1, almost

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[3] Given the rapid evolution of digital technologies, the definition of what is a digital or electronic device is a moving target. For example, while some years ago a television would not have been considered a digital device, at present, smart televisions can qualify as such. Similarly, as cars are increasingly based on electronics rather than on mechanics, they are becoming “computers on wheels”; according to Accenture (2022), an automobile may contain between 1,000 and 3,500 semiconductors.

[4] According to another estimate of the composition of smartphones, plastics and synthetics account for 30 to 50 per cent of the materials, glass and ceramics represent 10 to 20 per cent and metals represent 40 to 60 per cent (Berthoud, 2021). See also https://www.dailymail.co.uk/news/article-10727189/How-ton-iPhones-300-times-gold-ton-gold-ore-REALLY-screen.html.

[5] Recent work by UNCTAD in relation to plastics is available at https://unctad.org/data-visualization/global-plastics-trade-reached-nearly-1.2-trillion-2021 and https://unctad.org/news/how-build-concerted-multilateral-action-plastic-pollution. See also UNCTAD (2023b).

all materials deemed critical hold significance for both digital and low-carbon technologies, with the exception of potassium.[6]

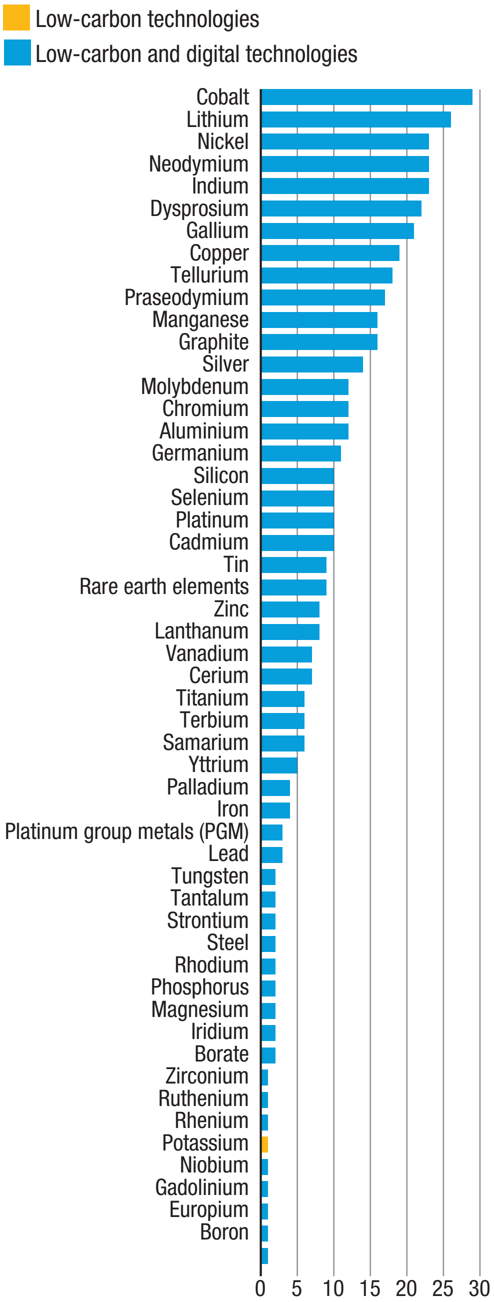
As noted, this report takes a broader approach than is generally seen and addresses the shift towards a low-carbon and digital economy as part of one single transition.

The high intensity of minerals and metals in the transition towards a low-carbon and digital economy implies that the world is moving from dependence on fossil fuels to dependence on multiple elements in the periodic table. Digital devices and hardware may contain dozens of minerals and metals, which are essential for their functioning and cannot be easily substituted. The amount of minerals and metals used in a device may be very small, particularly in view of the general trend towards miniaturization, which complicates recycling of these materials or metals once they become waste (chapter IV). However, as digitalization evolves, the larger volumes of minerals and metals needed to match global demands are accompanied by an increase in the variety of elements required at high degrees of purity; this is to allow for the higher complexity and continuously improved performance of devices. In the case of telephones, as illustrated in figure II.2, the number of elements used in telephones made in 1960 was 10, rising to 27 elements for telephones made in 1990. In 2021, a smartphone contained as many as 63 of the elements in the periodic table.

> Higher complexity and improved performance of devices require larger volumes and an increased variety of minerals and metals

Apart from being present in tiny amounts and in high numbers, minerals and metals are mixed in alloys, which makes separating for recycling and recovery purposes very difficult (chapter IV). Moreover, the high levels of purity needed are ensured through energy-intensive processing. Declining or low mineral concentration of the ores extracted also requires huge

Figure II.1
Number of lists compiled by countries of critical minerals/raw materials which include a certain critical mineral/raw material, by technology



Source: UNCTAD, based on IRENA (2023) and Carrara et al. (2023).

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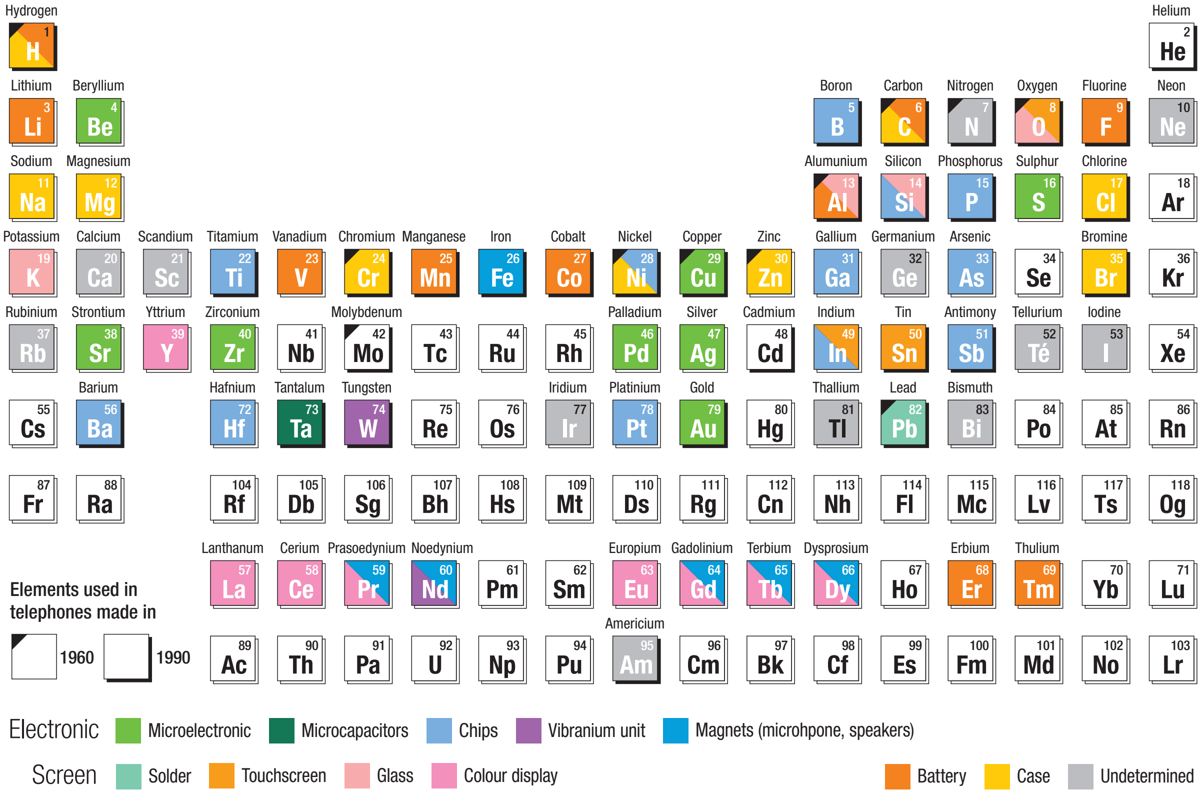
[6] Based on a review of various studies of digitalization and natural resources, including Carrara et al. (2023); Dedryver (2020); Deutsche Bank (2022); Eerola et al. (2021); Ganier (2021); Global Electronics Council (2021); GSMA (2022a); Marscheider-Weidemann et al. (2021); Poinssot et al. (2022) and University of Birmingham et al. (2021); see also https://www.visualcapitalist.com/visualizing-the-critical-metals-in-a-smartphone/.

Figure II.2

Evolution of elements of the periodic table contained in a phone

Elements used in smartphones in 2021, by component



Source: Le Monde Diplomatique, What's in a phone? October 2021.

amounts of ore to derive the final mineral content needed for the devices.

On average, over the past four decades, ore grades have declined by half for many commodities (Morrill et al., 2022). A study by the non-governmental organization Justice et Paix (2019) notes that manufacturing a 2 kg computer involves the extraction of 800 kg of raw materials. Generally, manufacturing electronic devices requires 50 to 350 times of their final material weight. Similarly, Ganier (2021) points out that 70 kg of raw materials are needed to produce, use and eliminate one smartphone.[7] Overall, this implies that the more efficient a product may be in terms of its performance for digitalization purposes, the less efficient it becomes in terms of material use (Valero et al., 2021).

While minerals and metals are essential for digitalization even if used in tiny amounts, the influence of their use for digitalization in global markets varies. For some, their application for digital purposes represents a relatively lower share when compared to other uses or to the demand for minerals and metals. In some other cases, digitalization represents a major share of minerals and metals use (Pitron, 2021; Ericsson et al., 2020; Malmodin et al., 2018).

As the discussion in this chapter cannot cover all the minerals and metals used in digital technologies, a selection of elements

> The more efficient a product may be in its performance for digitalization purposes, the less efficient it becomes in material use

---

[7] In a discussion about material input per service unit, which indicates the quantity of resources used for a product or service, Pitron (2021) and Ritthoff et al. (2002) note the high levels present in digital technologies. For instance, in the case of semiconductors, an integrated circuit of 2 g requires 32 kg of material, at a ratio of 16,000 to 1. Pitron also notes that the weight of a mobile telephone is not about 150 g but may reach 150 kg, see *Reporterre* (2021).

is considered, notably aluminium, cobalt, copper, gold, lithium, manganese, natural graphite, nickel, rare earth elements and silicon metal.[8] The selection can be considered as sufficiently representative to illustrate relevant points, as it includes elements from various parts of devices, as well as from different minerals-producing developing countries.

2. Digitalization trends contributing to increased demand for minerals and metals

The discussion in the previous section implies that rapid digitalization cannot take place without the significant use of physical raw materials, including minerals and metals. Several factors can influence increases in global minerals and metals demand, such as population and economic growth, as well as urbanization trends. The recent surge in mineral demand is mostly attributed to their use in low-carbon technologies, such as for renewable energies and electric vehicles (Hund et al., 2020; IEA, 2021a). According to IEA (2023a), as a result of increasing demand and prices, the market value for transition minerals doubled between 2017 and 2022.

However, exponential growth in the demand for digital devices and ICT infrastructure, as well as for computing power and data, is further accentuating the push for the increased extraction of minerals and metals (figure II.3).

Exponential growth in the demand for digital products and services is further accentuating the push for increased mineral extraction

This section provides some evidence of the evolution of Internet and data traffic, and discusses trends related to the demand for digital devices, hardware and equipment that enable connections; data transmission infrastructure; and dynamics in relation to data centres, which are essential for data storage, processing and use. While trends are presented with a broad time perspective, the focus is on the prospects for demand related to digital devices and hardware that could influence minerals and metals consumption in future. To the extent possible, trends are expressed in volume terms, as the environmental dimension is more closely associated with material aspects rather than with economic value.

a. Internet and data traffic

Internet traffic relates to the volume of different online activities, while data traffic encompasses the volume of exchanged data. UNCTAD (2019a, 2021a) has provided evidence of the surge in Internet and data traffic over the past couple of decades. Various industry sources suggest that these exponential trends are expected to continue, as follows:

- Reinsel et al. (2018) predicted that the global datasphere would grow from 33 zettabytes in 2018 to 175 zettabytes by 2025. Estimations by Burgener and Rydning (2022) project data to grow at a compound annual growth rate of 21.2 per cent between 2021 and 2026, to reach more than 221 zettabytes.[9]
- According to TeleGeography (2024a), the growth in international Internet bandwidth largely mirrors that of Internet traffic. Global Internet bandwidth has tripled from 2019, to reach 1,217 Tbps in 2023.[10]
- According to Ericsson (2023a),[11] global data traffic saw a fourfold increase from 2018 to 2023, when it reached 490 (EB) exabytes per month. Fixed data traffic represented about two thirds of overall data traffic, with mobile network traffic (i.e., mobile data and fixed wireless access

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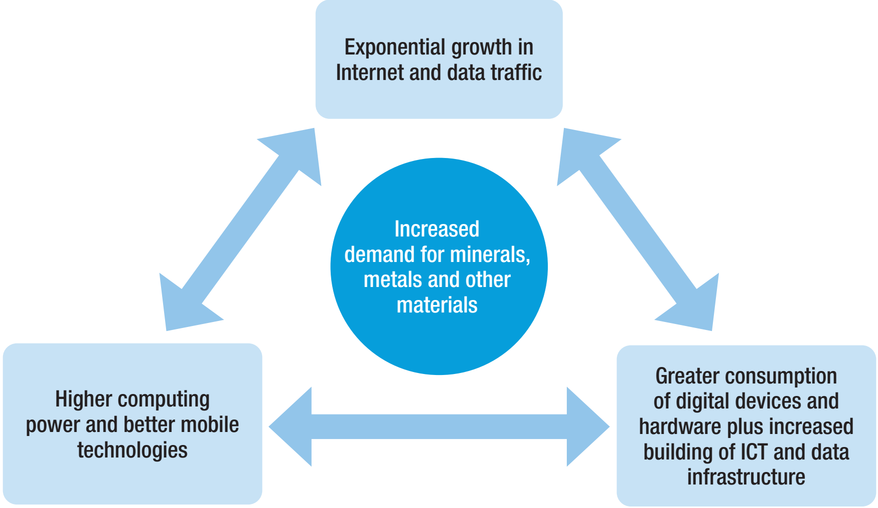
[8] The choice is based on a review of the studies on digitalization and natural resources cited in footnote 7.

[9] One zettabyte is equal to 1,000 exabytes.

[10] Tbps refers to Terabytes per second, i.e. 1,000 gigabytes per second.

[11] Total data traffic in this source includes mobile data, fixed wireless access and fixed data. Statistics on Internet and data traffic are often provided by private companies whose methodology is not standardized. It is therefore useful to look at more than one estimate. Nevertheless, all estimates show that the trend of rapidly increasing Internet and data traffic is likely to continue in future.

Figure II.3
Dynamics of increased material consumption and digitalization trends



Source: UNCTAD.

traffic) accounting for the remaining third. Global mobile network data traffic almost doubled in two years, to reach 160 EB/month in 2023 (Ericsson, 2022, 2023a).

- Video traffic is estimated to account for almost three quarters of all mobile data traffic (73 per cent), mainly through smartphone use. Globally, growth in mobile data traffic per smartphone can be attributed to three main drivers, namely, improved device capabilities, an increase in data-intensive content and growth in data consumption due to continued improvements in the performance of deployed networks.
- Concerning future trends, the volume of global data traffic is forecast to grow by a factor of 2.5 by 2029, reaching 1,223 EB/month. By 2029, the share of fixed data traffic is expected to shrink to 54 per cent, as mobile network traffic will experience faster growth, reaching 46 per cent (Ericsson, 2023a).

In 2023, almost one third of global mobile data traffic was generated in Northeast Asia, followed by the group formed by Bhutan, India and Nepal (figure II.4).[12] In China, mobile data traffic accounted for more than the combined mobile data traffic of North America and Western Europe. In absolute terms, developing regions are forecast to drive the global increase in mobile data traffic in the period 2023–2029. Large markets at early stages of launching fifth-generation (5G) mobile networks are likely to further boost mobile traffic. Sub-Saharan Africa had the lowest mobile data traffic in 2023, but this region is forecast to experience the most dynamic growth in 2023–2029 (Ericsson, 2023a).

Much of the increase in Internet and data traffic will be enabled by improvements in mobile technologies. The commercial roll-out (infrastructure supply side) of 5G technologies that started at the end of the 2010s reached 280 networks globally in 2023, a notable increase from 228 in 2022. Access to 5G networks is expected to experience the most significant growth in the near future, with global population coverage rising from an estimated 45 per cent in 2023 to around 85 per cent by 2029 (Ericsson, 2022, 2023a).

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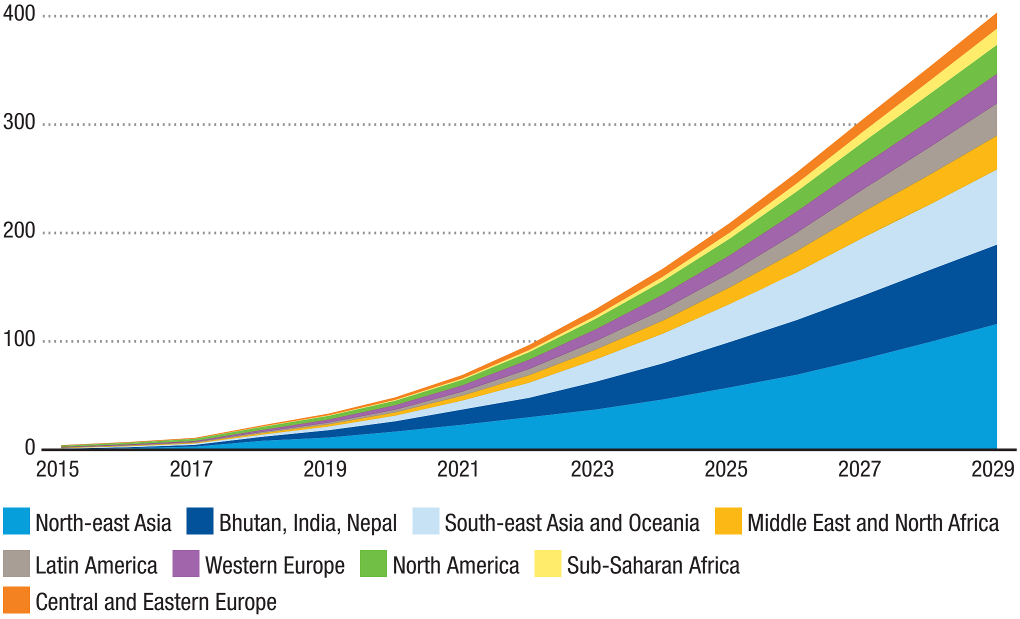
[12] This grouping is provided in Ericsson (2023a). The large volume of data traffic in the latter group likely reflects mainly usage in India.

Figure II.4
Mobile data traffic by country grouping, 2015–2029

(Exabytes/month)



Source: UNCTAD, based on Ericsson (2023b).

Note: Country groupings are as defined in the source.

Demand for 5G technology, in terms of number of subscriptions, is set to remain strong in the future. In 2023, such mobile networks represented about one fifth of all subscriptions. They are forecast to become the dominant mobile access technology by subscription in 2028 (figure II.5.a). By the end of 2029, there may be over 5 billion 5G subscriptions globally, accounting for almost 60 per cent of all mobile subscriptions.[13] This expansion will be led by Northeast Asia, notably China, followed by India. By 2029, these will account for half of all worldwide 5G subscriptions (figure II.5.b).

The shift to 5G will be accompanied by an increased supply of 5G-compatible devices, such as smartphones.[14] Devices operating on 3G and 4G are not fit to use 5G infrastructure. Sharply escalating data traffic due to 5G technology, coupled with a growing number of devices connecting to the Internet, could counteract potential gains in power efficiency brought about by 5G.[15] Building 5G networks requires extensive new and upgraded physical infrastructure, with only a small number of companies globally being able to provide the necessary equipment (*Foreign Policy*, 2021). Higher speeds and capacity enabled by 5G technology may lead to rebound effects and even more demand for devices, particularly smartphones. According to one forecast, shipments of 5G smartphones, as a share of all shipped smartphones, could rise from 61 per cent in 2023 to 83 per cent by 2027.[16]

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[13] A similar forecast is advanced in GSMA (2023b), which states that 5G connections will represent 54 per cent of all connections by 2030.

[14] In January 2022, 5G smartphone sales penetration was estimated to have surpassed 4G; see https://www.counterpointresearch.com/insights/global-5g-smartphone-sales-penetration-surpassed-4g-first-time-january-2022/.

[15] See https://www.ft.com/content/a679291a-0f93-48f2-aac8-8cc5b108c79b.

[16] See https://www.idc.com/getdoc.jsp?containerId=prUS51430223.

Figure II.5.a
Global mobile subscriptions, by technology, 2018–2029
(Millions)

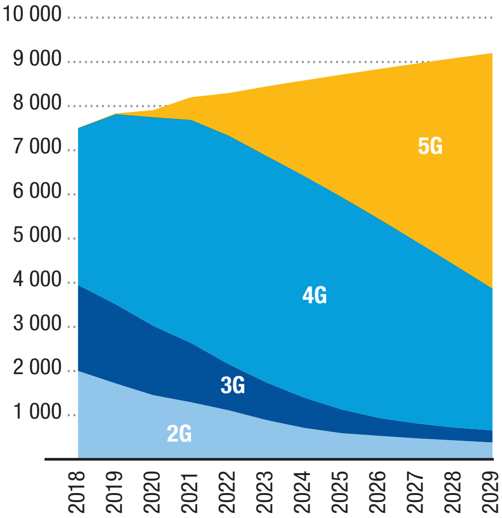
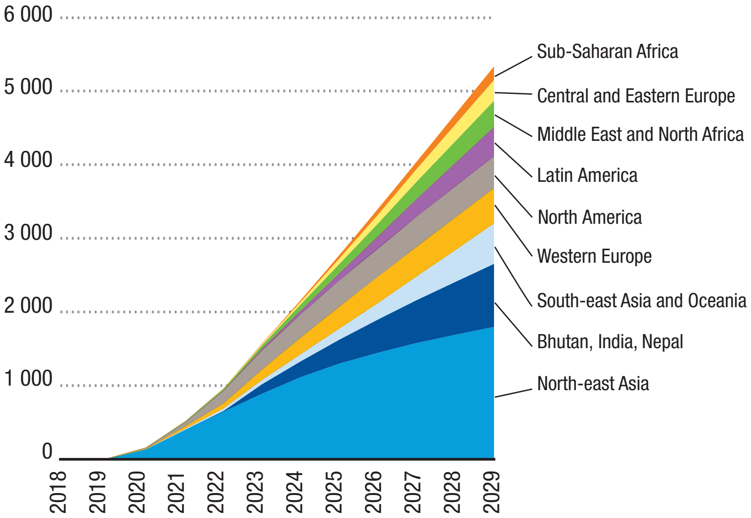


Figure II.5.b
Mobile 5G subscriptions, by country groupings, 2018–2029
(Millions)



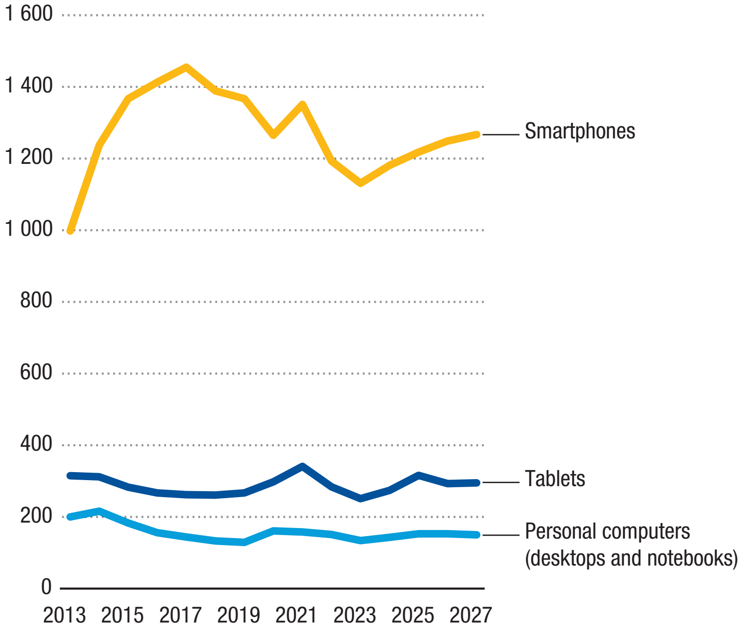
Source: UNCTAD, based on Ericsson (2023b).
Note: Country groupings are as defined in the source.

b. Devices and hardware for digital connections

The most popular digital devices over the past decade have been smartphones, personal computers and tablets, with smartphones accounting for the largest share (figure II.6). According to data provided by Canalys, global shipments of smartphones experienced robust growth from the beginning of the 2010s until 2017, when they peaked at nearly 1.5 billion units. Shipments then decreased until 2020, before bouncing back in 2021, linked to increased demand due to the pandemic. It is forecast that smartphone shipments will rebound in 2024 and reach almost 1.3 billion units by 2027.

The trend in personal computers (desktops and notebooks) has followed a different trajectory, declining until 2018 and then increasing, although recording a similar decline in 2022–2023. Worldwide tablet shipments also fell until 2019, followed by a rebound in 2020. Shipments of both

Figure II.6
Global shipments of selected digital devices, 2013–2027
(Millions of units)



Source: UNCTAD, based on data provided by Canalys.

personal computers and tablets are forecast to stay relatively flat between 2024–2027.[17]

An important growth area is seen in IoT devices, which include connected vehicles, machines, meters, sensors, point-of-sale terminals, consumer electronics and wearables.[18] It is estimated that about 39 billion connections will be related to IoT by 2029, compared to around 16 billion connections in 2023. As of 2021, such connections surpassed those of conventional devices (personal computer, tablet, mobile and fixed telephone), a trend which will strongly continue up to 2029.[19] The average number of IoT devices per capita will double from two in 2023 to more than four in 2029.[20] Other sources of data also show these increasing trends.[21] A forecast by GSMA Intelligence (Iji and Gurung, 2023), indicates that IoT connections will reach over 38 billion by 2030, with the enterprise segment accounting for more than 60 per cent of the total.

The regional distribution of cellular IoT connections reconfirms the dominance of North-east Asia (mainly China), with almost 70 per cent of the total in 2023 (figure II.7).

Demand for electric vehicles, which have become more like "computers on wheels" (Eisler, 2023), has become a leading factor in the increased consumption of minerals and metals.[22] It is estimated that electric vehicles use about six times more minerals than conventional vehicles (IEA, 2021b). According to estimations by IEA (2023b), sales of electric vehicles increased progressively during the 2010s, with 2 million units sold in 2018–2019, rising to 14 million in 2023.[23] Projected sales by 2030 are around at least 40 million.[24]

Apart from the demand generated by devices, trends in component sales are also linked to the demand for minerals and metals. Batteries and semiconductors, in particular, have been at the centre of supply chain bottlenecks in recent years. While there are different kinds of batteries, those used in electronic products are mostly lithium-ion batteries. In the 2000s, electronics were the primary drivers of demand for this kind of battery. This was maintained until the mid-2010s, when

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[17] Estimations by IDC also point to a decrease of shipments between 2022 and 2023 for smartphones and personal computers reaching 1.17 billion and 259.5 million units, respectively. However, with the migration to 5G smartphones in emerging markets, as well as scheduled updates for personal computers, among other factors, it is forecasted that both smartphones and personal computer shipments will increase from 2024 onwards, to reach almost 1.3 billion and 285 million by 2027, respectively. IDC also forecasts the trend for tablet shipments as upward but more moderate, from 134 million units in 2023 to around 136 million units by 2027. See IDC (2024a) for personal computers, IDC (2023a, 2024b) for smartphones and IDC (2023a) for tablets.

[18] For example, global annual shipments of wearable devices are expected to increase from about 520 million units in 2023 to 625 million units in 2027 (IDC, 2023b); shipments of smart home devices are expected to rise from 860 million units in 2023 to 1.1 billion in 2027 (IDC, 2023c).

[19] UNCTAD, based on Ericsson (2023b).

[20] UNCTAD calculations, based on Ericsson (2023b) and the UNCTADstat database.

[21] IoT Analytics estimated that there were 14.4 billion IoT connections in 2022, forecast to reach over 29 billion in 2027 (see https://iot-analytics.com/number-connected-iot-devices/). In 2022, GSMA Intelligence forecast that the number of IoT connections (enterprise and consumer) would reach 37.4 billion globally by 2030, up from 15.1 billion in 2021; enterprise connections would be the main driver of growth, accounting for 76 per cent of the increase over the forecast period. Enterprise connections will surpass consumer connections in 2024 (Hatt et al., 2022).

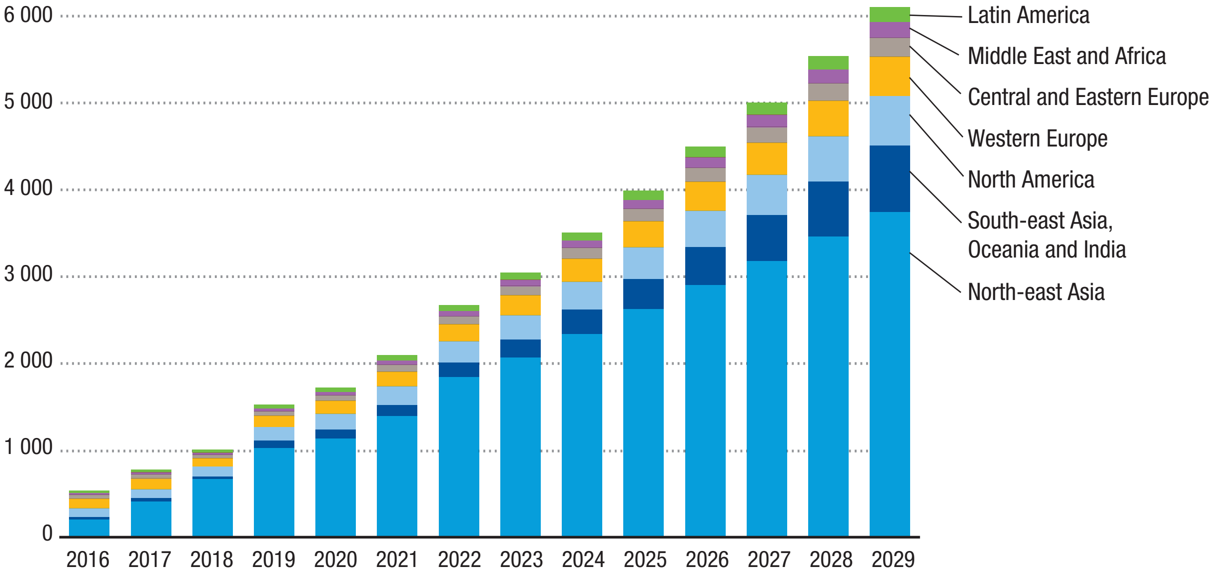
[22] See footnote 3.

[23] The term electric vehicle is used to refer to both battery electric and plug-in hybrid electric vehicles (IEA, 2023b).

[24] China is the main market for electric vehicles, accounting for around 60 per cent of global sales. More than half of electric vehicles in the world are in China. Europe is the second largest market, and sales increased by over 15 per cent in 2022, with electric vehicles accounting for one in every five vehicles sold. Electric vehicle sales in the United States, the third largest market, increased by 55 per cent from 2021 to 2022, reaching a sales market share of 8 per cent.

Figure II.7
IoT devices with cellular connections, by country grouping, 2016–2029

(Millions of connections)



Source: UNCTAD, based on Ericsson (2023b).

Note: Country groupings are as provided in the source (2023 data are estimates).

demand for lithium-ion batteries increased exponentially due to the growing popularity of electric vehicles. In 2022, electronics accounted for about 13 per cent of total lithium-ion battery demand, of about 90 GWh/year (BloombergNEF, 2023a).[25]

When analysing the demand for batteries by application, Liu et al. (2022) show that in 2018, demand for consumer electronics was 20.5 per cent of the total, although this share is expected to decline to 2.6 per cent in 2030. Thus, although demand is still increasing,[26] it plays a minor role compared to the 88.9 per cent share for electric mobility. In geographic terms, in 2018, China accounted for 68.5 per cent of the total battery demand, a share that is set to drop to 42.8 per cent in 2030.

In order to match increasing demand, there are projects in place to substantially increase production by building battery gigafactories around the world. Benchmark Source (2023) estimates that by the end of 2023, there were over 240 gigafactories in operation across the world, with forecasts for over 400 by 2030. In 2023, 82 per cent of gigafactory capacity was located in China. It is anticipated that as a result of policies in some developed countries encouraging domestic production may lead to a drop to 68 per cent in 2030. By comparison, in May 2022, estimates for gigafactories in the pipeline reached 304, marking a significant increase from the number planned in September 2019, implying a tripling of the initial figure. China is expected to remain the dominant player for the next decade (Stichting Onderzoek Multinationale Ondernemingen (SOMO), 2023).[27] By late 2023, no plans for battery gigafactories were known to have been registered in

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[25] Data based on BloombergNEF's web page for the presentation of the Electric Vehicle Outlook 2023, at https://about.bnef.com/electric-vehicle-outlook/ (accessed on 10 January 2024).

[26] Demand for consumer electronics would increase from 38 GWh in 2018 to 69 GWh in 2030 (see https://battery2030.eu/battery2030/about-us/impact-and-challenges/).

[27] On the increase in international investment in battery manufacturing projects, see also UNCTAD (2023d).

Africa or Latin America, where a large majority of battery minerals are extracted.

Semiconductors are another important component of electronic devices that have been registering increasing demand and, notably, supply shortages. Semiconductor sales reached record levels in 2022 in terms of both value and units sold. Unit sales surged from about 25 billion in 2001 to nearly 100 billion in 2022. Global demand for semiconductor manufacturing capacity is projected to increase by 56 per cent by 2030.[28]

The per capita use of devices and connections illustrates the magnitude of the digital divide between developed and developing countries

Beyond the absolute volumes of devices, the number of devices and connections per capita, as presented in figure II.8, illustrates the magnitude of the divide between North America and Western Europe, on the one hand, and developing regions such as Asia and Pacific, Latin America and the Middle East and Africa on the other.

Similarly, estimations by Baldé et al. (2024) of the global average number of per capita items in stock, by country income level, for the e-waste categories that refer more specifically to digitalization[29] show that in 2022, on average, ownership per capita was seven devices in high-income countries, 1.4 in upper middle-income countries, 0.7 in lower middle-income countries and 0.2 in low-income countries.

Additionally, trends in robotics are influencing demand for raw materials related to digitalization. Worldwide installations of industrial robots and professional service robots reached 553,000 and 158,000 units respectively, in 2022.[30] Over the previous decade, annual increases in industrial robots were registered, except in 2019 and 2020, due to the pandemic (International Federation of Robotics, 2023).

In 2022, seven out of ten industrial robots were installed in Asia and Oceania, followed by Europe and the Americas. China alone accounted for half of global industrial robot installations in 2022, up from 14 per cent in 2012. China was followed by Japan, the United States, the Republic of Korea and Germany; combined, these five countries reached almost 80 per cent of global installations in 2022. The electrical and electronics industry became the main user of industrial robots in 2020 (overtaking the automotive industry) and has maintained this position, reaching almost 157,000 units in 2022, accounting for more than one fourth of all robots (Müller, 2023a).

In terms of the operational stock of industrial robots (i.e. the accumulated number of robots in use), the installed base tripled between 2012 and 2022, from 1,235 to 3,904 thousand units (International Federation of Robotics, 2023). This is likely to grow in the future on the basis of increasing expectations of installations, which could reach 600,000 units per year worldwide by 2024 and 700,000 units in 2026 (Müller, 2023a).

c. Data transmission infrastructure

Most data flow through submarine cables. The total number of such cables worldwide is constantly changing, as older cables are decommissioned and new cables enter service. Nevertheless, the overall trend is upward. The number of submarine cables grew from 428 in 2017 to 574 active and planned cables in early 2021. During the same period, the combined length of such cables rose from 1.1 million to 1.4 million km (TeleGeography, 2017, 2021, 2024b). This

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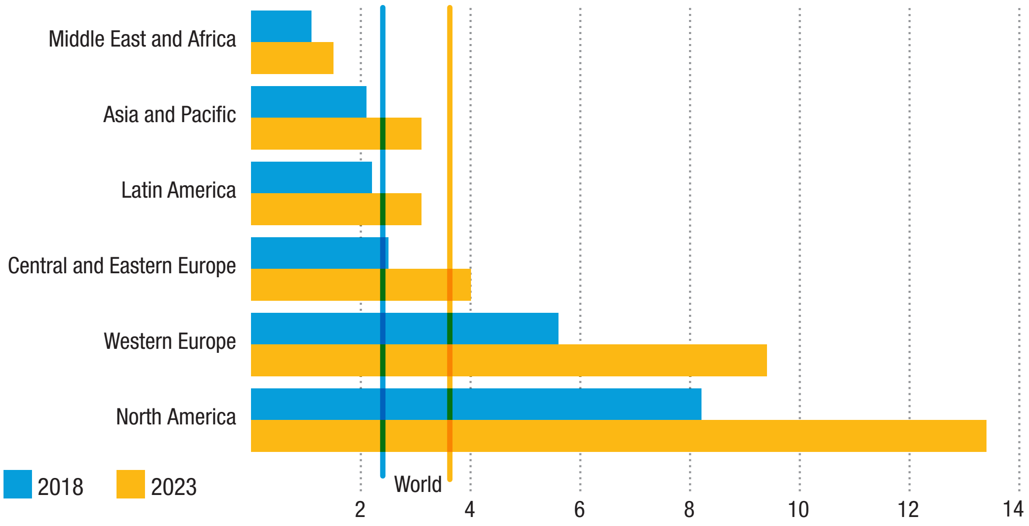
[28] See https://www.semiconductors.org/despite-short-term-cyclical-downturn-global-semiconductor-markets-long-term-outlook-is-strong/.

[29] This refers to screens and monitors, as well as small IT and telecommunications equipment. For a more detailed discussion on the e-waste categories used by UNITAR, see chapter IV.

[30] Robots are as defined by the International Organization for Standardization and the following categories of products are non-robot ones: software (bots, AI, robotic process automation), remote-controlled drones, voice assistants, autonomous cars, automated teller machines, smart washing machines. Consumer (as opposed to professional) service robots reached 5 million units in 2022 (International Federation of Robotics, 2023).

Figure II.8
Average number of devices and connections per capita, by region, 2018 and 2023



Source: UNCTAD, based on Cisco (2020).

Note: Country groupings are as defined in the source.

trend is expected to continue until 2025, reaching nearly 1.6 million km, then declining to around 1.4 million km in 2028–2032, before rising again to 1.6 million km in 2035 (Stronge and Mauldin, 2023).

Online content providers (such as Google, Facebook, Microsoft and Amazon) are now the major investors in new submarine cables. In recent years, the capacity deployed by private network operators has outpaced Internet backbone operators. Faced with the prospect of ongoing massive bandwidth growth, owning new submarine cables allows these users to have greater control of data flows (TeleGeography, 2021). Moreover, these companies can lay several cables along the same route, for security reasons and to prevent any slowdown in activity.[31]

Cables are engineered with a minimum design life of 25 years, although they may remain operational for longer. They may also be retired earlier, as cables become economically obsolete when they cannot provide as much capacity as newer cables at a comparable cost. It is expected that requirements for new cables will continuously increase from 2023; in 2035, half of the 1.6 million km of cables are likely to be newly built (Stronge and Mauldin, 2023).

Besides submarine cables, satellites also play a growing role in Internet traffic and data transfers, particularly for remote locations. As of April 2023, there were 7,560 operating satellites in space, a sharp increase by more than 2,000 units compared to the same period in 2022 (5,465 units). Almost 7 out of 10 satellite operators or owners were from the United States, followed by China, with 1 out of 10. The emergence of companies such as SpaceX and One Web, which operate low Earth orbit satellites to provide broadband Internet from space, has contributed to a sharp increase in the number of annual satellite launches. About 80 per cent of all operating satellites were launched in the period from 2019 to April 2023, with SpaceX accounting for more than half of all operating

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[31] See https://usbeketrica.com/fr/article/la-moitie-de-la-capacite-des-cables-mondiaux-est-aujourd-hui-utilisee-par-les-gafam.

satellites. In terms of use, 80 per cent (6,081 units) were commercial satellites, focussing mainly on communications.[32]

The extraordinary changes under way in outer space are expected to continue, with implications for sustainability, safety and security, as well as present and future governance (United Nations, 2023a).

d. Infrastructure for data storage, processing and use

Data centres are spaces where data are stored and processed. These facilities require huge computing capacity. While the relationship between data centres and the environment is mostly seen in terms of energy and water use (see chapter III), they also have a major impact on material demand through their use of computers and servers (Hoosain et al., 2023). The environmental sustainability of data centres needs to be assessed from a holistic perspective over their life cycles; decisions to frequently replace equipment to respond to energy efficiency requirements may lead to higher material consumption (Laurent and Dal Maso, 2020).

Frequently replacing equipment to respond to energy efficiency requirements may lead to higher material consumption

According to the Data Center Map, between January 2021 and January 2024, the number of co-location data centres increased from 4,714 to 5,522. The growth rate of installations was higher in developing economies (22 per cent) than in developed economies (16 per cent) in the same period. Still, more than 80 per cent of all data centres were located in developed countries as of January 2024.[33]

In addition to their increasing numbers, data centres have been evolving to meet the latest IT advancements and demand for compute-intensive workloads (cloud services, AI, machine learning, IoT, blockchain and cryptocurrencies, 5G networks, edge computing). These technologies require high processing power and high-density racks[34] that go beyond the traditional 2 to 5 kW. As a result, enterprise and on-premises data centres are increasing average rack density, a concern that was once unique to high-performance computing servers and hyperscale centres.[35] Increasing rack density means that more power and cooling capacity can be delivered for each server rack, which allows for more IT equipment to be hosted. For instance, a survey of data centres showed that average rack density had increased from 5 to 7.8 kW between 2018 and 2021 (Kleyman, 2021).

Data centres have also responded to demand for services by increasing the space of their facilities. For instance, while the number of hyperscale data centres has been growing rapidly, their total capacity has been growing even more quickly.[36] From 2016 to 2021, the number of hyperscale data centres doubled to 700 facilities worldwide, but it took less than four years (2017–2021) for their capacity to double. In 2022, there were already more than 800 hyperscale data centres, with the United States accounting for 53 per cent of their combined capacity, followed by Europe (16 per cent) and China (15 per cent). By mid-2023, the number of hyperscale data centres in operation was estimated to be 926, with a further 427 facilities in the pipeline. Meanwhile, the

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[32] UNCTAD calculations, based on data from https://www.ucsusa.org/resources/satellite-database (accessed on 30 March 2023).

[33] UNCTAD calculations, based on https://www.datacentermap.com/datacenters.html. Available data are based on entries primarily added and maintained by service providers. The database only includes countries with at least one or more data centre; if a country does not appear, this indicates that the country does not have a data centre or that data are not available.

[34] Rack density is the amount of power the equipment uses in a server rack, measured in rack density in kilowatts (kW) per cabinet and used as a factor in data centre design (particularly for capacity and cooling/ power planning). For more details, see Azap (2022).

[35] For a more detailed discussion, see Velimirovic (2021).

[36] Capacity is measured by critical IT load, which is the portion of electric power capacity, in megawatts, reserved solely for owners or tenants of a data centre to operate computer server equipment. The term does not include any ancillary load for cooling, lighting, common areas or other equipment. See Law Insider (2023).

average IT load of individual data centres is being ramped up and there is a likelihood of retrofitting existing data centres to boost capacity. The overall result is that the total capacity of all operational hyperscale data centres is expected to grow almost threefold between 2023 and 2029 (Synergy Research Group, 2021, 2022, 2023).

The surge in hardware and capacity in data centres is also the result of the increasing need to process data for use in new AI models. As these models grow and require more computing power and hardware to train the data, the environmental cost in terms of use of materials increases accordingly (Crawford, 2021).[37]

Taken together, the demand for digital devices and ICT and data infrastructure at all stages of the data value chain is set to remain strong over the next decade. Most of the demand for and the production of digital devices, data and ICT infrastructure is led by developed countries and Asia, particularly China, with limited contributions by Latin American and African countries. The dominance of a few large companies from the United States and China continues to increase (Moriniere, 2023; UNCTAD, 2021a).[38] These divides in terms of the demand and production of digital devices and hardware, as well as of digital infrastructure, suggest that developed countries and China together account for the majority of digitalization-related consumption of global minerals and metals. In contrast, other developing countries, particularly in Africa and Latin America, contribute much less.

> Developed countries and China account for most digitalization-related consumption of global minerals and metals, while other developing countries contribute much less

C. Demand projections and supply responses for transition minerals

1. Demand projections

Assessing future demand for minerals involves exploring potential scenarios that humanity may face in the coming decades. Numerous agencies and organizations have developed models to forecast such future scenarios. Until recently, most did not thoroughly consider the implications of mineral consumption stemming from the digital technologies they incorporated. However, concerns about the high demand for minerals for the technologies essential for the low-carbon transition have been noted. As emphasized above, digitalization relies largely on the same minerals. Two of the most prominent reports in the context of low-carbon technologies are from the World Bank (Hund et al., 2020) and IEA (2021a).

The study from the World Bank confirms that regardless of the chosen pathway to lower carbon emissions, the overall demand for minerals will inevitably increase significantly. Total anticipated minerals demand by 2050 varies from 1.8 billion to 3.5 billion tons, with the most ambitious scenario reflecting a fourfold increase compared to 2020 levels. To meet the growing demand for low-carbon technologies, production of minerals such as graphite, lithium and cobalt could increase by nearly 500 per cent by 2050.

Given the crucial role of mineral consumption, IEA (2023a) estimates the

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[37] Researchers measure the size of these models in terms of hundreds of billions of parameters, which are the internal connections used to learn patterns based on training data. For large language models such as ChatGPT, there was an increase from around 100 million parameters in 2018 to 500 billion in 2023 (Luccioni, 2023).

[38] See https://ecfr.eu/special/power-atlas/technology/.

The global response to surging demand for transition minerals mainly seems to centre on increasing minerals extraction

amount of the primary minerals required for the updated scenarios explored in the global energy and climate model of 2022 (figure II.9). The scenarios include the stated policies scenario and the net zero emissions scenario by 2050, and these are consistent with limiting the global temperature increase to 1.5°C. Consumption of each mineral is projected to increase substantially (except for silver), with platinum-group metals as the most prominent case, reaching almost 120 times the consumption level of 2022 under the second scenario. In addition, under this scenario, by 2050, low-carbon technologies could account for 40–50 per cent of the demand for copper and neodymium (a rare earth element), 50–60 per cent of the demand for nickel and cobalt and up to 90 per cent of the demand for lithium.[39]

Low-carbon technologies have rapidly emerged as the segment with the fastest growth in demand for transition minerals. A comparison of 11 reports providing critical minerals outlooks concurs on the increasing demand for minerals and their central role in the low-carbon transition (International Energy Forum and The Payne Institute for Public Policy at the Colorado School of Mines, 2023). However, these demand projections show large variations based on the different types of scenarios chosen, the mix of technologies deployed, assumptions about resource intensity, technology developments and recycling rates. Moreover, the focus of these models on the low-carbon or clean energy transition scenarios may lead to underestimations; demand for conventional purposes, reflecting usual growth and development trends, as well as for digitalization, may not be properly factored in. Overall, the share of increased demand for transition minerals that can be attributed to digitalization is not known.

2. Supply response in view of the limitations of a finite planet

The global response to surging demand for transition minerals mainly seems to centre on increasing minerals extraction. Importing countries aim to secure access to these minerals, often by ramping up domestic mining operations (section D.4), as part of widespread efforts to bridge the gaps between supply and demand in the mining sector. For example, global exploration budgets rose by 16 per cent in 2022, following a strong 34 per cent rebound in 2021. Latin America was the primary destination of 25 per cent of this exploration in 2022, while Africa was second, accounting for 17 per cent (S&P Global Market Intelligence, 2023). Investment in critical minerals development rose sharply, by 30 per cent in 2022, following a 20 per cent increase in 2021 (IEA, 2023a). It remains to be seen whether this investment will be enough to meet increasing demand.

Besides the push to extract more mineral resources around the world, and possibly reflecting concerns about the cost of extracting the anticipated volumes needed, there is interest in expanding the mining frontier beyond land-based territories. Growing demand for transition minerals, and the associated more exploration and extraction activity in mines on land is prompting actions towards expanding the mining frontier into uncharted areas. This includes mining in the deep sea and in space (box II.1).

Supply responses to the surging demand for transition minerals may lead to time lags and supply deficits in the short to medium term. This is because it takes several

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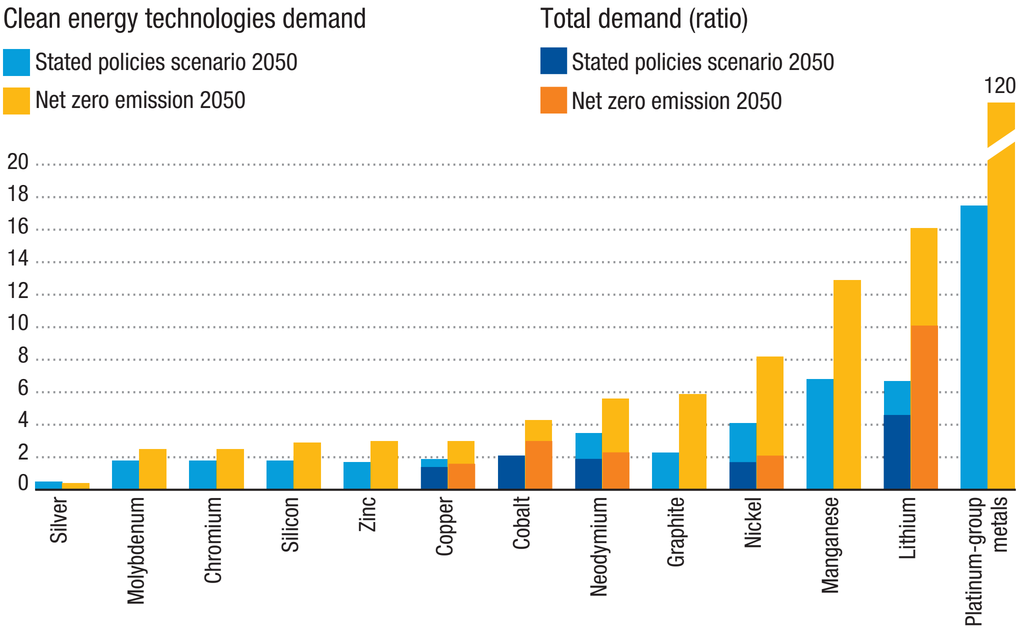
[39] UNCTAD, based on IEA (2023c).

Figure II.9
Projected increase in mineral demand by 2050
(Ratio of 2050 to 2022 consumption)



Source: UNCTAD, based on IEA (2023c).

Note: The figure shows minerals demand estimates for clean energy technologies for all minerals. Total demand estimates are provided by IEA only for copper, cobalt, lithium, nickel and neodymium

years between investing in exploration, developing mines and actual mineral production. However, a crucial question, from both an economic perspective and from an environmental and geological perspective, is whether there will be sufficient minerals to meet the huge needs for low-carbon and digital technologies.

As the world becomes more dependent on minerals that form the basis such technologies, the supply faces increasing pressures and extraction difficulties. Paradoxically, this could eventually become an obstacle to developing such technologies, as minerals could become increasingly costly to extract. Moreover, beyond the international inequalities related to mining, this could create intergenerational inequality. The overall conclusion of the potential limits to minerals supply on a finite planet, resulting from exponential demand and growth trends, is the need to rethink the use of transition minerals and move towards more responsible and sustainable modes of both consumption and production.

Most of the analyses of supply risk in the context of different criticality assessments for minerals and metals in many countries focus on the risks in producing countries, with an emphasis on geopolitical factors (see section D). Moreover, some optimistic views on the future availability of minerals resources tend to look at short to medium term behaviours and evolution, considering that the Earth has yet to be fully explored. However, these tend to neglect important physical geology aspects, including the technology required for extraction and the environmental, social and economic impacts that extreme mining could entail. All of these considerations are critical for making realistic assessments in this context. The annex to chapter II explores concerns about mineral depletion.

> A crucial question is whether there will be sufficient minerals to meet the huge needs for low-carbon and digital technologies

Box II.1
Is the expansion of the mining frontier sustainable?

In recent years, technological advances have made exploration in the deep sea and in space more feasible, and possible at relatively lower costs, which could lead to commercial mining in the near future. However, there is high uncertainty about the economic, social and environmental implications, as well as a lack of clarity about the international regulatory regimes that would apply. Notably, as both the deep sea and space are global commons, a key issue that needs to be clarified is the equitable sharing of benefits from the minerals extracted. The race for exploration and mining in the deep sea and in space is ongoing among major players with the expertise and necessary resources.

The 1982 United Nations Convention on the Law of the Sea restricted mining in the sea outside special "exclusive economic zones", i.e. the 200 nautical miles from the shores of countries. According to one of its provisions, if a country, collaborating with a mining company, applied to start deep sea mining, the International Seabed Authority (ISA), set up in 1994, had two years to finalize regulations or mining could commence. Nauru and the Metals Company made an application in June 2021, implying that if an agreement on new rules was not reached by July 2023, mining could start. By mid-2023, ISA had issued 31 exploration licences. Following negotiations, the Council of ISA was not able to finalize the regulations under the two-year rule, yet noted the intention to continue the elaboration of rules, regulations and procedures, with a view to their adoption at the thirtieth session of the Council in 2025.

The debate on the commercial exploitation of mineral resources from the deep sea has intensified in recent years. Those in favour point to the contribution to the necessary supply of minerals for low-carbon and digital technologies, as well as to unsustainable practices in land mining. By contrast, those against deep sea mining point to the need to protect the oceans, which may face significant environmental damage, and the need to increase research on little-known deep-sea ecosystems, before authorizing any extractive activity. One example is the exploitation of the Arctic. As the ice melts in this region due to the effects of climate change, mining activities could become more feasible, but with high costs for the environment and for communities, particularly indigenous communities whose livelihood and existence depends on Arctic ecosystems. In this context, there have been calls from a number of countries, the private sector, civil society and the scientific community in particular, to halt deep-sea mining, through a ban, moratorium or a precautionary pause.

Similar concerns arise from the race for mining in outer space, which relates to mining the resources of celestial bodies such as the moon, planets and asteroids, based on their significant economic potential. While there is ongoing review within the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), there is no agreed international framework on space resource exploration, exploitation and utilization, nor a mechanism to support its future implementation. Without agreed international principles on such activities, these economic incentives may carry a potential risk of conflict, environmental degradation and cultural loss. When related space treaties were negotiated, provisions were included to ensure that no nation could claim ownership of celestial bodies, recognizing the common interest of all humankind in the progress of the exploration and use of outer space for peaceful purposes. Some Governments have contended that the exploitation of space resources is permissible, including by private sector actors.

In sum, the expansion of the mining frontier towards the deep sea or outer space raises many questions. Before moving to commercial mining activities, it would be wise to allocate sufficient time to properly assess the related benefits and costs for inclusive and sustainable development. Moreover, the international community should work further to establish the proper international regulatory regimes, including on equitable benefit sharing. In 2021, the COPUOS began to collect information on space resource activities and to study existing legal frameworks, to develop a set of initial recommended principles, taking into account the need to ensure that any such activities are carried out in accordance with international law and in a safe, sustainable, rational and peaceful manner. This research is expected to be completed by 2027.

Source: UNCTAD, based on UNEP Finance Initiative (2022); IISD (2023); Standing (2023) for deep sea mining; and United Nations (2023a) for space mining.

D. Geopolitics and the dynamics of transition mineral markets

As transition minerals have become key inputs for both low-carbon and digital technologies, the importance of geopolitics, geoeconomics and geostrategic factors associated with their production, trade and access by different countries has intensified.[40] Transition minerals have become a major issue of concern on the international development agenda and are strongly interconnected with global challenges related to digitalization and environmental sustainability.

Increasing demand has been compounded by supply shortages linked to the pandemic and the war in Ukraine, leading to concerns about the availability of transition minerals globally. Moreover, transition minerals have become an additional factor in global trade and technology-related tensions, particularly among the leading actors in the digital economy.[41] Rivalry for resources is highlighted as "a potential cluster of interrelated environmental, geopolitical and socioeconomic risks relating to the supply of and demand for natural resources" that are contributing to the polycrisis of the current global context (WEF, 2023: 57).

This is reflected in the competition among various countries for securing access to transition minerals that are essential for sustainable technological, industrial, and economic progress. In this context, this section reviews the situation regarding global production, prices and international trade in transition minerals, as well as the different approaches towards dependence and supplier diversification taken by countries that import and those that export transition minerals.

1. Geographical concentration of reserves, extraction and processing

On the production side, the international market for transition minerals is characterized by high geographical concentration of mineral reserves, extraction and processing. Essentially, geography determines where mineral reserves and extraction are located. A large proportion of global extraction takes place in developing countries within Africa, Asia and Latin America; however, it is unevenly distributed between and within these regions.

In 2023, three countries in Africa had the largest global reserves of three transition minerals, as follows: the Democratic Republic of the Congo, with 55 per cent of global reserves of cobalt; Guinea, with 25 per cent of the global reserves of bauxite, used in aluminium production; and South Africa, with 32 per cent of global reserves of manganese. The latter country also held 9 per cent of global gold reserves. Madagascar, Mozambique and the United Republic of Tanzania together represented 24 per cent of global reserves of natural graphite.[42]

In Latin America, Chile and Peru led in terms of copper reserves. Together with Mexico, they accounted for 36 per cent of the total. The region also includes the "lithium triangle" which includes Argentina, the Plurinational State of Bolivia and Chile, with reserves of lithium accounting for

Transition minerals have become a major concern on the international development agenda contributing to global trade and technology tensions

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[40] See IRENA (2023); Lazard (2023); Nakano (2021) and Wu and Huy (2022).

[41] See, for example, Byamungu (2022), who notes a "race" for minerals, and other studies that use more confrontational terms, such as Fabry (2023); Gibson and Zhou (2023) and Pitron (2019).

[42] UNCTAD calculations, based on https://www.usgs.gov/centers/national-minerals-information-center/mineral-commodity-summaries.

46 per cent of the world total.[43] Brazil has diverse and large reserves of transition minerals, including 26 per cent of natural graphite, 19 per cent of rare earth elements, 14 per cent of manganese, 12 per cent of nickel and 9 per cent of bauxite.

In Asia, Indonesia holds 42 per cent of global nickel reserves. China accounts for 40 per cent of global reserves of rare earth elements, 28 per cent of reserves of natural graphite and 15 per cent of reserves of manganese. Viet Nam holds 19 per cent of bauxite reserves and 20 per cent of rare earth element reserves.

Among the developed countries, Australia holds large shares of reserves for manganese (26 per cent), lithium (22 per cent), gold (20 per cent), nickel (19 per cent), cobalt (15 per cent), bauxite (11 per cent) and copper (10 per cent). The Russian Federation holds 9 per cent of rare earth element reserves and 19 per cent of gold reserves.

The concentration of transition minerals extraction, or mine production, is even higher, as shown in figure II.10. Minerals extraction increased significantly between 2010 and 2023 in response to surging demand. For cobalt, the Democratic Republic of the Congo accounted for 74 per cent of worldwide production in 2023; for lithium, Australia and Chile together represented 72 per cent of global production; and for manganese, Gabon and South Africa accounted for 59 per cent of total extraction. Indonesia represented 50 per cent of world nickel extraction. China accounted for 77 per cent and 69 per cent respectively of the world production of natural graphite and rare earth elements in 2023, and for 80 per cent of silicon metal production in 2022.

While the concentration of extraction is fundamentally determined by the location of minerals deposits, this does not necessarily translate into geographical control of the production of a mineral by the host country. Much production is undertaken by multinational enterprises that invest in the country (Leruth et al., 2022).

As can be seen in Figure II.11, the position of China is pronounced at the minerals processing stage and, with regard to some minerals such as nickel and cobalt, mining has intensified since 2019 (IEA, 2023a). China accounts for over 50 per cent of processing for aluminium, cobalt and lithium, about 90 per cent of processing for manganese and rare earth elements and close to 100 per cent of processing for natural graphite.

The leading role of China in minerals processing is the result of a combination of factors, including robust economic growth, substantial investments in infrastructure and technology, government strategies[44] and a trend among developed countries to outsource manufacturing to China. As Asia, particularly China, has emerged as a global electronics manufacturing hub, proximity to markets of intermediary products or components has also bolstered burgeoning minerals processing activities. The prominent position of China in minerals processing provides both economic and strategic benefits to the country. This has raised concerns in some major economies about dependence on mineral imports.

2. Evolution of prices

Due to the nature of supply and demand in this sector, minerals and metals prices are inherently volatile. This volatility has been particularly high for transition minerals in recent years, as shown in figure II.12.

In terms of trends, in response to surging demand and lagging supply responses, prices have generally increased. This is especially the case for lithium, nickel and rare earth elements (figure II.12). Many transition mineral prices remain above historical averages (IEA, 2023a). According to Standard and Poor's (S&P) (2024), by early 2024, prices for most metals are down 20 to 30 per cent from record highs in

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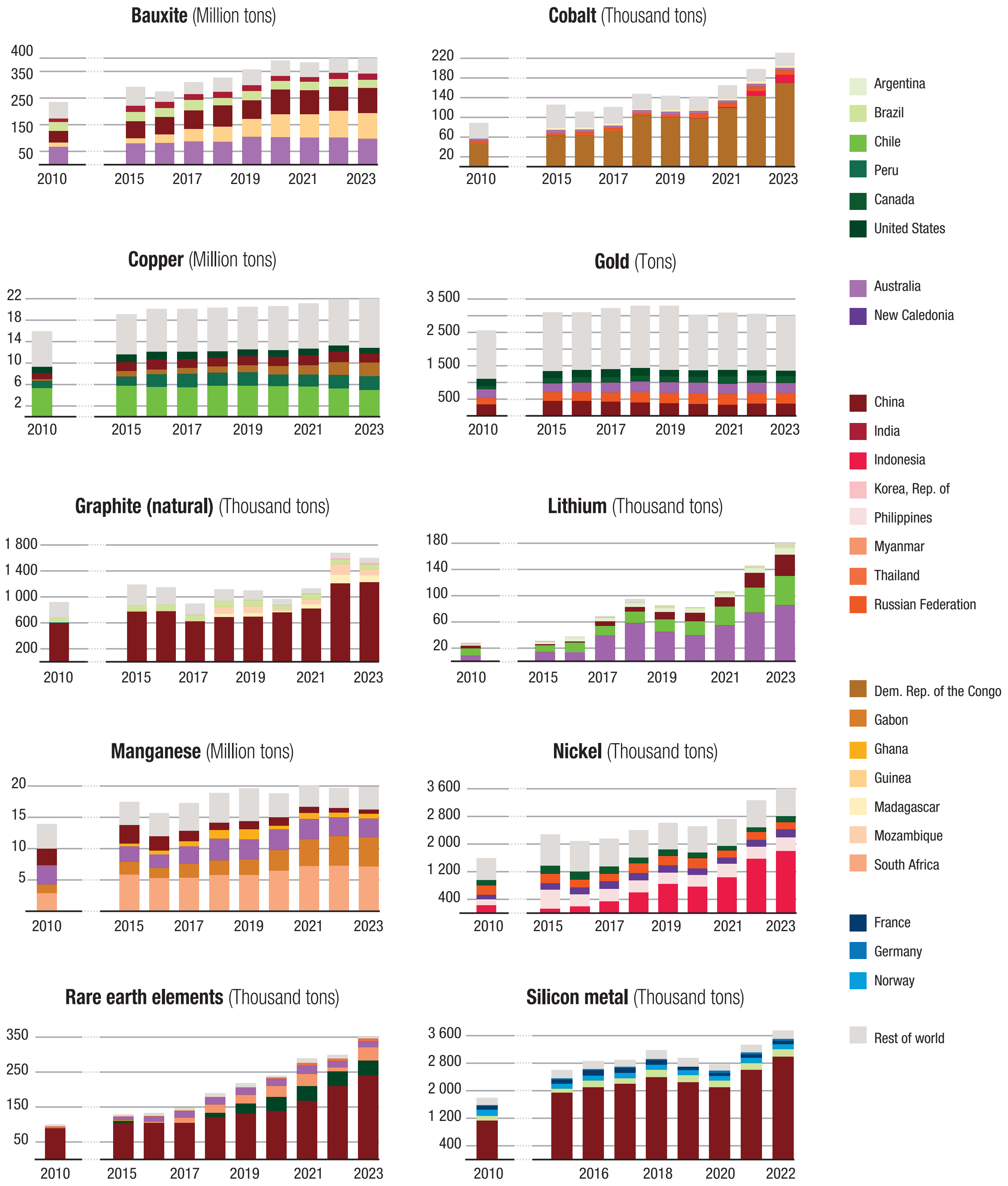
[43] Data from the United States Geological Survey do not include the Plurinational State of Bolivia, which has the largest lithium reserves in the world (see https://qz.com/bolivias-lithium-reserves-are-even-larger-than-it-previ-1850664027).

[44] See Müller (2023b).

Figure II.10
Extraction of selected transition minerals by volume, selected economies and years

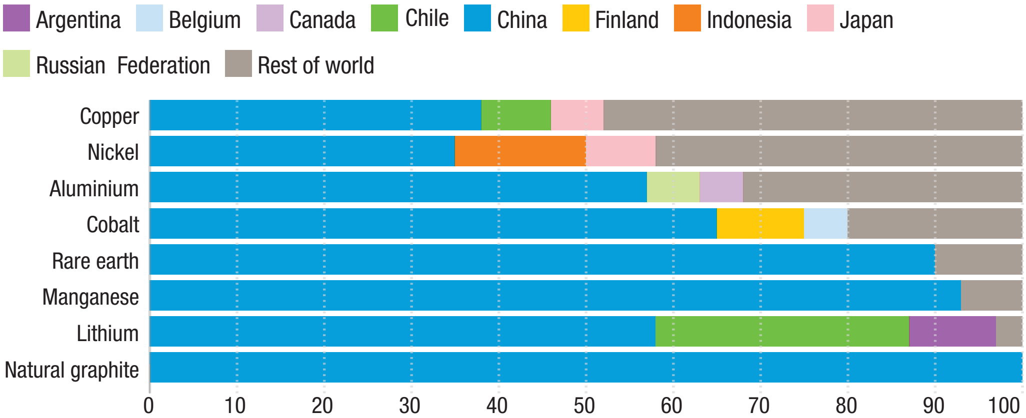


Source: UNCTAD, based on data from the United States Geological Survey.

2021–2022, but are still about 20 per cent higher than before 2020. Overall, the outlook is that prices will continue on a rising trend, as demand increases rapidly and supply growth lags behind, in a context of fewer discoveries and lower ore grades. Against this background, significant structural supply bottlenecks can be anticipated in the coming decades, leading to higher prices.[45]

Figure II.11
Share of top mineral processing countries in world total for selected minerals

(Percentage)

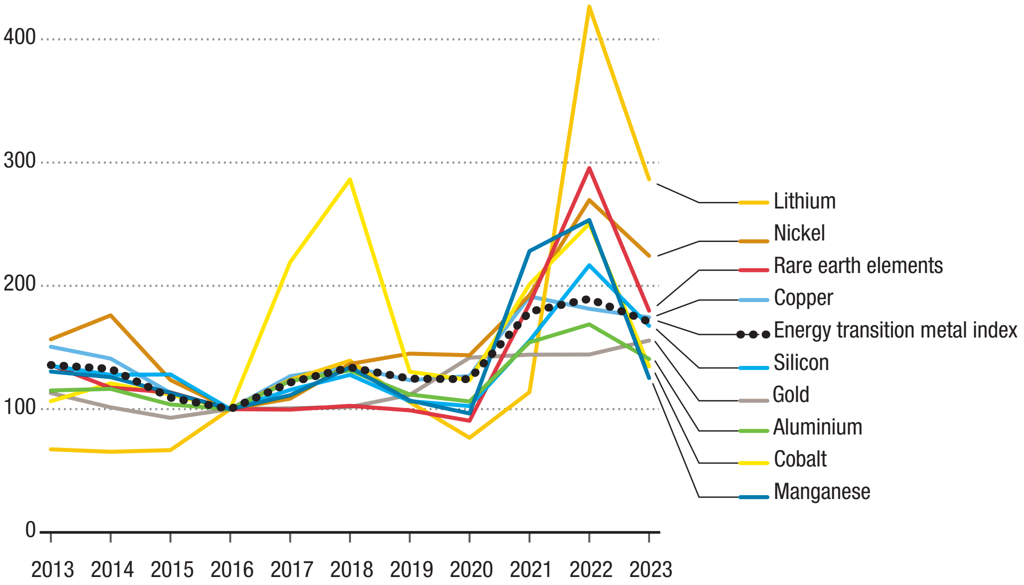


Source: UNCTAD, based on OECD (2023a).

Note: The geographical concentration refers to 2021 for rare earth elements and to 2019 for all other minerals.

Figure II.12
Evolution of prices of selected transition minerals, 2013–2023

(Index, 2016 = 100)



Source: UNCTAD, based on IMF Primary Commodity Price System (9 February 2024 update), available at https://www.imf.org/en/Research/commodity-prices.

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[45] See also https://www.policycenter.ma/publications/beyond-energy-crossroads-deciphering-key-trends-and-charting-path-2024; and Deutsche Bank Research (2023).

3. International trade of transition minerals along the global electronics value chain

a. International trade

International trade in transition minerals largely mirrors the geographical distribution of reserves and extraction presented above. Many developing countries in Africa, Asia and Pacific and Latin America are major exporters of mostly unprocessed minerals and metals for further processing, largely destined for developed countries and China. China, the United States and the European Union cannot meet their total mineral demand through domestic mining.

Refined minerals and metals go into the manufacturing supply chain to produce the various intermediary components that are assembled into final products. Over the past two decades, there have been significant regional shifts in the trade in metal raw materials. China has become the largest importer and exporter in the world, mostly importing ores and minerals and mainly exporting refined products and goods derived from them. By contrast, various developed countries such as the United States, as well as the European Union, have lost market shares (Perger, 2022).

Analysis by UNCTAD, in *The State of Commodity Dependence 2023*, shows that, in 2019–2021, the dominant commodity group in total merchandise exports among 31 countries was minerals, ores and metals, with several countries in Africa, Asia and Latin America showing an export dependence of more than 40 per cent on this commodity group in total merchandise exports. Australia is the only developed country that stands out among these exports (figure II.13). Burkina Faso, Mali and Suriname depend on gold for 80 per cent or more of their merchandise exports, and in Zambia and the Democratic Republic of the Congo, copper exports account for 69 and 53 per cent of total merchandise exports, respectively (UNCTAD, 2023e). By contrast, some developing countries with more diversified export economies also play a major role in international trade for different transition minerals. This is the case in Brazil for several transition minerals and in Indonesia for nickel.

Countries can be classified by position in terms of international trade as importers or exporters of transition minerals (using the 10 minerals selected for use in this chapter for analytical purposes) and according to level of development, as presented in figure II.14.[46] The figure categorizes economies into mainly exporters or importers of transition minerals, although they may export and import different minerals. The European Union has an import reliance of 81 per cent for cobalt, 100 per cent for processed lithium, 96 per cent for manganese, 99 per cent for natural graphite, 75 per cent for nickel, 64 per cent for silicon metal and 100 per cent for processed rare earth elements.[47] The United States has set import reliance records for minerals, as it was more than 50 per cent reliant on 51 minerals in 2023, up from 47 in 2022. It is also 100 per cent net import reliant for 15 of those 51 minerals, 12 of which are deemed “critical”.[48] Among developing countries, India is 100 per cent reliant on imports of, for example, lithium, cobalt and nickel, among other transition minerals (India, Ministry of Mines, 2023).

The above analysis is based on the value of trade, which has an impact on economic development. In order to consider the environmental aspects, it is also necessary to look at trade volume. The

> Many developing countries are major exporters of mostly unprocessed minerals and metals, largely destined for developed countries and China

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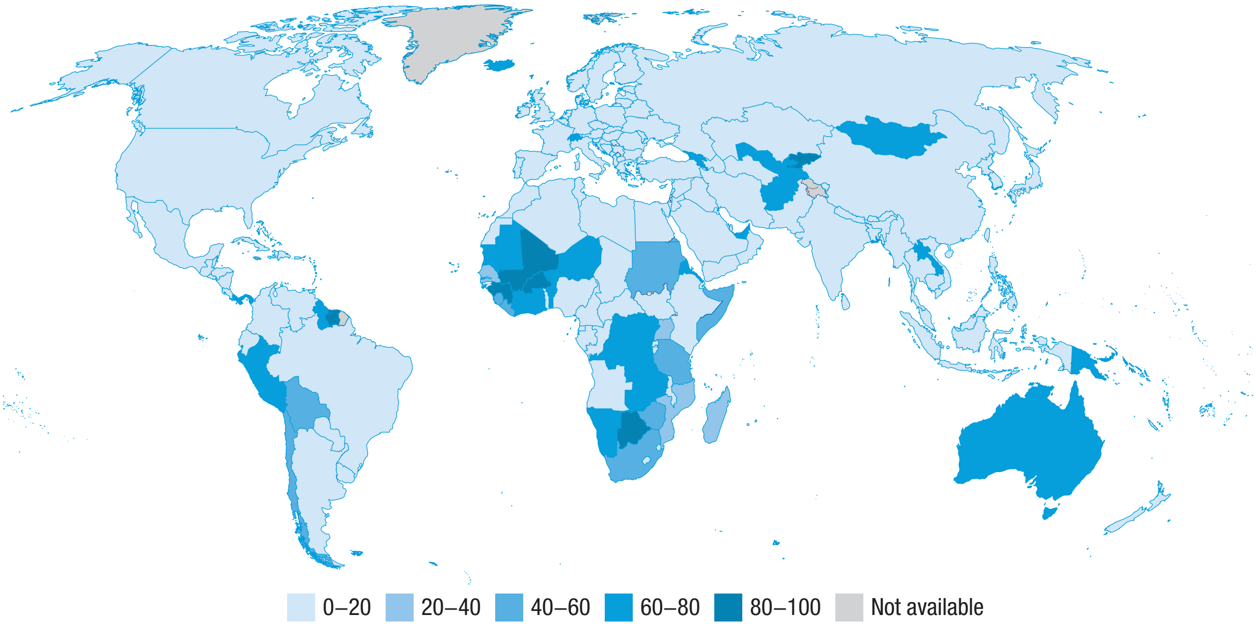
[46] This figure is not comprehensive, as it presents major exporters and importers in a representative manner. For more detailed analysis of international trade in critical minerals, including more countries and minerals, see https://www.trademap.org/Index.aspx, https://www.compareyourcountry.org/trade-in-raw-materials/en/2/BAUXI/all/default, https://resourcetrade.earth/ and https://oec.world/.

[47] See European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs et al. (2023).

[48] See https://mineralsmakelife.org/blog/u-s-sets-mineral-import-reliance-record and United States Geological Survey (2023).

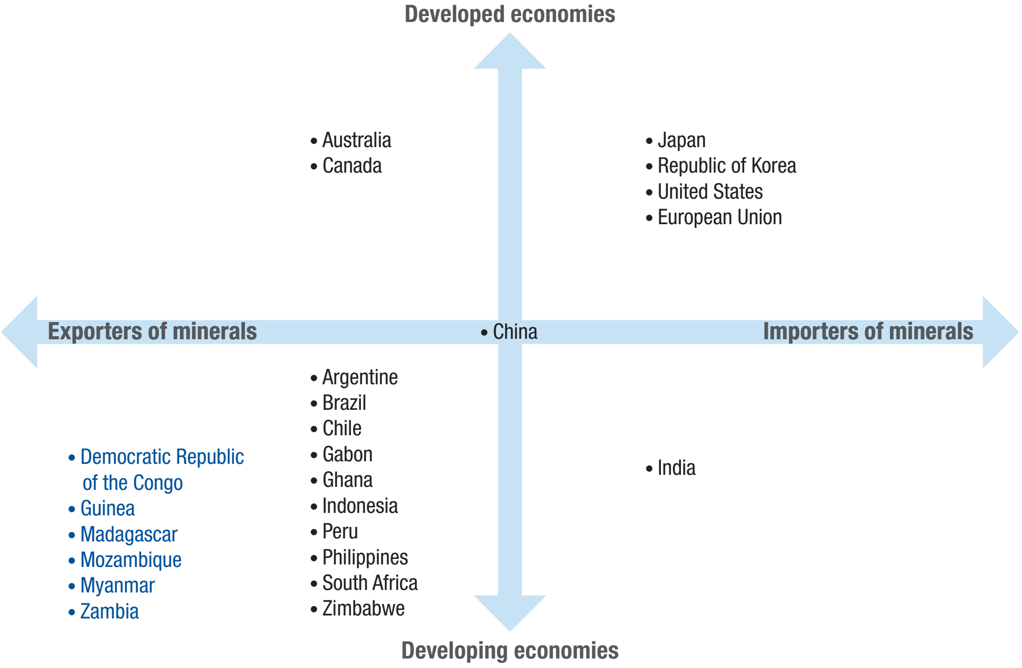
Figure II.13
Share of minerals, ores and metals in total merchandise exports, 2019–2021
(Percentage)



Disclaimer: the boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Source: UNCTAD (2023e).

Figure II.14
Classification of economies as exporters or importers of transition minerals, by level of development



Source: UNCTAD, based on data from the United Nations Comtrade database and UNCTAD (2023e).

Note: Countries in blue are LDCs.

volume of trade over the past half century has increased faster than the volume of extracted resources, which implies the growing dependence of the global economy on materials trade. The analysis of the material footprint of trade by UNEP and IRP (2020a), includes metals, ores and non-metallic minerals (in addition to biomass and fossil fuels), and highlights that resource-intensive processes have shifted from high-income importing countries to low-income exporting countries. This has been associated with a shift in environmental burdens towards the latter and is also relevant in the context of digitalization.

This dynamic is known as the "unequal ecological exchange" whereby activities with a higher value, which mostly include services and intangibles, are concentrated in developed economies.[49] Higher-income economies import resources and materials, yet outsource the material- and energy-intensive stages of production to other countries, while also externalizing the production-related environmental impacts to middle- and low-income countries. Developing countries therefore mostly export unprocessed and low-value minerals and metals and bear the environmental and social costs, and then have to import higher-value final products. In 2017, each person in the high-income group was dependent on the mobilization of an average of 9.8 tons of material resources in other parts of the world, with this reliance on external materials rising at a rate of 1.6 per cent per year since 2000 (UNEP and IRP, 2019). This cycle tends to self-perpetuate in a vicious circle unless it is actively reversed, which requires public policies at different levels (see chapter VI). ICT goods trade is an example of carbon costs and economic benefits being unevenly distributed among developed and developing countries, as discussed in the next section.

b. Mining in the global electronics value and production chain

The mining supply chain is just the first stage in the overall global electronics value and production or supply chain. When considering the environmental impact of the production stage of the digitalization life cycle, it is important to situate materials consumption in the overall chain of the manufacturing of ICT products.

In terms of value, figure II.15 shows the smile curve that represents the different activities in the global ICT goods value chain. Higher value is added at the pre-production stage, which includes activities such as research and development or design, as well as at the post-production stage, which includes activities such as distribution, marketing, branding and other services. All these activities tend to take place predominantly in developed economies. The production stage, which concerns the mining and processing of minerals, manufacturing and assembly of final ICT goods, is the phase that carries the highest environmental and social burden, and takes place mainly in developing countries. This is also the stage that generates the lowest value addition.

A simplified representation of the electronics or ICT goods production or supply chain is presented in figure II.16, focussing on the physical production stage. Upstream, in the mining supply chain, there is exploration, development of a mine, extraction of minerals and then processing (smelting and refining) to enable the metal to be of an appropriate quality for manufacturing. The middle stream entails manufacturing components from the raw materials. Finally, downstream, the components are assembled into the final electronics or ICT goods.

As noted, the extraction of minerals occurs mainly in developing countries in Africa, Asia and Latin America. Minerals are subsequently transported, mainly to some

> There is an "unequal ecological exchange" between developed and developing countries

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[49] For more on ecologically unequal exchange, see UNEP and IRP (2024), UNCTAD (2022a); for LDCs, see Infante-Amate et al. (2022); Alonso-Fernández and Regueiro-Ferreira (2022); and for Latin America, see Palacios et al. (2018).

developed countries and China, to be refined. Components manufacturing primarily takes place in several Asian countries, while developed countries produce most of the higher technology content components (and therefore capture the higher value). Assembly predominantly happens in a number of Asian countries, including China, Malaysia, the Philippines, Singapore and Viet Nam (Brodzicki, 2021). This production chain also implies significant transport activity among the different countries, in which the various suppliers producing the multiple components and materials are located. It is estimated, for instance, that a smartphone travels several times around the world before it reaches final production.[50]

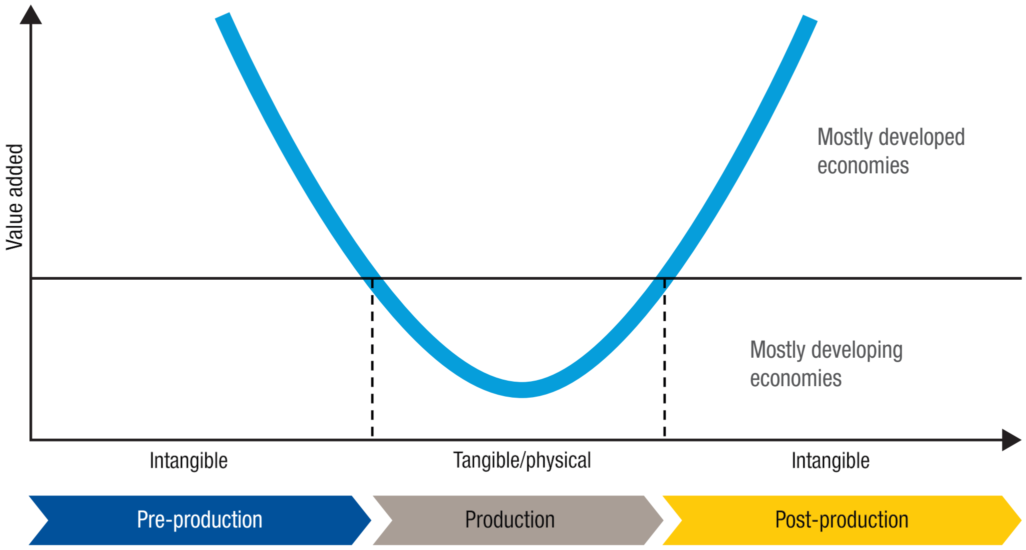
> The production processes of digital devices are modular, but the products themselves are not

It should be noted that this representation is an oversimplification. Even if the figure is presented in a linear manner, the production processes in electronics and ICT products are highly complex. Each product may comprise hundreds of components, which in turn are made of multiple transition minerals, metals and other materials.

Therefore, the final production chain is a network of intermediary production chains for this multitude of components and for the different transition minerals included in each component.[51] According to Thun et al. (2022, 2023), ICT can be considered a “massive modular ecosystem” or an “ecosystem of ecosystems” in which standard interfaces allow linkages both within and between industries, allowing for rapid increases in scale and complexity. Thus, the production processes of digital devices are modular, but the products themselves are not. Greater modularity would facilitate repair of the products and replacement of components, as well as remanufacturing by reusing different components that still function (see chapter IV).

Considering the global distribution of the different stages of the value chain and the fact that the geographical physical production stage is where the least value addition occurs and where there is the highest environmental cost of materials

Figure II.15
The smile curve of global value distribution in ICT goods production



Source: UNCTAD.

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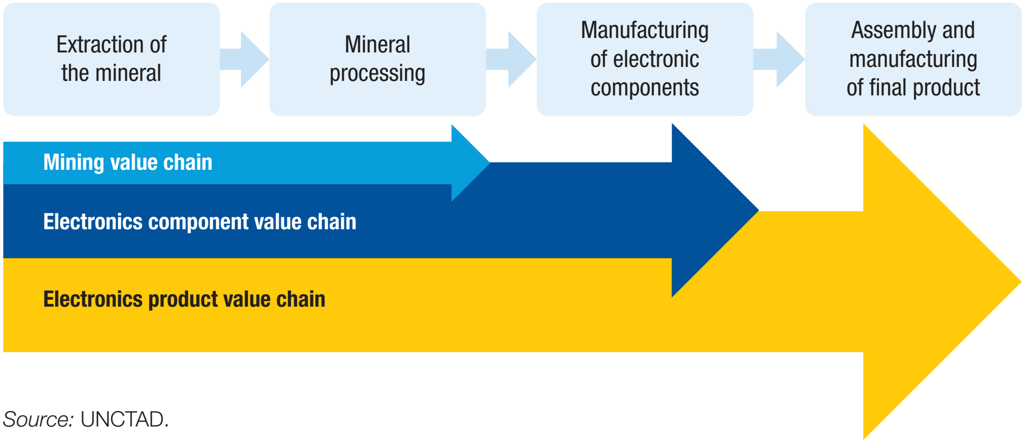
[50] See https://www.monde-diplomatique.fr/publications/manuel_d_economie_critique/a57189.

[51] For more detailed information on supply chains for various minerals, for example for cobalt, see Cobalt Institute (2022) and for minerals in a particular developing region such as Latin America, Lagos et al. (2021). In the case of components, Bridge and Faigen (2022) provide a detailed assessment of the lithium-ion battery production network, Obaya and Céspedes (2021) look at implications for countries in the “lithium triangle”. Moreover, the semiconductor supply chain is mapped by Thadani and Allen (2023) and Varas et al. (2021).

Figure II.16
The global electronics production chain



Source: UNCTAD.

extraction and manufacturing, trade in ICT goods provides an example of "unequal ecological exchange". According to Zhou et al. (2022), carbon losses and economic gains induced by ICT trade are unevenly distributed among regions. Eighty-two per cent of carbon emissions are attributed to emerging regions, while developed regions benefit from 58 per cent of the value added. This carbon-economic inequality arises from the fragmentation of international production.

4. Trade dependence and diversification: The two sides of transition minerals

Excessive dependence on trade in transition minerals, whether on the export or the import side, is a risk that needs to be addressed. One way to mitigate this risk is to diversify products and partner countries. In order to climb the value chain, countries that depend heavily on exports of transition minerals need to diversify exports towards products of higher value. Countries with excessive dependence on imports of transition minerals can reduce the risks by diversifying supplies from several countries. As transition minerals have become more important on the international agenda, many countries are implementing policies to this end.[52]

a. Countries exporting transition minerals

From the perspective of transition mineral-exporting countries, which are often developing countries, dependence refers to the high share of these commodities in their total production and exports, as shown in figure II.13 (UNCTAD, 2023e). Consequently, their overall economic growth, foreign exchange earnings and government revenues are highly dependent on the evolution of this sector. As a result, they are vulnerable to external conditions and shocks that can affect the demand for transition minerals. Moreover, given the high volatility of minerals and metals prices, the stability of the economy may be affected by boom and bust cycles.

Policymakers in developing countries, notably in LDCs, have long been concerned about the high reliance on the production and export of a few primary commodities. A shift away from such dependence requires diversification of the production and export structure in a country, as a development path.[53] Diversification towards manufacturing

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[52] See https://www.iea.org/reports/critical-minerals-policy-tracker and https://www.iea.org/policies?topic=Critical%20Minerals.

[53] Addressing commodity dependence through diversification and structural transformation has been at the core of the work of UNCTAD throughout its 60 years of existence. See United Nations (1964a) and UNCTAD (2012, 2019b).

activities is a way to reduce the dependence of developing countries on the production and export of primary commodities, while easing constraints in the balance of payments that affect development, by replacing imports or by increasing export earnings (United Nations, 1964b).

Diversification implies moving away from low productivity and value-added products to higher productivity and value-added production and exports (UNCTAD, 2022b). This means an increase in the share of manufactured goods, resulting in higher value addition in the domestic economy across total production and exports. Thus, while in absolute terms the extractive mining sector, which may generate relatively low value addition, can still grow, the higher value-added manufacturing and services sectors should grow at a greater pace.

Development policies should aim to capture, manage and use the proceeds arising from the production and exports of transition minerals to diversify the production and export structure and achieve structural transformation. Section E further elaborates on opportunities for developing countries that may emerge from the surging global demand for transition minerals.

Developing countries should aim to capture, manage and use the proceeds from exported minerals to **achieve structural transformation**

b. Countries importing transition minerals

From the perspective of countries that are dependent on imports of transition minerals from a few countries, diversification may involve searching for alternative sources from which to secure supplies. This would reduce the risks related to potential supply disruptions. Some countries may also explore ways to boost domestic production.

The security of transition mineral supply chains has emerged as a priority for many countries (Shiquan and Deyi, 2023), which has been coupled with a proliferation of national strategies to secure supply. In order to secure access to transition minerals and diversify supply sources, the United States and the European Union, among other mostly developed economies, have adopted industrial policies related to transition minerals and the industries that use them, including the electronics sector. This has led to support for the battery and semiconductors sectors, among others. This can be seen as representing a change in the focus of international economic relations from economic efficiency towards economic security or from "just in time" to "just in case" approaches in the global supply chain.[54]

Various measures have been taken to make value chains relying on transition minerals more resilient, both internationally and domestically, and to achieve higher levels of self-sufficiency and sovereignty, as well as control over production in critical sectors.[55] Moreover, several countries are seeking alliances and partnerships at the international level, with transition minerals-exporting countries providing possible alternative supply sources.[56]

At the domestic level, for example, the United States aims to secure a "made in America" supply chain for critical minerals" (United States, 2022a). Moreover, the 2022 Inflation Reduction Act establishes the shares of each critical mineral that have to be mined or processed (or recycled) in the United States, or in a country with which the United States has a free trade agreement. This share starts at 40 per cent in 2023, to reach 70 per cent in 2027. This is tied to the provision of tax credits for electric vehicles.[57] Similarly, the act awards a tax credit equal to 10 per cent of the cost of production to incentivize the domestic production of various components, including applicable critical minerals used in renewable energy generation, storage and related manufacturing.

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[54] See, for instance, https://www.ft.com/content/8a7cdc0d-99aa-4ef6-ba9a-fd1a1180dc82; and Zhang and Ha Doan (2023).

[55] A de-risking approach was endorsed by the Group of Seven in their communiqué of May 2023: "We are not decoupling or turning inwards. At the same time, we recognize that economic resilience requires de-risking and diversifying" see Group of Seven (2023).

[56] For reviews of different policies adopted by various countries to secure the supply of transition minerals, see Lazard (2023); OECD (2023b); Passi (2023) and Sancho Calvino (2022).

[57] See https://home.treasury.gov/news/press-releases/jy1379.

The European Union Critical Raw Materials Act was adopted by the Council in March 2024.[58] This act sets out a range of benchmarks for 2030 related to the strategic raw materials value chain and to diversifying European Union supplies, as follows:

- European Union extraction capacity covers at least 10 per cent of annual domestic consumption;
- European Union processing capacity covers at least 40 per cent of annual domestic consumption;
- European Union recycling capacity covers at least 25 per cent of the annual domestic consumption;
- No third country to provide more than 65 per cent of the annual domestic consumption of each strategic raw material in the European Union.

Securing the supply of critical raw materials features high on the overall new industrial strategy of the European Union (Ragonnaud, 2023). Moreover, both the United States and the European Union have adopted "chips acts" to support the domestic production of semiconductors, recognizing these as a critical component in the electronics supply chain. They have also considered measures aimed at increasing the domestic supply of batteries.[59] Industrial policies are increasingly used around the world to promote the use of electric vehicles.[60]

Beyond the domestic perspective, at the international level, many countries are looking abroad to secure access to transition minerals from alternative exporting countries. There is a trend towards creating alliances or partnerships with countries that may be considered "friends" or "like-minded", to allow for friendshoring of mineral production. Countries are actively engaging in "raw materials diplomacy" (Müller, Saulich, et al., 2023; Szczepański, 2021), in search of strategic agreements with reliable partner countries for the responsible and sustainable supply of transition minerals. Alliances are also being established in the private sector, for example, among electric vehicle and battery manufacturers.

One example of such an alliance is the Mineral Security Partnership, a multilateral forum launched in June 2022 by the United States, the European Union and nine partner countries.[61] These economies are mainly dependent on mineral imports (Majkut et al., 2023). The objective of this partnership is "to ensure that critical minerals are produced, processed and recycled in a manner that supports the ability of countries to realize the full economic development benefit of their geological endowments".[62] At the bilateral level, the United States has signed a critical minerals agreement with Japan, and is planning similar agreements with the European Union and the United Kingdom (White & Case, 2023).

Most of these alliances seem to be taking place, or are being planned, among developed countries, mainly transition mineral importers, although Australia and Canada are also participating in international partnerships.[63] Australia has a partnership with India, which is also mostly a mineral importer (Australia Trade and Investment Commission and Deloitte India, 2021). From

Beyond expanding domestic mining, many countries are looking abroad to secure access to transition minerals from alternative exporting countries

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[58] See https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en, https://www.europarl.europa.eu/RegData/etudes/ATAG/2023/754638/EPRS_ATA(2023)754638_EN.pdf, and https://www.consilium.europa.eu/en/infographics/critical-raw-materials/. The overall approach of the European Union on transition minerals is reviewed in European Parliament, Directorate General for External Policies of the Union et al. (2023).

[59] For semiconductors, see United States (2022b) and for the European Union Chips Act, see https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en. For batteries, see Federal Consortium for Advanced Batteries (2021) and European Court of Auditors (2023).

[60] See the chapter "Policies to promote electric vehicle deployment" in IEA (2021c).

[61] By March 2024, partners comprised Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, Norway, the Republic of Korea, Sweden, the United Kingdom, the United States and the European Union. See https://www.state.gov/joint-statement-of-the-minerals-security-partnership/.

[62] See https://www.state.gov/minerals-security-partnership/.

[63] For critical minerals partnerships for Canada, see https://www.canada.ca/en/campaign/critical-minerals-in-canada/our-critical-minerals-strategic-partnerships.html.

this perspective, these alliances may be more focussed on creating a "buyers' club" (Lazard, 2023; Lu, 2023a; Pilch, 2023). For these alliances to be beneficial to both developed and developing countries, they need to focus on ensuring that supply is socially responsible and environmentally sustainable, while leading to developmental benefits in exporting developing countries.

Countries are also starting to look at partnerships to secure transition minerals from exporting developing countries. For example, in the context of the Community of Latin American and Caribbean States Summit held in July 2023, a memorandum of understanding was signed to establish a partnership between the European Union and Chile regarding sustainable raw materials value chains.[64] By mid-2024, the European Union had completed sustainable critical raw materials partnerships with twelve partner economies across three continents in the context of its global gateway.[65]

There is a risk that such alliances, mostly among developed countries importing minerals, may result in even more asymmetrical negotiating power and be detrimental to the interests of countries exporting transition minerals. This would risk aggravating the historically unequal positions of developing countries and their ability to negotiate the supply of minerals to developed countries.

Basing partnerships between developed countries and developing countries exporting transition minerals on equity could help ensure mutual benefits and allow for domestic value addition and structural transformation in such developing countries (Andreoni and Roberts, 2022; de Brier and Hoex, 2023). This would represent a move towards reducing persistent inequalities and asymmetries in this sector that have negatively affected developing countries.

At present, geopolitical tensions among major powers are particularly relevant for transition minerals and the ICT sector. In 2023, China banned exports of some rare earth elements, as well as their processing technologies, both of which are critical for semiconductor production. This was reportedly in response to the United States, the Kingdom of the Netherlands and Japan banning exports of some technologies critical for the production of electronic products in China.[66]

An escalation of tensions in trade and global supply chains could have various adverse effects.[67]

Significant resources and capital invested in developing production capacities for transition minerals and ICT products in countries that do not succeed in achieving technological leadership would be wasted. This could lead to unnecessary extraction of natural resources and environmental damage, to the extent that the production processes associated with these industries have negative environmental impacts. Alternatively, such resources and capital could be better used to address global development challenges in a coordinated manner. Overall, international cooperation and solidarity for inclusive and sustainable development would be a preferable option.[68]

Basing partnerships on equity could help ensure mutual benefits and allow for **domestic value addition and structural transformation in developing countries**

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[64] See https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3897.

[65] See https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/raw-materials-diplomacy_en.

[66] See https://www.ft.com/content/5b031db7-23dd-43d3-afe1-cef14817296f, and https://www.reuters.com/technology/us-secures-deal-with-netherlands-japan-china-chip-export-limit-bloomberg-2023-01-27/.

[67] The Munich Security Report 2024 raises concerns about potential lose-lose dynamics (Munich Security Conference, 2024).

[68] On resources rivalries, as a potential cluster of interrelated environmental, geopolitical and socioeconomic risks related to the supply of and demand for natural resources, see WEF (2023), which discusses four hypothetical futures for 2030: resource collaboration, resource constraints, resource competition and resource control. All futures, even resource collaboration, would face significant challenges. The most confrontational future, that of resource control, could lead to aggravating self-perpetuating and compounding global polycrises.

E. Opportunities for developing countries

Surging demand for transition minerals presents opportunities for developing countries, which are major producers and exporters of these minerals, to leverage the domestic availability of such resources to generate long-term added value and development. Africa and Latin America hold significant untapped minerals potential that could be used for inclusive and sustainable development purposes.

Many developing countries, particularly LDCs, need to overcome significant challenges linked to structural capacity constraints, for example in terms of infrastructure and energy and the limited availability of financial resources, relevant skills, knowledge and technology, as well as institutional and governance capacities (UNCTAD, 2022a).

Moreover, the international trade and investment context should be supportive for developing countries in order that they may be better equipped to benefit from their mineral resources. Foreign direct investment plays a major role in complementing often insufficient domestic resources for minerals extraction. This has led to power imbalances and asymmetries among Governments and populations in producing countries and mining companies, often with the result of an unequal distribution of rents from minerals resources. This international context has favoured a model in which developing countries well-endowed with natural resources become “locked in” as exporters of unprocessed and low value-added raw materials and importers of processed manufactures with higher value added. Developing regions, such as sub-Saharan Africa and Latin America, are major exporters of transition minerals, mostly in their unprocessed form. These regions import more than 50 per cent of their electronics consumption needs, mainly from the Asia and Pacific region, including China (Jeongmin et al., 2022).

Lessons from past “extractivist” experiences, during which developing countries hardly benefited from their mineral resources, are relevant for the emerging transition mineral boom. Avoiding a new scramble for resources requires a move away from previous extractive dynamics, so that mining can function more as an engine for structural transformation and development in developing countries (Mazzucato, 2023). Within this path to development, mineral resources can stimulate a process of dynamic interaction, or a virtuous circle, between minerals production and export, through economic diversification, including by increasing manufacturing (Anzolin, 2021; Freytes and O’Farrell, 2021; UNCTAD, 2016). This could help to alter traditional global trade patterns, and improve the position of developing countries as exporters of higher value mineral-based products.

There is a key role for Governments in developing countries to apply proactive policies to tackle constraints and build capacities, to move up the mining and related manufacturing value chain. The mineral resources sector can contribute to inclusive and sustainable development by providing financial resources for productive investment, and by generating various linkages with and spillovers to the overall economy. This would add value and steer diversification towards structural transformation, growth and employment creation. Economic policies need to be directed towards these objectives (AfDB, 2023; UNCTAD, 2016) (see also chapter VI).

Some developing countries that export transition minerals are already exploring the potential of, and moving into, the production of higher value-added goods. For example, they are seeking to add value by processing minerals, manufacturing intermediate goods such as precursors, batteries and, in the longer term, even creating a regional value chain for manufacturing final products such as electric vehicles and smartphones

> International trade and investment context should be supportive for developing countries to be better equipped to benefit from their mineral resources

(Müller, Schulze, et al., 2023). This shift is in particular being observed in Africa, mainly in the Democratic Republic of the Congo with regard to cobalt, but also other minerals.[69] UNCTAD (2023f) shows that large reserves of critical minerals in Africa that are vital for the global supply chains of high technology-intensive industries could turn African economies into potential key suppliers of parts and components in sectors such as electronics and automotives.

In Latin America, lithium can play a major role, with significant potential for adding value to production in the three countries in the "lithium triangle" (ECLAC, 2023). In Asia, where the trade pattern is more diversified, Indonesia has imposed an export ban on raw nickel ore in order to increase domestic processing and value addition, including towards battery manufacturing (Huber, 2022).[70] The Indonesian strategy, although challenged at WTO, appears to be successful, attracting foreign investment and increasing downstream activities.[71] By mid-2023 the export ban was also extended to bauxite ore.[72]

A regional approach may allow developing countries to better harness their mineral resources

Beyond national policies, regional and international cooperation and support are needed to ensure the necessary fiscal and policy space for structural transformation and development. A regional approach may allow developing countries to improve their bargaining power with foreign investors, expand markets and achieve the necessary scale. Moreover, cooperation can help with pooling resources for research and development, as well as infrastructure development. This would promote the emergence of regional mining-related value chains.[73] For example, in Africa, the African Continental Free Trade Area can be leveraged to increase value addition in transition minerals (AfDB, 2023; Baskaran, 2022; Cust and Zeufack, 2023). Moreover, several regional organizations are working towards preparing an African green mineral strategy (Africa Natural Resources Management and Investment Center (ANRC), 2022).

Internationally, the agreement at OECD in October 2021 to set out a global minimum tax on multinational companies is a step in the right direction (IISD and ISLP, 2023). Moreover, in the emerging global geopolitical context, where competition is increasing for access to transition minerals in developing countries, these countries can benefit from a wider choice of investors. They should not be compelled to choose among sources of foreign direct investment. Rather, they should leverage this competition to negotiate the most favourable conditions that align with their development objectives. For this to happen, as noted, partnership agreements and resource diplomacy efforts to secure access to transition minerals by developed countries need to be mutually beneficial, unlike past experiences. This would entail boosting value addition in developing countries that produce these minerals. For example, the United States signed a memorandum of understanding with the Democratic Republic of the Congo and Zambia to strengthen the electric vehicle battery value chain.[74] Similarly, the European Union aims to contribute to sustainability and local value addition in developing countries in the context of the global gateway (Wouters, 2023).

As transition mineral-importing countries have been creating alliances or "buyers' clubs" that could potentially weaken the bargaining position of developing countries exporting such minerals, the latter may in turn create "sellers' clubs".

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[69] See Ahadjie et al. (2023); Diene et al. (2022); Karkare and Medinilla (2023); Mavhunga (2023); Müller (2023b) and World Bank (2023).

[70] See https://www.ft.com/content/0d2fba79-940f-4a28-8f4f-68f1e755200f; https://epsnews.com/2023/07/20/mineral-rich-nations-seek-to-raise-their-supply-chain-profiles/; and Lu (2023b).

[71] See https://foreignpolicy.com/2024/02/13/indonesia-election-nickel-economy-energy-jokowi-prabawo/ and https://eastasiaforum.org/2023/09/28/assessing-nickel-downstreaming-in-indonesia/.

[72] See *Xinhua*, Roundup: Indonesia pushes ahead with bauxite export ban despite controversy, 21 June 2023.

[73] See Grynspan (2022); Bridle et al. (2021) and Müller (2023b).

[74] See https://www.state.gov/the-united-states-releases-signed-memorandum-of-understanding-with-the-democratic-republic-of-congo-and-zambia-to-strengthen-electric-vehicle-battery-value-chain/.

Some approaches similar to those of the Organization of the Petroleum Exporting Countries have been proposed for minerals such as nickel and lithium (Hendrix, 2023).

Finally, international support is needed, particularly in LDCs, in the form of financial support and technical assistance so that they can overcome structural constraints and build capacity for diversification and structural transformation.

Taken together, there is significant potential for many developing countries to take advantage of the positive demand prospects for transition minerals and achieve sustained, inclusive growth. But minerals extraction also involves environmental and social risks and costs that need to be considered, as discussed in the next section.

F. Impacts of the production phase on the planet and people

Since the production of digital devices and ICT infrastructure requires the intensive use of minerals and metals, this life cycle phase is responsible for the environmental and social impacts associated with mining such minerals and metals.[75] Mining activities frequently have negative impacts on both the environment and surrounding communities. They are also often intricately intertwined with human rights implications. These issues are exacerbated in developing countries,[76] particularly in LDCs, which have limited capabilities for addressing negative externalities from mining (Lèbre et al., 2020). A study focusing on the extraction, processing, use and disposal of seven metals (aluminium, copper, iron, lead, nickel, manganese and zinc) forecasts that total environmental impacts could more than double, and in some cases even quadruple, by 2060 (OECD, 2019).

Environmental and social impacts, including on human rights, vary by type of mineral and metal, and geographical location. However, it is possible to highlight some general impacts that are typically observed. These are often interconnected; more often than not, environmental implications from mining are linked to social impacts, and may have a knock-on effect on human rights. Policy responses to some of the social and environmental challenges noted in this section are further considered in chapter VI.

Some of the major impacts observed include the following:[77]

- *GHG emissions and energy use:* Mining activities are energy-intensive, at both the extraction and processing stages, and mostly rely on fossil fuel energy. It is estimated that emissions associated with primary minerals and metals production were equivalent to approximately 10 per cent of total global energy-related GHG emissions in 2018 (Azadi et al., 2020). Achieving the transition to a sustainable socioeconomic pathway requires additional substantial efforts to reduce GHG emissions in this sector (Yokoi et al., 2022). Moreover, as mineral ores decline due to reserves becoming less easily accessible, emissions and energy demand from mining will increase, as will most of the environmental impacts listed in this section.

> **Environmental implications from mining** are often linked to social impacts, and may have a knock-on **effect on human rights**

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[75] As noted, data on the mineral extraction required for digital equipment manufacturing are not available. Therefore, it is not possible to accurately determine the part of the environmental and social impacts that can be attributed to digitalization.

[76] See https://unctad.org/news/developing-countries-pay-environmental-cost-electric-car-batteries.

[77] For more detailed discussions of the environmental and social impacts of mining, see Bolger et al. (2021); IEA (2021a); IRENA (2023); UNEP and IRP (2020b) and United Kingdom, Parliamentary Office of Science and Technology (2022).

- *Water use:* Extraction and processing operations require significant amounts of water. Many of these extractive activities take place in areas already experiencing water stress (Luckeneder et al., 2021). Heavy water use by the mining companies can complicate water access for the local population and have a negative effect on wildlife. For example, in lithium extraction from brines, huge amounts of groundwater are needed to pump out brines from drilled wells; estimates show that producing one ton of lithium requires almost 2 million litres of water (UNCTAD, 2020). Water issues in mining relate to both quantity and quality (IGF, 2022).
- *Pollution of soil, air and water*: Mining generates waste and toxic chemicals as by-products. These are generally disposed of in mine tailings that, if not properly managed, can lead to soil and water pollution as a result of leakages, as well as land erosion. Moreover, mining can release toxic substances (such as mercury) which are very harmful for the environment and the population. This toxicity can include fine particles and dust that contain toxic and heavy metals. Improper treatment of mine tailings can lead to negative environmental and humanitarian impacts. For example, rare earth elements incur high environmental costs not only in terms of water use but also because their extraction can acidify soil and groundwater, generate radioactive material, or cause heavy metal pollution from solid waste. These impacts are aggravated because such minerals are widely scattered over the Earth's crust, which makes mining difficult and expensive. Separation and processing also require the use of chemicals that generate toxic externalities (Zapp et al., 2022).[78]
- *Ecosystems and biodiversity*: Negative impacts can be particularly severe when mining activities take place in areas that are protected or that have high biodiversity value, threatening vulnerable ecosystems. By mapping mining areas and assessing their spatial coincidence with biodiversity conservation sites and priorities, Sonter et al. (2020: 1) find that "mining potentially influences 50 million km^2 of Earth's land surface, with 8 per cent coinciding with Protected Areas, 7 per cent with key Biodiversity Areas and 16 per cent with Remaining Wilderness".
- *Deforestation:* Mining is considered to be the fourth largest driver of deforestation. Kramer et al. (2023) highlight that over the past two decades, the direct deforestation impacts of mining have been highly concentrated, with almost 84 per cent of total direct mining-related deforestation taking place in only 10 countries. They estimate that computers and electronic products have driven 5 per cent of all deforestation worldwide related to mining expansion. It is also estimated that 44 per cent of all operational mines are in forests. In absolute terms, most forest mining takes place in large countries, including Brazil, Canada, China, the Russian Federation and the United States. However, if land area size, economic importance and forest cover are considered, major countries in forest mining include Brazil, the Democratic Republic of the Congo, Ghana, Zambia and Zimbabwe. Moreover, more than half of all existing forest mining occurs in lower- or middle-income countries (World Bank, 2019). For example, in the Amazon rainforest in Brazil, 11,670 km^2 of deforestation between 2005 and 2015 was caused by mining, which represents about 9 per cent of the total loss of forest in the Amazon during the period (Saracini, 2023). Overall, it is estimated that mining accounts for about 7 per cent of annual forest loss in developing countries (United Kingdom, Parliamentary Office of Science and Technology, 2022).
- *People's health and safety*: The pollution of soil, air and water can lead to impacts on population health in the mining

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[78] Golroudbary et al. (2022) show that an increase by 1 per cent of green energy production causes a depletion of rare earth elements reserves by 0.18 per cent and increases GHG emissions in the exploitation phase by 0.90 per cent and that between 2010 and 2020, the use of permanent magnets resulted cumulatively in 32 billion tons CO_2e of GHG emissions globally.

areas affected by the effects of toxic substances. In addition to potentially reducing access to water, pollution may lead to drinking water shortages.

- *Communities, particularly indigenous peoples*: Mining activities lead to changes in land use, which imply displacements of communities living in the corresponding areas, with significant disruptions to livelihoods, ways of life and cultural ties to the land. In considering the human rights implications of mining, indigenous communities are seen to be particularly impacted.[79] In a sample of 5,097 energy transition minerals projects, Owen et al. (2022) found that 54 per cent of projects were "located on or nearby Indigenous peoples' lands".
- *Working conditions*: Some mining activities are characterized by poor labour conditions, including lack of voice and freedom to participate in unions, as well as limited rights and access to social protection. In some cases, activities have been found to involve forced labour, child labour and human trafficking. Hazardous working conditions may also be related to unsanitary environments, as well as overall violations of safety, which may lead to injuries, illnesses, disability or death. According to ILO, when the number of people exposed to risk is taken into account, mining is the most hazardous occupation.[80] Mining can also lead to significant inequality, particularly for women (box II.2).
- *Artisanal and small-scale mining (ASM)*: While much of global mining occurs through large-scale mining, for some countries and minerals, such as the mining of cobalt in the Democratic Republic of the Congo, ASM plays a significant role. It is estimated that in 2020, 44.75 million people working across more than 80 countries made their living in ASM. This represents a threefold increase of people in this sector over the past 20 years. Sub-Saharan Africa has the largest proportion of such miners, accounting for one fourth of that number.[81] ASM is an important source of income for many poor and marginalized people. Such miners operate within an informal context, with low levels of safety, poor working conditions and instances of exploitation, even slavery. Weak management further exacerbates environmentally harmful activities at such mines, making them even more polluting than other forms of mining. Children are often found working in ASM mining.
- *Child labour in mining*: According to the ILO (2019a), more than 1 million children work in mines and quarries. This constitutes a serious violation of the rights of children because their health and safety are put at risk, and they are deprived of education. Due to its inherent dangers, ILO considers mining and quarrying hazardous work, and one of the worst forms of child labour. This problem is particularly acute in certain areas and minerals sectors, such as gold in Burkina Faso, Mali and the Niger, and cobalt and coltan mining in the Democratic Republic of the Congo.
- *Mining and conflicts*: If mining takes place in countries with armed conflict situations, there is the risk that it may help finance different parties in the conflicts. Mining could be the cause of a conflict and at the same time enable conflicts to continue. Beyond armed conflicts, resistance to the negative impacts of mining may give rise to conflicts among affected populations, with the mining companies or with the Governments concerned.[82] From a sample of 1,044 environmental conflicts affecting indigenous peoples, Scheidel et al. (2023) find that mining is the primary sector driving those conflicts, accounting for 24.7 per cent of the total.

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[79] See https://www.un.org/development/desa/indigenouspeoples/about-us.html.

[80] See https://www.ilo.org/global/industries-and-sectors/mining/lang--en/index.htm.

[81] See World Bank (2020, 2023) and https://www.worldbank.org/en/news/feature/2019/06/19/shining-a-light-on-a-hidden-sector and https://delvedatabase.org/.

[82] See https://ejatlas.org/.

Box II.2
Women and mining

According to ILO (2021), among some 21.4 million workers employed in mining and quarrying in 2019, only 3.1 million were women. This represents less than 15 per cent of the total. By contrast, women tend to be disproportionately affected by the negative economic, social and environmental externalities of these activities.

“Women and the mine of the future” is a collaborative project designed to increase understanding of the status quo for women in mining, so that stakeholders can anticipate, assess and address gendered impacts as the mining industry evolves. Project partners include the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development, International Women in Mining, ILO, the German Agency for International Cooperation, the Environmental Governance Programme operated by the Swedish Environmental Protection Agency and UNDP. It looks at a sample of 12 countries to uncover the gender-disaggregated employment profile for large-scale mining, focusing on women and their occupations in the sector. The countries included are Argentina, Australia, Brazil, Canada, Chile, Colombia, Ghana, Mongolia, Peru, South Africa, Sweden and Zambia.

The main conclusions from the global report for this project include the following:

- Large-scale mining is one of the economic sectors most over-represented by men. Among these countries, Sweden shows the highest share of women’s participation in total mining employment, at 25 per cent, while Peru accounts for the lowest, at 9 per cent. Nevertheless, the share of women employed in large-scale mining is gradually increasing, although at a slow pace. Moreover, women in the mining sector are more vulnerable to losing their jobs during economic downturns compared to men.
- Working conditions in the mining sector are not conducive to women’s employment. Basic facilities and equipment are still designed for men’s needs and there are challenges to full implementation of parental leave. Moreover, violence, harassment and gender-based discrimination are prevalent.
- Women are underrepresented in certain mining occupations, for example as technicians and associated professionals, craft and related trade workers and plant and machine operators, while they are overrepresented in others, such as clerical and support positions. They are also less represented in the “professional” occupational category, except for business and administration, as well as in professional, managerial and leadership positions.
- Barriers remain for women to obtain mining-specific skills and education. Overall, women in mining have a higher educational attainment than men. However, they have fewer technical and vocational qualifications. Furthermore, women are less likely to receive on-the-job training and apprenticeship opportunities than men.
- Women leave large-scale mining at a younger age. This is related to the occupations and the type of work they perform, and due to a variety of other reasons, including non-inclusive working conditions and lack of career growth.
- There is a persistent and significant pay gap in the mining workforce: women employees earn lower wages, despite their higher level of education. This gap is larger for better paid occupations. Moreover, women workers work fewer hours.

Source: UNCTAD, based on IGF (2023).

- *Human rights implications*: All of the above give rise to imbalances, injustices and possible violations of human rights. The transition minerals tracker of the Business and Human Rights Resource Centre monitors human rights implications of mining for six key technology-related minerals: cobalt, copper, lithium, manganese, nickel and zinc. It identified 510 allegations of human rights abuses from 2010 to 2022, including 65 in 2022. Over two thirds of all allegations are from just 14 companies, which are among the largest and most well-established companies in the extractive sector and from all around the world (Avan et al., 2023).[83]

Responding to concerns about how the sourcing of transition minerals may further exacerbate child labour, modern slavery, poverty and social exclusion, as well as worsening energy poverty levels and constraining access to land and other resources to vulnerable and historically excluded groups, the United Nations Working Group on the issue of human rights and transnational corporations and other business enterprises called for inputs on the extractive sector, just transition and human rights. This recognized the multitude and complexity of human rights issues that extractive sectors face. In an attempt to answer the question of how to achieve a human rights-based and just transition, the resulting report provided practical guidance to States, business enterprises and other stakeholders on the best ways to design and implement just, inclusive and rights-based transition programmes, investments and projects.[84]

In sum, the extraction of transition minerals should not come at the expense of the natural environment, local communities, human rights and peace. In recent years, there has been some progress in this regard, following technological advances, increasing awareness and concerns worldwide of the negative impacts of mining, as well as regulations and, mostly voluntary, standards at different levels. However, pressures from the increasing demand for raw materials may lead authorities to relax environmental impact assessment procedures, reduce permission times or weaken other environmental requirements for mining operations (Amigos de la Tierra and CIRCE, 2023). Thus, there is still a long way to go in properly and fully tackling harmful environmental, social and human rights impacts in the mining value chain. In the future, sourcing minerals and metals that are increasingly demanded by society will require the implementation of procedures that go beyond existing ecological, economic and social requirements and practices (Renn et al., 2022).

There is a need to balance the development of mining activities with benefits for producing countries, the rights of the local population and communities and the protection of the environment. This should apply along the entire value chain, which, beyond extraction, includes the processing of minerals and manufacturing the electronic products that contain such minerals (box II.3). Moreover, assessments of the environmental impact from mining should also consider transport, given that the different stages of the production of minerals, components and manufactured products take place in different countries around the world, before they are shipped to final markets.

> There is a need to balance the expansion of mining with the development benefits for producing countries, the rights of the local population and the protection of the environment

Supply chains of minerals and related electronics need to be properly governed at the national, regional and international levels, in an integrated and holistic way, to ensure that mining contributes to development in an inclusive, responsible and environmentally sustainable manner.

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[83] For key human rights-related risks in the mining and metals sector, see https://www.unepfi.org/humanrightstoolkit/index.php.

[84] See https://www.ohchr.org/en/calls-for-input/2023/call-inputs-extractive-sector-just-transition-and-human-rights and https://www.ohchr.org/en/documents/thematic-reports/a78155-extractive-sector-just-transition-and-human-rights.

Box II.3
Environmental and social impacts of electronics manufacturing

Electronics manufacturing, particularly semiconductor production, is one of the most toxic industrial processes. More than 400 chemical products are used in semiconductor manufacturing. It also requires large amounts of purified water and generates wastewater that contains heavy metals and toxic solvents. The production of components and the final assembly of electronic devices often involve wasteful processes.

Contrary to the mining sector, in electronics manufacturing, women workers make up the majority of the labour force, although they are primarily engaged in assembly line processes. A study by ILO, the European Union and OECD highlights the following decent work challenges in this area:

- Excessive working hours;
- Workforces with high shares of temporary or contract workers to accommodate flexible production demands;
- Limited training;
- Low wages, with a disproportionately higher share of women workers severely impacted;
- Forced labour, especially in relation to migrant workers;
- Occupational safety and health risks such as exposure to chemicals, uncomfortable working positions, repetitive work motion and problems related to eyesight;
- Most workers not able to exercise their union and collective bargaining rights.

Source: UNCTAD, based on Electronics Watch (2020) and ILO et al. (2023).

G. Conclusions

This chapter has looked at the production phase of the life cycle of digitalization, with an emphasis on the mining and processing of transition minerals. It has shown that digitalization is a material-intensive process. The world is undergoing significant transformations, strongly marked by the low-carbon and digital technologies, which are highly intensive in terms of minerals and metals. Without such materials there cannot be digitalization. Demand for transition minerals reflects the rapid development of new digital technologies, which necessitates more and more devices and the continuous development of the digital infrastructure needed to support the changing ecosystem.

The resulting surge in the demand for transition minerals raises major geopolitical and developmental concerns and challenges. Following global supply chain constraints resulting from the pandemic and the war in Ukraine, some reorganization of global production is taking place; developed countries importing transition minerals and electronics manufactures aim to secure supplies, including by increasing domestic production and forging new alliances. Their focus has been rebalanced from economic efficiency towards economic security, with an emphasis on increasing minerals supply, either primary supply or secondary supply from recycling, rather than on reducing overall consumption.

From the perspective of developing countries, this can provide an opportunity for development, provided they are able to add more value to minerals (see chapter VI). This scenario should help to reverse past trade asymmetries, in which developing countries export raw minerals yet import higher value-added manufactures, together with the related ecologically unequal exchange. Moreover, mining, as well as ICT goods manufacturing, can generate environmental and social impacts in developing countries, including on human rights, and these need to be minimized.

Taken together, there is a race to increase mining all around the world, as well as the production of electronic goods. This is part of a broader race for economic, trade and technological leadership, whereby securing access to transition minerals becomes vital for survival in a low-carbon and digital era. This has led to a worldwide push to increase mining and electronics manufacturing. Huge amounts of investment and public support are also provided for increasing minerals extraction, as well as expanding the production of, for example, batteries, semiconductors and electric vehicles.

From a global perspective, there is a risk that this can lead to overmining and manufacturing overcapacity. There may be a waste of resources from many countries that have invested significant resources without achieving comparable benefits, that is, resources that could have been used for other developmental purposes. Thus, approaches that may be perceived to be strategic from a perspective of national economic security may not only negatively affect global economic efficiency but also environmental sustainability. A more balanced, comprehensive, global approach may be preferable, one that considers supply and demand aspects and combines the interests of developing and developed countries, exporters and importers, while aiming for more responsible and sustainable consumption and production.

Addressing the surging demand for transition minerals will require rethinking models of consumption and production, looking not only at the supply side of the minerals, in terms of increased primary supply from mines, and secondary supply from recycling, but also at the demand side, in terms of reducing excessive consumption. Considering the significant digital divides between developed and developing countries, and in the spirit of the principle of "common but differentiated responsibilities", there could be much more of a margin for consumption reduction in developed countries.

Some hopes are also placed on technological advances that may lead to increased resource efficiency or to mineral substitutes. For example, changes in battery chemistry may reduce the use of minerals such as cobalt or lithium. These can bring uncertainty for countries producing these minerals. Recycling digitalization-related waste is also a useful option to reduce the extraction of minerals. Moreover, as discussed in chapter IV, by following a circular economy logic, there are several options before recycling that can help reduce mineral consumption.

Such an approach will require changes in consumption and production to make digitalization more responsible and environmentally sustainable. This should be enabled, promoted and regulated by public policies, including regional and global governance, which are discussed in chapter VI.

Chapter III explores the next phase of the digitalization life cycle, the use phase.

> Addressing the surging demand for transition minerals will require rethinking models of consumption and production

Annex to chapter II: Using thermoeconomics analysis to explain mineral depletion

Mineral depletion is the natural result of exponential behaviours and trends of consumption and growth.[85] At the current rate of extraction, in only one generation, humankind will have consumed as many minerals as during the entirety of human history. Moreover, the demand for minerals will have doubled or even tripled. In view of the growing demand for more minerals and metals to support the rapid development of low-carbon and digital technologies, it is important to pay attention to the volumes of resources that are extractable from the Earth. Some minerals are scarce but feasible to obtain, such as cobalt. Others are abundant but difficult and very costly to separate. Rare earth elements, for example, are more common than cobalt or copper, but costly to extract and separate. Others fall in the middle of this range.

As there is no economic theory that can give an objective value to the mineral wealth of the planet, economic analysis can be complemented with physics, and the principles of thermodynamics. “Thermoeconomics” combines ideas from thermodynamics and economics to measure materials transformation processes in energy units, instead of only in monetary units. This allows the analysis to go beyond subjective monetary value and the costs of mineral extraction, particularly as metals market prices fail to properly encompass the concept of mineral scarcity.

“Exergy” analysis is a valuable tool in assessing the depletion of mineral resources. The concept of exergy measures the quality and quantity of energy within a system. The exergy of an energy flow is the maximum amount of work that it can deliver (produce). In the case of minerals extraction, a scenario on Earth in which there is no concentration of minerals and, instead, there is maximum dispersion on the planet, would essentially constitute a state of bare, simple rock, or “thanatia”, a resource-exhausted planet.[86] The concept of thanatia offers a baseline for assessing the concentration exergy of mineral resources. In terms of mineral concentration, any state beyond thanatia would have exergy. Thus, a mine becomes valuable because of its concentration of mineral resources. In the same way, the higher the concentration level, the higher the exergy. As mines are depleted, their mineral concentration approaches that of thanatia, leading to exponentially increasing costs of extraction.

While the Earth’s crust is composed of minerals, it is only possible to extract those that are concentrated in deposits; the costs of extracting specific minerals or metals from bare rock would be unaffordable. However, concentrated mineral deposits are a geological rarity, representing only a small fraction of the outer crust, between 0.01 and 0.001 per cent. “Thermodynamic rarity”, i.e. the amount of exergy needed to extract metals from ordinary rocks (thanatia), considers the concentration of minerals in the Earth’s crust and the physical laws, based on real phenomena.[87]

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[85] This annex pays particular attention to mineral resources in the earth before extraction. The analysis is based on research at the Centre of Research on Energy Resources and Consumption, Spain. See Almazán (2021); Calvo et al. (2016, 2017); Valero et al. (2021); Valero and Valero (2014, 2015).

[86] Thanatia, named after the Greek for “death state”, is a hypothetical state explored in Valero et al. (2021).

[87] The second law of thermodynamics, also known as the entropy law, governs all physical systems. It implies that although the amount of energy remains constant, it becomes increasingly disperse, implying that everything will deteriorate until it cannot deteriorate any further.

In thermodynamic terms, going from a 1 per cent concentration to a 0.1 per cent concentration of ore requires at least 10 times more energy, water, tailings, infrastructure and ecosystem destruction for extraction. If ores with a richness of 0.01 per cent or 0.001 per cent have to be exploited. The energy requirements are at least 100 or 1,000 times higher compared to ores with 1 per cent concentration. Technology cannot exceed the efficiency limits set by thermodynamics; it can only approximate them.

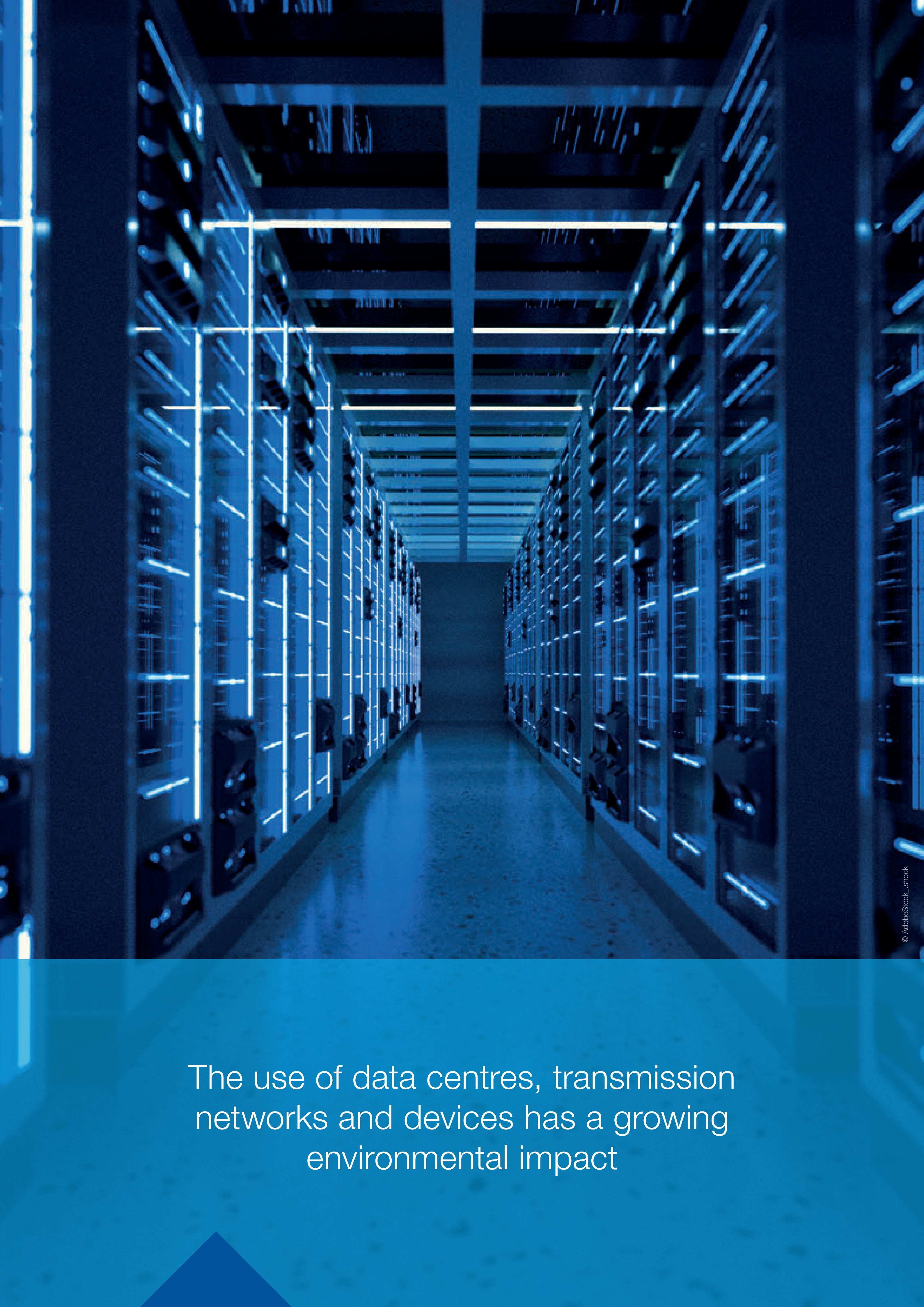
Increased extraction has resulted in a continuous decrease in ore grades, particularly for those minerals that are least abundant. This decline has an additional effect that can also be explained through thermodynamics: energy, water, chemicals and environmental impacts increase exponentially as mines become depleted. Furthermore, as extractive mining remains highly reliant on fossil fuels, it can be anticipated that mining-associated emissions will also increase, at least in the short to medium term.

Unfortunately, discoveries of new deposits of certain minerals have notably declined in recent years. The projection of the theoretical year for reaching peak extraction for several minerals, if the stated resources were available, within the next 50 years, shows that 12 elements (including indium, lithium, gallium and nickel, which are essential for low-carbon and digital technologies) would reach peak production levels. The extension of the timeline to the next 100 years shows that approximately 30 elements would reach peak production levels. These projections consider current growth rates, which may be expected to accelerate further in line with the low-carbon and digital transition objectives and available resources, including speculative quantities of minerals not yet feasible to exploit. While there is uncertainty surrounding the availability of mineral reserves, exponential surge in demand is eventually bound to collide with finite resources. The future availability of minerals is at stake under current consumption trends.

In short, mineral depletion is not a matter of geological scarcity, given the vastness of the Earth’s crust, but rather a result of the increasing costs required to extract continuously declining mineral ore grades. Although technology may improve, it likely cannot be enough to remove the ever-increasing millions of tons needed to meet future mining demand. Eventually, the once concentrated and utilized materials end up discarded in landfills worldwide, dispersed in the Earth’s crust, in oceans or in the atmosphere (such as gases produced by burning fossil fuels).

By employing exergy analysis, it is possible to account for the irreversibility (in kilowatt hours (kWh)) that occurs throughout the entire life cycle of mineral extraction, processing and market distribution. This approach can enable a more comprehensive understanding of the energy losses and inefficiencies associated with the minerals supply chain. Furthermore, it can help estimate the future depletion of mineral deposits using the same units (kWh) and provide a clearer picture of the gradual exhaustion of mineral resources over time, helping to make informed decisions regarding resource management and sustainability. It is important to develop accurate and comprehensive indicators to effectively monitor the depletion of such resources. Such indicators should consider the objective reality of mineral depletion, the multi-metal nature of deposits and their broader environmental and societal impacts.

In this mineral depletion outlook, those who first implement low-carbon and digital technologies may not face significant scarcity issues. Prices may initially rise, although at manageable levels. However, as demand continues to increase, there may be substantial increases in prices, as mines become more and more depleted. Moreover, the degradation of the planet’s mineral wealth will have major impacts on the environment and humanity, especially for future generations.



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The use of data centres, transmission networks and devices has a growing environmental impact

Chapter III

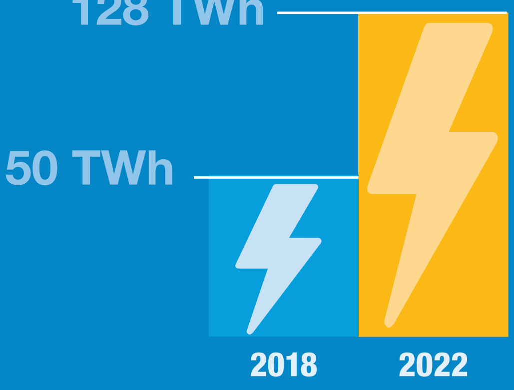
Environmental impacts in the use phase of digitalization

The growing use of rapidly evolving digital technologies and services around the world accounts for an important part of the environmental footprint of digitalization.

This chapter explores the primary environmental impacts stemming from the utilization of end-user devices, data transmission networks and data centres in light of current trends and developments.

The studies reviewed point to growing energy and water consumption as well as GHG emissions arising from this phase of the life cycle as a significant environmental concern. However, limited availability of data and transparency regarding the full picture of these environmental impacts hamper assessments.

With the adoption of ever more sophisticated, compute-intensive digital services, there is a need to give greater attention to the environmental footprint of digitalization and develop targeted policies to mitigate local and global impacts.



The electricity consumption of the 13 largest data centres operators more than doubled between 2018 and 2022

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A. Introduction

The operation of end-user devices, data transmission networks and data centres contributes to the environmental impacts of the ICT sector. Demand for digital technologies and services is rapidly increasing, generating a greater need for data to be transmitted, stored and processed. This triggers the use of a series of complex physical systems, including various digital devices, transmission infrastructure, data centres, servers, cables, satellites and routers.

Operating these digital technologies requires energy and can lead to adverse environmental impacts. Multiple criteria are important to assess the environmental footprint. This chapter focuses in particular on three, namely GHG emissions linked to energy use, water stress and noise pollution. Since digital technologies are widely deployed across all sectors, the environmental impacts of the use of digital devices and infrastructure should be closely understood, monitored and managed.

Energy consumption (especially electricity) and associated GHG emissions have drawn growing attention from the media and the research community. However, estimates of the electricity consumption and associated carbon footprint of the ICT sector diverge considerably due to the variety of different methodologies and data used (chapter I).

Other environmental considerations that should be taken into account – such as water consumption – are often overlooked when assessing the environmental footprint of the use phase. Improving the evidence base in this context is important to enhance public understanding, inform policymaking and influence business and consumer behaviour to achieve environmentally sustainable digitalization.

Against this background, this chapter summarises the state of research, identifies key data gaps and uncertainties and outlines potential future trends. It also explores opportunities for mitigating various environmental risks with a view to enhancing the sustainability of digitalization. Section B provides an overview of environmental impacts that may arise from the operation of data centres, data transmission networks and end-user devices. Section C takes a deep dive into data centres, focusing on their impacts at both global and local levels. The situation of data centres in developing countries is briefly explored in Section D. Section E investigates how potential environmental impacts depend on the services and underlying technologies used, including emerging technologies such as AI, blockchain, 5G and the Internet of things. Section F provides concluding observations.

> Operating digital technologies requires energy and can have adverse environmental impacts, such as GHG emissions, water stress and noise pollution

B. Main environmental impacts

In terms of energy use and GHG emissions, it is estimated that 56–80 per cent of the ICT sector's total life cycle impact can be attributed to the use phase (chapter I). However, the share varies depending on the different products used and on the energy mix associated with their use. For data centres and data transmission networks, due to their high energy intensity and utilization rates (i.e. operating 24/7) the use phase may account for over 80 per cent of GHG emissions over their life cycle

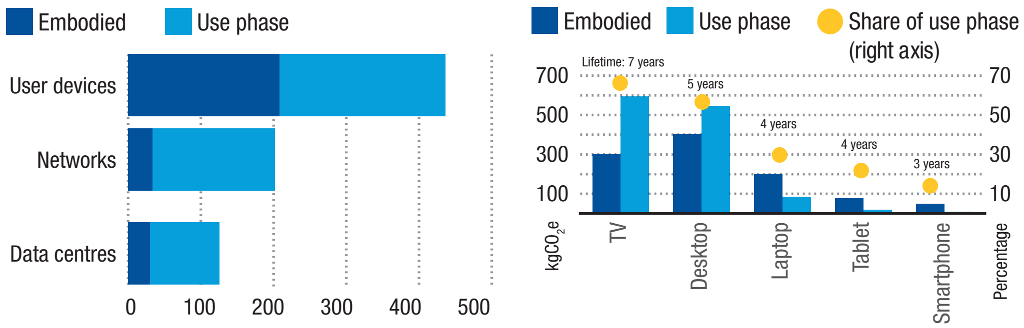

Figure III.1
Greenhouse gas emissions

a) by the three parts of the ICT sector, 2020
(megatons of CO_2 equivalent emissions)

b) by end-user device type, global averages
(kilograms of CO_2 equivalent emissions and percentage of total emissions)

Source: Malmodin et al. (2024, left) and Malmodin and Lundén (2018, right).

Notes: Carbon emissions for device types (right) are representative of global averages. Actual carbon emissions from devices depend on the carbon intensity of electricity supply and the device's assumed lifetime. Life cycle GHG emissions include use stage emissions and embodied emissions (embodied emissions are those occurring outside of the use stage, include those from raw material extraction, production and transport) in Malmodin et al. (2024).

(figure III.1.a).[1] In contrast, for connected devices, the use phase represents less than half of the life cycle energy and GHG impact; for battery-powered devices – such as smartphones and tablets, which are highly energy-efficient by design – the share is even lower, typically around 10–20 per cent. Around 80 per cent of the life cycle energy and GHG impact of a smartphone comes from the manufacturing stage (Clément et al., 2020; Ercan et al., 2016).

According to Malmodin et al. (2024), the ICT sector used about 4 per cent of global electricity in the use stage and accounted for about 1.4 per cent of global GHG emissions in 2020. Both electricity consumption and GHG emissions in the use phase have increased since 2015, reflecting the enhanced uptake of various digital technologies, devices and services.

Relatively little attention has been given to the water consumption associated with the use of digital technologies. This is starting to change. In recent years, several studies have stressed that the water footprint is an indispensable part of the overall environmental impact of digital technologies (Li, Yang, et al., 2023; Mytton, 2021). However, the evidence base is still limited. There is generally poor availability of relevant data, particularly from developing countries. This reflects various factors, including the reluctance of technology companies to share data and the lack of requirements and incentives for them to do so. Assessing the water footprint of digital technology therefore remains a challenge.

The following sections briefly look at use effects related to end-user devices, data transmission networks and data centres, respectively. For user devices and networks, energy consumption and the associated GHG emissions are the main environmental impacts under discussion; for data centres, water consumption is also explored.

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[1] For more information, see Andrae (2020); Malmodin and Lundén (2018); Malmodin et al. (2024); Masanet et al. (2013); Whitehead et al. (2015).

1. End-user devices

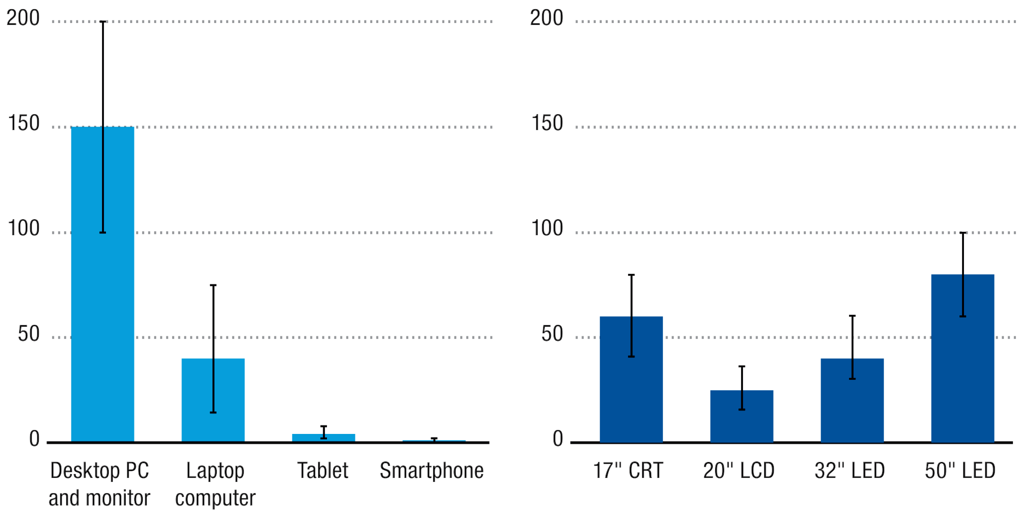
During the use phase of the ICT sector, end-user devices account for the largest share of GHG emissions (figure III.1.a). However, the share differs significantly between device types. For mains-powered devices, such as desktop personal computers, the relatively high level of power consumption means that more than half of life cycle energy use and emissions can be attributed to the use phase. While for more energy-efficient devices, such as smartphones, the production phase is the dominant source of emissions (figure III.1.b). The greater the number of devices used around the world, the greater the environmental impact in the production phase (chapter II), and on waste generation at the end of life (chapter IV).

Although the total number of end-user devices has increased rapidly over the past decade, overall energy consumption associated with their use has been found to be relatively flat (Malmodin and Lundén, 2018; Malmodin et al., 2024). This reflects in large part the shift towards smaller, more energy-efficient devices (e.g., from desktop computers to laptops, tablets and smartphones), as well as the shift to more energy-efficient screens (e.g., from cathode ray tube (CRT) to liquid crystal display (LCD) to more efficient light-emitting diode (LED) screens; figure III.2). The larger the screen of a computer device or monitor, the higher the level of power consumption. In some cases, smartphones have effectively replaced other consumer electronics (e.g., digital cameras, portable music players), reducing the need to manufacture and power a variety of single-function devices (Mims, 2012). At the same time, growing demand for larger screens for monitors and televisions is offsetting some of the efficiency gains from shifting to more efficient display ("panel") technologies.

Variations in time frame, scope, assumptions and data sources result in different estimates of the energy use of connected

Figure III.2
Typical daily power consumption of computing devices and monitors
(Watts)

a) by device **b) by monitor type and size**



Source: UNCTAD, based on Urban et al. (2017) and Kamiya (2020a).

Note: Error bars are illustrative of the lower and upper ranges of power consumption for most products in each device type. For example, a low-end desktop PC with a small monitor may consume 100W or less, while a gaming PC with a large monitor may consume 200W or more.

devices. For example, one set of studies estimates that ICT end-user devices – comprising mobile devices, PCs and customer premises equipment (such as Wi-Fi routers) – consumed 345 terawatt-hours (TWh) in 2020, and IoT devices (such as smart meters and surveillance cameras) consumed 75 TWh (Malmodin, 2020; Malmodin and Lundén, 2018; Malmodin et al., 2024). Televisions and other non-ICT consumer electronics and peripherals (for example, gaming consoles, set-top boxes) accounted for an additional 500 TWh.[2] Together, these devices bring the estimate to 920 TWh in 2020. Other studies have estimated that end-user devices, including televisions and other non-ICT consumer electronics, consumed 600–1,000 TWh in 2020, equivalent to 2.5–4 per cent of global electricity use (Andrae, 2020; Andrae and Edler, 2015).

Higher speeds of newer mobile networks induce **more use and traffic**, leading to rebound effects

2. Data transmission networks

Data transmission networks transmit data between two or more connected devices. They comprise all core networks, mobile access networks (2G to 5G), copper- and fibre-based fixed broadband access networks, traditional public switched telephone networks and enterprise networks.[3] Data transmission networks consumed an estimated 260–360 TWh in 2022, equivalent to 1.1–1.5 per cent of global electricity use. Mobile networks – mostly through radio access networks (GSMA, 2023c) – accounted for around two-thirds of the total (Malmodin et al., 2024). The main impact on GHG emissions from data transmission networks arises in the use phase (figure III.1). Total use stage GHG emissions for networks are estimated to be 168 megatons of CO$_2$ equivalent (MtCO$_2$e) in 2020 (figure III.1.a).

The energy efficiency of data transmission – measured in terms of energy use per unit of data transferred – has greatly improved in the past decade. The energy needed to transmit one gigabyte (GB) of data through fixed-line networks has been observed to halve every two years (Aslan et al., 2018), corresponding to annual efficiency gains of 30 per cent; while mobile-access network energy efficiency has improved by 10–30 per cent annually (Fehske et al., 2011; Pihkola et al., 2018). Each successive generation of mobile network uses less energy to transmit data than the previous generation.[4] For example, in 2015, 4G networks typically used around one fiftieth of the energy[5] of 2G networks to transfer the same amount of data (IEA, 2017).

However, higher speeds of newer mobile networks also induce more usage and traffic, thereby giving rise to rebound effects. Between 2015 and 2020, the number of mobile broadband connections more than doubled to nearly 7 billion, and mobile data traffic grew 17 times to 90 EB per month. As a result, despite improvements in energy efficiency, total mobile network energy use increased by around 25 per cent (Malmodin et al., 2024). Meanwhile, the energy used by fixed networks fell over the same period, helping to moderate overall network energy use (Malmodin et al., 2024). Some of the savings from fixed networks may be attributable to the replacement of traditional copper networks with more energy-efficient fibre optic networks (Obermann, 2020).

While energy per unit data (for example, kWh/GB) is a widely used and reported

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[2] See Malmodin and Lundén (2018); Malmodin (2020); Malmodin et al. (2024).

[3] Customer premises equipment, such as routers and modems, are not included in "data transmission networks" but are accounted for in "connected devices". For more details, see Malmodin and Lundén (2018) and Malmodin et al. (2024).

[4] See Pihkola et al. (2018); STL Partners (2019); 4E EDNA (2019); *Orange Hello Future* (2022).

[5] The average energy intensity of mobile networks can vary greatly depending on their capacity utilization. As traffic within a given access mode (for instance, 2G, 3G or 4G) increases, its overall average energy intensity (kWh/GB) can decrease, which makes comparisons highly case-specific. In general, energy use is not directly proportional to data traffic in networks, since data networks have a significant baseload energy demand, regardless of the amount of network traffic.

indicator of energy efficiency of data networks (Body of European Regulators for Electronic Communications, 2023; ITU, 2015), it does not appropriately characterize the energy performance of networks, in particular the last-mile access network (Coroamă et al., 2015). Moreover, it does not adequately measure the energy use of a specific digital service such as data-intensive, high-traffic applications.[6] To understand and monitor energy efficiency progress of transmission networks, it is important to track both total energy use and energy efficiency indicators, based on the number of connections, peak traffic, and/or coverage as well as quality of service (Next Generation Mobile Networks Alliance, 2023).

3. Data centres

Data centres require huge computing capacity and accordingly consume large amounts of both energy and water. Based on a literature review, the IEA (2023d) estimates that in 2022, global data centre electricity consumption (excluding cryptocurrency mining, section E.3) was 240–340 TWh, representing around 1–1.5 per cent of global electricity use.[7] This can be compared with the annual electricity consumption, for example, of the United Kingdom (250 TWh), Spain (256 TWh), Indonesia (270 TWh) and Mexico (294 TWh).[8] GHG emissions of data centres during use phase in 2020 have been estimated at 95 $MtCO_2e$, which is three times greater than the GHG emissions of the production stage, according to Malmodin et al. (2024) (figure III.1a).

In the use stage, water consumption is mainly associated with the operation, and especially the cooling, of data centres. For data centres, particularly hyperscale ones, which have massive computing power and generate a substantial amount of heat, effective cooling is needed to ensure uninterrupted operation. Water and electricity consumption are interlinked and need to be considered holistically.

Although some cooling technologies can be operated without water, they may then instead consume large amounts of electricity (Hidalgo, 2022). In the next section, a more detailed analysis is provided of the environmental implications of the operation of data centres.

> Data centres require huge computing capacity and thus consume large amounts of both energy and water

C. Deep dive into data centres

Data centres are at the heart of the digital economy, storing and processing vast volumes of data for consumers, businesses and the public sector. Data centres with various capacities are deployed to support the provision of digital services ranging from emailing to video streaming and technologies from blockchain to AI.[9] Demand for these services is rising rapidly, raising questions about their impact on energy use, GHG emissions, water consumption and other environmental concerns. Available research has mainly looked at data centres in developed countries, notably in the United States as well as in Europe (Mytton and Ashtine, 2022).

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[6] See DIMPACT (2022); Kamiya (2020a); Malmodin (2020); The Carbon Trust (2021).

[7] See also Andrae (2020); Hintemann and Hinterholzer (2022); Malmodin (2020); Masanet et al. (2020).

[8] For comparison with other end uses, the global electric vehicle fleet consumed 110 TWh in 2022, while space cooling globally consumed around 2,000 TWh (IEA, 2022a, 2022b). See also IEA (2023e, 2023f); Red Eléctrica de España (2022); United Kingdom, Department for Business, Energy and Industrial Strategy (2022).

[9] Data centre capacity can be measured in terms of power, space, cooling, and power/network port connections that are needed to meet the requirements of current and future IT demand.

1. Energy consumption

National statistical agencies and intergovernmental organizations, such as the European Commission and IEA, collect and publish official statistics on the energy use of many sectors and services, such as industrial subsectors (including steel, cement) and transport modes (for example, road transport, rail). However, to date, there has been a lack of data regarding the energy use of data centres, with only a few countries having measured or estimated this.[10]

Global data centre energy consumption data are all derived from modelled estimates, employing a variety of methodological approaches. These can be broadly categorized into three types – bottom-up, top-down and extrapolation, or a combination of them (Mytton and Ashtine, 2022) – each with their own advantages and disadvantages (box III.1).

Since 2015, several research groups have produced global estimates, with wide-ranging results (table III.1). A comprehensive review of 46 publications and 179 global data centre energy estimates between 2007 and 2021 identified a number of methodological issues and underlined the need for greater data transparency (*Data Centre Dynamics*, 2022a; Mytton and Ashtine, 2022).[11]

Estimates for global data centre energy use vary significantly, making it hard to compare and draw sound conclusions

Available estimates and projections for global data centre energy use in 2020 range from around 200 TWh to over 1,000 TWh (figure III.3). Differences in methodology, system boundaries and underlying data sources make it hard to compare the various estimates. Drawing sound statistical relationships and measures has proven practically infeasible (Mytton and Ashtine, 2022). This points to the need for more standardized and objective methodologies for measurement. That would enable Governments to better plan electricity management in zones where data centres operate or may be commissioned. Nevertheless, recent research suggests that energy use by data centres can be expected to grow significantly, fuelled by increased use of compute-intensive activities linked to, for example, cryptocurrencies and AI (section E).

2. Energy efficiency and cooling trends

Global data centre energy use (excluding cryptocurrency mining) appears to have grown less than may have been expected over the past decade, considering the strong expansion in demand for data centre services. This has mainly been attributed to efficiency improvements in IT hardware and cooling systems, and a shift from inefficient enterprise data centres towards more efficient cloud and hyperscale data centres (IEA, 2017, 2023g; Masanet et al., 2020; Shehabi et al., 2016). Running applications in the cloud requires 60–90 per cent less energy than using on-premise data centres.[12] Smaller data centres serving companies that are less reliant on cloud services tend to be much less energy-efficient and are not always included in studies estimating the global impact of data centres.

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[10] Data centre energy use has been estimated based on metered electricity consumption data in Ireland and the Kingdom of the Netherlands (Ireland, Central Statistics Office, 2022, 2023; Kingdom of the Netherlands, Statistics Netherlands, 2021). Government agencies have modelled national data centre energy use in Denmark (Denmark, Danish Energy Agency, 2023), Finland (Hiekkanen et al., 2021), France (Ademe and Arcep, 2022), Singapore (Singapore, Ministry of Communications and Information, 2021), Sweden (Sweden, Swedish Energy Agency, 2023) and the United States (Shehabi et al., 2016).

[11] Common problems include sources listed without explaining where or how they are used, citations of unreliable sources, assumptions without explanation and model parameters without values. For example, the underlying link between network traffic and energy consumption used to be a key assumption in some publications, which has been refuted in later research.

[12] See 451 Research (2019); Microsoft (2020); S&P Global Market Intelligence (2021a, 2021b); Zheng and Bohacek (2022).

Box III.1
Approaches to estimating data centre energy use

Bottom-up studies use detailed data on technology, such as equipment specifications (including server power use), data centre infrastructure characteristics (such as power usage effectiveness (PUE) and installed base and equipment shipment values.[a] Their main advantage is that they can explain underlying drivers and trends, and are useful for assessing efficiency potential. However, the substantial data requirements make them resource- and time-intensive. Some data inputs, such as proprietary market data, can be expensive or difficult to obtain, which limits transparency. Examples of bottom-up studies include Hintemann and Hinterholzer (2020; 2022), Masanet et al. (2020) and Montevecchi et al. (2020).

Top-down studies compile measured or estimated energy consumption data from Governments and companies. Their main advantage is that they are based on fairly reliable data that is easy to collate and update. At the same time, the limited availability of data from Governments and companies means that only a portion of the overall scope can be estimated, requiring extrapolation or other complementary approaches to ensure comprehensive coverage. Some government data (for instance, metered energy consumption) may focus only on large data centres and exclude smaller ones, while company-reported data may include non-data centre energy use (such as offices, stores). Examples of measured or estimated consumption data from Governments include Ireland, Central Statistics Office (2022, 2023) and the Kingdom of the Netherlands, Statistics Netherlands (2021). Malmodin et al. (2024) use a combination of top-down estimates from company data and other studies.

Extrapolation approaches combine high-level activity indicators, such Internet protocol (IP) traffic, with energy-intensity assumptions to project total energy use under different activity and efficiency-improvement scenarios. Extrapolation approaches require a baseline energy consumption estimate from a bottom-up or top-down model, and decisions around growth rate (including energy-efficiency improvement, data volume growth). These studies are typically more transparent and relatively easy to generate and update. The main disadvantages are their low explanatory power and a higher risk of misuse (for example, developing exaggerated estimates from long-term projections). Examples of extrapolation approaches include Andrae (2019a, 2020), The Shift Project (2019a, 2021) and Belkhir and Elmeligi (2018).

Source: UNCTAD, based on Mytton and Ashtine (2022).

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[a] PUE is a measure of how efficiently a data centre uses energy; the most efficient hyperscale data centres can have values of around 1.1, meaning that for every 1.1 kWh of electricity used, 0.1 kWh is used for cooling/power provision and 1 kWh is used for IT equipment.

Despite improvements in energy efficiency, the strong increase of workloads handled has resulted in energy use by co-location and hyperscale data centre operators expanding by 10–30 per cent per year since 2020.[13] In particular, for 13 of the largest data centre operators, for which data is available, the estimated company-wide electricity consumption more than doubled between 2018 and 2022 (figure III.4).[14]

Data centres need energy to power IT and infrastructure equipment. Globally, the vast majority of IT-related energy in data centres is consumed by servers (80 per cent),

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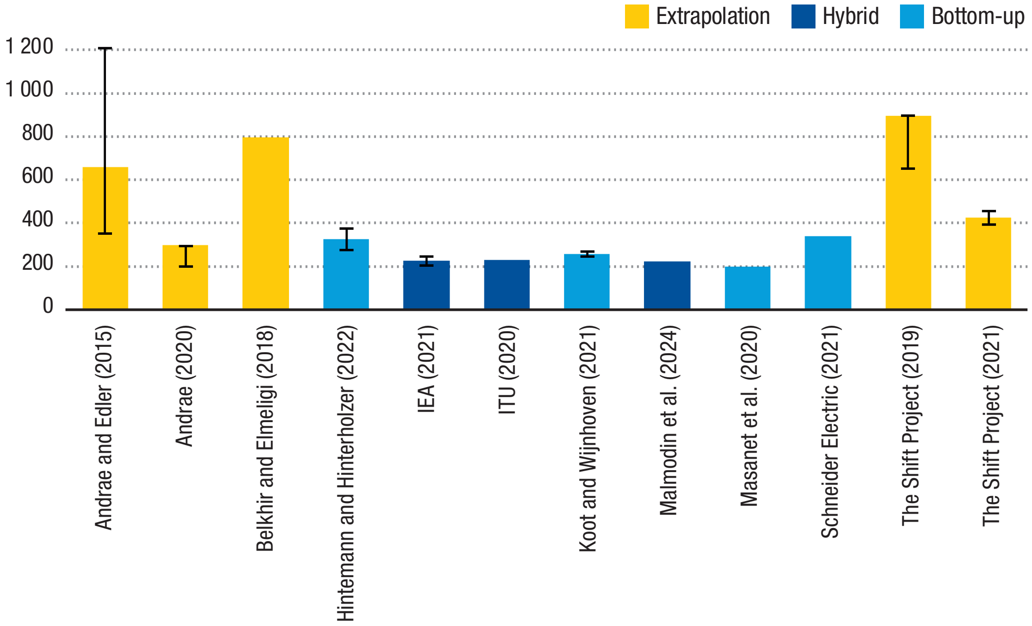
[13] See Alibaba (2022); Apple (2022, 2023); Baidu (2023); Digital Realty (2022, 2023); Equinix (2022, 2023); Google (2023, 2022); Meta (2022, 2023); Microsoft (2022, 2023a); Tencent (2021, 2022, 2023); VNET Group (2023).

[14] Some of these companies also have significant non-data centre business divisions, such as retail stores and warehouses that use electricity, but most of the electricity used by these companies is likely to be related to their data centres, making these trends an appropriate proxy for their data centre energy use trends.

Figure III.3
Global data centre energy use, selected estimates and estimation methodologies, 2020

(Terawatt hours)



Source: UNCTAD.

Notes: Error bars, where shown, indicate the range of estimates in each study. Values exclude cryptocurrency mining.

followed by storage devices (18 per cent) and network equipment (3 per cent), while most infrastructure-related energy use is related to cooling (Masanet et al., 2020). Currently, the global average PUE in data centres is around 1.6, meaning that for every 1.6 kWh of electricity used, 1 kWh is used for IT and 0.6 kWh for cooling and other non-IT equipment (Davis et al., 2022). The theoretical minimum value of PUE would be 1, where 100 per cent of the energy used is for IT. The average PUE of Google and Meta data centres – some of the most energy-efficient in the world – is already around 1.1 (Google, 2022; Meta, 2022).

Given the significant share of cooling in overall energy use by data centres, reducing such energy use has become a major focus for data centre operators. Traditional, inefficient cooling designs have been largely replaced by more efficient cooling systems, including hot and cold aisle contained cooling systems (Heslin, 2015). Allowing data centres to operate at slightly higher temperatures has also enabled energy savings, as has locating data centres in cooler climates. As the power density of racks (structures that hold computer equipment) increases, liquid cooling – such as immersion cooling, where dielectric fluids absorb heat from a computing device or processing chip – is becoming an important cooling method.

Other innovative approaches are currently being tested. For example, in 2020, Microsoft completed a two-year trial in which a data centre holding over 800 servers was placed on the sea floor off the coast of Scotland. The data centre was powered entirely by renewable energy from onshore wind and solar and offshore tidal and wave sources (Microsoft, 2023b). The underwater data centre did not use any water (BloombergNEF, 2023b) and required less energy for cooling (PUE of 1.07 compared with 1.125 for the company's new land-based data centres). It also reported almost 90 per cent lower failure rates

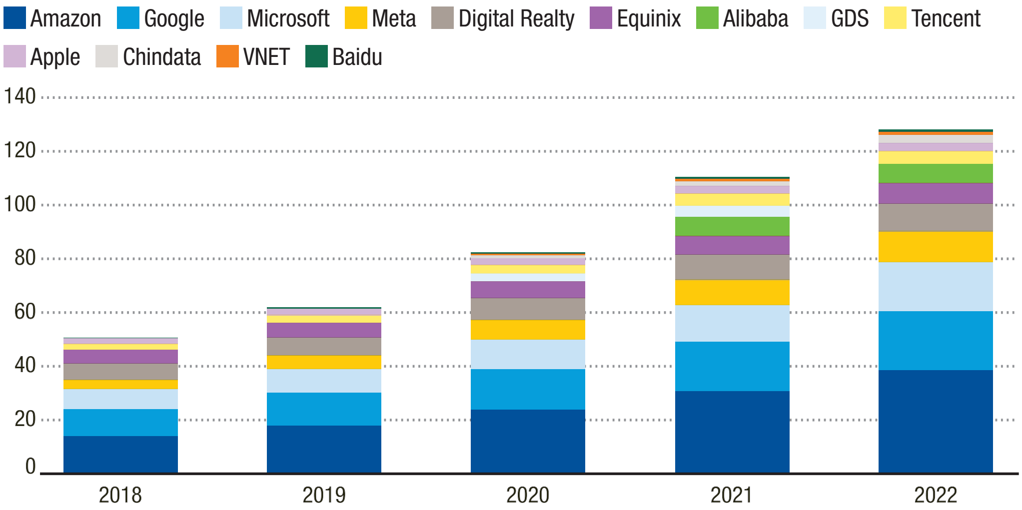
Table III.1
Global energy use of data centres: Overview of studies, 2015–2024

Institution and publications	Estimates	Approach
Beijing Normal University; Global Energy Interconnection Development and Cooperation Organization		
Liu et al.(2020)	450–550 TWh in 2017 600–800 TWh in 2020 (projection)	Based primarily on assumptions and approach in Andrae and Edler (2015), with revised projections for PUE under different decentralization scenarios.
Borderstep Institute		
Hintemann (2020)	310–330 TWh in 2018 (400 TWh including cryptocurrency)	Bottom-up estimate based on data centre market developments (primarily in Europe), technical characteristics of servers, storage, and networking (energy use, age) and data centre infrastructure (air conditioning, power supply, uninterruptable power supply). Some of the estimates include cryptocurrency mining.
Hintemann and Hinterholzer (2022)	270–380 TWh in 2020 (350–500 TWh including cryptocurrency)	
Ericsson; Telia		
Malmodin and Lundén (2018)	220 TWh in 2015 (245 TWh including enterprise networks)	Hybrid estimate based on bottom-up estimates based on hardware shipments, complemented by benchmarking to other studies and reported company data.
Malmodin et al. (2024)	223 TWh in 2020	
GreenIT.fr		
Bordage (2019)	312 TWh in 2019	Based on the number of servers in operation and life cycle assessments of three different data centres.
Huawei		
Andrae and Edler (2015)	397 TWh in 2015 (“Expected” case) 345–1200 TWh in 2020 (projection)	Extrapolation with data centre IP traffic extrapolations and energy intensity per unit of IP traffic under updated efficiency improvement scenarios.
Andrae (2019a)	211 TWh in 2018	Updated IP traffic and energy efficiency assumptions from 2015 study.
Andrae (2020)	196–299 TWh in 2020	
International Energy Agency		
IEA (2017)	194 TWh in 2014 200 TWh in 2020 (projection)	Global model based on expanded model from Shehabi et al. (2016).
IEA (2021d, 2022d, 2023c)	200–250 TWh in 2020 220–320 TWh in 2021 240–340 TWh in 2022	Hybrid estimate based on the bottom-up modelling in IEA (2017) and Masanet et al. (2020) and global estimates by Hintemann and Hinterholzer (2022) complemented by reported energy consumption data from large data centre operators.
International Telecommunication Union		
ITU (2020)	220 TWh in 2015 230 TWh in 2020 (projection)	Based primarily on IEA (2017), supplemented by Malmodin and Lundén (2018a), Shehabi et al. (2016) and Fuchs et al. (2017).
Lawrence Berkeley National Laboratory; Northwestern University; University of California Santa Barbara		
Masanet et al. (2020)	205 TWh in 2018	Bottom-up estimate based on shipment data for servers, drives, networking, energy use characteristics and lifetimes, combined with assumptions for each type of data centre class and region-specific PUE.
McMaster University		
Belkhir and Elmeligi (2018)	599 TWh in 2017 797 TWh in 2020 (projection)	Extrapolation using estimate on the data centre energy use in 2008 from Vereecken et al. (2010) and an annual growth of 10 per cent based on a market research company’s projection.
Schneider Electric Sustainability Research Institute		
Petit et al. (2021)	341 TWh in 2020	Bottom-up estimate based on workloads, data storage requirements and global average PUE.
The Shift Project		
The Shift Project (2019a)	559–593 TWh in 2017	Based on the model developed by Andrae and Edler (2015) with updated assumptions and scenarios.
The Shift Project (2021)	393 TWh in 2019 (438 TWh including cryptocurrency)	
University of Twente		
Koot and Wijnhoven (2021)	286 TWh in 2016 240–275 TWh in 2020	Hybrid approach combining top-down indicators and bottom-up data (e.g. workloads per application).

Source: UNCTAD, based on studies cited.

Figure III.4
Company-wide electricity consumption by data centres, selected companies, 2018–2022

(Terawatt hours)



Source: UNCTAD, based on company sustainability reports and external verification statements of environmental, social and governance data.

Notes: As Amazon did not publicly report electricity consumption in 2018 and 2019, these values are estimated by UNCTAD based on other publicly reported data from Amazon (scope 2 emissions, renewable energy share) as well as comparable data and indicators from other companies. For operators and years for which relevant data are not publicly available, estimates could not be derived, as follows: Alibaba (2018–2020), Baidu (2018), Chindata Group (2018–2019), GDS (2018–2019, 2022) and VNET (2018–2019).

compared with on-land data centres (Microsoft, 2023b).[15] Submarine data centres are also being explored in China (BloombergNEF, 2023b). However, the potential impact of underwater data centers on marine life and the environment will need to be further assessed.

The low PUEs at Google and Meta seem to have plateaued in recent years, suggesting declining opportunities for further improvements in the energy efficiency of cooling systems. In the future, energy efficiency improvements in the largest data centres are likely to come from improving the energy efficiency of computing activities. Such improvements cannot be captured by the PUE indicator since this does not measure the energy efficiency of the IT equipment (i.e. energy used per unit of useful output or service provided, such as computation and data storage). This again points to a need to track a wider range of energy indicators and environmental indicators related to GHG emissions, water usage and waste (Lin and Bunger, 2021).

Highly compute-intensive tasks, such as training large language models, are currently driving the use of specialized hardware such as application-specific integrated circuits (ASICs) and graphics processing units. For instance, Google's custom ASIC was found to be 30–80 times more energy efficient than general-purpose central processing units (Jouppi et al., 2017). However, the use of powerful graphics processing units and ASICs for machine learning applications could drastically increase the power density of data centre racks and the amount of heat generated, which may in turn require more energy and water for cooling (see also section C.4).

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[15] Land-based data centres are affected by corrosion from oxygen and humidity, temperature fluctuations, and movement from technicians who replace broken components.

Computing hardware has become ever more powerful and efficient over the past 50 years.[16] However, as efficiency improvements from hardware begin to slow – and eventually reach theoretical limits (see section E) – software-related opportunities to improve energy efficiency become more important (Leiserson et al., 2020). Substantial energy efficiency gains can be achieved by using more energy-efficient code, removing "software bloat",[17] and tailoring software to hardware features.

Storage devices account for about one-fifth of IT-related energy consumption by data centres (Masanet et al., 2020); reducing their energy use could therefore be an important source of efficiency gains. The share of solid-state drives, which are generally more energy efficient than hard disk drives (Tomes and Altiparmak, 2017), in installed storage capacity increased from less than 3 per cent in 2010 to around 30 per cent in 2018 (Masanet et al., 2020).

Addressing "dark data" and using cold storage could represent other means of storage (and energy) savings.[18] Some analysts estimate that such data account for over half of worldwide storage and are responsible for the emissions of millions of tons of CO_2 annually (Al Kez et al., 2022; Veritas, 2020). Companies and organizations should look into analysing existing dark data to derive insights and educate employees on how to overcome instincts to hoard unnecessary data (Gartner, 2017).

Overall, data centre energy use is likely to continue to grow significantly over the next few years. Longer-term trends are highly uncertain and depend on:

- The pace of overall demand growth for data centre services, particularly from emerging technologies and services such as AI and machine learning, blockchain and the metaverse (section E);
- The evolution of cryptocurrency prices and whether major cryptocurrencies move to less energy-intensive consensus mechanisms (section E);
- Further energy efficiency improvements in IT hardware and cooling technologies and approaches, including breakthrough technologies or efficiency limitations (section F);
- The extent to which existing workloads in enterprise data centres will be migrated to the cloud;
- Broader trends in digital technologies and services that influence data centre developments, such as a greater need for low latency services that would increase demand for edge data centres, and the development of global data governance (UNCTAD, 2021a).[19]

Data centre energy use is likely to continue to **grow significantly** over the next few years

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[16] Moore's Law describes the long-term trend that the number of transistors incorporated in a computer chip doubles every two years, making chips more powerful (Moore, 1965). While Koomey's Law refers to the doubling of peak-output efficiency every 1.57 years for computing hardware (Koomey et al., 2011). Peak-output efficiency is the number of computations that can be performed per kWh of electricity consumed. More recent analysis shows a slowing of this trend to every 2.7 years since 2000 (*IEEE Spectrum*, 2015; Koomey and Naffziger, 2016).

[17] Software that has increasingly unnecessary features use more memory, disk space or processing power.

[18] Dark data refers to unstructured and abandoned data that has been gathered or stored with little value potential (Al Kez et al., 2022). This includes, for example, old emails and attachments, and partially developed and then abandoned applications. Cold storage refers to the storage of inactive data that is rarely accessed, used, or shared in low-cost equipment (Seagate, 2023). Data is stored in a safe, low-cost location – in-house or in the cloud – that can be accessed when needed. Cold data storage is generally much more economical (and uses much less energy) than "hot storage" of active data (Dell, 2023)

[19] An "edge" data centre is a small data centre that is located close to the edge of a network. Its main benefit is the quick delivery of services with minimal latency. See https://www.techtarget.com/searchdatacenter/definition/edge-data-center.

3. Greenhouse gas emissions and sources of energy

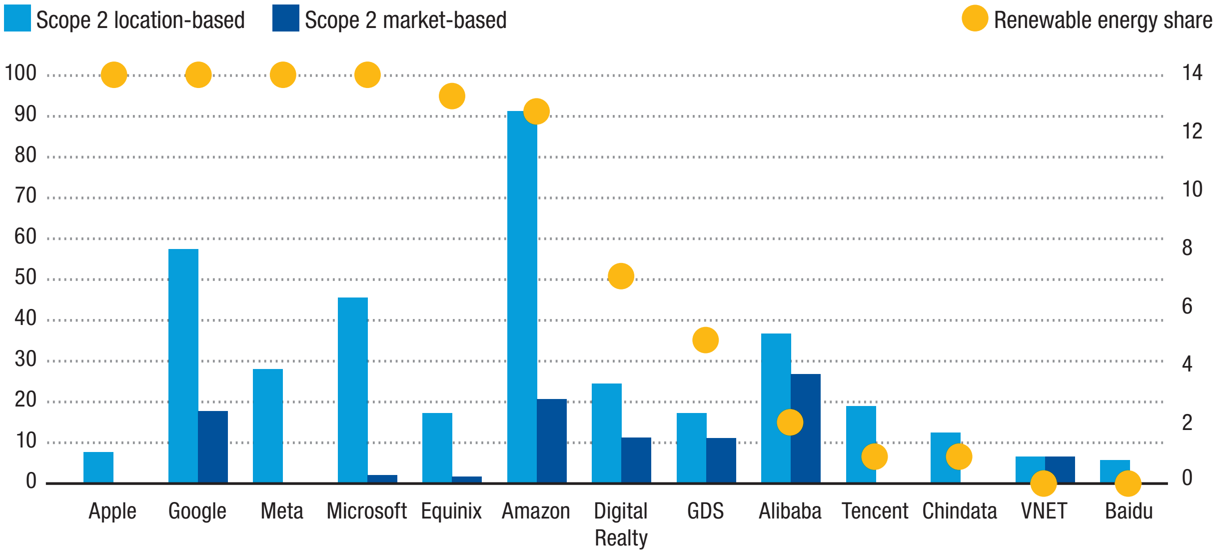
Data centres are highly electrified. This means that comparatively, it is easier to decarbonize than in sectors such as transport and manufacturing that rely more heavily on fossil fuel consumption (IEA, 2022b). The impact of data centres on GHG emissions depends primarily on the source of the electricity supply.

The largest data centre operators have sought to reduce GHG emissions by purchasing renewable energy, mainly in the form of power purchase agreements (PPAs). These agreements are long-term commitments between the buyer and renewable electricity generators. They seek to reduce risks for new projects and allow access to project finance, while locking in a low and stable price for the buyer.

Some companies have relied on energy attribute certificates, which are transferrable proofs of renewable energy generation.

These purchases can help reduce operators' market-based scope 2 emissions as reported under Greenhouse Gas Protocol standards relative to location-based ones (figure III.5). Apple (3.2 TWh), Google (21.8 TWh), Meta (11.5 TWh) and Microsoft (18.2 TWh) each purchased or generated enough renewable energy in 2022 to match 100 per cent of their total electricity consumption (Apple, 2023; Google, 2023; Meta, 2023; Microsoft, 2023a). Amazon, the largest data centre operator in the world, reached 90 per cent renewable energy matching across its operations in 2022 (Amazon, 2023a) and Equinix, one of the largest co-location data centre operators, reached a 96 per cent rate in the same year (Equinix, 2023). Data centre operators in China are relatively

Figure III.5
Renewable energy share and scope 2 emissions, selected data centre operators, 2022
(Percentage renewables in total energy use and megatons of CO_2 equivalents)



Source: UNCTAD, based on Alibaba (2023); Amazon (2023a, 2023b); Apple (2023); Baidu (2023); Chindata Group (2023); Digital Realty (2023); Equinix (2023); GDS (2022); Google (2023); Meta (2023); Microsoft (2023a); Tencent (2023); VNET Group (2023).

Note: Scope 2 accounting can use different methods that allocate emissions from the generator to end users. Location-based methods use the average emissions intensity of grids where energy is used, mostly based on average emission factors from those grids. Market-based methods reflect emissions from electricity that companies have intentionally bought through PPAs (World Resources Institute, 2015).

lagging behind in this area: renewables accounts for a smaller share of electricity use at Alibaba (15 per cent), Tencent (8 per cent) and Baidu (1 per cent), and at large data centre operators GDS (34 per cent) and Chindata (7 per cent).[20]

Large data centre operators based in the United States continued to dominate renewable energy purchasing in 2022, with Amazon, Google, Meta and Microsoft as the top four purchasers (BloombergNEF, 2023b). Amazon alone accounted for nearly one third of all renewable PPAs globally in 2022. As of the end of that year, Amazon had a renewable energy portfolio of over 20 GW, making it the seventh largest such portfolio globally, including utilities (Amazon, 2023b).

However, matching 100 per cent of annual demand with renewable energy purchases or certificates does not mean that data centres are powered exclusively by renewable sources. Wind and solar power may not always meet a data centre's energy demand, and renewable energy may have been purchased from projects in a different location to the demand (IEA, 2023d).

Energy attribute certificates, also known as renewable energy certificates and guarantees of origin, have been shown to have low or unclear environmental benefits (Bjørn et al., 2022). In contrast, on-site generation, PPAs and sourcing and matching zero-carbon electricity on a 24/7 basis within each grid where demand is located can increase additionality (IEA, 2022b).[21] These approaches have environmental benefits and can provide price predictability. However, on-site generation is limited by size and scale, while PPAs tend to have complicated contract structures and may not be available in all markets.

4. Water consumption

Water consumption during the use phase is mainly linked to the cooling of data centres. The water footprint of data centres is inherently context-specific. The cooling technology used is highly dependent on the climate and resource availability at the location of the data centre (Karimi et al., 2022). For example, in cooler regions (such as Northern Europe), relying on free air cooling is possible for most of the year, thus reducing the need for water consumption. In warmer regions (such as Africa and Southeast Asia), reducing water consumption for cooling is much more challenging. Given the anticipated expansion of data centres in these regions to support the growth of the digital economy and for reasons of data sovereignty, associated water demand may further complicate the effective management of often scarce water resources (section C.5) (Mytton, 2021).

In recent years, improvements in cooling technologies,[22] along with increased temperature tolerance of some IT equipment, have led to a reduction in the reliance on water-based cooling technologies[23] and offered more options for cooling data centres, especially large ones (Dietrich and Lawrence, 2022). In tandem with these developments, alternative sources of water such as reclaimed wastewater and even seawater are being explored to meet the high water demands of data centres.[24]

Water and electricity use by data centres needs to be considered holistically. Although some cooling technologies can be operated without water, they may instead consume large amounts of electricity (Hidalgo, 2022). Moreover, the water footprint of generating

> Matching 100 per cent of annual demand with renewable energy purchases does not mean that data centres are powered only by renewable sources

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[20] Data on renewable energy consumption has not been publicly disclosed by the two largest telecommunications data centre operators, China Telecom and China Unicom (China Telecom, 2023; China Unicom, 2023).

[21] In the case of renewable energy purchases, a purchase may be considered "additional" if the associated renewable energy generation capacity would not have occurred without that particular purchase (ElectricityMaps, 2023).

[22] For example, Microsoft's immersion liquid technology, see Microsoft (2023c).

[23] For example, Chindata Group's X-cooling waterless technology; see Chindata Group (2022).

[24] For example, the cloud service providers Alibaba Cloud and Tencent Cloud in China use reclaimed water in their data centres; see Alibaba (2023) and Tencent (2023), while on seawater use, see. for example, Google's project in Finland (Google, 2023).

this additional electricity may more than outweigh the gains of not having a direct water footprint (Ristic et al., 2015). Data centre operators need to consider trade-offs between energy and water consumption when seeking the optimal cooling system for each site's technical and climate conditions (Karimi et al., 2022). As advancements continue to be made, the most sustainable option will be the one that focuses holistically on energy efficiency and responsible water consumption (O'Donnell, 2022).

> A lack of transparency on the part of data centre operators makes it difficult to assess the water consumption of the sector

A lack of transparency on the part of data centre operators makes it difficult to access up-to-date information and to assess the water consumption of the sector at a national or regional level. Only a few studies have considered water consumption by data centres in the United States (Shehabi et al., 2016; Siddik et al., 2021) and Europe (Farfan and Lohrmann, 2023b). For instance, their total annual operational water footprint in the United States was estimated at 513 million m^3 in 2018, placing data centres among the top 10 water-intensive industries in the country (Siddik et al., 2021). More research is needed to obtain a reliable evidence base for policymaking aimed at promoting sustainable water management in data centres.

5. Local impacts of data centres

a. Impacts on electricity grids

Due to their large size and the high intensity of energy use, data centres can have significant local energy-related and environmental impacts. In the United States, data centres are 10 to 50 times more energy-intensive (per unit floor area) than a typical commercial office building (United States, Department of Energy, 2023).

New large data centre developments can significantly affect local power grids, with a hyperscale data centre requiring 100–150 MW of grid capacity and consuming hundreds of GWh of electricity annually (Kamiya and Kvarnström, 2019). New data centre developments in developing countries are likely to be smaller (up to tens of MW) as the electricity grids in these countries are generally less resilient, but the relative impact on each grid can still be significant.

Careful site selection and planning are essential to ensure that data centres have access to reliable electricity supplies to minimize the use of diesel backup generators and ensure high operational reliability. This is important to avoid any adverse impacts on local electricity grids, not least in countries with limited access to electricity.

Data centre buildings are usually constructed with excess capacity to allow for future growth, in anticipation of future customer demand, but they begin their operations well under maximum capacity. Grid capacity reserved for maximum usage may remain unused, blocking other users (Mytton et al., 2023). Managing capacity is an area where policy can be improved.

Although data centres (excluding cryptocurrency mining) only account for 1–1.5 per cent of global electricity consumption, in smaller countries with expanding data centre markets, their share can quickly become more significant. For example:

- In Denmark, data centres used about 1.1 TWh of electricity in 2021 (3 per cent of national use). By 2030, this is projected to increase to 8 TWh, which would be equivalent to around 13 per cent of national electricity consumption (Denmark, Danish Energy Agency, 2023);
- In Ireland, data centre electricity use more than quadrupled between 2015 and 2022, reaching 18 per cent of the country's electricity consumption in 2022 (Ireland, Central Statistics Office, 2023). The country's transmission system operator projects that this share could rise to as much as 28 per cent by 2031 (Ireland, EirGrid, 2022);
- In Singapore, data centres were responsible for around 7 per cent

of electricity demand in 2020 (Singapore, Ministry of Communications and Information, 2021).

In some communities and regions with a high or growing concentration of data centres there have been increasing concerns related to new data centre developments. Some Governments have also introduced restrictions or moratoriums on new investments, as follows:

- In Ireland, the County Council of South Dublin attempted to ban data centres in the region but, in accordance with a ministerial order, would allow their development. However, the country's transmission network operator, EirGrid, has stated that no new data centres are likely to be granted a grid connection until 2028 (*Data Centre Dynamics*, 2022b);
- In 2022, the Government of the Kingdom of the Netherlands announced stricter rules for hyperscale data centres and implemented a temporary moratorium on new developments in most of the country (*Data Centre Dynamics*, 2022c);
- The Government of Singapore implemented a moratorium on new data centres in 2019, which was lifted in 2022, though subject to strict conditions around resource efficiency.[25]

b. Impacts on water supply

In regions where water resources are under significant stress, data centre operators often compete with local communities for access to potable water. Cooling systems of data centres rely on clean freshwater sources to prevent issues such as corrosion and bacteria growth (Li, Yang, et al., 2023). In the United States, one-fifth of the direct water footprint of data centre servers reportedly comes from moderately to highly water-stressed watersheds, and nearly half of the servers are fully or partially powered by power plants located within water-stressed regions (Siddik et al., 2021). Given the energy needs discussed above, data centre operators are sometimes drawn to water-starved regions, especially if carbon-free solar and wind energy are available (*NBC News*, 2021).

Water consumption by data centres has recently stoked tension within local communities in both developed and developing countries:

- In the Kingdom of the Netherlands, the Parliament voted to subject a planned Meta data centre to an environmental review due to objections from the local farming community of Zeewolde;[26]
- Plans by Meta to build a data centre in Mesa, Arizona, United States, a desert city that is already home to large data centres owned by Apple, Google and other technology giants were opposed by local residents;[27]
- Google planned to build a data centre in Uruguay, which led to public debate. In 2023, the country experienced the worst drought in 74 years and more than half of its 3.5 million citizens were without access to potable tap water.[28]

In recent years, technology companies have shown more interest in exploring sustainable water management practices, illustrated by their commitment to reporting detailed water metrics and improving their sustainability credentials (Mytton, 2021). In its 2023 environmental report, Google (2023) disclosed that total water consumption at its data centres and offices globally in 2022 amounted to 5.6 billion gallons (about 21.2 million m^3). For the same year, Microsoft (2023c) reported that its water consumption was 6.4 million m^3. Amazon, Google and Microsoft have all

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[25] See https://www.straitstimes.com/tech/singapore-pilots-new-scheme-to-grow-data-centre-capacity-with-green-targets.

[26] See https://www.washingtonpost.com/climate-environment/2022/05/28/meta-data-center-zeewolde-netherlands/.

[27] See https://www.washingtonpost.com/climate-environment/2023/04/25/data-centers-drought-water-use/.

[28] See https://www.theguardian.com/world/2023/jul/11/uruguay-drought-water-google-data-center.

committed to replenishing more water than they consume.[29] The companies that reported total direct water consumption – Apple, Baidu, Digital Realty, Google, Meta, Microsoft and Tencent – together used an estimated 50 million m^3 of water in 2022. This figure does not include indirect water consumption, such as for electricity generation, which accounts for a significant share of their total water consumption. The impact of data centres' water consumption is primarily local, rather than global.

Transparency concerning water consumption has also seen an uptick among cloud service providers and data centre operators, including in developing countries. In China, leading carrier-neutral data centre operators GDS and Chindata revealed water consumption metrics for their data centres in 2021. Respectively, they reported 5.1 million tons[30] (about 4.5 million m^3) and 1.5 million tons[31] (about 1.3 million m^3) of water consumption (Chindata Group, 2022; GDS, 2022). Baidu Cloud (2023) began disclosing information on its water usage effectiveness in 2022.

These positive steps are primarily orchestrated by major hyperscale cloud providers. Most small and medium-sized data centres across the globe have yet to incorporate water data into their reporting. For example, in 2022, only 39 per cent of respondents to a data centre survey reported on their water consumption (Davis et al., 2022). Most operators stated that tracking water consumption lacked business justification. However, as a growing number of municipalities will only allow data centre developments if they are designed for minimal or near-zero direct water consumption, this metric is expected to become a more important factor in business decisions.

c. Impact on noise levels

Data centres generate noise from ventilation, air conditioning fans and diesel generators. Noise impacts can be a critical issue for residents and community officials, especially when data centres are built close to their customers to reduce latency (*Reuters*, 2022). Adverse health impacts observed in nearby residents include hearing loss, elevated stress hormone levels, hypertension and insomnia (Monserrate, 2022). For example, in 2019, residents in Chicago complained of constant fan noise from a nearby data centre, where levels of noise were reportedly higher than legally permitted.[32]

Noise control of data centres has gained the attention of some local governments in the United States, requiring more studies around noise and increased mitigation efforts, public outreach and regulation. One comprehensive study in this regard focused on Prince William County in the state of Virginia, finding that noise generated by data centres significantly exceeded the applicable ordinance levels (Lyver, 2022). However, as the local ordinance exempted the noise from ventilation and air conditioning systems, the study recommended that noise mitigation should be mandated at data centre sites in operation and form an integral part of data centre design during the planning process. It also argued that the local government should demand strong, contractual commitments for noise control (Shaw and Lyver, 2023). In 2023, the city of Chandler, Arizona, joined a list of cities across the United States to adopt a zoning

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[29] See https://blog.google/outreach-initiatives/sustainability/replenishing-water/; https://blogs.microsoft.com/blog/2020/09/21/microsoft-will-replenish-more-water-than-it-consumes-by-2030/; and https://sustainability.aboutamazon.com/natural-resources/water.

[30] This includes only the water consumption of operations at data centres that are leased and owned by GDS and its build-operate-transfer data centres. Water consumption at third-party data centres and individual offices is excluded.

[31] This includes only data centres located in Beijing, as Chindata states that data centres outside the city are outside of its full operational control. Water consumed includes both groundwater and municipal water supply.

[32] See https://www.datacenterdynamics.com/en/news/chicago-residents-complain-of-noise-from-digital-realty-data-center/.

code amendment to define the operation of data centres, including noise control.[33]

Some data centre operators have voluntarily attested to the responsible design and operation of their data centres. This includes leveraging new technology and solutions to ensure that the data centres operate as quietly as possible. For example, Microsoft has taken a series of measures in this regard, including infrequent use of backup generators, added attenuation to the generator design and minimizing the use of mechanic chillers when free air cooling can be used.[34]

There can be trade-offs between noise generation, energy use and water consumption in data centres. When data centres in Chandler, Arizona switched from water to electricity to cool their operations, noise complaints from nearby residents increased (*Reuters*, 2022). Data centre operators should assess potential local noise impacts during site selection and implement measures to mitigate impacts during operation. In some cases, this will require careful balancing between latency, energy use, water consumption and noise generation. Some new paradigms might avoid these trade-offs. For example, liquid-based cooling, a technique that is growing in popularity, is expected to eliminate the fans required to cool servers. It also tends to be more energy-efficient, making it doubly advantageous for businesses interested in reducing noise and increasing sustainability (IEA, 2023d; Kamiya and Kvarnström, 2019).

d. Mitigating local impacts

As low latency applications, data sovereignty and repatriation requirements drive more local data centre developments, operators will need to manage their impacts carefully, particularly in regions where energy and water are in limited supply. Data centres can mitigate some of their local energy-related impacts by developing, or investing in, local renewable energy projects, providing waste heat and participating in demand response programmes (IEA, 2023d; Kamiya and Kvarnström, 2019). These programmes aim to balance the demand on power grids by encouraging customers to shift electricity demand to times when electricity is more plentiful or other demand is lower, typically through prices or monetary incentives (IEA, 2023g).

In developing countries, Governments and utilities may consider opportunities to co-develop local electricity and water infrastructure with new data centre and network projects to expand electricity and water access in communities, with digital infrastructures serving as important anchor customers of electricity and water (Givens, 2016; International Solar Alliance, 2022; Ramchandran et al., 2016; Ranade, 2013).

Policymakers and regulators can play an important role in incentivising demand-side flexibility. For example, allowing for some leeway in ancillary service requirements (like longer notice periods or longer response times) may make it easier for data centre operators to participate in demand response programmes (IEA, 2023d; Malmodin, 2020; Malmodin and Lundén, 2018; Malmodin et al., 2024).

In some countries, data centres support local energy systems by providing waste heat to help warm nearby buildings or supply industrial heat users, including swimming pools and greenhouses (*Data Centre Dynamics*, 2022d; Lalonde et al., 2022; Ljungqvist et al., 2021). To overcome potential barriers to using waste heat, such as achieving sufficiently high temperatures and contractual and legal challenges, policymakers, data centre operators and district heating suppliers should work together to develop adequate incentives and guarantees (IEA, 2023d). Governments of European Union countries have until September 2025 to introduce new requirements for new data centres on their waste heat management, following the publication of the Directive 2023/1791

> Data centre operators need to carefully balance latency, energy use, water consumption and noise generation

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[33] See https://www.chandleraz.gov/news-center/chandlers-data-center-ordinance-now-effect.

[34] See https://local.microsoft.com/wp-content/uploads/2022/10/Noise-fact-sheet.pdf.

of the European Parliament and of the Council on energy efficiency.[35] Data centres above a certain size should use their waste heat or find options for others to use the heat they generate, except where a cost-benefit analysis renders this economically or technically infeasible.

D. Data centres in developing countries

Growth in data centre investments in developing countries is anticipated, and this comes with implications for local energy and water consumption

Most data centres are located in digitally advanced economies. This applies in particular to hyperscale data centres. At the same time, digital transformation in developing countries is driving increased demand for data centres in these countries. This is happening despite challenging climate conditions, limited availability of renewable energy, water scarcity, connectivity constraints and power outages. For latency reasons, the growth of IoT and 5G mobile networks also favours the establishment of data centres closer to users. Furthermore, various public policy objectives, such as protecting privacy and other human rights, national security and advancing economic development, mean that countries prefer to build data centres within their borders. Such preferences are likely to persist until there is a global approach to data governance, including for cross-border data flows, which would allow for value of data to be harnessed equitably for development independent of where data are stored (UNCTAD, 2021a). Further growth in data centre investments in developing countries is anticipated, and this comes with implications for local energy and water consumption. This makes it imperative to integrate sustainability concerns into the early stages of planning new data centres.

1. Africa

It is estimated that Africa accounts for less than 1 per cent of available data centre capacity in the world (Kadium Limited, 2022). According to Begazo et al. (2023), sub-Saharan Africa has only 0.1 data centre per 1 million people, compared with 0.5 per million in the world and 3.1 per million in North America. South Africa has emerged as a regional hub for data centres, accounting for more than two-thirds of data centre capacity in Africa, followed by Ghana, Kenya and Nigeria (Africa Data Centres Association, 2021). With growing numbers of Internet users, and in view of concerns related to data governance and data sovereignty, this region is expected to see a rise in data centre development.

Increasing demand for cloud-based services and modular data centre solutions from enterprises, particularly micro-, small- and medium-sized enterprises (MSMEs) and from government agencies, is expected to further boost the need for data centre capacity. The Africa Data Centres Association (2021) has estimated that the African data centre market will grow at a compound annual growth rate of 12 per cent between 2019 and 2025, reaching a value of $3 billion in 2025.

Electricity needs of data centres are estimated to increase from 1 TWh in 2020 to around 5 TWh in 2030, which would represent almost 5 per cent of total electricity demand growth in the services sector in Africa (IEA, 2022d). However, most sub-Saharan African countries find it difficult to meet even the basic (tier 1) reliability standards of electricity supply. For example, Eskom, the State-owned grid operator in South Africa, recorded at least 3,212 hours of load-shedding across the country's grid in 2022. On-site power generators, usually diesel-powered, are the most common

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[35] See https://energy.ec.europa.eu/news/new-energy-efficiency-directive-published-2023-09-20_en.

option for backup electricity supply, and are associated with relatively high GHG emissions (Smolaks, 2023). Growth of renewable energy and use of energy-efficient technologies (for instance, innovative cooling techniques) will be needed to meet demand from the anticipated increase in data centres (Begazo et al., 2023).

Some companies have already started to increase the share of renewable energy in the electricity supply. For example, Distributed Power Africa, a unit of the Zimbabwe telecommunications firm Econet, is overseeing the integration of alternative energy solutions into its data centres in Burundi, Kenya and South Africa (Africa Data Centres Association, 2021). Water consumption is also gaining more attention from data centre operators in Africa. There is an opportunity for data centre operators in Africa to spearhead a global drive to include water source and use metrics in their reporting and promote the wider use of water recycling in data facilities (Kadium Limited, 2022).

2. Asia

With rapid digitalization and surging demand for cloud-based services, the overall data centre market size in Asia and the Pacific is estimated to reach around $28 billion by 2024 (EcoBusiness Research, 2020). Much of the demand comes from global cloud providers, social media and e-commerce platforms, video streaming and banking, which all require robust IT infrastructure and data networks. According to the Digital Centre (2021), China leads the market in terms of data centre development, with India and Singapore among the frontrunners. Indonesia, Malaysia and Thailand are also making a sizeable contribution toward the region’s growth.

Sustainability is becoming a key business imperative in Asia as customers, shareholders and the public are demanding accountability from corporations. Some of the challenges faced by data centres include rising carbon emissions, a tropical climate, which tends to be too hot and too humid for data centres, overcoming land constraints and the need for more efficient cooling technologies (Digital Centre, 2021). Accordingly, some Governments are adopting new policies to promote the sustainability of data centres (box III.2).

3. Latin America and the Caribbean

In Latin America and the Caribbean, the data centre market is still evolving. Echeberría (2020) estimates that there are currently about 30 data centres in the region with power supply capacities in excess of 15–20 MW. Brazil leads the market, with Chile, Colombia and Mexico emerging as important data centre locations. Investments in data centres in this region are expected to amount to $9 billion between 2021 and 2027.

Sustainability has become an increasingly important issue for the data centre industry in Latin America. Pressure is increasing on hyperscale data centres to demonstrate more efficient and cleaner operations, regardless of energy consumption. There have also been growing concerns in parts of Latin America over the large amounts of water required by data centres (McGovern and Branford, 2023).

Policies to promote more environmentally sustainable data centres in the region are still at a nascent stage. In June 2023, the Ministry of Development, Industry, Commerce and Services of Brazil and the Brazilian Agency for Industrial Development launched a study on the development of data centres in Brazil that will, among other things, look at how to secure better access to renewable energy.[36]

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[36] See https://www.bnamericas.com/en/news/with-unprecedented-diagnosis-government-begins-to-debate-policy-for-datacenters.

Box III.2
Data centre sustainability policies: Singapore and China

In Southeast Asia, Singapore is the main data centre hub. With 100 data centres, 1,195 cloud service providers and 22 network fabrics, the country has emerged as a global cloud connectivity leader. Singapore has taken various steps towards making data centres more environmentally sustainable, as follows:

- *Green Data Centre Standard:* Published in 2011 and revised in 2013, the Singapore Standard 564 (SS564) was developed by the Green Data Centre Standards Working Group under the industry-led Information Technology Standards Committee. The standard is modelled after the ISO 50001 standard on energy management but is tailored to meet the needs of data centres in Singapore. It defines a set of performance metrics for measuring their energy efficiency and includes a comprehensive set of recommended industry best practices for data centre design and operations;
- *Green Mark for Data Centres:* The Green Mark, first launched in 2012, is a rating system that encourages the adoption of energy-efficient design, operation and management of data centres. Since 2022, new data centres must meet updated requirements, including obtaining “platinum” certification under the Green Mark for Data Centre criteria, achieving a design PUE of 1.3 or below, and providing evidence of a clear pathway to achieving 100 per cent renewable energy;
- *Green Data Centre Technology Roadmap:* To address energy and climate change, the National Climate Change Secretariat and the National Research Foundation jointly commissioned the Green Data Centre Technology Roadmap, which was published in 2014. The roadmap highlights the pathways from research and development to deployment for technologies that can help increase energy efficiency and lower carbon emissions of data centres in Singapore;
- *Tropical Data Centre Standard:* In 2023, Singapore launched one of the world’s first standards (SS697:2023) for optimizing energy efficiency for data centres in tropical climates. The new standard aims to help data centres develop a roadmap to support the gradual increase in the data centre operating temperatures to 26°C and above (instead of the current industry practice of 18–22°C). This could lead to 2–5 per cent cooling energy savings, with every 1°C increase in the data centre operating temperature. The tropical standard forms part of the Digital Connectivity Blueprint, in which sustainability is a paramount factor.

The Government of China has also developed various policies to make data centres more environmentally sustainable. For example:

- In terms of data centre standard evaluation systems, the Ministry of Housing and Urban-Rural Development released the Technical Rules for Green Data Centre Building Evaluation in 2015; the Chinese Institute of Electronics released the Green Data Centre Evaluation Guidelines (T/CIE 049–2018) in May 2018; and the China Academy of Building Research released the Green Data Centre Evaluation Standard (T/ASC 05–2019) to evaluate and grade data centres on their environmental sustainability in 2019;
- In terms of data centre policies, the promotion of green data centres was proposed in 2012, and a series of policies and measures was introduced in the following years, standardizing and guiding the environmentally sustainable development of data centres;
- In order to promote more sustainable technology products for data centres and encourage environmentally sustainable and low-carbon development, the Ministry of Industry and Information Technology has been updating the Green Data Centre Advanced Applicable Technology Product Catalogue since 2016. The latest one was released in 2020 and involved 62 technical products in four fields, including efficiency improvements when using energy and resources, the use of renewable energy, distributed energy supply and microgrid construction technology products, waste equipment recycling and treatment, restricted substance use control technology, environmentally sustainable operation and maintenance management technology.

Source: UNCTAD, based on Chow et al. (2023), Singapore, Infocomm Media Development Authority (2023), Interesse (2023) and Li, Sun, et al. (2023)

E. Implications of different digital services and technologies

Environmental impacts in the use phase are not only affected by the types of devices used, but also by the activities and technologies involved. Digital services can encompass a wide variety of online activity, from web browsing, email and instant messaging, to social media, content-sharing platforms and video conferencing as well as services that rely on advanced technologies, for example, AI-powered large language models. The array of digital services used on a daily basis differ in how they employ technologies and infrastructure.

This section discusses the environmental impact of some widely used digital services, including video streaming and email, web searches and online advertisements. It then turns to more sophisticated digital services and their emerging underlying technologies, such as blockchain, AI, virtual reality, 5G and the IoT. These are poised to increase the demand for data services and affect the environmental footprint of the ICT sector, with some technologies (such as blockchain) primarily impacting data centres, and others, such as 5G and IoT, largely affecting networks and devices. Mitigating and managing the environmental impacts of these emerging technologies will require concerted efforts from all stakeholders.

1. Video streaming

The delivery of videos from content providers to viewers requires energy consumption across the ICT system, including in data centres, through data transmission networks and viewing devices. The energy and carbon footprint of video streaming has attracted significant media attention recently. For example, one study concluding that half an hour of streaming emitted as much CO_2 as driving 6.5 km (equivalent to consuming 6.1 kW of electricity per viewing hour) was widely quoted in the media (Kamiya, 2020b). Another estimate was that 7 billion YouTube views of the song “Despacito” had consumed 1.66 kW per viewing hour (900 GWh) (Kamiya, 2020a). Marks et al. (2020) first estimated that streaming 35 hours of high-definition video consumed 11 kW per hour (382 kWh in total). These estimates have since been revised downwards by over 90 per cent to 0.78–0.98 kW per hour (Makonin et al., 2022). As a comparison, a typical 50-inch LED television consumes about 0.08 kW per hour.

More recent analyses, using updated assumptions and methodologies, have concluded that the initial studies significantly overestimated the energy and carbon footprints (Moulierac et al., 2023), by up to 140 times in some cases (IEA, 2021d; The Carbon Trust, 2021). The European Commission (2023a) found that the full life cycle emissions of a typical hour of video streaming in Europe were responsible for 55g CO_2e, including emissions from device and digital infrastructure manufacturing, distribution, use and end-of-life phases.

Although earlier analyses by Obringer et al. (2021) and the Shift Project (2019b) and media articles had recommended that viewers reduce the resolution of videos to minimize their environmental impact, other research suggests that reducing bitrates has almost no impact on network energy use (Adelin et al., 2010; Chen et al., 2022; Koomey and Masanet, 2021; Malmodin, 2020; Schien et al., 2023). This is because data and network energy use are not proportional. Most network equipment consumes a similar amount of energy regardless of the volume of data traffic (Chan et al., 2016; DIMPACT, 2023). For example, a home Wi-Fi router might consume 10 W when a connected user is browsing the web. When the same user starts streaming a 4K resolution video – increasing data

> Environmental impacts in the use phase are not only affected by the types of devices used, but also by the activities and technologies involved

traffic by around 3,000 per cent – the router might only use 10 per cent more energy, not 3,000 per cent more (Malmodin, 2020).

Actual environmental impacts for each user depend primarily on the viewing device and the electricity generation mix. For example, a 50-inch LED television consumes roughly 100 times more electricity per hour than a smartphone, and five times more than a laptop (figure III.2). Thus, the most effective way to reduce the energy footprint of video streaming is to use a smaller device. In developing countries, fewer individuals and households have a television compared with those who have mobile phones and use data. Typical viewing patterns in low-income economies may therefore be less energy intensive than in high-income economies.

> The most effective way to reduce the energy footprint of video streaming is to use a smaller device…

> …typical viewing patterns in low-income economies may therefore be less energy intensive than in high-income economies

Finally, assessing the energy and carbon footprint of video streaming (or any other digital service) requires a comparison with the relevant counterfactuals as well as an assessment of possible rebound effects. In the case of video streaming, the counterfactual case may be another form of video consumption (such as going to the cinema or renting a DVD). Rebound effects would be determined by how much more viewing is taking place due to the flat cost of video streaming. Incorporating both the positive and negative impacts is critical to understanding whether a certain digital service provides a net benefit or net cost to the environment.

2. Email, web searches and online advertising

Digital activities that are not data intensive, such as email and web searches, are also drawing media attention regarding their carbon footprints, with calls to cut back on emails to reduce carbon footprints. A widely cited suggestion is that more than 16,000 tons of CO_2 emissions per year in the United Kingdom could be avoided if every adult sent one less unnecessary email per day (*Bloomberg*, 2020; *Financial Times*, 2020; *The Guardian*, 2019).[37] More recent estimations are much lower. In fact, sending fewer emails is now seen to have almost no impact on energy use or GHG emissions (*BBC News*, 2020; Viana et al., 2022). Nevertheless, there can still be other environmental benefits – and, more importantly, operational and productivity-related benefits – from sending fewer unnecessary emails and sharing files through the cloud instead of sending them as email attachments.

Advertising is now ubiquitous on the Internet, with the average Internet user being exposed to thousands of advertisements per day. Pärssinen et al. (2018) concluded that online advertising used 20–282 TWh in 2016. More recent analysis by Cabañas et al. (2022) estimates that online advertisements consume 2–91 TWh per year, and Pesari et al. (2023) found that online advertisements and trackers consumed only 0.61 TWh in 2019. The significant variation in these figures – with low and high estimates differing by a factor of nearly 500 – reflect the lack of methodological consistency. Much larger environmental impacts of online advertising are likely incurred in other sectors through its indirect effects, for example, by influencing purchase decisions (like encouraging consumers to buy more items; see chapter V) and other unsustainable behaviours (for instance, encouraging vacation travel to distant locations) (Hartmann et al., 2023).

3. Blockchain

Blockchain and other distributed ledger technologies are major energy users and generators of digitalization-related

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[37] These claims were based on analysis by OVO Energy, an energy utility company in the United Kingdom, which assumed that one unnecessary email emitted 1g of CO_2 (*Financial Times*, 2020; Ovo Energy, 2019). In 2021, Ademe, the French Agency for the Ecological Transition, similarly reused estimates from 2011 regarding the GHG emissions impact of an email or web search (Bio Intelligence Service and Ademe, 2011; *TF1 Info*, 2021).

waste.[38] Blockchain uses energy to validate transactions and mine cryptocurrencies using ASICs.

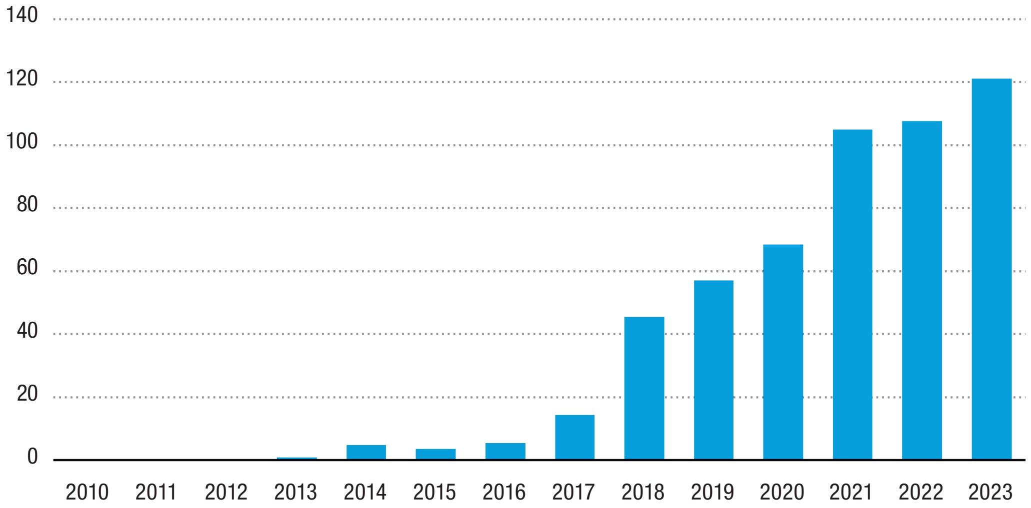
This hardware is often housed in facilities that are effectively data centres, some analysts have included cryptocurrency energy use when estimating global data centre energy consumption (Hintemann and Hinterholzer, 2022). But others have chosen to analyse the energy and climate impacts of these activities separately (IEA, 2023d; Malmodin et al., 2024; Masanet et al., 2020).

Including blockchain within data centre energy use metrics greatly increases overall energy use. Energy use specifically due to blockchain activities grew by 2,000–3,500 per cent between 2015 and 2022, while other data centre energy use grew by 20–70 per cent (IEA, 2023d). Highlighting the energy and climate impacts of cryptocurrencies can raise awareness to the issue and point to the need for developing the necessary technology and policy options to mitigate adverse impacts.

Bitcoin is the most prominent example of a "proof-of-work"[39] blockchain. It is the most valuable cryptocurrency by market capitalization. Bitcoin consumed an estimated 120 TWh in 2023, 33 times more than in 2015 (Cambridge Centre for Alternative Finance, 2024) (figure III.6). Ethereum, second behind bitcoin in terms of market capitalization and energy use, consumed around 17 TWh in 2021 (McDonald, 2022). In September 2022, Ethereum transitioned from a "proof-of-work" consensus mechanism to "proof-of-stake",[40] expected to reduce energy use by 99.95 per cent (de Vries, 2022). Some cryptocurrency advocates state that bitcoin mining is "green" because it absorbs

According to IEA, energy use due to blockchain activities grew by 2,000–3,500% between 2015 and 2022

Figure III.6
Annual bitcoin energy consumption, 2010–2023
(Terawatt hours)



Source: UNCTAD, based on Cambridge Centre for Alternative Finance (2024).

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[38] See Digiconomist (2023); de Vries and Stoll (2021); Cambridge Centre for Alternative Finance (2024); McDonald (2022); Gallersdörfer et al. (2020).

[39] "Proof-of-work" is a consensus mechanism that ensures trust across the network. Computers on the network – "miners" – compete with each other to solve a complex computational puzzle, requiring vast amounts of computing power and energy (Kamiya, 2019a).

[40] "Proof-of-stake" is an alternative consensus mechanism to proof-of-work. In this case, the scarce resource is no longer computing power as in proof-of-work, but capital (or stake) as proven by the ownership of cryptocurrency linked to the corresponding blockchain (Coroamă, 2021).

excess or stranded renewable energy generation, reducing curtailment and carbon emissions (Square, 2021; *Time*, 2022). This requires further analysis as cryptocurrency mining can be expected to be undertaken where electricity is cheap, not where it is supposedly plentiful (Coroamă, 2022).

The environmental footprint of cryptocurrencies is concentrated in a few countries that host most of the mining activities.[41] Following restrictions by China on cryptocurrency mining, introduced in May 2021, some mining capacity shifted to fossil-fuel heavy regions such as Kazakhstan (Cambridge Centre for Alternative Finance, 2024; de Vries et al., 2022). Kazakhstan hosts roughly one sixth of global cryptocurrency mining operations, with a very high water intensity for electricity generation (Siddik et al., 2023). The effect of the geographical redistribution of cryptocurrency mining operations has led to an increase in global water consumption associated with such activities of an estimated 73 per cent, but led to a 10 per cent decrease in GHG emissions (Siddik et al., 2023).

Other environmental aspects of cryptocurrency mining include digitalization-related waste generation from specialized mining hardware, which cannot be easily repurposed for other computing tasks. Given the enormous energy use of bitcoin mining, operators are incentivized to use the latest, most powerful and energy-efficient hardware. Although this can reduce energy use, it comes at the expense of creating more waste (chapter IV).

The increased demand in machine learning is likely to result in a significant net growth in total AI-related energy use

4. Artificial intelligence

Climate change implications of AI and machine learning are significant but highly uncertain (Cowls et al., 2021; Kaack et al., 2022; Rolnick et al., 2023). Just as ICT impacts climate change more generally, the environmental implications arising from AI and machine learning can be categorized into direct effects (GHG emissions resulting from computing) and indirect effects (the effect of GHG emissions from applications of AI or machine learning, as well as structural or "system-level" GHG effects induced by these applications) (Kaack et al., 2022).

Machine learning systems require computing resources and hardware, primarily in large data centres, that use energy, water and materials. The majority of machine learning-related GHG emissions today likely comes from computing loads in large data centres, with a smaller share from distributed computing (for example, PCs and smartphones). These emissions result both from operational energy use during computation and from other phases of the hardware life cycle (including embodied emissions).

Early studies of the environmental footprint of AI and machine learning focused on the energy use and carbon emissions associated with the training of large machine learning models.[42] However, training a single model represents only a share of the overall energy and GHG emissions of machine learning. Recent data from Google and Meta suggest that the training phase accounts for 20–40 per cent of overall machine learning-related energy use, with 60–70 per cent for inference (application/use) and up to 10 per cent for model development (experimentation) (Patterson et al., 2022; Wu et al., 2022).

Understanding inference-related energy use will become more important as mainstream AI applications become more widely adopted, especially if there are no financial costs to the user that could limit its deployment. OpenAI, the company behind ChatGPT, has estimated that the average cost "is probably single-digits cents per chat" (Kinsella, 2022). Semianalysis (2023) found that an average ChatGPT query

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[41] For example, Canada, China, Ireland, Kazakhstan, Malaysia, Singapore and the United States (Chamanara et al., 2023; Siddik et al., 2023).

[42] See Lacoste et al. (2019); Luccioni et al. (2020); Schwartz et al. (2019); Strubell et al. (2019).

costs around $0.0036 (3.6 cents). Based on this estimate, Ludvigsen (2023a, 2023b) concluded that ChatGPT used about 4 GWh in January 2023 (in a range of 1.1–23 GWh). This is about three times more electricity than was used to train GPT-3 (1.3 GWh) (Patterson et al., 2022), a large language model that provided the basis for ChatGPT. For comparison, 4 GWh is roughly equivalent to the monthly electricity consumption of 400 households in the United States.

Only a fraction of total ICT energy use is attributable to AI and machine learning, although its exact share is not known. There is limited data and no clarity on how to define the boundaries (i.e. what is included or excluded from AI and machine learning), and no established methodology for measuring energy use (Kaack et al., 2022). Based on estimates of global ICT energy use (IEA, 2022c) and shares of data centre workloads and data centre IP traffic attributed to AI (Cisco, 2018; Compton, 2018), machine learning and AI may have accounted for less than 0.2 per cent of global electricity use and less than 0.1 per cent of global GHG emissions in 2021 (Kaack et al., 2022).

While Google reports that machine learning accounts for less than 15 per cent of the company's total energy use, it is growing at a similar rate (20–30 per cent) as overall company-wide energy use (Google, 2022; Patterson et al., 2022). Computing demand for machine learning training and inference at Meta have increased annually by more than 100 per cent in recent years, compared with 40 per cent for its overall data centre energy consumption (Meta, 2022; Naumov et al., 2020; Park et al., 2018).

The combination of rapid growth in the size of the largest machine learning models (OpenAI, 2018) and the increasing energy needs for machine learning-related compute demand (Wu et al., 2022) are expected to outpace potential energy efficiency improvements in the coming years. This trend is likely to result in a significant net growth in total AI-related energy use. This will make measuring and reducing the energy, carbon and water footprint of AI even more critical. The use of low-carbon energy – both in powering data centres as well as in manufacturing machine learning-related hardware – will become essential to reduce GHG emissions from AI.

The need for more powerful hardware (such as graphics processing units) is also set to attract growing interest in AI-related water consumption in data centres (*Bloomberg*, 2023; Li, Yang, et al., 2023). Microsoft training of GPT-3 in its data centres in the United States directly consumed an estimated 700,000 litres of clean freshwater; that volume would have tripled if training had taken place in their data centres based in Asia (Li, Yang, et al., 2023). It is also necessary to reconcile the water-carbon conflicts for AI model training and inference to cut the water footprint. For example, to reduce the carbon footprint, it is preferable to "follow the sun" to where solar energy is more abundant, while to reduce the water footprint, it is preferable to "unfollow the sun" to avoid high-temperature hours in the day. Computing loads in general, and training AI in particular, cannot only be shifted in time, but also geographically, to take advantage of low-carbon electricity – a paradigm known as carbon-aware computing (Radovanović et al., 2023). Thus, a holistic approach is desirable to address water footprint along with carbon footprint to enable more sustainable AI (Adelin et al., 2010; Chen et al., 2022; Koomey and Masanet, 2021; Malmodin, 2020; Schien et al., 2023).

To reduce carbon footprint of data centres, it is preferable to **"follow the sun";** while to cut the water footprint, it is preferable to **"unfollow the sun"** to avoid high-temperature hours in the day

Policymakers and companies should also pay attention to the indirect effects of AI on climate change, given the potentially large impacts of such applications on GHG emissions. Artificial intelligence can induce various economic, environmental, and societal benefits in several other domains such as medicine or weather forecasting. Recently, for example, a machine learning model outperformed the best traditional numerical weather prediction algorithms (Lam et al., 2023). This not only induces economic, environmental and social indirect benefits, but even direct environmental benefits within the ICT sector, as traditional numerical weather prediction is computationally much more complex than the machine learning models that outperform them. Conversely, some uses of machine learning could escalate emissions in other sectors and services, for example, if they increase the competitiveness of emissions-intensive activities such as fossil-fuel extraction or induce additional consumption through recommender algorithms.

5. Virtual reality in the metaverse

The so-called “metaverse” provides a digital immersive environment for people to communicate, work, entertain and trade by using technologies such as virtual reality and augmented reality (Zallio and Clarkson, 2022).

Widespread adoption of augmented reality, virtual reality and the metaverse could present both positive and negative environmental impacts. On the one hand, immersive realities can have indirect positive effects and reduce GHG emissions by replacing physical travel, meetings and sightseeing with virtual events. On the other hand, the metaverse and the technologies that power it may have significant direct adverse environmental impacts. The metaverse generally requires advanced end-user devices, higher edge computing power and fast networks which consume substantial amounts of electricity and water and, accordingly, may generate more GHG emissions.

The metaverse consumes energy mainly through three layers, namely the infrastructure layer, which supports computation in the form of data centres and network infrastructures; the interaction layer, which supports human–computer and human-to-human interaction in the form of hardware, software, end-user devices and networking equipment; and the economy layer, which supports transactions between users in the metaverse in the form of cryptocurrencies (Liu et al., 2023).

It has been estimated that GHG emissions associated with the metaverse could be as high as 115 $MtCO_2e$ by 2030, which would account for an estimated 0.5 per cent of global carbon emissions (Liu et al., 2023).

Some believe that the metaverse may reduce more emissions than it causes by accelerating decarbonization and the energy transition, and by reducing gaseous pollutant emissions (Stoll et al., 2022; Zhao and You, 2023). For example, a study on GHG emissions of the metaverse in the United States suggested that a growing metaverse sector could reduce emissions by 10 $GtCO_2e$ in the United States by 2050 (Zhao and You, 2023). However, the risk of increased emissions due to inefficient substitutions, induced demand and rebound effects remains (Stoll et al., 2022). Further empirical research and model-based studies on net effects of virtual activities are needed to guide stakeholders onto a pathway that benefits rather than harms the progress towards net-zero.

The metaverse is still in a nascent state (Kshetri and Dwivedi, 2023). Policymakers, investors and other stakeholders need to help design a metaverse that is not only environmentally sustainable but also inclusive. Entry barriers, such as high upfront costs (due to, for instance, hardware) and required infrastructure (including high-speed Internet), could lead to the exclusion of relatively disadvantaged groups participating in the metaverse.

6. 5G and the Internet of things

As noted in chapter II, the share of 5G in global mobile data traffic is expected to rise significantly in the coming years. 5G mobile networks are anticipated to be more energy-efficient than 4G mobile networks per unit of traffic and benefit from improved “sleep modes” (*IEEE Spectrum*, 2018; *Orange Hello Future*, 2022; STL Partners, 2019). At the same time, higher traffic volumes and a larger number of base stations[43] will likely mean increased overall energy use and emissions from widespread 5G deployment, as indicated by studies from countries in Europe (Bieser et al., 2020; Golard et al., 2023; France, Haut conseil pour le climat, 2020; Williams et al., 2022).

IoT adoption is also set to grow rapidly, facilitated by the roll out of 5G mobile networks. IoT devices are generally expected to be energy-efficient, but the growth in their number could have important implications for standby energy use and embodied energy and material (chapter II). In addition, more and more applications involving video transmission and tracking large amounts of data will impact energy demand (Pohl and Hinterholzer, 2023).

Expansion of IoT significantly increases standby energy use and embodied energy and material

F. Concluding observations and recommendations

This chapter looked at the environmental footprint of the use phase of the digital economy. Special attention was put on the role of data centres, as their environmental impacts are particularly important during the use phase. It is expected that their role will continue to expand in view of the increased uptake of key emerging technologies and continuing digitalization. The chapter underlined the importance of not singling out individual environmental indicators (such as GHG emissions), as a guidepost for environmental sustainability. The most sustainable approach is one that focuses in particular on energy efficiency and responsible water consumption.

Given the rapid pace of technological progress, and difficulties associated with measuring energy use and its associated GHG emissions as well as water consumption, long-term forecasts of the environmental footprint of the use phase of the ICT sector beyond the next five years are extremely uncertain. One factor that contributes to this uncertainty is the scope for further energy efficiency improvements. If current energy efficiency trends in computing continue, processor efficiency limits could be reached by around 2040 based on the physical efficiency limits of transistors (Koomey et al., 2013).[44]

Data centre energy use is expected to continue to increase due to growing demand from compute-intensive AI applications and global expansion of digitalization. IEA (2024) estimated that in 2026, total electricity consumption by data centres (including cryptocurrencies) could more than double from 460 TWh in 2022 to more than 1,000 TWh. This increases the importance of powering data centres through renewable energy sources to curb GHG emissions (without crowding out the use of renewable energy by other sectors), while also reducing emissions from supply chains, and increasing circularity of data centre hardware (chapter IV). More attention will also need to be given to mitigating the impact of data centres on scarce water resources.

Forecasts beyond the **next five years** of the environmental footprint are **extremely uncertain**

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[43] As 5G transmission uses higher frequency ranges than previous generations, the distance between the antenna and the end devices must be shorter, meaning more antennas will need to be manufactured and deployed (Pohl and Hinterholzer, 2023).

[44] In 1985, physicist Richard Feynman estimated that improvement by a factor of 10^{11} would be possible compared to computer technology at the time. While Feynman assumed a three-atom transistor to calculate his limit, smaller ones, could push these limits further (Fuechsle et al., 2012). Some experts (Demaine et al., 2016) estimate that maximum possible efficiency may be reached by around 2060 due to Landauer's principle – the minimal amount of energy needed to erase one bit of information (Bennett, 2003). They further assume that improvements in energy efficiency could slow down before reaching his limit.

To enable a global distribution of data centres that contributes to environmental sustainability, measures need to be taken to foster better data governance. Policymakers around the world need to assess the costs and benefits involved in deciding the physical location of data, taking into account the specificities of a country and their own development strategy needs. This points to the need for a robust international framework regulating cross-border data flows to ensure access and guarantee that any income gains from data are equitably shared. Such a framework would also need to be flexible, so that countries with different levels of readiness and capacities to benefit from data have the necessary policy space when designing and implementing their development strategies in a data-driven digital economy. These efforts should be complemented by improvements in the capacity to process data in developing countries (UNCTAD, 2021a).

Connected devices already consume more electricity than data centres. The sheer number of devices and the standby power consumption of connected devices are of particular concern. An increasing number of smart IoT devices use energy continuously to maintain connectivity. This trend adds to electricity demands linked not only to device usage, but to transmission networks and data centres.

Government policies to promote good practices together with efforts by the ICT industry to improve energy efficiency could play an important role in slowing down energy demand growth more generally. For instance, in data networks, policies to accelerate the early phase-out of energy-intensive legacy networks could be particularly important (Langham, 2022).

As energy already accounts for a significant share of the operating costs for data centres and network operators, there is a clear incentive to look for ways to make these even more energy-efficient. Even if further efficiency improvements are achieved, there is a need to ensure that future adoption of ever more sophisticated, compute-intensive digital services pays sufficient attention to their environmental footprint. Limiting the environmental impacts of these services will require careful planning and major investments in renewable energy and grid infrastructure.

On a smaller scale, users can influence the outcome by adapting their online behaviour. Even if some early assessments exaggerated the direct effects of sending emails or video streaming, important steps can still be taken. For example, an effective way to reduce the energy footprint of video streaming is to use devices with smaller screens and keep the devices for longer. Companies and organizations can also look into analysing dark data to derive insights while also educating employees on how to overcome instincts to hoard unnecessary data.

Some countries are beginning to act with a view to mitigating negative environmental effects from the use of ICT goods and services. However, these remain at a nascent stage in most parts of the world. Improved data and more research are needed, in particular studies and information that relate to the specific challenges faced in many developing countries. This would help to create a reliable basis for policymaking that promotes the use of sustainable energy and better water management for data centres. There is a lack of detailed data on the energy and water consumption characteristics of data centres and networks, as well as on particular segments (such as smaller data centres and supply chains). Better and more frequent tracking of a wider range of indicators related to GHG emissions, water consumption and noise generation are also required.

Given the anticipated growth of energy and water consumption by data centres and data transmission networks, it is critical to ensure that these operations are increasingly powered by low-carbon energy. This is the responsibility of both the public and the private sector. Corporations can minimize impacts by locating data centres in areas with sufficient renewable energy and water resources, while continuing to improve the efficiency of energy and water use. They should also transparently report data on relevant environmental indicators, including with regard to the energy and carbon footprints of AI.

Governments can play a leading role in accelerating research and development to advance more efficient, next-generation technologies and systems. Through regulation, they can promote the improved energy efficiency of data centres and renewable energy mandates to reduce the carbon footprints. Regulation needs to provide long-term planning security for private-sector investment, while recognizing the dynamic character of the ICT sector. This may require agile policymaking. Regulators should ensure that electricity market design provides clear and sufficient price signals for data centres and other large electricity users to participate in demand response programmes. For example, allowing for some flexibility in ancillary service requirements, such as longer notice periods and response times, may make it easier for data centre operators to participate in such programmes. Progress on demand response policies has recently been made in Australia, Brazil, the Republic of Korea, Singapore and California in the United States, as well as in the European Union (IEA, 2023g).

In developing countries, Governments and utilities could consider opportunities to co-develop local electricity and water infrastructure with new data centre and network projects to expand electricity and water access in communities, with digital infrastructure serving as important anchor customers of electricity and water.

To achieve sustainable digitalization, it is unlikely that further improvements in the energy and water consumption efficiencies of end-user devices, communications networks, data centres and service provision will be sufficient. Other steps are needed to reduce the environmental footprint. Sector regulations are important to foster circularity and sufficiency (Pohl and Hinterholzer, 2023). For example, considering the energy impact of AI from a sustainability perspective, it is crucial to weigh the risks and benefits of using AI. Given the limited availability of information on resource use related to AI, regulators could consider introducing specific environmental disclosure requirements to enhance transparency across the AI supply chain (de Vries, 2023).

> Corporations should transparently report data on environmental indicators, including the carbon footprint of AI


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Digitalization-related waste is increasing year-on-year

Chapter IV

End of the cycle? Digitalization-related waste and the circular economy

This chapter focuses on the last stage of the life cycle of digitalization. It describes global trends in digitalization-related waste, highlighting that these can represent challenges and opportunities from an economic and an environmental sustainability perspective.

Current waste management practices are insufficient, and marked by inadequate recycling and informal handling, especially in developing countries. Addressing this situation is necessary to deal with environmental and health impacts of improper disposal of digital devices.

The chapter calls for a more circular digital economy, which would enable longer lifespans of devices and more efficient recycling, to reduce waste. This would not only help to alleviate pressure on raw material supplies but could also enable economic opportunities. The challenge involves developing coordinated global efforts and robust policies for waste treatment and circularity along the life cycle of digitalization.

Per capita generation of digitalization-related waste in 2022

People in developed countries generate on average **15 times** more digitalization-related waste than those in LDCs.

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A. Introduction

The last stage of the digitalization life cycle is when users either no longer want or can use digital devices or ICT infrastructure. From a sustainability perspective, there is an urgent need to minimize the generation of waste related to digitalization. In addition, there is a need to ensure that when these devices reach the end of life, they are recycled in a way that allows for valuable resources to be recovered.

Digitalization-related waste is a complex waste stream. It has a dual character, as it contains both hazardous substances and valuable parts and materials. This waste needs to be managed in an environmentally sound manner to ensure that the dangerous materials are treated safely and dealt with separately. If not properly managed, it can result in significant negative environmental, health and other social impacts, often affecting the most vulnerable. When digitalization-related waste is managed effectively, valuable materials can be recovered. These can provide economic and environmental benefits, by increasing the supply of secondary raw materials and substituting the primary supply of minerals and metals for the manufacturing of new equipment.

Moreover, a circular economy that adheres to the principles of “reduce, reuse and recycle” can reduce waste generation, by extending device lifespans and reducing the need to extract raw materials needed to produce new devices. Services connected to activities in the circular economy can also provide economic development potential, including job opportunities, in developing countries.

In a circularity context, the end of a cycle becomes the beginning of another. Circular economy activities can lead to a more rational demand for digital products. Addressing overconsumption of ICT goods in some parts of the world, especially among the wealthier population, is key for reducing the overall environmental footprint of digitalization. However, environmental issues related to energy and water use, as well as mineral extraction, cannot be solved solely through recycling and recovery at the end-of-life stage. Reducing overconsumption is essential for achieving sustainable consumption and production.

This chapter addresses trends in the generation and management of digitalization-related waste and associated challenges, as well as the potential opportunities that can emerge from a circular digital economy. The definition of digitalization-related waste is discussed in section B. Section C looks at trends in this waste, while section D explores the factors behind the trends observed. Environmental, health and other social consequences of digitalization-related waste, typically linked to unsound waste management, are presented in section E. Section F explores the elements of a circular digital economy. International flows of digitalization-related waste are discussed in section G. Section H looks at the potential opportunities that developing countries can leverage from the circular digital economy, while section I presents concluding observations.

B. What is digitalization-related waste?

Defining digitalization-related waste is not straightforward. It is related to the term “electrical and electronic waste”, also known as “e-waste” or “waste electrical and electronic equipment” (WEEE) and “e-scrap”. Definitions for these terms usually refer to the process of a physical object becoming waste, which then determines whether it is classified as e-waste. A complication in the definition of e-waste is that there does not seem to be a clear distinction between what constitutes “waste” and what does not, nor when an item becomes waste.[1] Further, it may be misleading to consider “e-waste” as items that could potentially be disassembled into useful parts that could re-enter the production process. Similarly, it is not evident that products that contain valuable materials that can be recycled and recovered can be considered as “waste”.

> There are two broad global definitions of e-waste, which vary depending on the context in which they are applied: the legal definition and the statistical definition

There are two broad global definitions of e-waste, which vary depending on the context in which they are applied: the legal definition and the statistical definition. In the legal context, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal,[2] which was adopted in 1989 and entered into force in 1992, has historically defined WEEE as electrical or electronic equipment that is waste, including all components, sub-assemblies and consumables that are part of the equipment at the time the equipment becomes waste.[3] The Convention defines wastes as “substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law” (article 2, paragraph 1).

At the fifteenth session of the Conference of the Parties in 2022, the Parties adopted amendments to annexes of the Basel Convention that add precision to the definition of e-waste, particularly when listing hazardous and non-hazardous e-waste, which could prevent illegal trade activities. The amendments cover more than WEEE by including “components” and “waste arising from processing” within the definition of electrical and electronic waste (box IV.1).

In the statistical context, the Global E-Waste Statistics Partnership follows the definition outlined by “Solving the E-waste Problem” (StEP, 2014): “e-waste is a term used to cover items of all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of reuse”; EEE refers to a range of products “with circuitry or electrical components with power or battery supply”.[4] This definition was developed by the UN Partnership for Measuring ICT for Development. StEP has provided statistical guidelines (Forti et al., 2018) which are followed by the Global E-Waste Statistics Partnership and

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[1] This depends on national legislation; countries may define items as non-waste, e-waste and their parts, when these can be repaired or refurbished. Also, parts of e-waste that can be disassembled and enter back into the production process may or may not be considered waste.

[2] See https://www.basel.int/Portals/4/Basel%20Convention/docs/text/BaselConventionText-e.pdf and https://www.basel.int/.

[3] See https://www.basel.int/Implementation/Ewaste/Overview/tabid/4063/Default.aspx.

[4] See https://globalewaste.org/ and https://www.step-initiative.org/.

Box IV.1
Amendments to annexes of the Basel Convention

Under the new binding definition of electrical and electronic waste, which is to become effective on 1 January 2025, non-hazardous electrical and electronic waste includes:[a]

- WEEE not containing or not contaminated with constituents as established by the Convention annexes, or in which none of the components contain or are contaminated with such constituents;
- Waste components of electrical and electronic equipment (e.g., certain circuit boards, certain display services) not containing and not contaminated with constituents as established in the annexes;
- Waste arising from the processing of WEEE and electronic equipment or waste components of electrical and electronic equipment (e.g., fractions arising from shredding or dismantling) not containing and not contaminated with constituents as established in the annexes.

Hazardous electrical and electronic waste includes:

- WEEE containing or contaminated with cadmium, lead, mercury, organohalogen compounds or other constituents as established in the annexes;
- WEEE with a component containing or contaminated by constituents as established in the annexes.

Moreover, to facilitate the way in which it is applied, the most recent Basel Convention technical guidelines on transboundary movements of electrical and electronic waste and used electrical and electronic equipment have a particular focus on the distinction between waste and non-waste.[b] These guidelines, which are non-binding, note that “national provisions concerning the definition of waste may differ and, therefore, the same material may be regarded as waste in one country but as non-waste in another country”. In this case, the Parties agreed that, when a transboundary movement occurs, the most stringent definition applies.

Source: Basel Convention.

[a] See https://www.basel.int/TheConvention/ConferenceoftheParties/Meetings/COP15/tabid/8392/Default.aspx.

[b] The guidelines are available at https://www.basel.int/TheConvention/ConferenceoftheParties/Meetings/COP16/tabid/9311/Default.aspx.

used in monitoring progress in achieving the Sustainable Development Goals.[5]

This statistical definition of e-waste is similar to that of WEEE under the Basel Convention, without the most recent amendments mentioned above. In this context, e-waste statistics from the Global E-Waste Statistics Partnership through UNITAR (SCYCLE),[6] which are developed in cooperation with ITU and UNEP, cover six categories:

1. *Temperature exchange*: Temperature exchange equipment, more commonly referred to as cooling and freezing equipment, such as refrigerators, freezers, air conditioners and heat pumps;
2. *Screens, monitors*: Items such as televisions, monitors, laptops, notebooks and tablets;
3. *Lamps*: Including fluorescent lamps, high intensity discharge lamps and LED lamps;

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[5] Building on the Partnership on Measuring ICT for Development, in 2017, ITU, United Nations University – Sustainable Cycles (UNU-SCYCLE) and the International Solid Waste Association, jointly created the Global E-waste Statistics Partnership to address the challenges associated with managing e-waste. Since January 2022, SCYCLE has been a programme under the United Nations Institute for Training and Research (UNITAR). The Global E-Waste Statistics Partnership is managed by ITU and UNITAR-SCYCLE, see https://globalewaste.org/about-us/.

[6] See https://www.scycle.info/.

4. *Large equipment*: Items such as washing machines, clothes dryers, dish-washing machines, electric stoves, large printing machines, copying equipment and photovoltaic panels;
5. *Small equipment*: Equipment such as vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, calculators, radio sets, video cameras, electrical and electronic toys, small electrical and electronic tools, small medical devices and small monitoring and control instruments; and
6. *Small IT and telecommunications equipment*: Items such as mobile phones, global positioning systems (GPS), pocket calculators, routers, personal computers, printers and telephones.

Given rapid progress in digital technologies, and in particular IoT, the **definition of digitalization-related waste** is a **moving target**

Given the focus of this report, it would be desirable to have a subset of the e-waste statistical scope that matches digitalization-related waste. This would require separating electronic equipment from electrical equipment to monitor electronic equipment separately. However, e-waste or WEEE cannot be easily divided into two mutually exclusive categories of "waste electronic equipment" and "waste electrical equipment", as there is no statistical definition for these separate categories.

Based on the six categories listed above, category 2 (screens and monitors) and category 6 (small IT and telecommunications equipment) are considered to be the most relevant for the purposes of this report. They are therefore used as a proxy for digitalization-related waste. Their composition and prime functionality mostly rely on aspects related to digitalization, such as automated data processing and visualization. Thus, the statistical analysis in this chapter focuses on these two categories, which together are referred to as "waste of screens, computers and small IT and telecommunications equipment", or "SCSIT waste".[7]

This proxy does not cover all aspects of digitalization-related waste. Conceptually, white goods and refrigerators that are connected to the Internet should fall under digitalization-related waste, as should the e-waste of data centres and servers. However, it is neither possible to extract such information from statistical data sets, nor to make reasonable estimates at the country level.[8] Given rapid progress in digital technologies, and in particular IoT, the definition of digitalization-related waste is a moving target. Non-electrical and electronic equipment or equipment that in the past was electrical, have become, or are becoming electronic goods. For instance, vacuum cleaners are increasingly digital and becoming robotic, and white goods are increasingly becoming connected to the Internet. This could also be the case for vehicles in the future as they are increasingly manufactured with electronic components, although to date they have been classified in statistics as end-of-life vehicle waste and not as e-waste.

Moreover, current e-waste statistics do not include batteries, which follow a different waste management path and are often regulated under dedicated battery waste legislation. However, it can be expected that the waste from batteries in electronic equipment will show similar trends as the equipment itself. Nevertheless, waste from batteries is covered separately under the

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[7] The terms "digitalization-related waste" and "waste of screens, computers and small IT and telecommunication equipment" (SCSIT) are used in this report only for analytical purposes and do not imply any position from UNCTAD either from the legal or the statistical perspective. Moreover, although some of the discussions in this chapter may equally apply to e-waste and to digitalization-related waste, the latter term is used, given the focus of the report.

[8] The detailed description of the product classification, presented in Forti et al. (2018), includes United Nations University subcategory 0307, professional IT equipment (e.g., servers, routers, data storage, copiers). However, statistics are not available for all the components that allow for the calculation of e-waste. The underlying data sets of the Global E-Waste Monitor show that the amount of sub-category 0307 equipment in e-waste generation globally is less than 5 per cent of the total of the aggregate of SCSIT waste. Thus, the latter may still be considered a suitable proxy.

Basel Convention, as it contains hazardous materials and is highly flammable.

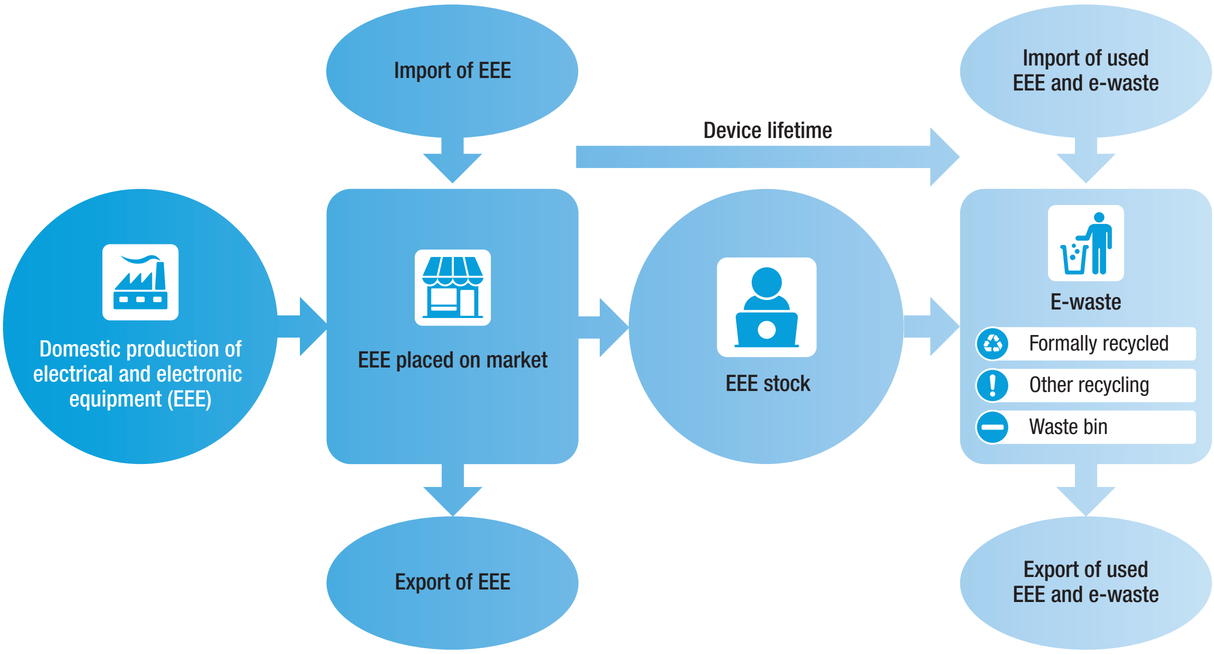
In addition, the waste that Internet and telecommunications satellites generate in outer space can also be considered digitalization-related waste (see section C) but is not included in e-waste statistics.[9]

Overall, it can be concluded that not all e-waste is categorized as digitalization-related waste, nor does all digitalization-related waste qualify as e-waste. The framework for measuring e-waste statistics developed in Forti et al. (2018), shown in figure IV.1, provides a useful basis for understanding how digitalization-related waste is generated.

Electrical and electronic equipment placed on market is the result of domestic production plus imports, minus exports. The equipment sold is added to the stock of EEE in use by consumers, businesses and the public sector, i.e. users. This use lasts for the lifespan of the equipment, including second-hand reuse, repair within the country and dormant time. However, if a second-hand functioning product is exported, it leaves the stock of the exporting country, while entering the stock of the importing country for the remainder of its lifetime (see section G). At the end of its lifespan, EEE is discarded and becomes "e-waste generated", which is the total amount of e-waste before any waste management activity takes place.

Out of the overall volume of generated e-waste, there is a part that is environmentally soundly managed. This is collected separately by formal entities, which can be designated organizations, producers, recyclers or the public sector. Collected e-waste is processed in dismantling and treatment facilities as regulated under the corresponding national legislation on e-waste. This can be considered formally managed waste.

Figure IV.1
From electrical and electronic equipment to e-waste



Source: UNCTAD, based on Forti et al. (2018).

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[9] An additional element would be the waste generated by military electronics, but this issue is beyond the scope of this report.

However, the remaining part, which is normally substantial, can follow different management routes:

- E-waste may be disposed of and managed together with metal-containing waste to reclaim the ferrous metal and easy to reclaim non-ferrous metals;
- Valuable items may be selectively scavenged by the informal sector and separately treated;
- E-waste may be disposed of in residual waste bins to be managed by incineration facilities or end up in landfills; and
- E-waste can be exported to other countries.

C. Trends in digitalization-related waste

Having statistics that properly reflect the situation with regard to digitalization-related waste is essential for its management

Tracking the entire life cycle and global trends in digitalization-related waste is not an easy task. Most e-waste, including the part related to digitalization, is not formally managed, recorded or documented, escaping scrutiny or monitoring. This is because there are significant e-waste activities in the informal sector and in the context of illegal trade. Many users do not follow formal procedures to dispose of this waste to ensure that it is properly managed in an environmentally sound manner.

Nevertheless, there has been progress in measuring e-waste, especially in the context of the Global E-Waste Statistics Partnership and the e-waste statistics measurement guidelines (Forti et al., 2018). The Global E-Waste Monitor series, which is led by UNITAR, ITU and other partners, was launched by the UNU-SCYCLE programme in 2015 and represents the main source of statistics on e-waste, globally.[10] This measurement framework provides a standard methodology for statistics to be available and comparable around the world. The Global E-Waste Monitor for 2020 highlights that only 41 countries were using this methodology and producing their own national statistics (Forti et al., 2020). Statistics for the remaining countries are estimated by UNITAR, using a similar methodology and official statistical data sets from those countries. Having statistics that properly reflect the situation with regard to e-waste, as well as other digitalization-related waste, is essential for policymakers and other relevant stakeholders to make informed decisions and to manage such waste in an environmentally sound manner. Countries should strengthen their efforts to measure such waste to better deal with risks and to reap the potential benefits arising from proper waste management.[11]

As indicated in the previous section, the proxy used in this analysis is the sum of categories 2 and 6 of e-waste statistics, SCSIT waste. Although the results are to be taken with caution, they provide a useful indication of the evolution of digitalization-related waste globally and by region, in terms of development levels. When extrapolating these trends, it is likely that overall digitalization-related waste trends follow similar geographical patterns as those presented in table IV.1, even if the amounts are larger than for SCSIT waste alone.

The table shows the evolution of SCSIT waste in absolute volumes as well as in per capita terms between 2010 and 2022. During this period, the volume increased globally by 30 per cent, from 8.1 million

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[10] See https://ewastemonitor.info/global-e-waste-monitors/.

[11] Challenges in relation to e-waste statistics, as part of overall waste statistics, are discussed in UNECE (2022a).

tons to 10.5 million tons.[12] In developed countries, the increase was 11 per cent and in developing countries, 48 per cent. Lower growth in developed countries reflects the fact that these markets may be close to maturity in relation to existing digital devices and equipment, while developing countries are still expanding their digital sectors and reducing digital divides to be able to benefit from rapid digitalization trends. Accordingly, the share of developed countries in global SCSIT waste generation decreased from 48.6 to 41.5 per cent between 2010 and 2022.

The top three generators of such waste in 2022 were China (20.9 per cent), the United States (13.9 per cent) and the European Union (12 per cent). In absolute volume terms, these three economies generated more than 4.9 million metric tons of SCSIT waste, which was almost half of the world total.

The share of developing countries in global SCSIT waste generation increased from 51.4 to 58.5 per cent over the same period. Developing countries in Asia generated most of such waste in 2022, with China representing almost half of the waste generated in this region. India exhibited the highest growth rate in the volume of such waste, at 163 per cent, more than doubling its share in the world total, from 3.1 to 6.4 per cent.

By contrast, the share of developing countries in Latin America and the Caribbean in global SCSIT waste generation was relatively stable, reaching 9 per cent in 2022. Africa accounted for the lowest share in the world total, at 5.9 per cent. In developing countries in Oceania, the volume of SCSIT waste was negligible. Moreover, LDCs generated very small volumes, accounting for just 2.3 per cent in 2022.

A more complete picture of the evolution of SCSIT waste emerges from considering per capita trends in kilograms. Between 2010 and 2022, SCSIT waste per capita increased globally from 1.16 to 1.33 kg, a growth of 14 per cent, with significant differences between countries. In developed countries, it was 3.25 kg in 2022, 3.5 times the per capita SCSIT waste in developing countries (0.93 kg). This significant gap reflects the digital divide between developed and developing countries in terms of access, affordability and use of digital devices and equipment, and the higher level of demand in developed countries (see chapter II).

This may also reflect overconsumption of digital devices and equipment in developed countries, which suggests greater potential to reduce the generation of waste through more environmentally responsible and rational consumption and use. Overconsumption can be defined as “excessive consumption or use of goods and services (energy, land, water or materials) that cause harm or detrimental effects to humans and/or the environment, namely by exceeding the carrying capacity and life-supporting systems of the planet and its ecosystems”.[13] To define excessive consumption, defining sustainable consumption would be required.

Sustainable Development Goal 12 focuses on ensuring sustainable consumption and production patterns. Sustainable consumption and production refers to “the use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or product so as not to jeopardize the needs of future generations”. In other words, this can be summarized as “doing more and better with less”.[14]

Overconsumption in the digitalization era can, for example, be linked to the frequent

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[12] As a comparison, according to the Global E-Waste Monitor 2024, total e-waste amounted to 62 million tons in 2022 (Baldé et al., 2024).

[13] See https://www.eionet.europa.eu/gemet/en/concept/15382.

[14] See https://www.unep.org/explore-topics/resource-efficiency/what-we-do/sustainable-consumption-and-production-policies.

Table IV.1
Digitalization-related waste, by volume and per capita, selected country groupings, countries and years

	Volume (Millions of metric tons)				Growth (Percentage)	Share in world (Percentage)				Per capita (kg)				Growth (Percentage)
	2010	2015	2019	2022	2010–2022	2010	2015	2019	2022	2010	2015	2019	2022	2010–2022
World	**8.070**	**9.801**	**10.345**	**10.508**	*30*	**100.0**	**100.0**	**100.0**	**100.0**	**1.16**	**1.33**	**1.34**	**1.33**	*14*
Developed economies	**3.924**	**4.515**	**4.511**	**4.358**	*11*	**48.6**	**46.1**	**43.6**	**41.5**	**3.02**	**3.41**	**3.36**	**3.25**	*7*
United States	1.233	1.477	1.498	1.466	*19*	15.3	15.1	14.5	13.9	3.92	4.50	4.43	4.29	*10*
European Union	1.223	1.351	1.322	1.261	*3*	15.2	13.8	12.8	12.0	2.77	3.04	2.96	2.81	*1*
Japan	0.466	0.507	0.484	0.453	*-3*	5.8	5.2	4.7	4.3	3.63	3.98	3.84	3.66	*1*
United Kingdom	0.279	0.297	0.302	0.282	*1*	3.5	3.0	2.9	2.7	4.44	4.54	4.50	4.16	*-6*
Republic of Korea	0.103	0.137	0.152	0.159	*54*	1.3	1.4	1.5	1.5	2.11	2.68	2.94	3.06	*45*
Canada	0.130	0.155	0.157	0.152	*17*	1.6	1.6	1.5	1.4	3.84	4.34	4.19	3.96	*3*
Australia	0.085	0.109	0.113	0.110	*30*	1.0	1.1	1.1	1.0	3.84	4.58	4.47	4.21	*10*
Developing economies	**4.146**	**5.286**	**5.834**	**6.150**	*48*	**51.4**	**53.9**	**56.4**	**58.5**	**0.73**	**0.87**	**0.91**	**0.93**	*27*
Developing economies, Africa	0.425	0.560	0.606	0.621	*46*	5.3	5.7	5.9	5.9	0.40	0.47	0.46	0.44	*8*
Egypt	0.091	0.115	0.124	0.128	*40*	1.1	1.2	1.2	1.2	1.05	1.18	1.17	1.15	*10*
Nigeria	0.047	0.080	0.091	0.097	*108*	0.6	0.8	0.9	0.9	0.29	0.44	0.45	0.44	*53*
South Africa	0.062	0.077	0.081	0.081	*29*	0.8	0.8	0.8	0.8	1.21	1.38	1.39	1.35	*12*
Developing economies, Asia	3.031	3.863	4.304	4.584	*51*	37.6	39.4	41.6	43.6	0.76	0.91	0.98	1.02	*35*
China	1.547	1.918	2.092	2.195	*42*	19.2	19.6	20.2	20.9	1.15	1.38	1.47	1.54	*34*
India	0.254	0.402	0.549	0.668	*163*	3.1	4.1	5.3	6.4	0.20	0.30	0.40	0.47	*131*
Indonesia	0.259	0.315	0.327	0.328	*27*	3.2	3.2	3.2	3.1	1.06	1.22	1.21	1.19	*12*
Developing economies, Americas	0.688	0.860	0.921	0.941	*37*	8.5	8.8	8.9	9.0	1.20	1.42	1.46	1.46	*22*
Brazil	0.246	0.309	0.325	0.325	*32*	3.1	3.2	3.1	3.1	1.25	1.51	1.53	1.51	*21*
Mexico	0.148	0.177	0.194	0.206	*39*	1.8	1.8	1.9	2.0	1.31	1.48	1.55	1.61	*23*
Argentina	0.058	0.073	0.077	0.077	*32*	0.7	0.7	0.7	0.7	1.42	1.70	1.72	1.69	*19*
Developing economies, Oceania	0.002	0.003	0.004	0.004	*54*	0.0	0.0	0.0	0.0	0.24	0.29	0.29	0.29	*19*
Papua New Guinea	0.001	0.002	0.002	0.002	*119*	0.0	0.0	0.0	0.0	0.13	0.18	0.20	0.21	*64*
Fiji	0.001	0.001	0.001	0.001	*10*	0.0	0.0	0.0	0.0	1.11	1.34	1.31	1.19	*8*
Solomon Islands	0.000	0.000	0.000	0.000	*106*	0.0	0.0	0.0	0.0	0.11	0.15	0.17	0.17	*54*
Commonwealth of Independent States	**0.278**	**0.341**	**0.354**	**0.359**	**29**	**3.4**	**3.5**	**3.4**	**3.4**	**1.24**	**1.48**	**1.50**	**1.51**	**21**
Russian Federation	0.210	0.252	0.260	0.263	*25*	2.6	2.6	2.5	2.5	1.47	1.74	1.78	1.81	*24*
Memo items														
Developing economies, excluding China	2.599	3.369	3.742	3.954	*52*	32.2	34.4	36.2	37.6	0.60	0.72	0.75	0.77	*27*
LDCs	0.145	0.200	0.227	0.241	*66*	1.8	2.0	2.2	2.3	0.17	0.21	0.22	0.21	*24*
Developing economies, excluding LDCs	4.000	5.087	5.607	5.909	*48*	49.6	51.9	54.2	56.2	0.83	1.00	1.05	1.08	*30*

Source: UNCTAD calculations, based on data from UNITAR-SCYCLE.

Notes: Digitalization-related waste refers to SCSIT waste which is the sum of categories 2 and 6 of the e-waste statistics. Countries inside the regions are ranked in terms of absolute value of waste generated.

replacement of functional devices, driven by consumerism and aggressive marketing that promotes marginal upgrades. Another example is the destruction of unsold electronics (Hynes, 2022). Such behaviours not only fuel demand for materials but also contributes to e-waste. Programmed obsolescence further exacerbates this issue by diminishing the durability and repairability of ICT goods (see section D).

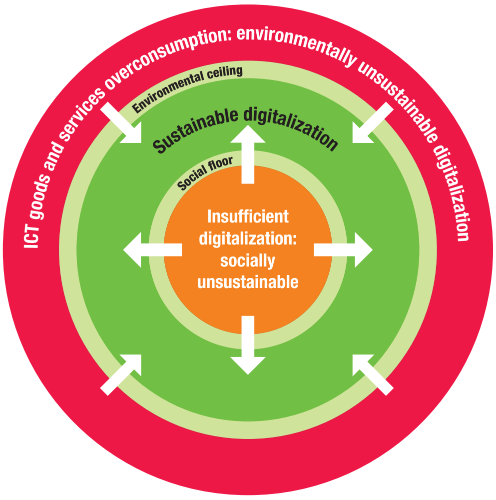
This pattern of excess consumption is closely related to broader socioeconomic inequality, of which digital divides are both a symptom and a cause (see chapter II). While in most developing countries only a limited number of digital devices (predominantly mobile phones) are used to meet various needs, households in developed countries often have multiple devices per person.

Moreover, digital corporations' strategies to extend user engagement and monetize the data generated perpetuate overconsumption (Marry and Souillot, 2022; Wu, 2017). There are now therefore more calls to embrace a sufficiency-oriented lifestyle that prioritizes meaningful needs-based consumption that can mitigate the environmental impact of overconsumption (Wiedmann et al., 2020).

Moving towards sustainable digitalization would require that those overconsuming moderate their consumption of devices, so that the part of the global population that is not sufficiently connected can continue to digitalize for development. This can be illustrated as in figure IV.2, which is based on the concept of doughnut economics (Raworth, 2017).[15] In this context, there would be moves towards increasing digitalization among those countries lagging behind, and efforts to reduce the excessive consumption of digital products in more affluent parts of the world. The inner circle illustrates the scenario of insufficient digitalization – which is socially unsustainable – and which falls below the threshold of what could be considered as the social floor, or baseline of digitalization.

This does not imply that the objective should be to reach the unsustainable levels of digitalization and overconsumption of digital devices. Such a scenario would require mining several Earths to meet the associated material demand.[16] On the contrary, overconsumption of ICT goods and services, represented by the outer circle of the figure, should be reduced to avoid bypassing the Earth's environmental ceiling. The objective of society should be to attain the middle circle of sustainable digitalization. This would also be in line with ideas of "digital sufficiency" and "digital sobriety" (Santarius et al., 2023; Hynes, 2022; Ferreboeuf, 2019). IPCC (2022b: 35) defines sufficiency policies as "a set of measures and daily practices that avoid demand for energy, materials, land and water while

Figure IV.2
Conceptual illustration of sustainable digitalization



Source: UNCTAD, based on Wiedmann et al. (2020).

Achieving sustainable digitalization requires the moderation of overconsumption, allowing those not sufficiently connected to digitalize for development

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[15] The doughnut concept highlights the dependence of human well-being on a healthy environment and stresses the need for improved equity in incomes and resource use, and greater efficiency in the latter. It has been used in the context of evaluating progress on achieving the Sustainable Development Goals and by several United Nations organizations. See, for instance, UNEP (2019a: 20).

[16] As noted by Consumers International (2020), if everyone lived the lifestyle of the average person in Western Europe, there would be a need for three planets; if the lifestyle of the average person in the United States was the model, there would be a need for five planets.

delivering human well-being for all within planetary boundaries".

In developed countries, the highest levels of SCSIT waste generated per capita in 2022 were reported for Norway (5.06 kg) and Switzerland (4.66 kg).[17] Among the countries included in table IV.1, an average inhabitant in Australia, the United Kingdom and the United States generated more than 4 kg of such waste in the same year.

All developing economy regional groupings, except Africa, exhibited higher growth in per capita terms compared with developed economies and the world. The highest amount of SCSIT waste generated per capita among developing countries in 2022 was in Latin America and the Caribbean, with 1.46 kg, which can be compared with 0.29 kg in Oceania. In China, the amount of such waste generated was, on average, 1.54 kg. Per capita SCSIT waste in Africa was 0.44 kg, but this average masks large differences in the region, for example, the amount in Egypt was 1.15 kg, while it was 1.35 kg in South Africa. Moreover, in LDCs, the amount of per capita SCSIT waste increased from 0.17 kg in 2010 to 0.21 kg in 2022. Accordingly, in 2022, the average citizen from developed economies generated 15.5 times more SCSIT waste than the average citizen in LDCs.

Unequal waste trends between developed and developing countries are expected to continue, driven by asymmetries in demand for devices

These unequal waste trends are expected to continue, driven by the growing demand for electronic devices and equipment, and their asymmetric distribution between developed and developing economies (see chapter II).

Digitalization-related waste is expected to continue to grow rapidly as it has done in recent years. According to Baldé et al. (2024), e-waste amounts are projected to further increase from 62 million tons in 2022 to 82 million tons in 2030. For SCSIT waste, the increase is projected to be from 10.5 to 11.2 million tons, over the same period.[18]

Another aspect of digitalization-related waste, which is not reflected in the statistics of the Global E-Waste Statistics Partnership, is the growing concern with waste in outer space. As discussed in chapter II, satellites are increasingly used for digitalization-related purposes. This is contributing to the problem of "space debris" (box IV.2).

Waste from data centres is another important component of digitalization-related waste, which is not fully captured in e-waste statistics. Fast data centre growth has a significant environmental impact through the increased generation of associated waste (Murino et al., 2023). Rapidly refreshing technologies in data centres contributes to the global e-waste challenge (ITU and World Bank, 2023; ITU, 2021). While some operational good practices to improve energy efficiency with existing equipment are being implemented (see chapter III), significant energy efficiency gains have been achieved by replacing older, less efficient hardware with newer, more efficient hardware. Servers in large data centres are typically replaced every three to five years, which can result in increased operational energy efficiency.[19] While hardware refresh cycles may be getting longer, the potential waste from data centres could be significantly reduced if companies could slightly compromise on having the latest and greatest machines, to allow for a longer usable lifespan (Swinhoe, 2022). An additional major factor for large generation of waste in data centres is the destruction of hard drives for reasons of data security. Progress in data sanitization methods and techniques can allow for fast and secure removal of all data on a device, enabling second use and reduced waste (Hands et al., 2022).[20]

A significant activity in some data centres is cryptocurrency mining. Bitcoin mining with specialized mining hardware, which

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[17] UNCTAD analysis based on UNITAR-SCYCLE.

[18] Data provided by UNITAR-SCYCLE.

[19] According to the survey by Davis et al. (2022), the typical time between refreshes was five years in 2022, compared with three years in 2015.

[20] See also *Financial Times* (2022).

Box IV.2
Digitalization-related waste in outer space

The outer space environment has been impacted by major trends over the last decade, including renewed exploration and use of outer space, a growing number of objects in orbit, decreasing costs of launching them and the increasing presence of the private sector. This can provide significant opportunities for humanity, but also heightened risks. The increase in space debris that this entails is a major global concern. The large number of satellites being launched into low-earth orbit, which tend to have shorter life spans than other types of satellites, will aggravate this challenge. However, there is no international mechanism to monitor space debris or facilitate its retrieval yet.

According to the United Nations (2023a), there are more than 24,000 objects of 10 cm or larger in space and circling the Earth. There are 1 million objects smaller than 10 cm, and likely more than 130 million objects smaller than 1 cm. Another important problem with space debris is its velocity. Even very small objects, travelling at more than 28,000 km per hour, can cause significant damage. The potential destruction of ICT-related satellites could dramatically affect communications on Earth. The Inter-Agency Space Debris Coordination Committee (2023) reports that post-mission disposal compliance remains low.

Moreover, the risks are compounded by what is called the “Kessler syndrome” (United Nations, 2023a); with an increasing density of objects in orbit, the likelihood of collisions increases, with each one creating more debris in a chain reaction, leading to exponential increases. This raises the challenge of orbital pollution. Overall, security, safety and sustainability in space are compromised.

Objects without control in space may end up falling to Earth, which can be a danger for people and the planet. Part of the mass may vanish through combustion when entering the atmosphere. But part of it will reach Earth. For controlled deorbiting of space debris, Point Nemo in the Pacific, the location in the ocean that is farthest from land, is considered the “spacecraft cemetery”. This has impacts on the local marine environment (De Lucia and Iavicoli, 2019).

There is increasing congestion and competition in outer space. Considering that space is a global commons, its governance goes beyond the jurisdiction of a single State. The private sector is exploring the development of constellations of thousands of new satellites, which can hamper access and use for future generations. Technology for space debris removal or remediation is currently in development. Yet there are important legal issues that need to be considered, such as jurisdiction, control, liability and responsibility for space pollution. And, given the cost of recovery or recycling, there may not be enough incentives for the private sector to ensure recovery. Increasing concerns about space sustainability and the need to address the space debris challenge are illustrated by the fact that the United States Federal Communications Commission (2023) has issued its first fine to a company that violated its anti-space debris rule. Moreover, this can be considered as sending a strong signal to other companies (O’Callaghan, 2023).

Governance arrangements for outer space need to be updated, as most of the existing rules were established when activity in space was exclusively carried out by States. Moreover, these rules only provide general guidance. Some progress has been made, for example with the 2019 Guidelines for the Long-term Sustainability of Outer Space Activities, but more needs to be done. The guidelines highlight that the “proliferation of space debris, the increasing complexity of space operations, the emergence of large constellations and the increased risks of collision and interference with the operation of space objects may affect the long-term sustainability of space activities. Addressing these developments and risks requires international cooperation by States and international intergovernmental organizations to avoid harm to the space environment and the safety of space operations”. The United Nations Committee on the Peaceful Uses of Outer Space pays particular attention to the issue of preventing and minimizing the creation of space debris. For example, it prepares a compendium of space debris mitigation standards adopted by States and international organizations (United Nations Office for Outer Space Affairs, 2023).

> The increase in space debris is a major global concern, aggravated by large numbers of satellites being launched into low-earth orbit

In the report, *Our Common Agenda*, the United Nations Secretary-General notes that "consideration could be given to a multi-stakeholder dialogue on outer space as part of a Summit of the Future… bringing together Governments and other leading space actors. The dialogue could seek high-level political agreement on the peaceful, secure and sustainable use of outer space, move towards a global regime to coordinate space traffic and agree on principles for the future governance of outer space activities" (United Nations, 2021a: 62).

Source: UNCTAD, based on sources cited.

cannot be easily repurposed for other computing tasks, has a considerable impact on e-waste generation. Given the enormous amount of energy use in bitcoin mining, operators are incentivized to use the latest, most powerful and energy-efficient hardware. Although this can reduce energy use, it comes at the expense of e-waste. It has been estimated that bitcoin mining operations generate over 3.7 tons of e-waste annually (de Vries and Stoll, 2021).

D. Factors driving the growth of digitalization-related waste

The growth of digitalization-related waste can be related to a number of factors:

- *Increasing consumption* of electronic devices and ICT equipment due to society digitalizing at a rapid pace. This is linked to population and economic growth, higher levels of disposable income and more people being connected to and using the Internet, as well as changing lifestyles. Moreover, as incomes increase, individuals are more likely to own several devices;
- *Declining prices* of digital devices and ICT equipment;
- *Limited awareness* among the population about the waste associated with digital devices and ICT infrastructure and its adverse effects on human health and the environment when this is not properly disposed of; and about potential benefits for society when e-waste is properly managed;
- The *linear model of production*, based on take/extract–make–use–waste, leads to a throwaway culture that does not incentivize consumers or producers to prevent or reduce the generation of digitalization-related waste. A lack of or insufficient implementation of policies to enable and regulate activities linked to reducing, reusing and recycling digitalization-related waste also plays a major role;
- *Inability to repair* devices and equipment and a lack of repair options. This is linked to the complexity in design of the products. In most devices, components cannot be separated because they are glued together. As the components are not assembled into a modular product, it is not possible to easily replace parts or components (e.g., batteries) and extend the life of devices. Similarly, barriers to disassembling devices or equipment limit the possibility of using components that could still be functional if they were properly separated and reintegrated back into the production cycle for remanufacturing or refurbishing. A design that favoured such activities would help reduce the consumption of electronic products and decrease digitalization-related waste generation. Large manufacturers may also impose

The linear model of production leads to a **throwaway culture without incentives to limit** the generation of digitalization-related waste limitations on independent repairers. Although some manufacturers may offer self-repair kits, devices remain difficult and costly to repair;

- *Shorter life cycles* of the devices and ICT equipment, in what may be called "fast tech", reflecting the tendency to change the equipment increasingly often. For example, the European Environmental Bureau (2019) notes that typical product lifetimes are four to five years for laptops and three years for smartphones; this contrasts with estimates suggesting that an optimal lifetime to mitigate the global warming potential of such products would be in the range of 20 to 44 years for laptops and between 25 and 32 years for smartphones.[21]

The "fast tech" factor is probably one of the most significant contributors to the increased generation of digitalization-related waste in recent years. The rapid evolution of digital technologies can shorten the lifespan for the use of digital devices and ICT equipment, as new, better-performing models replace existing ones and render them obsolete. Commercial practices by private companies, such as promotions by telecommunications companies offering devices at a low cost or for free as part of subscriptions, negatively affect digitalization-related waste reduction efforts. Moreover, manufacturers often lock devices to specific peripheral components, such as cables and chargers that are not standardized and therefore do not allow for interoperability with devices from different manufacturers.

Some activities heavily rely on digital devices and ICT equipment and require more frequent replacement. This is the case of data centres, including data centres for cryptocurrencies and other blockchain technologies, as they operate at all hours and require technologies that cannot easily be repurposed for other uses, as discussed above.

Overall, the lifespan of devices and equipment is linked to the concept of obsolescence. If this is intentionally integrated by the manufacturer, it is known as planned, programmed or built-in obsolescence, which is commonly used in the market of consumer electronics (Bisschop et al., 2022). This business strategy results in devices and equipment being manufactured in such a way that they prematurely grow out of use. Thus, high repair costs, difficulties in repairing, limited availability of spare parts and marketing tactics all lead consumers into product replacement instead of keeping the devices for longer (box IV.3). It is estimated that in Europe, average actual lifetimes of electronic devices are at least 2.3 years shorter than either their designed or desired lifetimes (European Environment Agency, 2020).

The origin of the idea of planned or built-in obsolescence can be traced to December 1924, when the world's largest producers of incandescent light bulbs colluded to artificially limit the lifespan of their products. This practice was developed during the crisis years at the end of the 1920s and was a way to induce people to buy an ever-increasing variety of consumer goods, not only for practical use but to stimulate the faltering economy at the time.[22]

Different types of obsolescence have been identified, such as:[23]

- *Technical, functional or structural obsolescence*, which is when a device no longer works because one of its essential components has a limited lifespan and cannot be removed and replaced;
- *Software obsolescence*, which relates to software updates and support. Technical support may be limited or there is incompatibility between versions.

The rapid evolution of digital technologies shortens the lifespan of devices as new models render existing ones obsolete

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[21] See also https://quantumlifecycle.com/en_CA/blog/whats-the-average-lifespan-of-your-electronics.

[22] See Bisschop et al. (2022), Franklin-Wallis (2023) and *The Guardian* (2020).

[23] For more discussion on the obsolescence of electronic goods, see Alfieri and Spiliotopoulos (2023), Bachér et al. (2020), Bhanarkar (2022) and https://www.stopobsolescence.org/.

Updating may impact the functionality of devices; and

- *Aesthetic, psychological, perceived or cultural obsolescence* is linked to a constant search for innovation, for producers to always manufacture and commercialize new, rapidly changing devices and for consumers to have the latest model. This need for the newest model is encouraged by marketing and advertising by manufacturing companies to boost sales, even though advances in these new devices may be marginal. This kind of obsolescence is linked to fashion movements that promote having the latest devices and upgrades.

Box IV.3
The reality of programmed obsolescence

The concept of programmed obsolescence remains controversial. Some may be argued that there is insufficient evidence to support its existence. In fact, demonstrating intention to shorten the lifespan of a product is not possible as manufacturers are unlikely to affirm it. However, this does not imply that it does not exist. Millions of consumers around the world have witnessed the declining life of devices and experienced difficulties in repairing them. Moreover, various digital device manufacturers have shown that devices can be designed for a longer life, while being easily repairable at a reasonable cost, or reused, remanufactured, refurbished or recycled (*The Washington Post*, 2022a). Thus, since there are ways to prolong lifespans of devices, it may be inferred that those devices with shorter lifespans are designed with such an intention.

Moreover, there are some documented cases of programmed obsolescence, whereby manufacturers have faced lawsuits and decisions by authorities, which have led companies settling or being fined. A well-known case, referred to as “batterygate”, involved an agreement by Apple to pay $500 million, starting in 2024 following charges of intentionally slowing down older mobile phone models (Brady, 2023; Cooper, 2024). Apple and Samsung have both been fined by the Competition Authority of Italy, and Apple has also faced fines in France. The companies were charged for intentionally slowing down phones through software updates that forced consumers to replace batteries or purchase new devices. Similarly, Apple was fined in Chile on smartphone programmed obsolescence.[a] Epson settled a class action suit on the suspension of the function of printers even when cartridges were not yet empty, as has Hewlett Packard, with regard to a chip that indicated that ink cartridges were to be replaced before they were empty (Bisschop et al., 2022; Malinauskaite and Erdem, 2021). Regarding software support-related obsolescence, the abandonment of Windows 10 support by Microsoft could render obsolete about 40 per cent of the personal computers in use; estimates of the numbers of personal computers to be discarded range from 240 to 400 million, depending on the source (Gutterman, 2023a; *Reuters*, 2023a).

Additionally, the United States Federal Trade Commission (2021) highlighted various repair restrictions used by manufacturers, including physical restrictions; unavailability of parts, repair manuals, and diagnostic software and tools; designs that make independent repairs less safe; application of patent rights and enforcement of trademarks; disparagement of non-original equipment manufacturer parts and independent repair; software locks, digital rights management and technical protection measures; and end-user licence agreements. The report concludes that “there is scant evidence to support manufacturers’ justifications for repair restrictions”. Reasons that companies have cited to oppose repairs include the protection of intellectual property rights and reputation; as well as effects on safety and security (Stone, 2023).

Concerns about planned obsolescence and limits to the right to repair are increasing around the world. Civil society movements such as Stop Planned Obsolescence, Right to Repair and Public Interest Research Group are active in raising awareness on this matter, putting pressure on manufacturers and policymakers to address the issue.[b] This is translating into the design and adoption of policies to address planned obsolescence and the related right to repair in many countries. After having opposed the right to repair for some time (Green, 2021), device manufacturers seem to be starting to turn the tide towards supporting it (Stone, 2022). For

Concerns about planned obsolescence and limits to the right to repair are increasing around the world example, Microsoft released an independent report highlighting the environmental benefits of fixing devices in terms of the reduction of both waste and emissions associated with manufacturing new devices (Oakdene Hollins, 2022). However, various remaining barriers to repair indicate that there is still a long way to go (Stone, 2023).

The Consumer Information for Sustainable Consumption and Production Working Group on "Product Lifetime Extension to Advance Circularity", under the One Planet Network's SDG 12 Hub led by UNEP and the Akatu Institute, has researched existing policy instruments that aim to make products more repairable and to communicate product reparability information to consumers. Product lifetime extension reduces the replacement of products, lessening resource use and digitalization-related waste generation, as well as preserving the economic value embedded in devices. It also has a beneficial economic development impact as low-income consumers cannot afford to frequently replace devices. In general, consumers would benefit from savings related to keeping devices for longer. The use of removable batteries in Europe would save consumers about $20 billion and reduce GHG emissions by 30 per cent compared with business as usual, according to the International Institute for Industrial Environmental Economics and the European Environmental Bureau (2021). Similarly, in the United States, Proctor (2023) estimates that product lifetime extensions could reduce household spending on electronics and appliances by 21.6 per cent.

UNEP (2017) provides recommendations on the opportunities available to consumers, the private sector and Governments in both developed and developing economies to address product lifetime extensions. Access to product repairability and effectively communicating repairability information to consumers are central factors for achieving the Sustainable Development Goals, in particular targets 12.2 (on the sustainable management and efficient use of natural resources), 12.5 (on the reduction of waste generation) and 12.8 (on ensuring that people have the relevant information and awareness for sustainable development).[c]

UNEP and the Akatu Institute (2021) map countries' policies and regulatory measures, aiming to prolong product lifetimes by designing more durable products, extending desirability or use through maintenance, upgrades and repurposing, and by recovering broken products through repair, refurbishment or remanufacturing. They conclude that engagement in the creation and promotion of policies to encourage resource efficiency as well as policies on waste management have increased over the past two decades. However, more attention needs to be directed to products' design and use phases, as well as measures to address psychological obsolescence. In this context, Consumers International (2019) highlights the following policy and industry actions to increase product lifespan and reduce waste: a law against planned obsolescence, minimum durability criteria, product lifetime labelling, affordable and accessible repairs, right-to-repair legislation, monitoring of trends in product lifetimes and consumer education and information.

Coutherut et al. (2022) show that there are increasing initiatives to address programmed obsolescence. Policies and regulations in this area are emerging, notably in the United States and the European Union.[d] Among developing countries, countries in Latin America appear to be the most active in this policy area. In Asia, India is making advances in moving towards the right to repair (Ray, 2023). Policies can promote the repair of products to extend their lifespan while reducing the purchase of new products. Such policies also send a signal to market players to avoid deliberately destroying new devices or reducing device lifespans through programmed obsolescence (Dalhammar et al., 2023).

There have been various calls to ban programmed obsolescence, including by the European Economic and Social Committee (2013) and by various authors, such as Becher and Sibony (2021) and Malinauskaite and Erdem (2021). France was the first country to ban planned obsolescence in 2015 (Perreau, 2023). In Canada, the provincial government of Quebec banned planned obsolescence in 2023.[e] According to Bisschop et al. (2022), programmed obsolescence, whether through hardware, software or difficult repairs, should be considered a form of corporate crime.

All of these actions and initiatives, by both civil society organizations and policymakers, show that programmed obsolescence is a real and serious concern for socioeconomic and environmental reasons and needs to be addressed.

> Policies can promote product repair to extend their lifespan, reduce new purchases and avoid programmed obsolescence…

> ...which is a real and serious concern that needs to be addressed

Source: UNCTAD, based on sources cited.

[a] See https://www.dw.com/es/apple-pagar%C3%A1-en-chile-34-millones-de-d%C3%B3lares-tras-demanda-colectiva/a-57127927.

[b] These organizations, together with media reports, provide, for example, repairability indices and information on product failures, which are useful for consumers to take informed decisions (see Gutterman, 2024; *The Washington Post*, 2022b and https://www.test-achats.be/trop-vite-use). They may also lead manufacturers to produce devices that last longer (Gutterman, 2023b).

[c] See https://www.oneplanetnetwork.org/programmes/consumer-information-scp/product-lifetime-extension, and https://www.oneplanetnetwork.org/news-and-events/news/search-more-repairable-products-policies-aim-make-products-more-repairable.

[d] For the United States, see https://www.whitehouse.gov/briefing-room/statements-releases/2021/07/09/fact-sheet-executive-order-on-promoting-competition-in-the-american-economy/, Seddon and West (2021) and Senkowski et al. (2023). In the European Union, the Parliament adopted the right-to-repair directive on 23 April 2024 (see https://www.europarl.europa.eu/news/en/press-room/20240419IPR20590), as part of the Circular Economy Action Plan. The plan includes various measures to ensure that products become more durable and repairable, and that consumers are empowered to make more sustainable decisions (see https://www.consilium.europa.eu/en/policies/circular-economy/). The European Union is also funding activities by the PROMPT Consortium on Premature Obsolescence Multi-Stakeholder Product Testing Programme (see https://www.oneplanetnetwork.org/knowledge-centre/resources/prompt-consortium-releases-premature-obsolescence-multi-stakeholder-0).

[e] For France, see https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000032225325/2020-02-12, and for Canada, see https://www.publicationsduquebec.gouv.qc.ca/fileadmin/Fichiers_client/lois_et_reglements/LoisAnnuelles/en/2023/2023C21A.PDF.

E. Environmental, health and other social impacts

Digitalization-related waste contains **hazardous materials** which, if not properly handled, can damage the environment and human health

Digitalization-related waste contains hazardous materials which, if not properly handled and treated, can have damaging effects on the environment and human health. Toxic materials include heavy metals and substances such as arsenic, cadmium, lead, and mercury, as well as persistent organic pollutants. At the same time, this rapidly growing stream of solid waste requires special treatment as it also contains valuable parts and materials that can be recovered and recycled. Thus, this treatment can provide livelihoods to workers and incomes to enterprises involved in these activities.

A large part of digitalization-related waste is handled in informal settings, particularly in developing countries. At such informal sites, MSMEs and workers use rudimentary tools and techniques to refurbish the equipment for a second sale or dismantle and process parts to extract valuable material. Such activities contribute to reducing poverty and digital divides as the latter are made more affordable.

However, the suboptimal processes often used in this context lead to the inefficient and insufficient recovery of valuable resources. Workers often lack the necessary skills and knowledge about how to effectively manage digitalization-related waste to recover the maximum potential value. They also experience poor working conditions linked to weak labour rights, lack of social protection schemes and limited opportunities to organize and improve their livelihoods (ILO, 2019b).[24]

When women participate in such informal digitalization-related waste management sectors, they often occupy positions at the lower levels of the working hierarchy. Gender stereotypes may perpetuate misconceptions about their abilities, including assumptions about women being less skilled or having less physical strength. This leads to reduced participation in more lucrative activities. As a result, women are not properly compensated for their time and efforts. Moreover, they often face discrimination and harassment. Overall, women are often marginalized into high-labour, low-paying jobs with little opportunity for growth and progress (UNEP and International Environmental Technology Centre, 2022a, 2022b).[25]

Several unsafe and environmentally unsound practices in the management of digitalization-related waste in informal settings have been observed. These include scavenging, dumping waste on land or in water, landfilling along with regular waste, open burning or heating, acid baths or acid leaching, stripping and shredding plastic coatings and manual disassembling of equipment without proper security measures. As such, informal workers are more exposed to injuries from the manual work they carry out because they often lack protective equipment.

These activities also release toxic pollutants that contaminate air, soil, dust, water, and food, both at digitalization-related waste recycling sites and in neighbouring communities. Burning or heating is considered one of the most hazardous activities due to the generation of toxic fumes. Toxic effects observed in human health include neurodevelopmental, renal, cardiovascular and reproductive damage, as well as cancers, allergies, bone, liver and lung damage, neurogenerative diseases, DNA damage, and endocrine disruption.[26] In addition, when waste is not collected but is disposed of with regular household garbage it leads to the loss of materials and components. The ashes from incineration and residues of landfills also have a high concentration of hazardous elements and require special treatment.

Children and pregnant women are especially vulnerable to the effects of hazardous pollutants from informal digitalization-related waste recycling activities. Exposure to such waste can be associated with various health effects during pregnancy, in infants and among children. These include adverse neonatal outcomes such as increased rates of stillbirth and premature birth; negative neurodevelopmental, learning and behaviour outcomes, especially linked to lead released through informal waste recycling; and reduced lung and respiratory function and increased asthma incidence, which may be due to high levels of contaminated air pollution in many recycling sites. It is estimated that between 2.9 and 12.9 million women may be at risk from exposure to toxic e-waste from work in the informal sector. Additionally, over 18 million children of 5–17 years of age could be involved in industries in which child labour is present, with waste processing as a subsector of many of these industries. The exploitation of children in the informal digitalization-related waste sector is mainly because their smallert

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[24] In 2019, the ILO Global Dialogue Forum on Decent Work in the Management of E-waste reached points of consensus to promote decent work in this sector (see https://www.ilo.org/resource/record-proceedings/final-report-global-dialogue-forum-decent-work-management-electrical-and). The work of ILO in connection to decent work in e-waste management is detailed in ILO (2023a). From a more practical perspective, ILO (2019c) provides a manual to assist e-waste workers in improving their safety, health and working conditions.

[25] For further discussions on the environmental and health-related impacts of e-waste, see Baldé et al. (2024), Sonny et al. (2023), Ghulam and Abushammala (2023), Jain et al. (2023), Rajesh et al. (2022) and Ankit et al. (2021). Andeobu et al. (2023) consider informal e-waste recycling and environmental pollution in Africa. Lebbie et al. (2021) focus on e-waste as a threat to the health of children and Park et al. (2017) discuss the effects of electronic waste on developing countries.

[26] For a review of the health consequences of exposure to e-waste, see Parvez et al. (2021). See also https://www.who.int/news-room/fact-sheets/detail/electronic-waste-(e-waste).

hands allow them to dismantle the waste more easily than adults (WHO, 2021b).

There can be tensions in developing countries arising from the urgent need in the short term to ensure that waste pickers in the informal sector have a living income and in the longer-term to address risks for health and the environment that arise from the inadequate processing of e-waste.

F. Circular digital economy: Turning waste into resources

Rapid growth in the generation of digitalization-related waste is a growing concern globally, both in developed and developing countries. As the former still produce considerably more waste per capita, the latter are rapidly digitalizing, generating a growing part of this waste. However, persisting digital divides also reflect the uneven capacity to manage the associated waste.

Managing digitalization-related waste is challenging, especially in developing countries

When this waste is properly managed in a safe and environmentally sound manner, environmental and health risks can be minimized or avoided. It is therefore important to take action towards strengthening formal systems of collecting digitalization-related waste. This would also promote the more efficient recovery of valuable resources. However, this is not an easy task. Managing digitalization-related waste poses significant challenges. This is particularly the case in developing countries where there is an absence of formal collection systems to handle such waste sustainably, and often also a lack of relevant facilities for the treatment and reuse of components and products as well as the necessary skills. Even in developed countries, despite better formal collection systems, collection rates are not high enough.

The management of digitalization-related waste primarily targets recycling and resource recovery. These activities are vital for mitigating health-related and environmental risks when performed in an environmentally sound manner. They can also increase the secondary supply of materials, including minerals, for electronics manufacturing. However, recycling and recovery should not be the sole focus. To reduce the generation of waste more effectively, the approach needs to be broadened to include strategies that lower the overall demand for electronic products and their components. This means adhering to core principles within the circular economy, namely reducing consumption and reusing more, with recycling materials and resource recovery as a last resort.

1. Management of digitalization-related waste: Is focussing on recycling and resource recovery enough?

The rapid increase in digitalization-related waste creates significant challenges for its management, notably in developing economies. The analysis of statistics of collected SCSIT waste, presented in table IV.2, shows that globally, formal collection of such waste increased from 1.7 million tons in 2010 to 2.5 million tons in 2022. This represents an increase of 50 per cent over the period, which reflects some progress in this area. However, the increase in global SCSIT waste generation over the same period (2.4 million tons) was about three times the increase in the collection of such waste (0.8 million tons). Thus, progress in SCSIT waste collection for recycling and recovery of materials, including minerals, was not enough to match the increase in the amounts of waste generated.

Developed economies account for about 81.6 per cent of the global formal collection of SCSIT waste, down from 99.6 per cent in 2010. The United States accounted for the highest share, representing 36.5 per cent of the world total collected in 2022, while the European Union accounted for 30 per cent. The share of developing economies was 18.4 per cent, mostly from Asia, which accounted for 17.4 per cent. The share of China was 14.2 per cent of all SCSIT waste collected. The shares of other developing countries are generally negligible.

Additional insights can be obtained from an analysis of collection rates, which are calculated by dividing the volume of SCSIT waste collected by the volume generated (see table IV.1). The collection rate worldwide increased from 20.7 per cent in 2010 to 23.8 per cent in 2022. This implies that less than a quarter of the global SCSIT waste generated in 2022 was formally collected. This leaves more than three quarters of such waste worldwide not formally collected and therefore undocumented.

Collection rates tend to be greater in countries with relatively high levels of waste generation. They are significantly higher in developed economies (averaging 46.8 per cent) than in developing economies (averaging 7.5 per cent). The top collection rates in the world are seen in the United States (62.2 per cent) and the European Union (59.5 per cent). In developing economies, Asia registers the most elevated collection rate (9.5 per cent), with China leading (16.2 per cent). If China is excluded, the average collection rate declines to 2.7 per cent. The collection rate in Africa is 0.8 per cent; with South Africa at 4.3 per cent. In Latin America, the collection rate is 2.1 per cent, with that of Mexico at 3.5 per cent, of Argentina at 2.8 per cent and of Brazil at 0.1 per cent. Thus, there is significant variation within regions. The collection rate for LDCs is 0.2 per cent.

In 2018, ITU member States, as part of the Connect 2030 Agenda for Global Telecommunication/ICT Development, set a global e-waste target for 2023 to increase the global e-waste recycling rate to 30 per cent and to raise the share of countries with e-waste legislation to 50 per cent. They also committed to reducing the volume of redundant e-waste by 50 per cent. Considering the e-waste generated in 2022 and the number of countries with relevant legislation, these targets remain, at present, out of reach (Baldé et al., 2024).

There are several challenges in managing, collecting and recycling digitalization-related waste which are closely linked to the factors explaining growth in such waste (see section D):

- *Complexity of electronic products*: minerals and metals are mixed in alloys, which complicates the separation of the different materials;
- *Recycling and recovering technology*: availability of technology for the recycling and recovery of these complex alloys remains limited;
- *Economic viability*: the high cost of recycling certain metals can outweigh the benefits, even when the technology is available;
- *Legislative framework*: insufficient, or a lack of, legislation leads to low e-waste collection rates, with additional challenges in implementation, monitoring, and enforcement;
- *Limited collection and treatment infrastructure*: infrastructure for proper waste collection and subsequent treatment remains underdeveloped;
- *Worker awareness and training*: particularly in the informal sector, a lack of training in safe and environmentally sound waste treatment practices persists;
- *Consumer awareness*: low awareness of the impacts of improper disposal contributes to reduced recycling rates, exacerbated by sufficient recycling options;

Progress in digitalization-related waste collection for recycling and recovery has not matched the increase in waste generated

Table IV.2
Collection of digitalization-related waste: Volume and collection rate, selected country groupings, countries and years

	SCSIT collected													Legislation		
	Volume (Millions of metric tons)				Growth (Percentage)	Share of global volume (Percentage)				Collection rate (Percentage)				By country	By grouping	Proportion (Percentage)
	2010	2015	2019	2022	2010–2022	2010	2015	2019	2022	2010	2015	2019	2022	2022	2022	2022
World	**1.669**	**2.455**	**2.545**	**2.499**	***50***	**100.0**	**100.0**	**100.0**	**100.0**	**20.7**	**25.0**	**24.6**	**23.8**	**..**	**82**	***42.9***
Developed economies	**1.663**	**2.048**	**2.106**	**2.039**	***23***	**99.6**	**83.4**	**82.8**	**81.6**	**42.4**	**45.4**	**46.7**	**46.8**	**..**	**46**	***95.8***
United States	0.590	1.116	0.936	0.911	*54*	35.4	45.5	36.8	36.5	47.8	75.5	62.5	62.2	Yes	..	..
European Union	0.549	0.562	0.794	0.751	*37*	32.9	22.9	31.2	30.0	44.9	41.6	60.1	59.5	..	27	*100.0*
Japan	0.304	0.068	0.068	0.071	*-77*	18.2	2.8	2.7	2.8	65.3	13.4	14.1	15.6	Yes	..	..
United Kingdom	0.109	0.137	0.093	0.079	*-28*	6.5	5.6	3.7	3.2	39.1	46.1	31.0	28.1	Yes	..	..
Republic of Korea	0.027	0.042	0.061	0.076	*178*	1.6	1.7	2.4	3.0	26.5	30.4	39.8	47.6	Yes	..	..
Canada	0.012	0.023	0.020	0.019	*57*	0.7	0.9	0.8	0.8	9.4	14.6	12.7	12.7	Yes	..	..
Australia	0.000	0.012	0.058	0.055	..	0.0	0.5	2.3	2.2	0.0	10.7	51.3	50.3	Yes	..	..
Developing economies	0.006	0.406	0.438	0.460	*7416*	0.4	16.6	17.2	18.4	0.1	7.7	7.5	7.5	..	36	*25.2*
Developing economies, Africa	0.000	0.004	0.005	0.005	*1306*	0.0	0.2	0.2	0.2	0.1	0.8	0.8	0.8	..	11	*20.4*
Egypt	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Yes	..	..
Nigeria	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Yes	..	..
South Africa	0.000	0.003	0.004	0.004	..	0.0	0.1	0.1	0.1	0.0	4.3	4.3	4.3	Yes	..	..
Developing economies, Asia	0.000	0.389	0.415	0.435	..	0.0	15.8	16.3	17.4	0.0	10.1	9.6	9.5	..	15	*33.3*
China	0.000	0.326	0.338	0.355	..	0.0	13.3	13.3	14.2	0.0	17.0	16.2	16.2	Yes	..	..
India	0.000	0.000	0.008	0.010	..	0.0	0.0	0.3	0.4	0.0	0.0	1.4	1.4	Yes	..	..
Indonesia	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No	..	..
Developing economies, Americas	0.006	0.013	0.019	0.020	*239*	0.3	0.5	0.7	0.8	0.8	1.5	2.0	2.1	..	10	*30.3*
Brazil	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	Yes	..	..
Mexico	0.006	0.006	0.007	0.007	*25*	0.3	0.3	0.3	0.3	3.9	3.5	3.5	3.5	Yes	..	..
Argentina	0.000	0.001	0.002	0.002	..	0.0	0.1	0.1	0.1	0.0	1.7	2.8	2.8	Yes	..	..
Developing economies, Oceania	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	..	0	*0.0*
Papua New Guinea	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No	..	..
Fiji	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No	..	..
Solomon Islands	0.000	0.000	0.000	0.000	..	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	No	..	..
Commonwealth of Independent States	**0.000**	**0.017**	**0.023**	**0.024**	**..**	**0.0**	**0.7**	**0.9**	**0.9**	**0.0**	**5.0**	**6.6**	**6.6**	**..**	**3**	***37.5***
Russian Federation	0.000	0.016	0.016	0.017	..	0.0	0.7	0.6	0.7	0.0	6.3	6.3	6.3	Yes	..	..
Memo items																
Developing economies, excluding China	0.006	0.080	0.100	0.105	*1613*	0.4	3.3	3.9	4.2	0.2	2.4	2.7	2.7	..	35	*24.6*
LDCs	0.000	0.000	0.000	0.001	..	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	..	7	*15.6*
Developing economies, excluding LDCs	0.006	0.406	0.438	0.459	*7408*	0.4	16.6	17.2	18.4	0.2	8.0	7.8	7.8	..	29	*29.6*

Source: UNCTAD calculations, based on data from UNITAR-SCYCLE.

Notes: Digitalization-related waste refers to SCSIT waste which is the sum of categories 2 and 6 of the e-waste statistics. Countries inside the regions are ranked in terms of absolute value of waste generated. “..” means non applicable. For growth, “..” applies when the increase is from 0.

- *Data and information*: the absence of robust data hampers evidence-based policymaking and the design of effective management systems; and
- *Investment needs*: significant funding, both public and private, is required to address these issues, but is often lacking in developing economies.

Digitalization-related waste collection is therefore highly related to the presence of relevant policies, regulations and legislation. Many Governments around the world have adopted policies and legislation to address the increasing amounts of this waste. To date, 82 countries have an e-waste policy, legislation or regulation in place, representing roughly 43 per cent of countries. This is an increase from 61 countries in 2014 and 78 countries in 2019 (Forti et al., 2020).

While in 2022 there were 46 developed countries covered by legislation, representing 96 per cent of the group total, only 36 developing countries were covered, accounting for just 25 per cent of the total number of countries in the group. In particular, Africa lagged behind, with only one out of five countries having relevant legislation in place. This shows that, while there is ongoing progress, more efforts are needed to design and implement digitalization-related waste policies and regulations.

In a review of recent developments in e-waste legislation around the world, Baldé et al. (2024) show that 68 countries have an instrument containing provisions on extended producer responsibility (EPR). This is one of the most used principles as a foundation of national e-waste management systems. EPR aims to ensure that the producer, importer or distributor has responsibility for a product at the post-consumer stage of its life cycle. Moreover, 62 countries are covered by legislation referring to environment, health and safety standards, 45 countries have e-waste collection targets at the national level and 36 countries have e-waste recycling targets.[27]

E-waste legislation should at least include key provisions addressing clear stakeholder definitions, roles and responsibilities, as well as a clearly defined product scope. There should also be clarity in the stipulations on enforcement measures and penalties for non-compliance, and details on financing mechanisms. Furthermore, there should be clear conditions for organizational mechanisms for electric and electronic equipment producers, together with clear terminology outlining who will cover the cost of managing e-waste (Baldé et al., 2024).[28]

With regard to e-waste, in the European Union, Directive 2012/19/EU on WEEE was being amended in 2023–2024, following a judgment by the Court of Justice in 2022 which declared it partially invalid (European Parliament, 2024).

Reducing waste, including updating the definition of WEEE mentioned above, is a key aim. In this context, the European Union is revising its rules to better regulate trade in waste, both within the European Union and with non-European Union countries, to ensure that waste exports do not harm the environment and human health, and to address illegal shipments. The European Union aims to create a well-functioning market for secondary raw materials and has set an objective of at least 25 per cent of critical raw materials consumption in the European Union each year to come from domestic recycling.[29]

Despite advanced regulations, the rate of recycling remains low in the European Union. The European Court of Auditors (2021) has highlighted that, although there has been progress, countries often face difficulties in enforcing legislation and achieving set targets. Progress was mostly seen in the 2010s and by 2019, the rate of recycling of

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[27] On relevant e-waste legislation, see https://globalewaste.org/map/.

[28] ITU provides useful supporting tools for policy making in the context of e-waste. See, for instance, ITU (2018) and ITU and WEF (2021).

[29] See https://www.consilium.europa.eu/en/policies/circular-economy/.

WEEE had reached 40 per cent. However, it declined to 39 per cent in 2021. This is the lowest recycling rate among the different waste streams in the European Union (European Environment Agency, 2023).

Low recycling rates of e-waste are mirrored by low recycling rates of raw materials, including minerals and metals. While a high proportion of bulk metals and minerals such as aluminium/bauxite, cobalt and copper may have relatively high rates of recovery, many transition minerals have very low rates of recycling and recovery, or are not recycled at all in the European Union (Watkins et al., 2023). Considering that the European Union tends to register some of the highest rates of material recycling in the world, rates in most other parts of the world are likely to be lower.

Policies, regulations and legislation have mostly focused on the management of digitalization-related waste through recycling and resource recovery...

...limited attention has been paid to reducing waste

In summary, policies, regulations and legislation have, to date, mostly focused on the management of digitalization-related waste through recycling and resource recovery, as well as measures against environmental pollution or that support the occupational safety and health aspects of such activities.[30] Thus, the current focus is on increasing the secondary supply of materials and minerals and avoiding the negative impacts of such waste. Limited attention has been paid to reducing the volumes of digitalization-related waste, which is the focus of the next subsection. Recycling should be the last resort, and priority should be given to preventing and minimizing such waste and its final disposal. Moreover, from an economic development perspective, policies should seek to enable developing countries to capture more of the value from digitalization-related waste management.

2. Reducing digitalization-related waste: Prevention as the priority

Beyond increasing the secondary supply of materials to complement the primary supply, it is important to pay more attention to activities that can reduce digitalization-related waste volumes and prevent waste generation in the first place. According to the Basel Convention framework for the environmentally sound management of hazardous wastes and other wastes (UNEP, 2013: 9): "…stakeholders should respect the waste management hierarchy (prevention, minimization, reuse, recycling, other types of recovery, including energy recovery, and final disposal). It is recommended that resources and tools be allocated in accordance with the hierarchy. Waste prevention should be the preferred option in any waste management policy. By not generating wastes and by ensuring that the wastes generated are less hazardous, the need to manage wastes and/or the risks and costs associated with doing so are reduced. Prevention, however, will not solve all the problems associated with waste management. Some wastes are already, or will inevitably be, generated and such wastes should be managed in an environmentally sound manner. When prevention and minimization possibilities have been exhausted, reuse, recycling and recovery techniques that deliver the best overall environmental outcomes, in accordance with the best available techniques, best environmental practices and a life-cycle approach, are to be encouraged".[31]

Activities to prevent and minimize digitalization-related waste in line with the

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[30] More attention should be paid to the role of labour market policies and the policies of enterprises, cooperatives, employers, workers and ministers of labour or employment in advancing decent work in the management of digitalization-related waste (ILO, 2019c).

[31] This is further developed in the Basel Convention draft guidance to assist parties in developing efficient strategies for achieving the prevention and minimization of hazardous and other wastes and their disposal (UNEP, 2017).

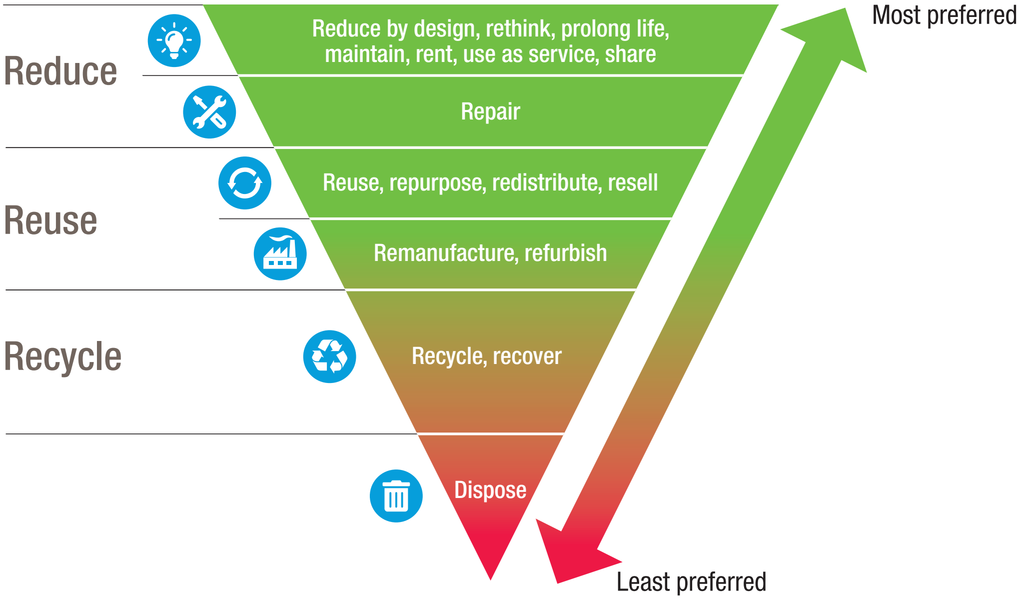
three Rs[32] of the circular economy – reduce, reuse and recycle – include extending the life of devices through sharing, rental or donation; maintenance and repair; resale and redistribution; and remanufacture and refurbish. Such activities can lower demand for new electronic devices and equipment and, in turn, reduce demand for minerals and other materials, ultimately reducing the generation of waste.

This can be illustrated as an inverted pyramid of the digitalization-related waste hierarchy, as shown in figure IV.3. At the top of this inverted pyramid, the preferred options for reducing environmental impact relate to extending the life of devices and equipment, achieved through changes in consumer behaviour and supportive business models. The second most preferred option is repair. Both options align with the overall need to reduce global consumption of electronic products. In the middle of the pyramid, options include reuse-related activities such as reuse, repurpose, redistribute and resell, as well as remanufacture and refurbish. At the bottom of the pyramid, the recycling and recovery of materials are among the least preferred options. Overall, the aim is to minimize the disposal of waste.

There is no generally accepted definition of the circular economy. For instance, Kirchherr et al. (2023) find up to 221 definitions. The circular economy is essentially an alternative model to the linear economy of take/extract–make–use–waste. Resolution 1 adopted by the United Nations Environment Assembly at its fourth session from 11 to 15 March 2019 acknowledges “that a more circular economy, one of the current sustainable economic models, in which products and materials are designed in such a way that they can be reused, remanufactured, recycled or recovered and thus maintained in the economy for as long as possible, along with the resources of which they are made, and the generation of waste, especially hazardous waste, is avoided or minimized,

Reduce, reuse and recycle can lower demand for new devices and, in turn, reduce demand for minerals and other materials, ultimately reducing the generation of waste

Figure IV.3
The digitalization-related waste hierarchy of options for reducing environmental impact



Source: UNCTAD.

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[32] Many other circular economy principles based on Rs can be found in the literature. For instance, Uvarova et al. (2023) discuss 60 economy principles classified within the four groups of reduce, reuse, recycle and reverse logistics.

and GHG emissions are prevented or reduced, can contribute significantly to sustainable consumption and production”.[33]

A circular economy approach can be seen as an opportunity to recover valuable resources and enable economically beneficial activities

A circular economy approach requires rethinking the whole life cycle of digitalization (see chapter I). It can be seen as an opportunity to recover valuable resources and enable economically beneficial activities. Minimizing the amount of waste generated contributes to environmental sustainability objectives, including reducing the pressure on the primary supply of minerals and other materials. This would help reduce GHG emissions caused by mineral extraction and processing related to manufacturing electronic devices and their final disposal. The following outlines major features of key activities in the circular electronics sector:[34]

Reducing requires that people rethink how they can best meet their needs and achieve their aspirations with minimal impact on the planet and the people around them. This may imply a conscious consumer choice to use functioning items and services for longer, and to buy less frequently.[35] This approach can be implemented at no cost and has significant potential for retaining the value of a product or service for a longer time period. Business models that allow for the rental of devices under “product as a service” schemes can also support consumption reduction.[36]

Refusing is another sustainable lifestyle choice, whereby people buy or use less and decline unnecessary products or services. It can also apply to a specific element of a product, such as refusing to purchase products that have been designed using hazardous substances. Refusing can send a strong signal to the market, helping economies to transition to more circular models.

Direct reuse refers to reusing a product for its original purpose, without needing to repair or refurbish it. Reuse and resell imply that a user chooses to hand the product to another user, usually without an intermediary and without modifying the product or service. It also applies to the use of second-hand products, or products that are reused after refurbishment. Reuse and resell incur little cost and can help the product or service retain its value for longer. As the potential for reuse becomes a selection criterion when purchasing a product, users encourage manufacturers to offer more robust products and materials, with a longer lifetime, hence fostering more sustainable consumption and production patterns.

Repairing refers to fixing a fault in an item (either waste or a product) or replacing defective components, to make the item fully functional again and available for its original purpose. Repair extends the lifespan of a product. A user may send a product to a business intermediary via the retailer to be repaired or take it directly to a repair shop. The product is returned to the user, or provided to a new user, in a fully functional order.

A major barrier to repairing is that most digital devices are not designed to be repaired. Even if a consumer would be willing to do so, it may not be possible. This is linked to programmed obsolescence and a lack of access to repair manuals and components, or costly access to specialized repairers. Thus, the only possibility may be

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[33] See https://www.unep.org/environmentassembly/unea-4/proceedings-report-ministerial-declaration-resolutions-and-decisions-unea-4 and https://buildingcircularity.org/.

[34] Descriptions of circular economy-related activities are based on the glossary of terms of the Basel Convention (Secretariat of the Basel Convention, 2017) and https://buildingcircularity.org/.

[35] The Product Lifetime Extension Hub of the Programme on Consumer Information of the One Planet Network (available at https://www.oneplanetnetwork.org/programmes/consumer-information-scp/product-lifetime-extension) is a useful tool with which to explore resources that address the extension of the lifetime of products, including in the electronics sector, for a more circular economy.

[36] These are still novel concepts for consumers; a survey of consumers in France, Germany, Italy, the United Kingdom and the United States reveals that only 10 to 15 per cent of consumers would be open to renting (see https://www.kearney.com/service/sustainability/article/-/insights/electronics-as-a-service-a-sustainable-alternative-to-business-as-usual).

to replace the item. In response, the “right to repair” movement is actively advocating for the ability to repair products. This movement began in the United States, where the emphasis is on consumer rights, and has been extended to other parts of the world. In the European Union, emphasis is also placed on repair in relation to the circular economy and the environment (ILO, 2023b). However, regulation in this direction has been met with significant opposition, particularly by big technology companies (Moeslinger et al., 2022).[37]

In 2022, the French Government introduced the Repairability Index, which is included in the law against waste and for the circular economy.[38]

All of these actions are creating increasing pressure on manufacturers and promoting healthy competition in this regard (see chapter VI).[39]

Refurbishment refers to the modification of an object – either waste or a product – to increase or restore performance or functionality or to meet applicable standards or regulatory requirements, resulting in a fully functional product suitable for its originally intended purpose or beyond. The restoration of functionality but not value, enables a partially new service life for the product. Comprehensive refurbishment differs from standard refurbishment in that it involves a more rigorous process within industrial or factory settings, with a high standard and level of refurbishment. The addition of value during comprehensive refurbishment enables an almost full new service life for a product. It brings the product up to “state of the art” level, with newer or more advanced components. It also enables access to high-quality products with significantly fewer environmental impacts and lower costs to producers and, potentially, customers.

Remanufacturing refers to a standardized industrial process within industrial or factory settings, in which cores (product or module that has been sold, worn or is no longer functional) are restored to same-as-new, or a better condition and performance level. The remanufacturing process is in line with technical specifications, including engineering, quality and testing standards, and typically yields fully warranted products. This process enables the production of “as new” products, lowering environmental impacts, costs and prices. It implies product improvement, whereby the full structure of a multi-component product is disassembled, checked, cleaned and, when necessary, replaced or repaired in an industrial process.

In **repurposing**, discarded goods or components are reused and adapted for another function so that the material gets a distinct new life cycle. Converting old or discarded materials into something useful returns them into the economy in a way that retains some, if not all, of their value. From a production perspective, repurposing enables financial savings, either by reducing the cost of production by obtaining reclaimed material, or by reducing waste generation and its associated treatment requirements.

Recycling involves processes that prevent materials from being discarded and allows materials to be reused instead. Recycling usually involves reprocessing waste into materials, substances, minerals, and metals. Recycling does not cover operations that only recover energy from waste. Different techniques are used in recycling, including manual work, mechanical work or chemical and metallurgical processes that remove impurities and improve material quality. While recycling is key, it can often be costly, and even impractical in some cases. This is reflected, as

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[37] See https://repair.eu/. See also Stokel-Walker (2023) for a review of the evolution of laws in relation to the right to repair. The extension of this right around the world is described in Chamberlain (2022).

[38] See https://www.ecologie.gouv.fr/indice-reparabilite and UNEP and Akatu Institute (2023).

[39] See https://www.bloomberg.com/news/articles/2023-01-19/why-consumers-are-fighting-tech-firms-for-right-to-repair. Some companies appear to be softening their stance in relation to the right to repair; for instance, Apple has expressed support for the related law in California, United States (see https://www.emergingtechbrew.com/stories/2023/09/06/apple-right-to-repair-support.

discussed above, in the low rates of recycling of digitalization-related waste and of recovery of minerals and metals.

Recovery, unlike final disposal, makes use of the resources to obtain some useful benefit from waste, either by bringing materials back into production or recovering energy from them. Recovery of minerals is also called urban mining. Technological progress is leading to the e-waste mining of metals becoming cost-competitive in comparison with virgin mining (Zeng et al., 2018). Thus, it may be preferable to mine e-waste rather than mining the Earth. E-waste may also have higher levels of mineral concentration. The value of metals in SCSIT waste was estimated to be $27.5 billion in 2022.[40]

Unlike fossil fuels, minerals are not lost once used. In theory, they may be reused over and over again. However, achieving full recyclability for all elements of the periodic table is far from realistic. This is not only because of existing technological limitations, but also for reasons related to thermodynamics. Thus, completely closing the cycle, as the circular economy aims to do, is impossible. A term that more accurately reflects this reality is the "spiral economy", which acknowledges that in each cycle, there is inevitably the loss of some materials and energy (Valero and Valero, 2019). Nevertheless, both concepts move in the direction of more sustainable consumption and production. Therefore, the concept of circular economy, which is gaining attraction, serves the achievement of the Sustainable Development Goals.

Circular digital economy activities need to be based on one **crucial overarching principle**; to design electronic products with **circularity in mind**

At the outset, all of these circular digital economy actions require one critical overarching action. The design of electronic products with circularity in mind. Properly designing products according to their end of life is critical. "Reducing by design" leads to products and services that use fewer materials per unit of production, or during their use. This influences all stages of the product or service life cycle: less raw material is extracted; production uses fewer inputs and hazardous materials; consumption patterns and the end of life of products and services are influenced by the design, minimizing waste. Reducing by design requires increasing connections and information exchanges among different actors in a life cycle; for example, recyclers would require relevant information from manufacturers about the material content in order to deal with waste.

Design for circularity should also help to minimize the use of hazardous substances and promote the use of recycled materials. Moreover, products should be designed to avoid over-mixing minerals, and to be easily repaired and disassembled so that components can go back into the production cycle. Designing modular electronic products could be a valuable option (Amend et al., 2022). Designing for effective disassembly and recycling is key, as physical separation offers a more cost-effective solution. All of this would result in a sustainable electronic product, which would be designed to be durable.[41] This can also be supported by legislation; for example, regulating against planned obsolescence. For instance, the European Union is working towards a regulation on ecodesign for sustainable products.[42]

Circularity is also about responding to changing consumers' preferences, as they are increasingly aware of, and concerned about, their environmental impacts. Multiple consumer surveys point to a growing demand for more sustainable electronic

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[40] Data from UNITAR-SCYCLE.

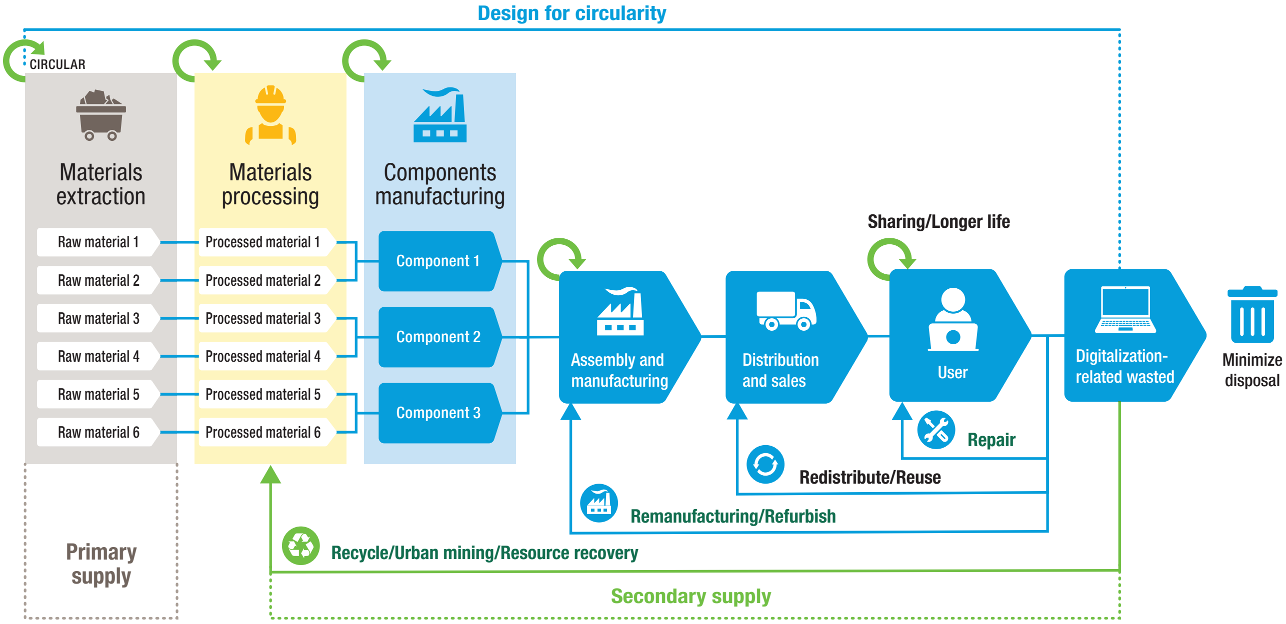
[41] There are already some examples in the market, such as Fairphone, see https://shop.fairphone.com/about-us.

[42] See https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en#ecodesign-from-an-international-perspective

products.[43] Nevertheless, the cost of devices continues to be a major factor in purchase decisions. In recent years, inflation has significantly influenced the fact that consumers keep devices for longer, repair them or buy second-hand devices.

The circular economy approach for electronic products, taking into account their life cycle, can be compared with the linear model of production presented in chapter II (figure II.16), and further illustrated in figure IV.4. This shows the initial stage of minerals extraction, reflecting the primary supply of minerals and metals. However, a linear model moving from extraction to waste only offers a limited view of potential opportunities. There are various ways to shift towards the circular economy, to close the loop and either increase the supply of materials or reduce demand for materials. Recycling and resource recovery, including urban mining, can be a source of secondary supply for minerals. The remaining activities that promote reintegration back into the production chain would contribute to reducing the demand for ICT goods and, consequently, the raw materials needed to produce them.[44] Therefore, items can move back and forth in the chain. Some items might initially be categorized as "waste", but if they can be reclaimed or repurposed for the production process, they reach "end of waste" status, and are no longer classified as waste. Indeed, end of use does not necessarily mean end-of-life, as the item or its components may continue to be used. Moreover, circularity should apply to all stages of the production chain, not only

Figure IV.4
Circular economy for ICT goods



Source: UNCTAD, adapted from Deloitte (2023).

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[43] In the European Union, 79 per cent of citizens think that manufacturers should be required to make it easier to repair digital devices or replace their individual parts, and 77 per cent would rather repair their devices than buy new ones (see https://www.europarl.europa.eu/news/en/press-room/20220401IPR26537/right-to-repair-meps-want-more-durable-and-more-easily-repairable-products). See also Trojan Electronics (2023), Hatchett (2022), Société Générale de Surveillance (2021), Perzanowski (2020) and Society for the Promotion of Consumer Electronics and OliverWyman (2022).

[44] Activities that imply reintegration back into the value chain, in the opposite direction as that of the linear model, are also known as reverse logistics. Their purpose is to collect, disassemble, remanufacture, recycle and minimize disposal of end-of-life electrical and electronic products to mitigate the risk of environmental damage and maximize the extraction of economic value (Ni et al., 2023).

at the user level; there should be circular mining, processing and manufacturing.[45]

Relatively few countries have adopted legislation on circular economy activities, with references to repair or ecodesign. For example, the European Union – which may have the most advanced regulatory regime in this context globally and is a pioneer in e-waste legislation – is taking measures in this regard in its circular economy action plan.[46]

Actions that support the circular economy seek to ensure the development of sustainable products, such as ecodesign, which includes a digital product passport, and right to repair; circularity in production processes; and empowering consumers to have access to reliable information to make the best choices, including on early obsolescence and repairability. Actions also target key sectors including electronics and ICT, with a push to improve durability and recycling and to enable consumers to buy products that are more energy-efficient, durable and easy to repair. Similarly, the European Union has adopted a regulation on batteries to create a circular economy for the battery sector by targeting all stages of the battery life cycle, from design to waste treatment. In addition, the European Union has approved rules to establish a common charger for mobile phones and tablets, in order that consumers may choose to buy a new device with or without a charging accessory. This allows consumers to continue using functioning chargers when buying new devices of different brands.[47]

The potential economic value of the resources recovered depends on the type of equipment. For example, WEEE in data centres contains more high-grade recycling material than small IT devices such as laptops. Data centres use high-grade circuit boards and backplanes that have, on average, a higher precious metal content than the typical circuit boards from individual consumer or small IT devices (ITU, 2021a).

The growth in the electronics market and the subsequent rise in waste generation has also led to increased demand in the second-hand market for electronic products, as well as markets for repairing, remanufacturing, refurbishing and recycling. Considering the projections for continued growth, the value of these markets is likely to increase further, as shown by various market research studies:[48]

- The global market for electronics *recycling* is estimated to grow from \$37.2 billion in 2022 to \$108.3 billion by 2030, led by the United States and China (Research and Markets, 2024);
- The value of *refurbished* electronics is estimated to increase from \$85.9 billion in 2022 to \$262.2 billion in 2032. In 2022, the largest shares were seen in North America, Europe and Asia and the Pacific, with the latter expected to overtake Europe by 2032. The share of the rest of the world is small in comparison (Market Research Future, 2024);
- The global consumer electronics *repair* and maintenance industry generated \$15.3 billion in 2021 and is expected to generate \$21.6 billion by 2031 (Allied Market Research, 2023); and
- The *second-hand* electronics product market in Europe, which was valued at \$78.9 billion in 2022, is estimated to reach \$225.5 billion by 2031 (Transparency Market Research, 2023).

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[45] For more discussions on the circular economy in the ICT sector, see https://www.itu.int/en/mediacentre/backgrounders/Pages/e-waste.aspx, Ellen MacArthur Foundation (2018), PACE and WEF (2019), APC (2024), Roura et al. (2021), GSMA (2022a, 2022b), CEP (2022), PACE (2021) and United Kingdom, House of Commons Environmental Audit Committee (2020).

[46] See https://www.consilium.europa.eu/en/policies/circular-economy/.

[47] See https://www.europarl.europa.eu/news/en/press-room/20220930IPR41928/long-awaited-common-charger-for-mobile-devices-will-be-a-reality-in-2024.

[48] Multiple market research studies look at the evolution of the market for activities related to circular electronic products, with significant variety in terms of coverage, time period and methodology. However, there seems to be agreement on a positive outlook.

Overall, the markets for recycling, refurbished electronics and second-hand electronics are all estimated to approximately triple their value in the coming decade.

There is a strong business case for such circular economy activities, which generate economic value and job opportunities. This also creates environmental benefits by reducing the resources extracted and emissions linked to extraction, manufacturing and waste treatment processes. Circularity allows for resource recovery and an increase in the secondary supply of minerals. It can also lead to the reduced consumption of electronic devices and equipment, and in turn reduce the demand for materials used in their manufacturing. This alleviates some of the pressure on the mining supply and the associated environmental and social impacts from extractive activities.

The circular digital economy should not necessarily be associated with less digitalization, but with better, more environmentally sustainable digitalization. Overall, as materials are kept in use as products or components, waste and pollution can be significantly reduced, and the potential value of products and materials and minerals better captured.

The market for **recycling, refurbished electronics and second-hand** electronics is **estimated to triple** in the coming decade

G. International trade in digitalization-related waste

International flows of digitalization-related waste are a critical issue, representing both opportunities and risks for developing countries. A common belief is that this trade is characterized by substantial dumping of such waste from developed to developing countries (Abalansa et al., 2021). While flows from developed to developing countries may have been more significant in the past, when digitalization was primarily taking place in developed countries, this is no longer the case. As developing countries have been rapidly digitalizing, they have been generating increasing volumes of digitalization-related waste. Accordingly, an increase in intraregional flows of this waste can also be observed. Assessing the implications of these international flows of waste is complicated by the limited availability of statistics.

The transboundary movement of all e-waste is regulated by the Basel Convention (see section B), which now applies to both hazardous and non-hazardous electrical and electronic waste. The objective of the Convention is to protect human health and the environment against the adverse effects of hazardous waste. By mid-2024, 191 countries were Parties to the Basel Convention; the United States had not yet ratified it.

The implementation of the Basel Convention in the context of e-waste may be challenging, given the magnitude of informal shipments and illegal trade of such waste.[49] Thus, the correct implementation of the Convention requires ongoing improvement and adjustment, to include clear definitions related to e-waste fractions, better waste statistics and practical solutions (Meidl, 2023; Mihai et al., 2022; Baldé et al., 2023). For this reason, Parties to the Basel Convention adopted e-waste amendments which extend the scope of the Convention to all e-waste, effective 1 January 2025.

Some of the trade flow scenarios for digitalization-related waste are legal, while others are illegal. Trade is legal if the waste is to be recycled in an environmentally sound manner and the trade follows national regulations, as well as international and regional agreements. Problems emerge

Assessing the implications of international flows of digitalization-related waste is complicated by the **limited availability of statistics**

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[49] For example, implementation issues in Latin America are discussed in Hernandez et al. (2023).

with illegal trade, in the form of smuggling or trafficking, when waste is disguised as second-hand electronic equipment or other goods. Mixing legal and illegal items is one of the main strategies used by criminal actors; in instances of illegally shipped waste, criminals frequently use tactics such as misclassification, misdeclaration and fraud to mix the items (Baldé et al., 2024).

Informal activities in a developing country that is importing digitalization-related waste can provide economic opportunities and livelihoods for people in need. Even if the electronic equipment does not work, if it can be repaired, it can help generate business and job opportunities. Refurbished or repaired devices can also increase access to and affordability of equipment. If components could be easily disassembled, there could be trade in components that may be reintegrated into the production cycle for remanufacturing or refurbishing. Such trade could also contribute to economic activity in the receiving country. However, the process carries significant environmental, health-related and other social costs, while it is less efficient in terms of value and resources recovery.

The most recent comprehensive global analysis of international flows of e-waste is the Global Transboundary E-waste Flows Monitor 2022 by UNITAR (Baldé et al., 2022). It notes that the quantification of such shipments is difficult, and that their true magnitude remains unclear. Accurately estimating international e-waste flows is challenging for various reasons, including limited global data and lack of harmonization. Data stemming from national reporting in the context of the Basel Convention show incomplete reporting, ambiguous definitions, incorrect categorizations, discrepancies in reporting and inaccuracies. Moreover, there is no obligation to report on international trade of used electronic equipment. All of these problems are also connected to the illicit nature of illegal trade in e-waste.

The transboundary movement of e-waste has, to date, been divided into controlled and uncontrolled flows.[50] Controlled transboundary movements include international flows of e-waste that are reported as hazardous waste, in compliance with the Basel Convention control regime. Under the Basel Convention reporting, it is not possible to distinguish between categories 2 and 6 of the statistical definition of e-waste, so records of these movements refer to overall e-waste. Controlled flows also include trade in waste of printed circuit boards (PCBs) to the countries where the specialized processing facilities are located. Such trade is highly relevant because PCBs are among the most valuable parts of electronic products. Uncontrolled flows may include used ICT equipment and digitalization-related waste, including cases where parties introduce exceptions into national legislation regarding used equipment that has been sent for failure analysis or repair. Although the respective shares of functioning equipment and waste are not known, it is normally understood that the uncontrolled nature of this trade, and limited inspection capacities, make this a significant channel for illegal e-waste trade.

Against this background, Baldé et al. (2022) find that controlled shipments under the Basel Convention mostly occur either between high-income regions or into high-income regions (figure IV.5). Only 9 per cent of this trade is between continents.

In the case of PCB waste, it is mainly imported into East Asia, North America and Northern and Western Europe. Globally there are less than ten specialized facilities that can handle such waste, and these are located in developed countries. Due to its higher value, this type of waste has a higher collection rate (34 per cent in 2019) than e-waste in general (17 per cent) and

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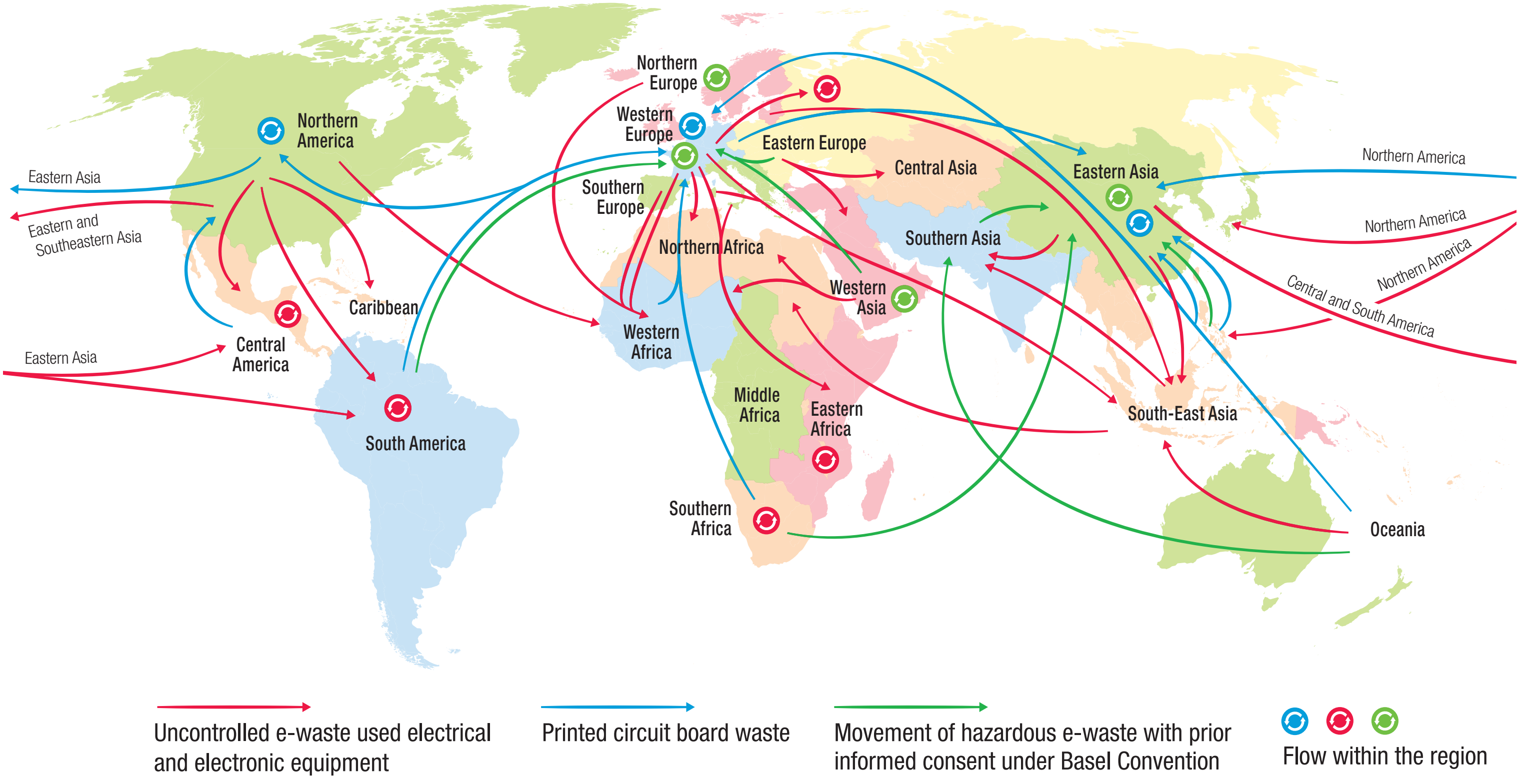
[50] The recent decisions by the Basel Convention can help address uncontrolled trade in the future.

SCSIT waste (25 per cent).[51] More than half of international trade in PCB waste is intercontinental, while much of it is from developing to developed countries.

Uncontrolled international trade of used electrical and electronic equipment or e-waste flows mainly from developed to developing economies, and in most cases constitutes illegal traffic. Intraregional movements also take place towards the poorest economies in a given region. As shown in figure IV.5 Northern and Western Europe are sources of exports to Western Africa. Western Europe also exports such waste to Southeast Asia and, at the regional level, to Eastern Europe. North America exports to Western Africa, Asia and Latin America and the Caribbean. East Asia exports mostly at the regional level to Southeast Asia and Southern Asia. Developed countries in Oceania export used equipment and e-waste to Southeastern Asia.[52]

Figure IV.5
International trade in controlled e-waste and uncontrolled used equipment and e-waste



Disclaimer: the boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Source: UNCTAD, based on Baldé et al. (2022).

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[51] Although the most recent Global E-Waste Monitor provides data for 2022, the information provided here is for 2019 because the last available international trade data are only for the latter year.

[52] Figure IV.5 and the analysis provided in Baldé et al. (2022) refer to e-waste, i.e., electrical and electronic waste. While it is not possible to obtain data from Basel Convention reporting for categories 2 and 6, statistics for categories 2 and 6 (SCSIT waste) on uncontrolled flows point to the same conclusions. More detailed analyses on transboundary flows of e-waste are available at https://ewastemonitor.info/regional-e-waste-monitors/. For a recent account in the case of Asia and the Pacific, see United Nations Office on Drugs and Crime and UNITAR (2022).

Uncontrolled trade in used electrical and electronic equipment and digitalization-related waste flows from developed to developing economies…

These estimations suggest a pattern of unequal ecological exchange, where uncontrolled trade in used electrical and electronic equipment and most likely digitalization-related waste flows from developed to developing economies, and within regions from the most developed to the less developed economies. This implies the transfer of responsibilities and risks, with the burden of environmental and social costs placed on those that are receiving the waste streams. In contrast, the higher value parts of the waste chain are exported from developing to developed countries. Thus, as in many international trade dynamics, developing countries remain locked in at the low-value part of the digitalization-related waste value chain, while developed economies capture the highest value.

...developing countries remain locked in at the low-value part of the digitalization-related waste value chain, while developed economies capture the highest value

There are some well-known digitalization-related waste dumping sites in developing countries. WHO (2021b) maps locations of informal e-waste dismantling and recycling sites reported in research literature, including Bangladesh, Cameroon, Chile, China, Egypt, Ghana, India, Mexico, Pakistan, the Philippines, Thailand, Uruguay, Viet Nam and the State of Palestine.

These results are also shown in other analyses, including case studies.[53] For instance, the Basel Action Network is a non-governmental organization that works to combat against illegal hazardous waste trade. By using GPS trackers, the network has highlighted holes in the circular economy through e-waste leaking in Europe and illegal exports of e-waste from Australia (Basel Action Network, 2018a, 2018b). These findings are complemented by anecdotal evidence of crime related to e-waste trade. For example, in January 2023, authorities in Spain dismantled a criminal network that was using forged documents to ship hazardous e-waste from the Canary Islands to Western Africa. This included 14 containers with 300 tons of material ready for shipment.[54]

A major challenge in preventing digitalization-related waste imports is limited capacity to enforce legislation, or to carry out the necessary monitoring and controlling of imports. This is mostly due to insufficient financial and human resources. Exporting countries also face challenges with regards to controlling exports. For example, through the “person in the port” project, a two-year study into used EEE sent to Nigeria, mostly from European ports, severe problems were highlighted with regard to non-compliance with international and national rules governing such shipments; the equipment often arrived mixed with other goods such as bicycles, kitchenware, sports equipment or furniture (Odeyingbo et al., 2017).

Wider access and use of the UNCTAD Automated System for Customs Data (ASYCUDA) could reduce the efforts needed to assess and evaluate import documentation in relation to digitalization-related waste. However, this would still need to be combined with inspections to identify incorrect declarations of imports of used electronic equipment. Cooperation between major stakeholders, including customs and port authorities, as well as enforcement agencies, is essential (Forti et al., 2018).

It is important to ensure that digitalization-related waste is not dumped into developing countries. In light of the experience of illegal trade and the limitations in implementing the Basel Convention, amendments to the Convention were adopted at the fifteenth session of the Conference of the Parties in 2022. All transboundary movements of e-waste, whether hazardous or not, will be subject to the procedure known as “prior informed consent”. Previously, this was only required for hazardous e-waste. These amendments will become effective on 1 January 2025. However, this has raised concerns within the e-waste management industry as it may negatively affect recycling. Procedures that are too strict may become overly cumbersome and discourage

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[53] See Favarin et al. (2023), Meidl (2023), Mihai et al. (2022) and Tong et al. (2022). Moreover, the European Court of Auditors (2021) highlights the challenge of illegal e-waste trade and the urgent need to address it.

[54] See https://www.occrp.org/en/daily/17220-spain-nabs-europe-africa-electronic-waste-smugglers.

exports for legitimate recycling purposes. Moreover, in an effort to address illegal imports of such waste, some countries, including Ghana, Kenya and Uganda, have reportedly imposed bans on such imports, including for second-hand items.[55]

Although there is a clear need to ban imports of digitalization-related waste that do not meet legitimate purposes, the case for a wholesale ban on imports of used functional digital equipment may not be as straightforward. If the equipment can be reused, is truly second-hand and can be repaired or refurbished, it can contribute to value addition, job creation and affordability, alleviating digital divides, therefore advancing developmental objectives. However, some countries may ban imports of second-hand equipment to stimulate the growth of domestic electronics manufacturing.

Thus, there is a need to balance out the requirement to refrain from dumping digitalization-related waste in developing countries with the ability to harness circularity and development opportunities from international trade in used EEE.

All of this shows that digitalization-related waste is a worldwide challenge that requires a globally coordinated approach. When factoring in trade flows, the circular economy can become global and contribute to a just transition that is environmentally sustainable. However, one additional factor to consider is transportation, which may have an influence on the environmental and economic efficiency of the circular economy.

Using the example of illegal trade between the European Union and Nigeria, Thapa et al. (2023) highlight that current EPR schemes do not focus on the entire global value chain of digitalization-related waste. When this waste is exported to another country, financial support for proper waste management is not transferred with it. Thus, the receiving country, normally with little waste management capacity, bears the environmental and social costs of the waste, without the corresponding financial compensation to help improve waste management efforts. Implementation of EPR on a global scale is fragmented and is not aligned with international waste flows. Thus, these authors note the need for “ultimate producer responsibility”, making producers responsible for managing waste globally.[56]

> There is a need to refrain from dumping digitalization-related waste in developing countries, while harnessing circularity and development opportunities from international trade in used electronic equipment

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[55] See https://www.graphic.com.gh/news/general-news/ghana-bans-importation-of-some-substandard-used-appliances-list.html, https://peopledaily.digital/news/state-bans-secondhand-electronics-importation-9643/; https://www.itnewsafrica.com/2010/04/uganda-effects-ban-on-used-electronics-imports-controversy-continues/, and Denmark, Ministry of Environment and Food, Environmental Protection Agency (2015).

[56] For a discussion of EPR in the global context, see ITU et al. (2022).

H. Circular digital economy opportunities for developing countries

The circular digital economy provides **opportunities for new players** and contributes to inclusive and sustainable development

Beyond the potential benefits for the environment in terms of sustainable consumption and production, the circular digital economy can also bring substantial economic benefits. With proper management of waste, including with regard to possible health risks, the process of extracting valuable materials by recycling and recovering digitalization-related waste can represent an opportunity for value addition and job creation along the waste value chain. The value of activities related to the circular economy in the digital equipment sector, such as repairing, refurbishing and the second-hand electronics market, is expected to continue its upward trajectory. There is a business case for many activities in the circular economy for digital equipment, with innovative business models that can extend the lifetime of electronic products, such as through reuse, or by offering electronics as a service (UNEP, 2021b).

Opportunities to create economic value in the circular economy of digital equipment arise in both developing and developed countries (Lee et al., 2023; Rizos et al., 2019). These go beyond the focus on end-of-life activities, such as recycling and material recovery. This is particularly the case in a circular digital economy, in which products and processes are designed for easy repair and disassembly from the outset, with the objective of minimizing digitalization-related waste.

According to the Circularity Gap Report 2024, the global economy is still only 7.2 per cent circular, with declining trend driven by rising material extraction and use (Circle Economy Foundation, 2024). This indicates significant potential for economic gains from related activities, as well as for reducing resource use and recovering resources. There may, however, be vested interests to keep the linear economy model, as it is led by large corporations focused on profits. The circular digital economy provides opportunities for new players and contributes to inclusive and sustainable development.

At present, the pattern of international trade in digitalization-related waste is one in which developing countries are mostly involved at the lower value-added parts of the digital equipment value chain. Nevertheless, global flows of second-hand electronics can provide economic opportunities in the importing developing countries, as long as it is not related to illegal trade.

Furthermore, the management of digitalization-related waste in developing countries is mostly handled in the informal sector. While informal activities are thriving in some developing countries, they tend to carry significant environmental, health-related and other social costs. Moreover, the methods used for recycling and recovering materials are typically less efficient, resulting in fewer opportunities for economic value. It is important to ensure that the potential value from circular economy activities can be properly captured without exposing people involved to health risks. The distribution of benefits of the global digitalization-related waste value chain should be equitable between and within countries, to enable a just and environmentally sustainable digital transformation (Ghisellini et al., 2022; Ogunseitan, 2023; Thapa et al., 2023).

The economies of developing countries tend to be more circular than those of developed countries.[57] This arises from necessity, as lower levels of income compel people to engage in circular economy activities; users tend to buy more affordable second-hand devices or try to keep the devices for longer by repairing them. For example, enterprises focusing on repair and refurbishment are widespread across Africa. In particular, Ghana and Nigeria have a well-organized repair and refurbishment sector, representing an important economic activity for many households (ILO, 2023b). Such businesses play a key role in bridging the digital divide between wealthy consumers and those whose access to electronic devices is limited due to prohibitive costs. Thus, used and repairable equipment can have significant economic and social benefits in developing countries (Maes and Preston-Whyte, 2022).[58] Reusing electronic equipment for social good can support the transformation towards a more sustainable and equitable society by providing it a new life among disconnected people (Good Things Foundation et al., 2023).

Businesses, particularly local MSMEs, including in the informal sector, can create value from digitalization-related waste and contribute to keeping products and materials in use through upcycling. Small enterprises focused on repairing, remanufacturing, updating and recycling benefit the environment by extending the life of products and recovering materials, thereby reducing the need for raw materials and diminishing harmful waste and pollutants. Collaboration between businesses and other stakeholders is key in moving towards the circular digital economy in a coordinated manner (UNEP, 2021b).

Such small businesses also provide benefits for the local population by providing income and job opportunities. However, challenges remain in terms of scalability. Among circular economy activities, repairing has a high level of labour intensity, holding significant potential for domestic job creation in developing countries (ILO, 2023b; Meysner and Urios, 2022). According to ILO et al. (2023), the transition to a circular economy (in all sectors) could generate 7 to 8 million new jobs. However, this study highlights a lack of research in developing countries. Moreover, the link between circularity and achieving social and economic progress remains significantly overlooked. Research also tends to focus disproportionately on job creation, while largely disregarding job quality, including working conditions and wages.

Working conditions and value creation in the informal digitalization-related waste management sector can be improved by integrating it with formal sector infrastructures. One way to do this would be to create cooperatives and associations. This can help informal workers to organize and reap greater benefits in terms of claiming enhanced value from the recovery of resources and other economic activities (Awasthi et al., 2023; United Nations, 2021b). By contrast, banning informal waste-related activities without having a formal structure in place can be counterproductive. It may leave a significant part of the poorest population without much-needed livelihoods. For example, when the Agbogbloshie, Ghana, e-waste dumping site was dismantled in 2021, it had significant negative impacts on poor and vulnerable communities, who were deprived of this income source.[59] It may be more advisable to build on existing collection networks already developed by the informal sector, to make concerted efforts to formalize them, and to continue to raise awareness of the negative environmental and health-related effects arising from improper e-waste disposal and handling.

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[57] For regional analyses of the circular economy in the electronics sector, see, for instance, UNEP (2021c) for Africa; SAICM and GEF (2023), and Clerc et al. (2021) for Latin America; and SAICM Secretariat (2022) for Central and Eastern Europe.

[58] For a discussion of opportunities from responsible e-waste value chains in Africa, see Avis (2022).

[59] See Akese et al. (2022) and https://electronicajusta.net/crisis-in-agbogbloshie-ghana-caused-by-forced-dismantlement-of-the-landfill/?lang=en.

A regional approach to managing digitalization-related waste can offer opportunities for **value addition**

Promoting skills development and sustainable enterprises, formalization, and the establishment of employer and worker organizations and social dialogue are all part of a just transition in e-waste management (ILO, 2022). While formalization should be the ultimate long-term objective, in countries where a large part of waste is handled informally, it may also be important to ensure effective ways of involving the informal sector as part of the overall strategy for sound e-waste management.

Moreover, persistent illegal exports of digitalization-related waste into developing countries transfer the responsibility for the management of such waste to them, while their capacities for doing it are limited. There is a need for developing countries to build capacities for the management of e-waste and proper oversight and to strengthen circular economy activities in the digital economy. This requires increased financial resources, stakeholder skills and infrastructure to collect and recycle digitalization-related waste in a way that mitigates health-related and environmental risks. Also needed are the institutional capacities to monitor and enforce legislation.

Given the limited resources available domestically in many countries, international support in this context is essential. There are already some ongoing capacity-building programmes. UNIDO offers an e-waste management programme in Latin America and a UNEP programme in Nigeria is focusing on circular economy approaches for the electronics sector.[60] At the individual donor level, the German Development Agency has provided capacity-building on environmentally and socially responsible handling of e-waste in different countries; it has, for example designed an e-waste training manual (GIZ, 2019).

A regional approach in this area can also offer development opportunities to create value. Developing countries in a region could pool resources to build processing facilities for the higher-value parts of waste. There is also room for cooperation at the regional level, by harmonizing e-waste management strategies and collecting e-waste data. For instance, the East Africa Communications Organization (EACO) has developed a regional e-waste management strategy (EACO, 2017). Moreover, in collaboration with the EACO secretariat, ITU and the UNITAR-SCYCLE programme have provided technical assistance to EACO member States through the EACO Regional E-Waste Data Harmonization project.[61]

At the international level, for example, the Basel Convention Partnership for Action on Challenges related to E-waste provides opportunities for sharing experiences in e-waste policies and regulations. It supports the development of innovative solutions and guidance on the environmentally sound management of certain e-waste streams, such as mobile phones, computing equipment, television screens, refrigerators and cooling and heating equipment. This partnership includes original equipment manufacturers, recyclers, academia, NGOs and municipalities along with government representatives and international organizations.[62]

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[60] See https://www.unido.org/news/cooperacin-regional-en-gestin-de-residuos-electrnicos-en-pases-de-amrica-latina, and https://buildingcircularity.org/recycle/circular-economy-approaches-for-the-electronics-sector-in-nigeria/.

[61] See https://www.itu.int/en/ITU-D/Environment/Pages/Spotlight/E-waste-EACO.aspx.

[62] See https://www.basel.int/Implementation/TechnicalAssistance/Partnerships/PACEII/Overview/tabid/9284/Default.aspx.

I. Conclusions

Rapid digitalization globally is leading to increasing demand for digital equipment and the minerals used to manufacture it. The world's primary supply of minerals and metals face a high level of pressure from the expected surge in demand resulting from the global transition to low-carbon and digital technologies (see chapter II).

This can be alleviated to a certain extent by increasing secondary supply through recycling digitalization-related waste, allowing for recovery of some materials through urban mining activities. Recycling alone is not enough to fill potential materials gaps or reduce the major environmental impacts that arise from producing and disposing of electronic equipment. Other circular digital economy activities discussed in this chapter can reduce the pressure on supply by contributing to moderating the growth in demand for new digital equipment.

Technological progress can also help with new processes that can lead to increased efficiency in the use of resources, as well as with emerging substitute materials that may be more environmentally friendly. It can similarly lead to better technologies for the proper management of digitalization-related waste.

The circular digital economy approach can contribute to environmental benefits through the sound management of digitalization-related waste, and by reducing the demand for natural resources, as well as through potential economic opportunities, including in developing countries.

Circular digital economy activities require a change in mindset in the modes of consumption and production to make them more responsible and sustainable. These activities can help to ensure progress towards attaining the Sustainable Development Goals. E-waste is mostly addressed under Sustainable Development Goal 12 and is included in indicators 12.4.2 and 12.5.1; the proper management of digitalization-related waste can also contribute to many of the other Goals.

Moving towards a more circular approach in the context of digitalization requires joint action and responsibility from all stakeholders. Manufacturers play a major role, notably in designing digital equipment for circularity, so that it lasts longer and can easily be repaired, disassembled and recycled. Consumers also need to reconsider their behaviour towards digitalization, to allow for a longer lifespan for products and make conscious decisions to consume more sustainable digital equipment. Consumers should reduce overconsumption in those parts of the world where this phenomenon exists, while in other regions, an increase in sustainable digitalization is required in order to harness it for development.

Actions for more sustainable consumption and production need to be supported by appropriate policies at the national, regional and international levels that provide the enabling factors and that are adequately enforced. Achieving an inclusive low-carbon and digital transition requires policies to be based on the principle of common and differentiated responsibilities, considering the respective capabilities and needs of different countries and actors. The necessary policies and the possible actions by consumers and producers are explored in chapter VI.

A major prerequisite is to strengthen the measurement of digitalization-related waste and its international flows. Without better data, it is not possible to properly inform the debate and ensure that related policymaking is based on accurate evidence. This should also include greater efforts towards clarifying and standardizing the definition of digitalization-related waste. This will help ensure better understanding of the dynamics of international trade in digitalization-related waste and used equipment.

Moving towards the circular digital economy also needs to be supported by digital tools.[63] For instance, digital product passports could be key in tracking materials and products enabling more informed consumption decisions, as well as policies.

Circular digital economy activities require **a change in mindset in consumption and production** to make them more responsible and sustainable…

...and **joint action and responsibility** from all stakeholders

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[63] See, for instance, ITU (2021b).

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Making e-commerce more environmentally sustainable requires collaborative efforts, focussing on sourcing, logistics, packaging as well as consumption behaviour

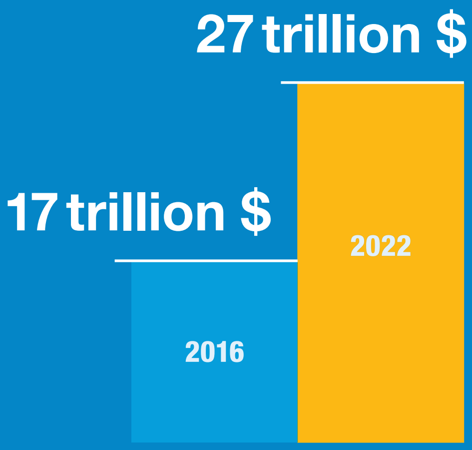
Chapter V

E-commerce and environmental sustainability

While the preceding chapters focused on the three phases of the life cycle of digitalization, this chapter discusses a specific application of digital technologies, namely e-commerce.

Attention is turned to the indirect implications of digitalization on the environment, which can be both positive and negative. As stressed in chapter I, assessing these indirect effects is even more challenging than measuring the direct environmental footprint of digitalization.

This chapter has a particular focus on business-to-consumer (B2C) e-commerce, and explores how it can be as sustainable as possible.



E-commerce sales

by businesses in 43 developed and developing economies surged between 2016–2022

Based on info in figure V.2

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A. Introduction

Digitalization has had a major impact on domestic and international commerce. Boosted by the COVID-19 pandemic, more people and businesses are going online to look for the goods and services they wish to purchase (UNCTAD, 2021e, 2022c).

“E-commerce” refers to all transactions in which goods or services are ordered over a computer network (e.g. over the Internet) (UNCTAD, 2021f). Any economic entity, whether a business, household, government unit or non-profit institution, can engage in e-commerce as a buyer or seller. E-commerce transactions often cross international borders, with the seller being in a different economic territory from the buyer. Business-to-business (B2B) e-commerce plays an important role in global value chains and often involves electronic data interchange and online versions of traditional transactions for goods, which are then sold to consumers through retail outlets. B2C e-commerce involves sales by “pure play” e-commerce enterprises that only sell through their single online presence (such as Alibaba or eBay) to consumers, as well as sales by traditional bricks-and-mortar firms that operate through an additional online sales channel. Consumer-to-consumer (C2C) e-commerce refers to buying and selling transactions between individual consumers and households (UNCTAD, 2015, 2023g).

The shift to e-commerce brings both opportunities and challenges. It can transform economic processes, trade and consumption patterns and open up new trade and business opportunities for entrepreneurs and small businesses that would otherwise have a limited geographic footprint. E-commerce can improve export opportunities and offer better access to suppliers abroad. Consumers also stand to benefit from access to greater choice, convenience and lower prices. At the same time, various factors – including obstacles relating to ICT infrastructure and services, trade logistics, payment solutions and legal frameworks – pose critical challenges to engaging in and benefiting from e-commerce, especially in low-income countries (UNCTAD, 2021e, 2021g). For countries with low levels of readiness, the growth of international e-commerce may expose local firms to increased import competition and thereby impact on employment and growth prospects.

E-commerce has potential implications for environmental sustainability that are both positive and negative. For example, under certain conditions, buying a product online can be more energy efficient than driving to a physical store to purchase the same product and can lead to reduced GHG emissions. Today, some physical products can be obtained in digital formats, such as films and music that can now be streamed, thereby enabling dematerialization. On the other hand, online marketing and enhanced convenience for consumers, together with lower prices, can boost consumption, which may lead to more production and different methods of land use, as well as increased transportation and waste – both domestically and across borders. High return rates of online purchases can lead to returned goods being thrown away; this also represents an inefficient use of energy and materials and adds to waste generation. Environmental impacts differ for e-commerce relating to goods and services. In both cases, however, e-commerce increases the demand for and use of various digital devices, transmission and data centre services,[1] contributing to the direct environmental effects discussed in previous chapters.

> E-commerce has potential implications for environmental sustainability that are both positive and negative

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[1] For example, according to China Communications Services (2023), a State-owned enterprise, e-commerce accounts for a considerable portion of the energy consumption and carbon footprint of data centres in China.

The primary emphasis of this chapter is on the indirect effect of digitalization through the environmental impact of e-commerce related to goods, specifically for those that are physically delivered to buyers. This environmental impact is linked to increased CO_2 emissions and energy usage across the logistics supply chain – from retailer warehouses and distribution centres, to transport, product packaging, returns and consumer behaviour.

While this chapter extensively delves into the environmental implications of B2C e-commerce (which have also been more widely studied), occasional references are made to B2B and C2C transactions. Section B presents recent trends in e-commerce. Section C provides a comparative review of the environmental impact of B2C e-commerce with that of traditional bricks-and-mortar retail. Section D turns to measures that have been taken, and could be further leveraged, to reduce negative environmental impacts and build more sustainable and inclusive e-commerce. Section E discusses the potential for e-commerce business models to help enable circular and sharing economies. The final section provides specific recommendations to relevant stakeholders on how to make B2C e-commerce more environmentally sustainable.

B. E-commerce trends, opportunities and risks

The proliferation of the Internet has rapidly and fundamentally transformed business and trade practices. In 1991, the Internet had less than 3 million users around the world and e-commerce was non-existent. By 1999, an estimated 250 million users were accessing the Internet and about one quarter of them made purchases online from e-commerce sites, worth an estimated $110 billion (OECD, 2000). Just over two decades later, the number of people shopping online has surged.

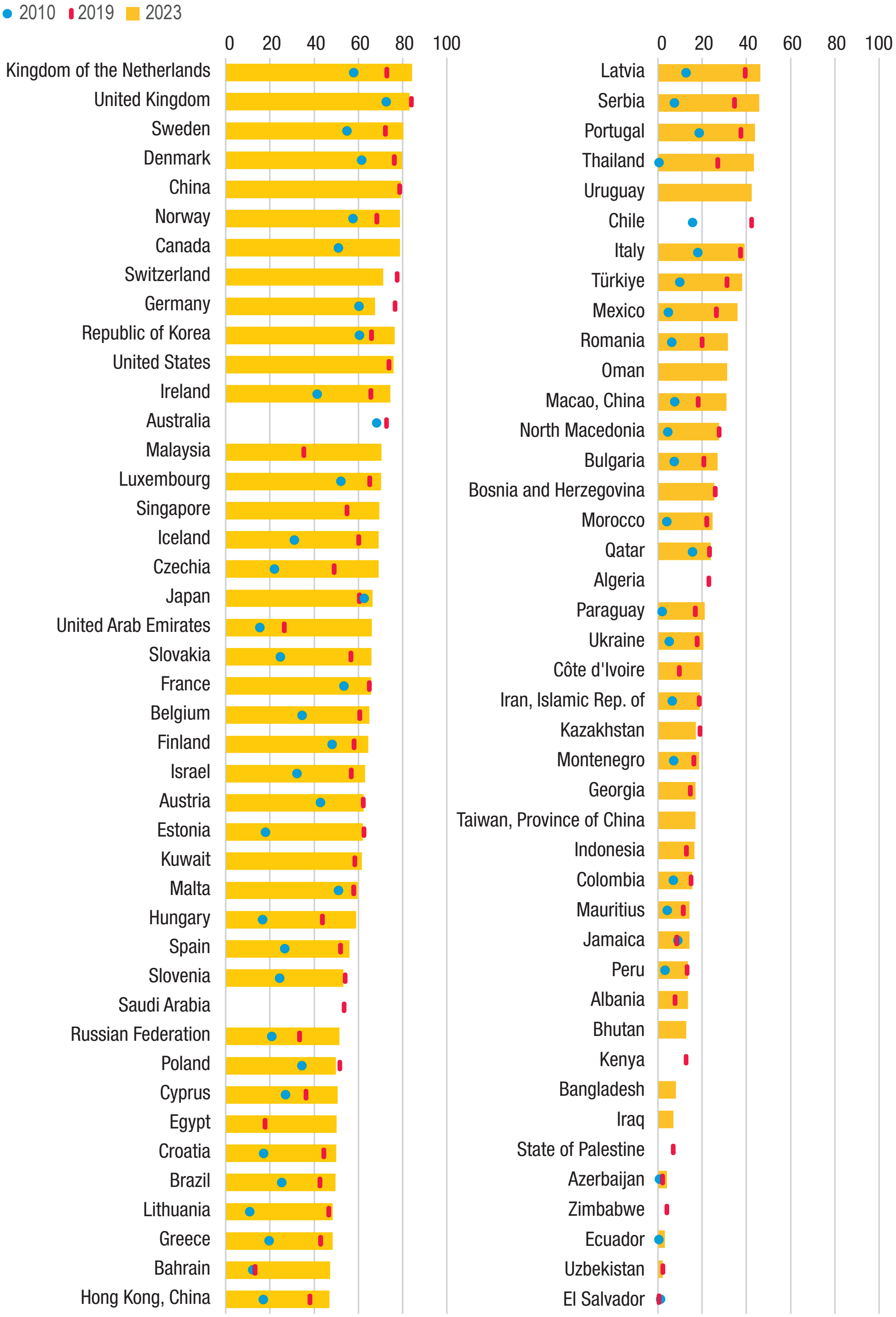
According to the Global Findex Database (World Bank, 2021), an estimated 2.3 billion people shopped online in 2021. Since 2010, e-commerce has greatly increased in many countries, further boosted by the COVID-19 pandemic (figure V.1). At the same time, the extent to which people engage in e-commerce still varies considerably. In countries reporting the highest uptake, more than 80 per cent of the population shop online; in most LDCs, that share remains below 10 per cent.

UNCTAD estimates that the value of e-commerce sales by businesses in 43 developed and developing economies, representing three quarters of global GDP, was close to $27 trillion in 2022, up from around $17 trillion in 2016 (figure V.2). For example, in China, sales almost tripled from $1.6 trillion in 2016 to $4.5 trillion in 2022 and in the United States, e-commerce sales by businesses increased from $7 trillion in 2016 to an estimated $11 trillion in 2022.

E-commerce sales by businesses in developed economies far exceed those in developing economies. Furthermore, while the latter account for around 40 per cent of global GDP, their share of business e-commerce sales is at most 25 per cent, suggesting significant growth potential. It is further estimated that in 2022, cross-border e-commerce (digitally-ordered exports) was worth around $3 trillion, though based on very limited data. This value corresponds to businesses in economies that collectively account for approximately three quarters of global GDP and exports (figure V.3).

Consumers can engage in e-commerce through a range of online channels. Sellers may use their own dedicated

Figure V.1
Share of Internet users making online purchases, selected economies and years
(Percentage)

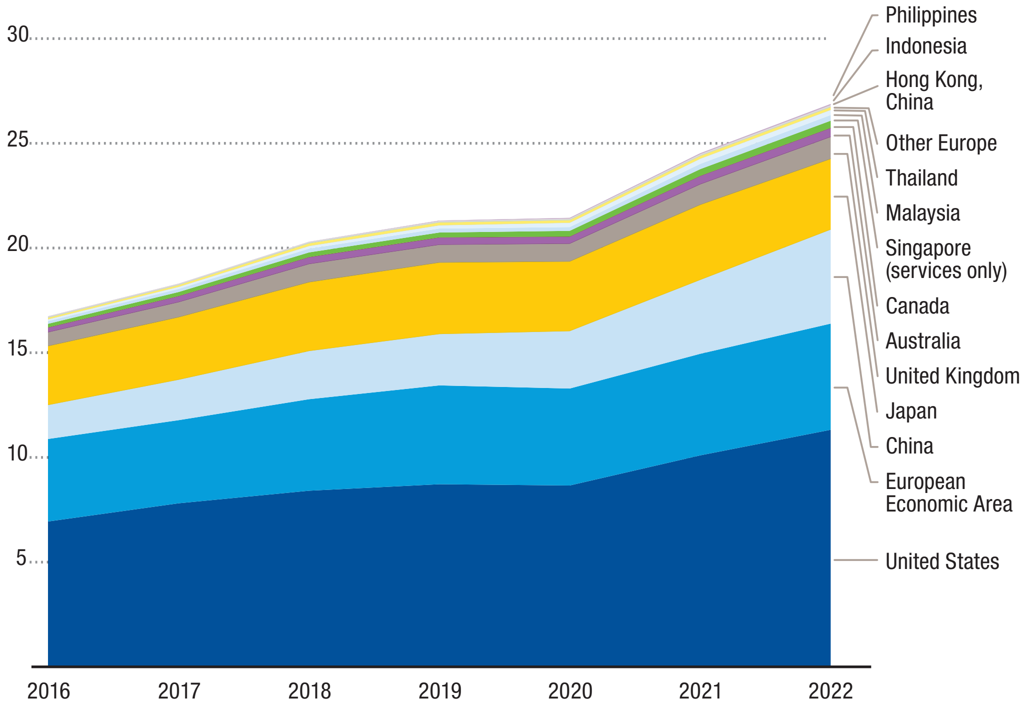


Source: UNCTAD (2024).

Notes: The statistics reflect online shopping reported by individuals during the three months prior to the survey, although recall periods of up to 12 months apply for some economies.

Figure V.2
E-commerce sales by businesses, selected economies and country groupings, 2016–2022

(Trillions of dollars in current prices)

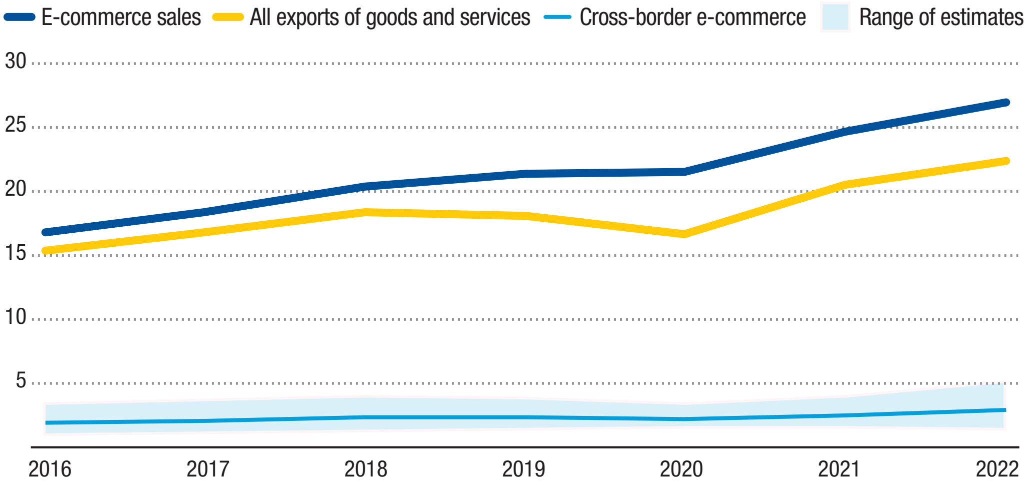


Source: UNCTAD (2024), based on national sources.

Notes: 2022 data are estimates. Economies included account for three quarters of global GDP. See source for more information on economies included and methodology. "European Economic Area" consists of the 27 European Union countries plus Iceland, Liechtenstein and Norway. "Other Europe" includes Bosnia and Herzegovina and Serbia.

Figure V.3
E-commerce sales, exports and cross-border e-commerce sales, selected economies, 2016–2022

(Trillions of dollars in current prices)



Source: UNCTAD (2024), based on national sources.

Notes: 2022 data are estimates. See source for more information on economies included and methodology.

e-commerce websites and third-party online marketplaces (such as Alibaba, Amazon, eBay and Jumia), as well as various social media platforms. Rather than relying on going to a traditional bricks-and-mortar store or placing an order online from home, many retail companies offer combinations of the two, for instance, ordering online and using a drive-in option for food supplies. In some countries, this type of "omnichannel" commerce has become increasingly important to meet consumer demand.[2]

Online platforms have emerged as key players in the e-commerce landscape (UNCTAD, 2019a). They act as market makers, facilitating transactions between multiple buyers and sellers who communicate through the platform. In some cases, the platform owner (e.g. Amazon) also sells its own branded products (e.g. Amazon Basics) on the same marketplace. Some platforms provide ancillary products such as payment, logistics and financial services (e.g. loans).

During the pandemic, the value of transactions through the largest online platforms sharply increased, from around $2.6 trillion in 2019 to $4 trillion in 2021 (figure V.4). Growth continued in 2022 but at a slower pace. The landscape is dominated by a small number of well-known platforms that facilitate vast amounts of transactions; just six platforms facilitate about 80 per cent of the gross merchandise value, as shown in figure V.4. While this market concentration raises questions about potential abuse of market power and other competition issues, it is crucial that these companies act as leaders when it comes to taking action to make e-commerce environmentally sustainable.

There is significant room for improving the capabilities of many developing countries to deal with opportunities and challenges related to e-commerce. Many Governments, including with support from UNCTAD and members of the "eTrade for all" initiative, are fostering enabling environments to better harness e-commerce for development and to assist businesses of all sizes to tap into national and international markets and supply chains, reduce trade costs, drive efficiency through competition and contribute to economic growth and social well-being (UNCTAD, 2018, 2022d).

E-commerce can also offer women opportunities for flexible entrepreneurship and the possibility to earn additional income (International Finance Corporation, 2021a).[3] Online platforms provide new ways of overcoming traditional gendered barriers to trade, such as lack of access to trade finance, trade costs associated with physical distance and entry into male-dominated sectors and distribution networks. Closing gender gaps in sales performance on e-commerce platforms between 2025 and 2030 could yield an additional $280 billion in platform revenues in South-East Asia, while in Africa, additional gains of $14.6 billion have been foreseen (International Finance Corporation, 2021a, 2021b).

Nevertheless, opportunities for development gains from e-commerce must be viewed against a backdrop of highly uneven levels of digital readiness (see chapter I). Future trajectories and the ability of developing countries and LDCs to unlock the potential of e-commerce for all depends on policy actions that address the root causes of the digital divide (box V.1). These policy actions can strengthen the capabilities of domestic enterprises to cope with digital disruption and competition from abroad.

In addition, there is a knock-on effect of these opportunities, namely the implication for the environment. The impact varies depending on the type of e-commerce. B2B

It is crucial that the **dominant platforms** take the lead in making **e-commerce environmentally sustainable**

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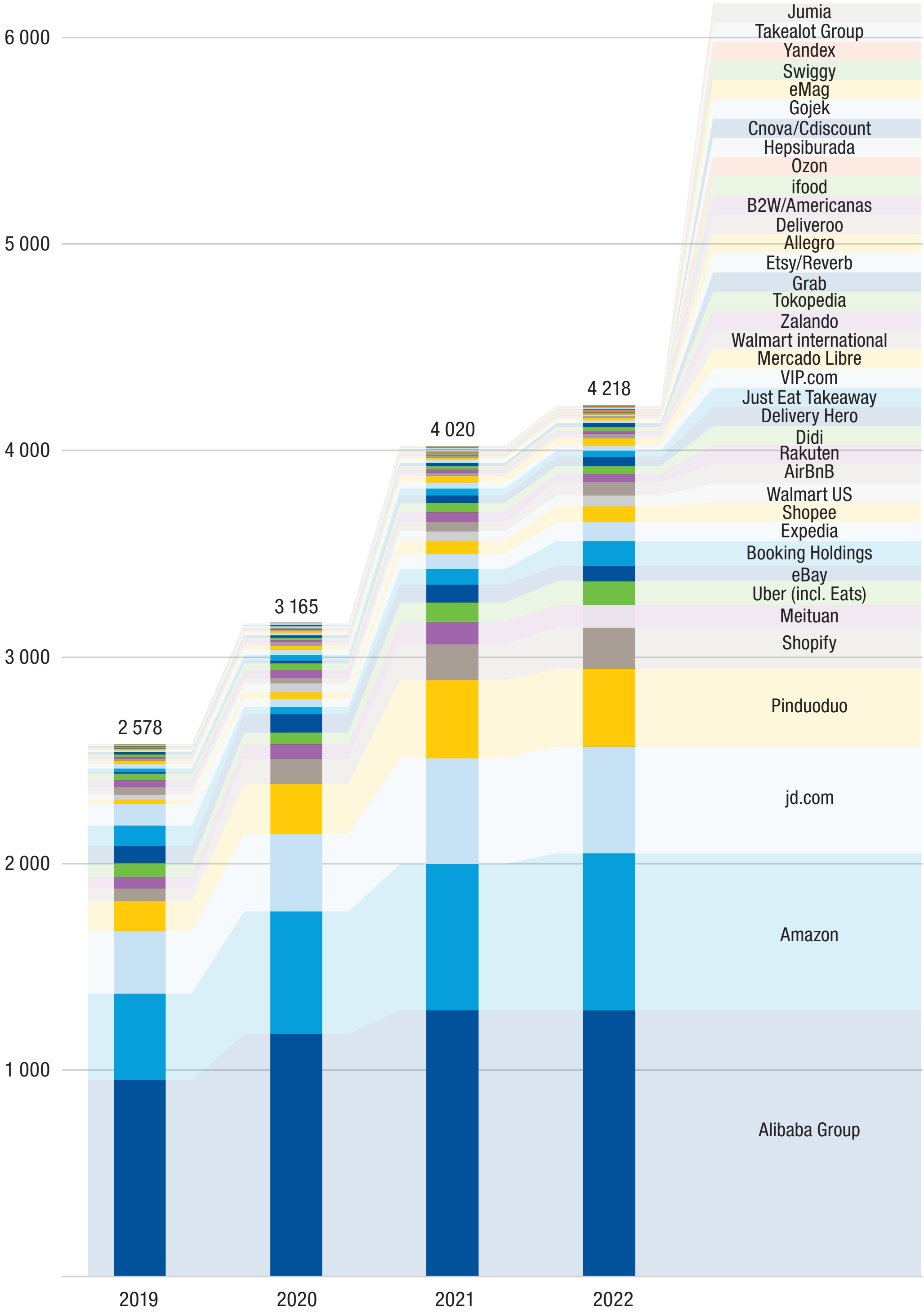
[2] See, for example, https://www.economist.com/special-report/2021/03/11/the-importance-of-omnichannel-strategies.

[3] On Jumia's e-commerce platforms in Africa, over one third of businesses in Côte d'Ivoire and over half in Kenya and Nigeria are owned by women, while in South-East Asia, women own about one third of businesses in Indonesia and two thirds of business in the Philippines on the Lazada platform (International Finance Corporation, 2021b).

Figure V.4
Gross merchandise value reported by selected companies operating online platforms, 2019–2022

(Billions of dollars)



Source: UNCTAD (2024), based on company reports.

Notes: For Alibaba, B2B/Americanas, Meituan and Pinduoduo figures for 2022 are not available. Their 2021 figures are used to calculate the total; the actual total for 2022 could be higher or lower. Gross merchandise value gives the total sales value for goods and services sold through a given platform. Companies vary in what they include or exclude from the value they report.

Box V.1
Progress in e-commerce in least developed countries and possible policy actions

Between 2017 and 2021, e-commerce use in LDCs rose by 140 per cent. However, this still represents only 5.8 per cent of individuals making online purchases, compared to 62 per cent in developed countries.[a] Consequently, there is important scope for e-commerce to expand. Since 2017, UNCTAD has undertaken eTrade readiness assessments in 36 countries, including in 25 LDCs, identifying critical gaps that limit countries from harnessing e-commerce for economic development. Importantly, the majority of LDCs lack comprehensive e-commerce policies and ways to integrate e-commerce into national development plans.[b]

Furthermore, e-commerce readiness in LDCs is hampered due to inadequate ICT infrastructure, as only about one third of the population is online. Digital divides persist, both between urban and rural areas and across genders. Moreover, the quality of Internet services lags, with low bandwidth and high costs (monthly costs in LDCs range from 1 to 24 per cent of GNI per capita),[c] which also hinders e-commerce adoption.

Limited progress in logistics, such as underdeveloped addressing systems and scarce delivery facilities, leads to costly e-commerce operations. What is more, cross-border e-commerce in LDCs is marginal due to high costs and logistical challenges. Furthermore, trade facilitation reforms are progressing slowly, causing LDCs to fall behind developed countries in implementing digital and sustainable trade practices,[d] hampering their participation in global trade.

Legal and regulatory frameworks in LDCs for e-commerce need further development, affecting trust in digital transactions. According to the UNCTAD Cyberlaw Tracker 2022, there was some progress in this regard, yet only 70 per cent of LDCs had cybercrime laws, 63 per cent had electronic transactions laws, less than half had privacy and data protection laws, and even fewer had consumer protection laws.[e]

The share of people in developing countries using digital payments grew from 44 per cent to 57 per cent from 2017 to 2021.[f] This is due to more digital payments by public administrations and the widespread use of mobile money and e-wallets. However, a gender payment access gap persists. More efforts are needed to improve and maximize the impact of cross-border payment solutions.

Moreover, digital skills development is hindered by limited access to computers and a focus on mobile and social media use. Only 8 per cent of households own a computer, and while there are moves to embed ICT education from primary levels and support digital entrepreneurship, especially for women, these areas require further enhancement.

More than 40 per cent of MSMEs in developing countries, particularly in the digital sector, face a significant funding shortage, with a collective shortfall of $5 trillion. Traditional banking has not adjusted to the e-commerce business model, making it difficult for start-ups that lack conventional collateral to secure funding. This challenge is even greater for women-owned businesses.[g]

Overall, the pandemic-driven surge in digital activities did not translate into LDCs leveraging the full potential of e-commerce to contribute to the Sustainable Development Goals. Enhanced support is crucial for LDCs to strengthen their enabling environment and to bolster their e-commerce readiness.

Policy actions required

- Develop and implement comprehensive e-commerce strategies.
- Invest in affordable and widespread ICT and logistics infrastructure and improve trade facilitation.
- Establish clear legal and regulatory frameworks for e-commerce, including cybercrime, electronic transactions, consumer rights and digital payments.
- Promote digital skills through education reform and support for digital literacy.
- Create financial products suited to the needs of e-commerce enterprises, with an emphasis on inclusion for women entrepreneurs.

Source: UNCTAD.

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[a] Based on share of individuals who purchased something online (World Bank, 2021).
[b] UNCTAD (2023a).
[c] ITU (2023).
[d] United Nations (2023).
[e] See https://unctad.org/news/least-developed-countries-still-lag-behind-cyberlaw-reforms.
[f] World Bank (2021).
[g] International Finance Corporation (2017).

The future of e-commerce in developing countries hinges on policies that tackle the root causes of the digital divide

e-transactions typically involve larger orders, which can result in more efficient last-mile delivery and less packaging per item, as goods are packed and transported in bulk. In contrast, B2C and C2C e-commerce often require multiple, smaller deliveries and more packaging and yield higher returns per order. E-commerce may provide opportunities to support a circular and sharing economy by enabling the reuse, reselling and lending of products and services to individuals. The environmental impact is also product specific. For instance, items requiring refrigeration, commonly sold online, have a substantial carbon footprint due to the need for specialized packaging and its disposal.

Impacts also depend on whether e-commerce is domestic or international, and whether it consists of goods that are delivered over traditional transit routes through ports, airports and land border crossings (UNCTAD, 2021g). The impact is potentially higher for international e-commerce, especially where air transport is used, as emissions per flight and item are many times higher than those of domestic e-commerce last-mile delivery (European Commission, 2022a).

Each component of the e-commerce logistics supply chain carries potential environmental risks that can have adverse impacts on biodiversity, food and water security and local livelihoods. Research, data and information that consider such environmental and social impacts are mainly available in developed countries. Yet, in view of the significant growth of e-commerce, a better understanding of its environmental footprint is of growing relevance for countries at all levels of development.

C. Environmental effects of online and offline retail: A comparative analysis

Various factors related to warehousing, transportation, packaging and consumer behaviour affect the environmental footprint of e-commerce

How has the shift from traditional retail sales to e-commerce impacted the environment? To respond to this question, the following section reviews the findings of academic studies that have empirically assessed the environmental sustainability of online and offline retail options, with a special focus on GHG emissions, packaging waste, energy use and consumption patterns based on data mostly from developed countries. Only a few studies have been undertaken in developing countries to date. The section identifies key variables and influencing factors with potentially positive and negative implications for the environment. However, some findings may not necessarily apply to countries with less advanced digital environments. The results are of general relevance for enhancing understanding of how the shift to online retail may affect the environment.

1. Factors impacting the environmental sustainability

Different parameters and influencing factors related to warehousing, transportation, packaging and consumer behaviour all affect the environmental footprint of both retail channels (Buldeo Rai, 2021; Pålsson et al., 2017; van Loon et al., 2015; Weideli, 2013). Studies reviewed in this chapter cover different timespans, countries and sectors, while no standardized approach is applied. Some assessments rely on econometric models and simulations that use a range of parameters and variables, while others are based on case studies. The most commonly used indicator of environmental impact is related to the carbon footprint. Other environmental impact indicators include energy efficiency per unit fulfilled, calculated on the basis of energy consumption per unit, as well as water use, land use and road traffic arising from e-commerce (Collini et al., 2023). Unsurprisingly, findings of different studies are often not consistent. In short, the jury is still out when it comes to determining what is more desirable – online or offline retail – from an environmental perspective.

As the two sales channels (online and offline) do not differ in their environmental footprint of production, use, repair and disposal of the goods sold, most studies tend to exclude these factors (Collini et al., 2023; van Loon et al., 2015).[4] This comparative analysis is structured along the key stages of the fulfilment process, initiated by the sale of a product which triggers the movement of the good from the retailer warehouse to the final consumer. The focus is on stock replenishment, order picking and assembly, delivery and post-sale activities as well as on specific components that influence the environmental impact of online and offline fulfilment processes (Mangiaracina et al., 2016; Siragusa and Tumino, 2022). Both the size and the nature of environmental impacts vary by phase and are influenced by other factors, such as consumer behaviour. Figure V.5 presents the different stages and components that influence the environmental footprint of online and offline fulfilment processes.

a. Warehousing and distribution centres

Online and in-store retail both rely on warehouses and distribution centres for stock replenishment. These centres are essential for ensuring that products are available for purchase and can be delivered to customers in a timely and cost-effective manner. For online retail, stock replenishment consists of transferring goods from a central warehouse (upstream) to a dedicated warehouse to fulfil online orders (downstream). In the case of bricks-and-mortar retail, stock replenishment orders are managed in a central warehouse and subsequently transported to various retail outlets (Siragusa and Tumino, 2022).

The order picking, assembly and packing phase is specific to online purchases and takes place in a dedicated warehouse (Mangiaracina et al., 2016; Siragusa and Tumino, 2022). In the case of traditional retail, it is performed by the customer at the store. Important aspects of the environmental footprint in this phase include packaging, land use, energy consumption and CO_2 emissions. While "pure-play" e-commerce companies just require a warehouse to store their products, e-commerce omnichannel operations can require three times the warehouse space compared to traditional retail (Prologis, 2016). Bricks-and-mortar stores also need physical space for consumers to browse and make purchases and, in many cases, park their vehicles (Collini et al., 2023). Greater physical space implies increased energy use for lighting, heating and cooling systems. It could also entail occupying more land, which might otherwise have been kept as green space.

A study of eight European countries found that e-commerce warehouses occupy less than 0.3 per cent of artificialized land (natural land that has been converted into artificial land surfaces, ranging from urban green spaces to industrial zones) and that, when factoring in logistics, selling and parking space, overall land use was considerably higher for physical retail. At the same time, e-commerce warehousing experiences higher CO_2

> The jury is still out if online or offline retail is more desirable from an environmental perspective

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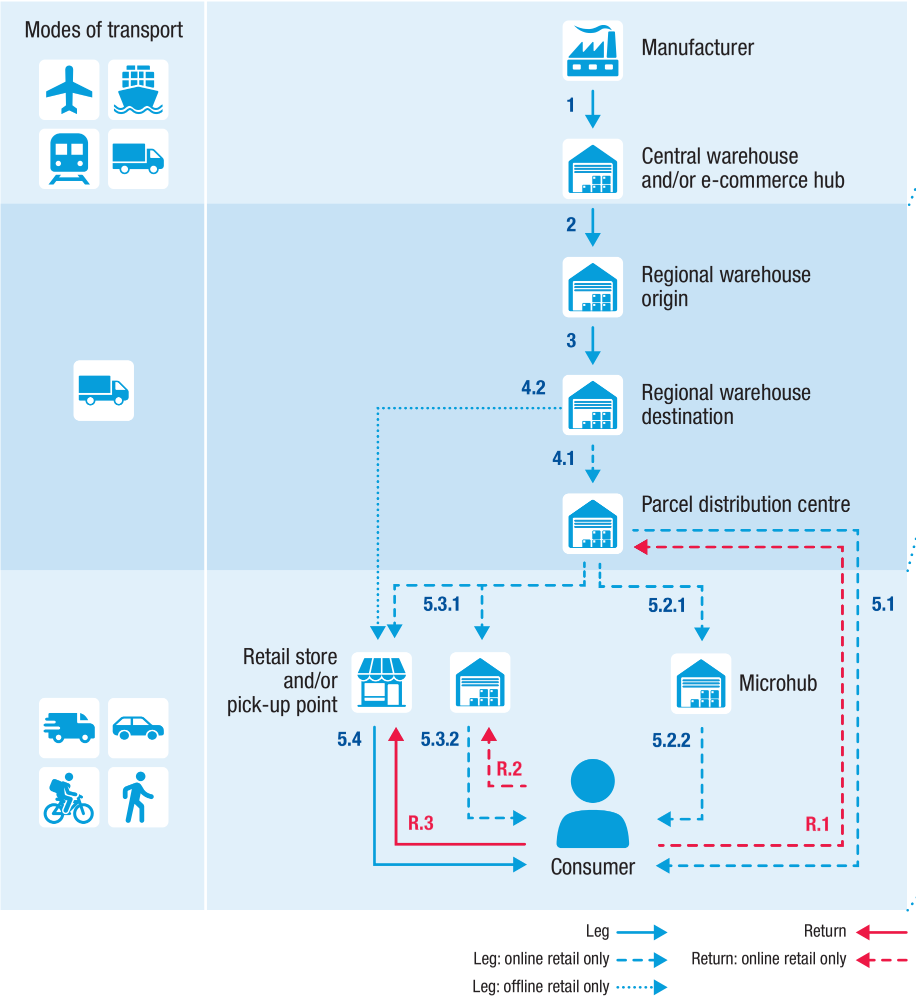
[4] This is justified by the fact that products sold are the same between retail channels and therefore should not be included as a basis for comparison. There is limited information on how much of the energy consumption in the production and use of products that may be attributable to e-commerce. Moreover, it is difficult to arrive at an accurate assessment of CO_2 emissions specifically associated with search engines used for online shopping (van Loon et al., 2015).

Figure V.5
Offline and online retail: An illustrative journey



Leg	From		To
Pre-carriage	**1**	Manufacturer	Central warehouse and/or e-commerce hub
Main-carriage	**2**	Central warehouse and/ or e-commerce hub	Regional warehouse origin
	3	Regional warehouse origin	Regional warehouse destination
	4.1	Regional warehouse destination	Parcel distribution centre
	4.2	Regional warehouse destination	Retail store and/or pick-up point
Post-carriage	**5.1**	Parcel distribution centre	Home delivery, consumer (last-mile)
	5.2.1	Parcel distribution centre	Microhub (splitting last-mile)
	5.2.2	Microhub	Home delivery, consumer (last-mile)
	5.3.1	Parcel distribution centre	Pick-up point/click and collect in retail store (splitting last-mile)
	5.3.2	Pick-up point	Consumer
	5.4	Retail store	Consumer
	R.1	Consumer	Parcel distribution centre
	R.2	Consumer	Pick-up point
	R.3	Consumer	Retail store/click and collect

Source: UNCTAD, based on European Commission (2022a).

Note: Bypassing certain legs is always possible.

emissions due to the expansion of logistics centres away from cities and associated fragmentation of last-mile deliveries (Oliver Wyman, 2021).[5] Moreover, order picking and assembly activities for e-commerce warehousing have been found to generate higher CO_2 emissions than traditional retail, as a result of the handling and packing of individual items (Mangiaracina et al., 2016). On the other hand, shared warehouses that stock products for 100 online shops resulted in considerably less energy use than relying on 100 individual storage facilities (Holubar, 2022).

b. Product packaging and waste generation

Packaging is part of the order picking and assembly phase, where items are sorted and placed directly in packaging used for deliveries to limit damages during transport, returns and re-deliveries. It is a particularly important parameter in the context of e-commerce (Siragusa and Tumino, 2022; Buldeo Rai, 2021). E-commerce packaging can be distinguished from traditional retail packaging. For example, books bought online tend to be packed in small, corrugated cardboard boxes for courier shipping, whereas those sold in conventional bookstores tend to use a light paper or plastic bag. An analysis of the quantitative impact of e-commerce on packaging waste in the Republic of Korea found that e-commerce generated 4.8 times more packaging waste than goods sold in bricks-and-mortar stores, with implications for GHG emissions (Kim et al., 2022). In particular, e-commerce significantly contributes to environmental waste and carbon pollutants through the use of cardboard boxes, with the issue being exacerbated when increased packaging and low-grade, hard-to-recycle materials such as printed return forms and sticky labels are used for online returns (Escursell et al., 2020; Zhang et al., 2023).

While packaging is necessary to protect products during transportation, overpackaging in e-commerce can increase energy consumption and carbon emissions (Xie et al., 2021). In the case of book deliveries, again, packaging has been found to consume, on average, five times more energy per book in home delivery systems than in the store supply chains (Pålsson et al., 2017). Similar findings were reached in an older study in Japan (Williams and Tagami, 2003). Additional packaging for e-commerce led to considerably more energy use per book sold in densely populated urban areas. In suburban and rural areas, energy consumption of the two systems was nearly equal, as the relatively high efficiency of courier services compared to personal automobile transport balanced out the negative impact of additional packaging. Regardless of the delivery method, reducing unnecessary layers of packaging, changing box dimensions or removing boxes altogether can reduce carbon emissions by up to 36 per cent (MIT Real Estate Innovation Lab, 2020). This echoes findings for fast-moving goods in the United Kingdom, suggesting that packaging made from corrugated cardboard plus some filling material resulted in 16 times more CO_2e per item compared to the use of shopping bags in van-based home deliveries and consumer shopping trips (van Loon et al., 2015).

Due to data and measurement constraints, the global impact of e-commerce-related packaging on plastic litter found on land and the ocean floor cannot be ascertained. However, it is likely to be significant. For example, in 2020, Indonesia reported over 67 million tons of waste, with plastic waste accounting for approximately 6.8 million tons, and e-commerce sales identified as a major contributor (Florene, 2021). The proliferation of plastic pollution transcends national boundaries and disproportionately impacts the health and rights of vulnerable communities (UNEP, 2023a). Box V.2

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[5] Further development concerns relate to community land rights, worker safety, health hazards as well as precarious working conditions (Palmer, 2023; The Guardian, 2023b).

Box V.2
Plastic pollution impacts on human rights and development

Plastic pollution threatens marine resources and the livelihoods of approximately three billion people living in coastal developing countries who rely on the ocean for food and income. More than an estimated 17 million tons of plastic entered the world's oceans in 2021, making up the bulk (85 per cent) of marine litter. Single-use plastic bags pose a particular threat as they account for an estimated 89 per cent of plastic litter found on the ocean floor.[a] Plastic pollution has a negative toll on the ability of countries to create jobs and revenue in sectors that depend on clean ecosystems, such as tourism and fisheries.

When plastics are burned, people are exposed to toxic fumes and particles. As a result, drinking water and the entire food chain can be contaminated. Similarly, when plastics end up in landfills, they leak toxic chemicals into groundwater and the surrounding environment. These negative impacts undermine the right to a clean, healthy and sustainable environment, and several other fundamental human rights. Persons and groups in vulnerable conditions are disproportionately exposed to the impacts of the plastics cycle, depending on factors such as age, gender, ethnicity, education, profession and poverty. In many developing countries, "waste pickers", mainly women and children, bear the brunt of plastic-related toxicity risk due to higher exposure to Bisphenol A (BPA) and phthalates, which affect reproductive capacity, among other health disorders.

Sources: UNCTAD, based on OHCHR (2019); UNCTAD (2023b); UNESCAP and the ASEAN Secretariat (2022); The SeaCleaners (2022).

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[a] See https://www.un.org/sustainabledevelopment/wp-content/uploads/2019/07/14_Why-It-Matters-2020.pdf.

sets out a range of implications, both direct and indirect, of plastic pollution for human rights and development.

In terms of packaging and waste generation, studies suggest that e-commerce performance is worse than traditional retail sales

In summary, in terms of packaging and waste generation, available studies suggest that e-commerce performance is worse than traditional retail sales. This applies both to the amount and the kind of packaging used. Excess packaging related to e-commerce deliveries generates more waste than goods sold in bricks-and-mortar stores, with consequent implications for GHG emissions and energy consumption. Cardboard boxes used in e-commerce account for some of the largest carbon pollutants.

c. Transportation and delivery

Several studies have assessed the impact of the transportation of goods associated with online and conventional retail shopping in terms of energy consumption and CO_2 emissions.[6] In the case of e-commerce, the delivery process begins when items are picked up by the courier at the warehouse and ends with delivery at the consumer's home. For traditional retail, the delivery phase consists of the consumer's return trip from the store after the purchase (Mangiaracina et al., 2016). The environmental footprint of e-commerce is significantly influenced by the method used for last-mile delivery and how customers choose to travel to and from physical stores if they are collecting the goods (Edwards and McKinnon, 2009).

Last-mile delivery is the final link in the supply chain from retailer/supplier to the consumer and considered to be the most energy- and carbon-intensive segment (Buldeo Rai, 2021; Edwards and McKinnon, 2009). It may involve delivery fleets of fossil fuel-powered trucks and vans that generate relatively high CO_2 emissions (Perboli and

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[6] See, for example, Cullinane (2009); Edwards et al. (2010); Wygonik and Goodchild (2012); Mangiaracina et al. (2015); Pålsson et al. (2017); Shahmohammadi et al. (2020)

Rosano, 2019). The use of alternative vehicles can significantly reduce emissions. In China, the use of electric bicycles instead of vans to deliver books was found to save up to 13 per cent of energy and cut 71 per cent of CO_2 emissions (Zhang and Zhang, 2013). Similarly, electrically assisted cargo bikes and tricycles, which make it possible to cover long distances and carry substantial loads while navigating hills, were identified as the most effective logistics vehicles for urban last-mile delivery in Brazil, China and Germany (de Mello Bandeira et al., 2019; Siegfried and Zhang, 2021).

Emissions increase with distance. The greater the distance travelled by the customer to the store, the higher the emissions, because of fuel consumed during transport (Siragusa and Tumino, 2022). It is generally more environmentally sustainable for consumers to shop online and have their goods delivered to home than to travel to the shops and back by car (Buldeo Rai, 2021; Edwards and McKinnon, 2009). For instance, in one study, CO_2 emissions from personal car-based travel were 24 times greater than those produced by a single “drop” within the average home delivery round (Edwards et al., 2010). Similar findings were made for online grocery shopping in the Helsinki metropolitan area in Finland (Siikavirta et al., 2002).[7] However, when a traditional retail consumer travels by bus instead of car and makes several purchases, emissions per item are lower compared to a home delivery van delivering just one item to an online consumer’s home (Edwards et al., 2010).

A study comparing CO_2 emissions from the use of personal vehicles to shared-use vehicles for grocery shopping in Seattle, Washington (United States), concluded that emissions were most reduced when the delivery service served a cluster of customers in close proximity to each other (Wygonik and Goodchild, 2012). In this case, a delivery service reduced CO_2 emissions by 80–90 per cent, compared with 17–75 per cent when customers were randomly assigned to a driver’s route. Similarly, while delivery vehicles tend to have higher rates of GHG emissions per mile than private vehicles, they were able to transport more items and use route optimization to travel directly from one destination to another, as opposed to private trips that required unique round trips (Wygonik and Goodchild, 2018; Zimmermann et al., 2020; Klein and Popp, 2022).

The number of items purchased per shopping trip is another important factor, as emissions are allocated based on the number of items transported (Siragusa and Tumino, 2022). For both e-commerce and in-store retail, the higher the number of items in a basket, the lower the CO_2 emissions per item. In the United Kingdom, on average and subject to several qualifications, when a customer purchased fewer than 24 non-food items in one standard car-based trip, home delivery was likely to generate less CO_2 emissions per item purchased (Edwards et al., 2010).

Emissions and energy use from e-commerce may also exceed those generated from in-person shopping if consumers order more online and opt for fast delivery. Demands for the convenience of being able to have products delivered on the same or next day greatly increases the carbon footprint (Roberts et al., 2023). Expedited shipping – same-day, bullet-speed or express deliveries – produces almost 0.75 kg of CO_2e per shopper, more than twice that of regular delivery methods (Mohamed Zein, 2021). This is especially the case if goods need to be shipped by air, which is more energy- and carbon-intensive than transportation by rail or road.[8]

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[7] Online grocery shopping was found to produce more environmentally friendly outcomes than when customers visited the store using their own cars, reducing the distance driven by 54–93 per cent and GHG emissions by 18–87 per cent.

[8] In a life cycle assessment in the United States in 2009, e-commerce generally produced more environmentally friendly outcomes than on-site shopping, but when air-only delivery was involved, the probability that in-store shopping would have a lower carbon footprint was about 50 per cent (Weber et al., 2009).

Failed deliveries that occur when no one is at home to receive the goods ordered online generate additional emissions and kilometres, either by delivery companies having to redeliver to another place, by redelivery to the same place at another time or by consumers making trips to collection points (Buldeo Rai et al., 2022). In the United Kingdom, a 25 kilometre round-trip by car to pick up a missed parcel emitted approximately 5.2 kg of CO_2 (or the equivalent of 16 redelivery attempts by a delivery van), while collecting the item by bus incurred about 3.6 kg of CO_2 emissions (equivalent to 11 redelivery attempts) (Edwards and McKinnon, 2009).

Emissions from e-commerce are likely to exceed those from in-person shopping if consumers order more online and choose faster delivery options

In conclusion, last-mile delivery is the most costly and polluting element of online retail, as well as the most energy- and carbon-intensive. E-commerce in most cases implies lower environmental footprints at this stage than traditional retail. The impact greatly depends on the kind of vehicles used for delivery. Failed deliveries result in additional vehicle kilometres and higher emissions, while parcel consolidation in delivery vans as well as route optimization reduces emissions. Emissions and energy use from e-commerce are especially likely to exceed those from in-person shopping if consumers order more online and choose faster delivery options involving air transport.

d. Returns

Returns are part of the post-sale phase. Activities linked to the return of a purchased item have environmental impacts that are affected by the use and choice of return packaging and labelling, reconditioning, storing, order picking, repackaging and new deliveries. Returns in this phase for bricks-and-mortar retail entail the customer's trip to the store, with the intention of returning (Mangiaracina et al., 2016). The growth of e-commerce has been accompanied by a rise in product returns, the rates of which tend to be much higher for online shopping than for in-store purchases (Roberts et al., 2023). In the United States, for example, 30 per cent of all products ordered online in 2018 were returned, compared to 9 per cent in the case of bricks-and-mortar stores (Saleh, 2019). In-store returns can significantly cut warehouse and transportation costs, but consumers may decide against driving to a bricks-and-mortar store as this may not be the most convenient option (Peinkofer, 2023).

One reason for the high rate of returns in e-commerce is that the consumer cannot see or try out the products before buying them (Pålsson et al., 2017; Ghezzi et al., 2012). Free returns also influence customer purchase decisions, sometimes resulting in buyers ordering more products with the clear intention of returning some or most of them. Higher return rates for e-commerce are also associated with more packaging waste than returns to bricks-and-mortar stores (Zhang et al., 2023). Similarly, the repackaging and transportation of items to a retailer's dedicated returns warehouse increases CO_2 emissions, as trucks and planes carry items over long distances (Peinkofer, 2023). In some cases (e.g. Boozt.com), returns from customers in Sweden are sent to a third country for repackaging, before being resent to the main warehouse in Sweden for resale. This involves more international transportation and more emissions. Often, returned items are not reconditioned or repackaged for sale and may end up as waste. The environmental harm associated with the wilful destruction of returned products is especially problematic from a sustainability point of view (Roberts et al., 2023). While there is little evidence on the amount of waste generated by returns in Europe, the Middle East and Africa (Owens and Pynadath, 2022), in the United States, e-commerce returns produced about 14 per cent more landfill waste than bricks-and-mortar returns in 2020 and an estimated 24 million tons of CO_2 emissions (Optoro, 2020, 2022).

The environmental impact of returns from online purchases is strongly influenced by the method used. For instance, there will be little net increase in energy use and emissions when parcel carriers collect returned items as part of their planned delivery rounds. In one study, CO_2 emissions ranged from 416 g, when a parcel carrier collected the unwanted item on a subsequent delivery round, to as much as 4.5 kg, when the online shopper made a separate trip by car to return the item to a conventional shop (Edwards and McKinnon, 2009).

Conversely, returning the item as part of another shopping trip or by "trip chaining" significantly reduced CO_2 emissions. In one of just a few studies in developing countries, an analysis of return options in Jordan concluded that the delivery courier method of picking up unwanted goods by a delivery van that returned them to the central warehouse was an environmentally friendly and efficient return method. However, making use of the nearest post office or petrol station as both collection and delivery points, and limiting personal car trips, reduced CO_2 emissions even more (Nabot and Firas, 2016).

The carbon footprint associated with returns also depends on the products involved. A study of eight European countries found that the return of a non-food product purchased through e-commerce generated estimated emissions of 112 g of CO_2e per product compared to 68 g for products purchased in a physical retail store (Oliver Wyman, 2021).

In summary, available evidence suggests that returns are much higher for online shopping than for in-store purchases, and sometimes end up as waste, despite being new. E-commerce returns also tend to involve more packaging than returns to bricks-and-mortar stores. Returns can result in increased transportation emissions due to additional trips for product collection, sorting and redistribution, especially if return centres are far away from the customer's location.

e. Consumer behaviour

E-commerce has been found to boost consumption overall due to enhanced accessibility and convenience, lower prices and greater product variety. Furthermore, the behaviour of the online consumer greatly affects the environmental footprint of e-commerce (Buldeo Rai, 2021; Buldeo Rai et al., 2022). With omnichannel purchase behaviour, consumers have the flexibility to interact with retailers through multiple channels. On the one hand, combining online browsing with click-and-collect or delivery can optimize shopping and reduce the need for unnecessary transportation of items. On the other hand, showrooming (online purchases following an in-store visit) or home delivery of in-store purchases, may lead to negative environmental effects if they induce additional trips related to a single purchase. Similarly, behaviour which involves more frequent and fragmented purchases across different platforms and retailers, together with impulsive buying, leads to overconsumption and increased transportation emissions and (packaging) waste (European Commission, Joint Research Centre et al., 2020; Buldeo Rai, 2021). Frequent shopping trips, information-seeking and social and recreational shopping also contribute to additional transportation emissions, especially if consumers rely on private motorized vehicles for their trips.

Online advertising and marketing significantly influence consumer behaviour, fostering a culture of consumption and disposal and contributing to an increased carbon footprint. As online marketing increases and advertisements become more effective through personalization and data analytics, its influence on consumption gains new relevance from a sustainability perspective (Frick et al., 2022). Targeted advertising and personalization have also become increasingly sophisticated in e-commerce. Online businesses are harnessing vast amounts of structured, semi-structured and unstructured customer data, including critical information on demographics, browsing habits, and purchasing history. Social media has emerged as a significant data source, offering insights into consumer preferences and behaviours (Popoola and Abolarin, 2023). This personalization can lead to increased consumer engagement, potentially contributing to overconsumption.

Online advertising and marketing significantly shape consumer behaviour, promoting a culture of consumption and disposal that **increases the carbon footprint**

At the same time, targeted advertisements and other persuasive online marketing strategies, including flash sales and limited-time offers can create a sense of urgency and trigger impulsive buying behaviours, as consumers fear missing out on a great deal.[9]

Meanwhile, some studies suggest that younger consumers are more environmentally conscious when shopping online. A 2023 survey of more than 16,000 shoppers across 16 countries found that 39 per cent of shoppers born between 1997 and 2012 ("Gen Z") and 34 per cent of those born between 1981 and 1996 ("Millennials") engage in cross-border shopping 12 or more times per year. Concern for sustainability was expressed by 94 per cent for Gen Z shoppers and 93 per cent for Millennial shoppers, compared with only 77 per cent of those born between 1946 and 1964 (Ndure, 2023).

In comparing the environmental impact of online and traditional retail, the choice of travel method, e-fulfilment method and basket size also matter (van Loon et al., 2015). While a 2013 study found that traditional shopping had twice as high a carbon footprint as online shopping (Weideli, 2013), the advantage of e-commerce diminished when taking into account the entire buying process, based on fast deliveries, the customer's location (urban versus suburban) and choice of transportation (personal car versus public transport). Regionally, online shopping can reduce GHG emissions in car-reliant areas but may increase emissions in places where consumers may be more used to walking or cycling to shops (Weideli, 2013; van Loon et al., 2015; Shahmohammadi et al., 2020).

Reliable and transparent information that allows consumers to make conscious and sustainable purchase decisions is often not available, hampering the ability of consumers to make informed decisions (UNEP and ITC, 2017; Penz et al., 2019). Other consumers may have limited interest in information related to sustainable practices. In a 2019 survey of Brazilian consumers on last-mile delivery options, two thirds reported that environmental information was of "very low" to "medium" importance to them (Nogueira et al., 2021). Similarly, consumers surveyed in Belgium supported reducing vehicle kilometres for last-mile deliveries but were unwilling to pay for deliveries that used more sustainable alternatives, such as electric vehicles or cargo bicycles (Buldeo Rai, 2019). Consumers may also doubt the credibility of sustainability information, and this stems from concerns related to greenwashing, a practice that may become increasingly prevalent in e-commerce (One Planet Network and adelphi, 2022).

In summary, as consumer behaviour has a major impact on environmental outcomes, it is important to improve the availability of reliable and transparent information that can enable consumers to make conscious and sustainable purchase decisions.

2. Conclusions from the comparison

As for other assessments of secondary (indirect) environmental effects of digitalization, it is hard to draw definite conclusions on whether traditional or online retail is preferable from an environmental sustainability perspective. The environmental footprint depends on many factors. Comparing results from various studies is challenging due to the absence of a common approach to assessing environmental impacts, and the fact that the studies often cover different time periods, countries and types of products. Moreover, the net impact greatly depends on the way in which the purchasing process is conducted. Mode of transport, distance travelled, speed of delivery, number of products purchased, return rates, packaging material, consumer behaviour and geography all influence the outcome.

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[9] See https://www.europeanbusinessreview.com/flash-sales-frenzy-the-impact-of-limited-time-offers-on-consumer-behavior/.

Ultimately, the issue is not so much whether e-commerce is more or less environmentally friendly than traditional bricks-and-mortar retail. In many countries, buyers do not rely completely on offline or online purchases but make use of both channels. Indeed, many retailers nowadays offer alternative options for consumers to buy their products. However, in view of the observed environmental risks of e-commerce, it is essential to consider how to ensure that e-commerce is as environmentally sustainable as possible, moving forward. Given the particularly scarce evidence on the environmental impact of e-commerce in developing countries, it is important to build a stronger knowledge base for these countries.

The next section explores different policy measures, legislation and sustainable practices and technologies that may contribute to more sustainable and inclusive e-commerce.

D. Making e-commerce more environmentally sustainable

The environmental impacts of e-commerce can be influenced in a number of ways. Government policy and legislation can play a role, as can adopting more inclusive and environmentally sustainable e-commerce practices and business models and encouraging consumers to be better informed and to change their behaviour. Large e-commerce platforms also have a responsibility to foster more environmentally sustainable practices. The design of policy measures and transformative actions across the e-commerce supply ecosystem – from sourcing and production to distribution, retail and consumption – can be improved. It should aim to mitigate overconsumption, cut GHG emissions, reduce returns, lower waste and drive sustainable development.

Making e-commerce more environmentally sustainable can help create interconnected benefits across the Sustainable Development Goals, including on Goal 6 (clean water and sanitation), Goal 8 (decent work and economic growth), Goal 9 (industry, innovation and infrastructure), Goal 11 (sustainable cities and communities), Goal 12 (sustainable consumption and production patterns), Goal 13 (climate action), Goal 14 (life below water) and Goal 15 (life on land).

This section focuses on how to mitigate risks and harness opportunities for improving environmental sustainability in e-commerce. Attention is given to government policies as well as actions by e-commerce platforms and other businesses, including women-led online enterprises and consumers.

1. Reducing the impact of warehouses and distribution centres

There are multiple ways to reduce the environmental footprint of warehouses and distribution centres. One approach is to use renewable energy sources, such as solar photovoltaic panels, to power operations (Lewczuk et al., 2021). Several e-commerce companies are already taking action in this area. For example, Daraz, a leading e-commerce platform in Pakistan, has installed solar panels on the rooftops of its warehouses (*News Update Times*, 2021). In the case of Alibaba, energy generated from 30 MW of solar panels and other renewable energy sourcing led to a reported cut in emissions of 21,003 $MtCO_2e$ in 2023, while it has committed to expanding solar power to all its logistics warehouses by 2030 (Alibaba, 2023). The express courier

Making e-commerce more environmentally sustainable can create interconnected benefits across the Sustainable Development Goals

By adopting sustainable practices and optimizing logistics, **e-commerce warehouses** can **bring down their carbon footprint** and help to protect the environment

company, Fedex, uses sunlight to heat the refrigerant for its air conditioners, with significant cuts in energy demand and GHG emissions as a result (Foundation for Future Supply Chain, 2022). Warehouses that make use of energy-efficient compact fluorescent lights or LEDs and other smart lighting systems can also reduce CO_2 emissions and energy consumption even further (Füchtenhans et al., 2021).

Implementing sustainable packaging practices within warehouses as well as right-sizing packaging to minimize waste, significantly lowers their environmental footprint. For example, following the introduction of government bagging guidelines in Singapore, Lazada, a major e-commerce platform in Southeast Asia, started to exclude mandatory packaging for specific items at its fulfilment centre warehouse. This led to a reduction of plastic waste by more than half (Lazada Group, 2022). Prioritizing effective waste management practices, including recycling programmes, can reduce the amount of waste sent to landfills (Abubakar et al., 2022), while the implementation of water-efficient technologies and practices can decrease water consumption and support sustainable water management (Utilities One, 2023).

Locating warehouses closer to customers can help stem mileage and reduce fragmented last-mile transportation (Shahmohammadi et al., 2020; Oliver Wyman, 2021). Placing them near urban and residential areas facilitates faster delivery and supports the transition to more sustainable transportation modes. For instance, Jumia has built an integrated warehouse and logistics network facility in Nairobi, enabling multiple warehouses and networks to operate under one roof. According to the company, this has enabled significant cuts in truck trips per day and lowered CO_2 emissions (Jumia, 2022).

The redesign of warehouses from large, traditional centres to microhubs or microfulfilment centres that link suburban warehouses to final delivery points present additional opportunities for reducing energy consumption and transportation use. At the same time, this can also create inefficiencies that include generating more aggregate energy consumption across multiple sites and higher overall inventory levels (DHL, 2021). Integrating e-commerce warehouses into dense, mixed-use urban areas can also present other development challenges, including adverse health and environmental effects on the local population (Buldeo Rai, 2023).

By adopting sustainable practices and optimizing logistics, e-commerce warehouses can bring down their carbon footprint and help to protect the environment. From a broader sustainable development perspective, such efforts should be accompanied by measures to ensure decent work conditions of e-commerce warehouse workers (ILO, 2023c). This includes engaging with workers, local communities and civil society organizations on issues such as community displacement and supply chain transparency, as well as investing in skills development and training.

2. Minimizing the impact of product packaging and waste

E-commerce packages have been found to use up to seven types of packaging materials, including envelopes, cardboard boxes, plastic bags, woven bags, tape and buffer materials such as bubble wrap or polystyrene foam (Maraithe, 2020). In particular, single-use packaging materials such as cardboard boxes, plastic air pillows and bubble wrap are often not recycled, leading to an increase in packaging waste and environmental pollution (Oceansix, 2023). E-commerce reportedly used approximately 950 million tons of plastic packaging globally in 2019. The two largest e-commerce markets, China and the United States, each accounted for approximately one fifth of this total, which is projected to reach an estimated 2 billion tons by 2025 (Oceana, 2020).

A few positive trends have been observed. Some consumers are becoming more conscious about their packaging footprint. In a survey on packaging sustainability trends, 66 per cent of consumers across Europe, North America and South America found it important to purchase products packaged in environmentally friendly materials (Trivium Packaging, 2022). Governments are responding to growing concerns about plastic pollution. For example, recognizing the impact of packaging waste, including from e-commerce, the Government of Indonesia and the Global Plastic Action Partnership launched a National Plastic Action Partnership in 2019, with the goal of reducing ocean plastic pollution by 70 per cent by 2025 and making the country free of plastic pollution by 2040 (Florene, 2021; WEF, 2019).

Some countries have sought to address the production of packaging waste in national legislation. Measures range from outright bans to the phasing out of single-use plastic packaging (box V.3), as well as efforts that promote a shift to more reusable, recyclable or compostable packaging for e-commerce.

Other measures include subsidizing research and development related to recyclable and degradable materials and offering subsidies for the consumption of these materials (Wang et al., 2023). The design of innovative packaging systems, such as reusable plastic crates to counter the growing use of single-use cardboard boxes, can also reduce plastic packaging waste (Coelho et al., 2020). Creating a reusable packaging system, supported by national governments and postal services could streamline the return and reuse of packaging to retailers, fostering both sustainability and responsible resource management in e-commerce.

In the private sector, some e-commerce companies in developed and developing countries alike are incorporating sustainable packaging as part of new environmentally friendly business models, including:

- A decision by Mercado Libre to ship certain products in their primary wrapping material has resulted in less packing and waste as well as savings on transportation fuel. The company uses packaging that is recyclable and has received the Forest Stewardship Council-certified or soon-to-be certified seal, guaranteeing that all manufacturing processes adhere to responsible forest practices (Mercado Libre, 2023).
- Amazon India has taken steps to achieve complete elimination of single-use plastic, including by replacing plastic packaging material, such as bubble wraps and air pillows with “paper cushion”. The company has also introduced 100 per cent plastic-free and biodegradable paper tape, which is used to seal and secure customer shipments (Amazon, 2020).
- Unilever’s Easy Green e-commerce sustainability partnership with Lazada aims to reduce the use of plastic packaging materials in delivery parcels. It entails using carton boxes and recycled shredded paper instead of plastic fillers (Unilever, 2022). These alternative packaging solutions are provided as “eco” (plastic-reduced) and “zero” (plastic-free options), with the latter making use of paper tape instead of plastic tape to seal packages (Lazada Group, 2022).
- Cainiao, a logistics company owned by Alibaba, has launched a green recycling programme that focuses on packaging. This initiative has established over 110,000 “pick-up, drop-off” stations, which had resulted in the recycling and reuse of 24 million packaging items as of March 31, 2023.[10] Additionally, Cainiao has pioneered the use of e-shipping labels to replace paper labels, leading to savings of over 400 billion pieces of paper and offsetting a billion kilograms of carbon emissions annually (*Time*, 2020).

> Creating a publicly supported reusable packaging system could streamline the return and reuse of packaging, fostering sustainability and responsible resource management in e-commerce

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[10] See https://www.cainiao.com/en/esg-environmental.html?spm=a2d524.28499376.0.0.658f55e3lBQxkY.

- Some e-commerce companies in the United States are shifting from single-use packaging to form a multi-use packaging loop, including through initiatives that offer reusable containers, envelopes and capsules for businesses to deliver products to customers (Maraithe, 2020). Once a customer receives a product, the reusable container is sent back to the company, where it is cleaned and sanitized for reuse.
- In France, certain e-commerce companies are removing additional boxes for shipment when the original packaging of the product does not require extra protection. In Switzerland, some companies are experimenting with sending certain products without any additional packaging, relying solely on the product's original box (Ecommerce Europe and EuroCommerce, 2022).

Box V.3

Government measures to minimize the environmental impact of plastic and packaging waste

As plastic and packaging waste becomes ever more visible, both on land and in the oceans, calls to tackle this escalating crisis are growing. Governments around the world have implemented various mitigating measures. While policies may not always target packaging generated from e-commerce specifically, bans on single-use plastic can help to prevent plastic and packaging waste from e-commerce as well.

China has released and implemented a series of policies and regulations on plastic pollution management. These are primarily characterized by conducting plastic pollution management by region, time and industry. A plastic ban enacted in 2020 restricts the production and use of multiple single-use plastics, including packaging from the large e-commerce sector. The use of electronic waybills instead of paper ones, and reusable courier containers have become common practices in logistics companies in the country. In 2021, the Ministry of Commerce in China issued a notice to promote the green development of e-commerce enterprises. It encourages energy savings and low-carbon development, green packaging and consumption; and requires platforms to report on their environmental protection efforts. In response, e-commerce enterprises have adopted measures to "slim" the packages of express parcels and promote more sustainable packaging solutions, including through the so-called "Feng box" – a recyclable parcel package launched by the express service delivery company, SF Express. Notwithstanding these efforts, Greenpeace in 2020 reported a substantial amount of hard-to-recycle plastic packaging still being used for delivery.

In India, the Plastic Waste Management Amendment Rules, 2021, prohibit since 2022 the use of identified single-use plastic items which have low utility and high littering potential.

Rwanda implemented a nationwide ban on plastic bags in 2008 in its law relating to the prohibition of manufacturing, importation, use and sale of plastic carry bags and single-use plastic items, N° 17/2019 of 10 August 2019.

The European Union Packaging and Packaging Waste Directive sets out measures to reduce packaging waste. It requires European Union countries to take measures to prevent the generation of packaging waste and to minimize the environmental impact of packaging. They are also required to adopt measures to increase the share of reusable packaging placed on the market and to reuse packaging, without compromising food hygiene or consumer safety. The Directive also sets recovery and recycling targets for packaging waste.

Sources: UNCTAD, based on Greenpeace (2020) and IPEN (2022).

3. Towards more sustainable transportation and delivery

Increased pressure is being placed on the last-mile delivery system, whereby products are transported (often in fossil-fuelled trucks and vans) from distribution centres to final consumers (WEF, 2021). Contributing approximately one quarter of all energy-related GHG emissions, the transport sector is one of the largest sources of both urban and regional air pollution (UNEP, 2023a). In the context of e-commerce, short delivery windows in response to consumer demand may drive companies to compete for clients by offering faster delivery solutions (Muñoz-Villamizar et al., 2021).

Fast delivery entails more urgent and frequent deliveries, resulting in more vehicles on the road, traffic congestion, higher fuel consumption and increased CO_2 emissions (section C). Delivery companies that prioritize speed as a core component of their business models often pay less attention to the environmental impact of the deliveries; when dealing with a one- or two-day shipping window, companies are more likely to use trucks that are only half filled, generating more traffic and carbon emissions per item (Igini, 2023).

Growing demand for e-commerce is estimated to increase by 36 per cent the number of delivery vehicles within inner cities by 2030 (WEF, 2020a), with consequent environmental risks. For example, without effective intervention, urban last-mile delivery emissions and traffic congestion are on track to increase by over 30 per cent in the top 100 cities globally. With an ecosystem-wide change, however, different measures could reduce emissions and traffic congestion by 30 per cent, and delivery costs by 25 per cent, compared to a "do-nothing" scenario. Greater use of battery electric vehicles and hydrogen fuel electric vehicles could reduce CO_2 emissions by 16 per cent and 24 per cent respectively, while mobile parcel lockers could reduce delivery costs by 2 to 12 per cent, thus easing congestion by 5 to 18 per cent (WEF, 2020a).

In urban settings, last-mile delivery can be made more sustainable by employing electric L-category vehicles, such as mopeds, motorbikes and compact electric vehicles (Ranieri et al., 2018), which significantly reduce emissions when charged with renewable energy (IPCC, 2022b). Cargo bikes present notable environmental advantages. For example, in London, replacing 10 per cent of van traffic by cargo bikes could reduce CO_2 emissions by about 133,000 tons per year. A shift to cargo bikes would also reclaim around 384,000 square metres of public space currently occupied by parked vans, and decrease vehicle traffic by some 17,000 hours (about two years) each day (Possible, 2021).

Walking or biking when returning products at parcel lockers (ideally when picking up a new parcel) can result in more environmentally friendly outcomes. The introduction of drop-off and collection points can reduce the number of trips and distance travelled, leading to lower emissions (Klein and Popp, 2022; European Commission, 2022a). Other measures include optimizing routes and consolidating deliveries. Policies that facilitate innovation for more sustainable and efficient systems and services present additional environmental benefits. Examples include setting regulations for loading and unloading parking, creating projects for urban consolidation centres, testing new vehicles in pilot programmes and defining specific working hours for logistics operations (Viu-Roig and Alvarez-Palau, 2020).

In some African cities, to avoid inefficient last-mile deliveries, the Jumia Group has designed conveniently located pick-up stations that allow consumers to walk or take less carbon-intensive means of transportation to retrieve their orders. The company uses an open source technology solution called Opta Planner that helps identify the most efficient delivery routes (Jumia, 2021). In China, Cainiao saw reductions in

> Without intervention, emissions and traffic congestion from urban **last-mile delivery** are set to **rise by over 30%** in the top 100 cities globally

carbon emissions due to duplicated delivery through the use of a "smart consolidation engine", which combines multiple packages ordered by the same consumer in one shipment (Alibaba, 2021).

Some e-commerce companies are moving towards more environmentally sustainable delivery modes, with positive environmental and social impacts. Lazada, for example, has partnered with PT Smoot Motor Indonesia, to launch a specialized electric motorcycle for delivery that allows depleted batteries to be swapped for fully charged ones at exchange locations across Jakarta. For last-mile deliveries, Lazada also deploys zero-emission cargo bicycles in densely populated regions in Indonesia and electric scooters that cover up to 20 km and can deliver more than 100 parcels per charge in Viet Nam (Lazada Group, 2022). In Romania, e-commerce platform eMAG, together with Sameday, a courier company, has a "green delivery" service using only electric cars (Ecommerce Europe, 2020). In the United Kingdom, Ikea has invested $5.56 million in charging infrastructure to achieve 100 per cent zero-emission deliveries by 2025 with a renewable energy-powered fleet of 500 electric vehicles (Fleetnews, 2023).

Zypp Electric, a last-mile delivery company in India, delivers goods using a fleet of zero-emissions electric scooters and has invested in a charging network in urban centres. Similarly, in South Africa, the delivery company Green Riders makes deliveries using electric motorcycles as a viable alternative to traditional gasoline-powered delivery fleet (Green Riders, 2022). In Rio de Janiero, Pedala, an urban delivery social enterprise, employs bicycle couriers to deliver items bought online, reducing traffic congestion and pollution, while creating employment opportunities for at-risk youth from low-income backgrounds (Nesst, 2021). Around the world, women-led online businesses are pioneering sustainable transportation solutions that align with broader climate change and sustainable development goals (box V.4).

The uptake of electric vehicles offers a promising pathway for decarbonizing the transportation sector and transitioning to a more sustainable transportation system. However, the effectiveness of this shift depends in part on the source of electricity generation. The transition could exacerbate challenges facing power systems in developing countries. Potential solutions include smart charging strategies which limit negative impacts while leveraging the potential benefits of vehicle-grid integration. Other mitigation strategies include battery swapping systems to reduce the burden on the power grid during peak demand periods and reducing electric vehicle energy consumption through more efficient cooling systems (Energy Sector Management Assistance Program, 2023).

4. Reducing return rates

As noted above, return rates and costs are much higher for online shopping than for in-store purchases. In 2020, total returns in the United States resulted in over $400 billion in lost sales for retailers, and in 2022 it was twice as high ($816 billion) (National Retail Federation, 2021, 2022). In the United Kingdom, customers return an estimated $8.9 billion of purchases every year. According to a survey of British retailers, companies reimburse nearly half of the amount consumers initially spend on online clothing orders (Barclaycard, 2018).

Understanding the factors that drive returns is important for developing targeted solutions that reduce and manage returns. Multiple purchases, wrong product delivery and dissatisfaction with the product remain key drivers of online product returns (Frei et al., 2023). Return rates have been found to be particularly high for clothing and shoes, at 88 per cent and 44 per cent, respectively (Power Reviews, 2021).[11] Inconsistencies between the expected and

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[11] In Australia, about 30 per cent of all online clothing purchases are returned – sometimes because people order several sizes or styles with the intention of sending most back (*Australian Financial Review*, 2019).

Box V.4
Sustainable e-commerce transport and logistics innovation: The case of TruQ in Lagos, Nigeria

Foluso Ojo, the female founder of TruQ, an online logistics and delivery company in Lagos, Nigeria, has prioritized three interventions in her company's business model to reduce the carbon footprint associated with traditional logistics and delivery methods:

- Strategically locate warehouses across Lagos to leverage the benefits of warehouse consolidation, minimize travel distances and alleviate traffic congestion, thereby helping reduce fuel consumption and transport emissions.
- Use the TruQ software that aggregates and matches orders with suitable drivers, minimizing unnecessary trips and the associated negative environmental impact.
- Apply route optimization technology to identify the shortest delivery routes, limiting unnecessary mileage, fuel consumption and CO_2 emissions.

Ms. Ojo underlines that targeted support to nurture an ecosystem of environmentally conscious, women-led e-commerce businesses is critical. Financing for online businesses that embrace environmentally friendly practices could provide the capital needed for investments, including in electric and low-emission fuel vehicles, and other eco-friendly logistics solutions.

Targeted regulations and guidelines in the logistics sector would further encourage the adoption of sustainable practices and bring the transport industry in line with broader environmental objectives. Finally, government-led public environmental awareness and education initiatives could influence the perception of sustainable transport practices and encourage behavioural change.

Source: UNCTAD, based on an interview with Foluso Ojo, founder of TruQ.

the received product, including problems with sizing, colour and resulting multiple item purchases can be linked to poorly designed product description pages and displayed images (Frei et al., 2023; Deloitte, 2019).

Free returns and free shipping influence customer purchase decisions and the likelihood of buying with the retailer again, but they also increase the return rate and, thereby, the environmental impact (Frei et al., 2023). In the United States, for 96 per cent of surveyed consumers, free shipping was the most important consideration when making an online purchase, followed by free returns (79 per cent) (Power Reviews, 2021). In the United Kingdom, flexible return policies have become the norm, with half of consumers stating that a retailer's return policy influences where they shop, and 18 per cent only choose retailers that offer free returns (Barclaycard, 2019).

There are various measures to safeguard the rights and interests of consumers in the context of online returns. Paragraph 14 (e) of the United Nations guidelines for consumer protection recommends that Member States establish consumer protection policies that encourage "a transparent process for the confirmation, cancellation, return and refund of transactions" (United Nations, 2016). Under European Union rules, a trader must repair, replace, reduce the price or provide a refund if goods bought turn out to be faulty or do not look or work as advertised (European Union, 2023): Consumers who have purchased a product or service online or outside a shop, have the right to cancel and return their order within 14 days, for any reason and without a justification. While return and refund laws and other convenient return policies seek to protect the consumer and improve customer satisfaction, they may inadvertently also lead to unnecessarily high rates of returns.

When it is expensive to restock or refurbish a product, it may be cheaper for the retailer to discard or destroy a returned item, potentially resulting in additional environmental impacts (Frei et al., 2023).

The destruction of unsold and returned goods is particularly harmful as it has been found to generate 5 to 20 times more GHG emissions than reuse (Ellen MacArthur Foundation, 2021). There have been several reports of fast fashion and luxury brands burning and shredding unused and unsold stock to prevent the reselling of stock by unauthorized vendors on the grey market or its return for cash (Lee, 2023; *Financial Times*, 2023). Some companies may have neither the time nor the technology to distinguish damaged goods from those returned (Symons, 2023). Smaller e-commerce companies may also opt to send unwanted goods to an incinerator or landfill instead of paying for the warehouses of larger platforms (European Commission, Joint Research Centre et al., 2020).

Product destruction needs to be addressed through a wide range of interventions (informative, administrative and market-based). This area is receiving increasing policy attention. On 30 March 2022, the European Commission proposed the "Ecodesign for Sustainable Products Regulation" to establish a framework for setting ecodesign requirements for sustainable products (European Commission, 2022b). This framework is intended to apply to all products on the internal market, with the aim of making them more durable, reusable, reparable, upgradable, recyclable and generally less harmful to the environment. The proposed regulation includes rules on a digital product passport, green public procurement and banning the destruction of unsold goods. As a first step, large companies would be mandated to publicly disclose the number of products they discard per year. They would need to inform on and justify the volumes of discarded products sent out for reuse, remanufacturing, recycling, energy recovery and disposal.

Banning the deliberate destruction of unsold goods can promote environmentally sustainable e-commerce

Regarding e-commerce, the regulation recognizes the role of online marketplaces in the supply chain and how these platforms allow economic operators to reach more customers. Given their role in intermediating the sale of products between economic operators and customers, online marketplaces are required to take responsibility for addressing the sale of products that do not comply with ecodesign requirements and to cooperate with market surveillance authorities (article 29). The Council of the European Union and the European Parliament reinforced the regulation, through a direct ban on the destruction of unsold and returned textiles, with an exemption for micro- and small enterprises and a transition period for medium-sized companies (Council of the European Union, 2023; European Parliament, 2023).

Some European Union countries have sought to address these issues in national legislation. France was the first country to ban the destruction of unsold non-food products as part of a 2020 anti-waste law. Companies have to reuse, donate or recycle the unsold products (France, 2020). In Belgium, value added tax (VAT) relief has been introduced on products donated to charity as an economic incentive to encourage reuse over destruction. Germany has put in place a "duty of care" legal principle for producers and retailers along with mandatory reporting requirements for the types and volumes of products being destroyed (Roberts et al., 2023). The introduction of policy instruments banning the deliberate destruction or disposal of unsold goods can promote environmentally sustainable e-commerce. However, achieving this goal requires more than legislative and regulatory measures. It is important to prioritize environmental sustainability in the design of business return practices, as well as influence consumer behaviour.

An immediate measure that businesses could adopt is to end the practice of free returns. Charging a nominal fee for online returns would help to reduce unnecessary orders and returns, while fostering more responsible online buying behaviour. Some retailers are already moving in this direction. The number of retailers in the United States charging for returns increased from 33 per cent in 2021 to 41 per cent in 2022

(Narvar, 2022).[12] Similarly, the Spanish retailer, Zara, now charges customers $2.13 for online returns, with the cost deducted from their refund (*Reuters*, 2023b), while H&M, a Swedish retailer, charges customers $2.40 since the pandemic (*BBC News*, 2023). As a way of eliminating unnecessary returns, the Swedish e-commerce company, Boozt, has introduced a fair use policy to its terms and conditions, which sets limits to the number of returns a customer can make within a specific time period. As a result, the company was reportedly able to cut emissions by approximately 791 tons of CO_2e in 2022 and to use 538 fewer delivery trucks (Boozt Group, 2022).

E-commerce companies can also take measures to reduce the risk of customers returning products. For example, they can offer customers more comprehensive and precise information about a product, including colour, weight, size and other pertinent dimensions. Ensuring consistency between the image, the description and the product empowers consumers to make more informed purchasing decisions, thereby minimizing the occurrence of online returns caused by confusion or dissatisfaction (Frei et al., 2023). In this context, digital technologies, such as augmented reality, could reduce returns of goods bought online due to misunderstandings or dissatisfaction with the product and associated GHG emissions (*Bloomberg*, 2022). So-called augmented reality virtual try-on, spatial planning, product visualization and measurement assistance apps enhance user experience and enable immersive virtual environments (box V.5 includes examples of companies making use of such applications). However, such practices raise broader security and privacy risks, including the potential loss of privacy if hackers gain access to augmented reality devices and record user behaviour (Harborth and Pape, 2021).

A market survey of over 4,000 shoppers in France, Saudi Arabia, the United Kingdom and the United States revealed

Two-thirds of shoppers who used **augmented reality technology** while shopping were less likely to return purchases

Box V.5
Use of augmented reality applications to reduce product returns

- In the United States, Disguise, a costume company, has partnered with technology company Snap to introduce an augmented reality lens that enables users to visualize the fit, style and colour of their online purchases. Snapchat users take a full body photograph and browse the Disguise store for costumes, which they can virtually “try on” and then directly order from their phones.
- Moreover, the retailer Gap has developed an augmented reality application that allows customers to select a body type and enter their height and weight to create an approximate model of themselves for online shopping.
- Zara’s in-store augmented reality application allows customers to hold up their phone to designated shop windows or sensors within the store to see models wearing a selection of outfits. This experience helps customers to visualize how the clothing fits and moves.
- Ikea has introduced Ikea Place, an augmented reality application that allows customers to take a picture of a room in their house and virtually place Ikea furniture to see how well it fits the space. The application increases user engagement rates by providing features that grant consumers the ability to accurately measure room dimensions and visualize how light and shadow impact the texture of furniture. As a result of this interactive experience, the company reported a 30 per cent drop in return rates.

Sources: UNCTAD, based on Ikea (2017); Deloitte (2020); Walk-Morris (2022).

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[12] For example, clothing retailer American Eagle charges $7 to return purchases; Saks Fifth Avenue, $9.95; and TJ Maxx, $10.99 (*BBC News*, 2023).

that roughly two-thirds of those who used augmented reality technology to aid their shopping decisions were less likely to return their purchases (Walk-Morris, 2022).

Investing in an environmental sustainability framework for product returns would further promote sustainability goals. This could include increased awareness, management commitment and cross-departmental coordination to achieve joint goals, collaboration with third parties and developing environmental impact assessments (Zhang et al., 2023). It should be noted that such market surveys come with the "cost" of more data use and may be difficult to implement in less digitally developed economies.

The convenience of online shopping, coupled with persuasive advertising and marketing plays a significant role in promoting overconsumption

Leveraging consolidated shipments and economy delivery services to reduce transportation and associated emissions is another way to minimize the environmental impact of returns. For example, an express return delivery service of Optoro, which provides over 1,000 drop-off locations across the United States, consolidates returned items into fewer shipments for retailers, reducing cardboard use and lowering the company's carbon footprint (Optoro, 2022). Jumia reportedly managed to avoid shipping 16,800 and 28,000 packages in 2020 and 2021 respectively, by reducing reverse shipments and allowing qualifying customers to keep certain items they wished to return, with a refund (Jumia, 2021). Other responsible practices include promoting the refurbishment or resale of returned items, rather than sending items to a landfill or to be destroyed (Vembar, 2021).

5. Influencing consumer behaviour

Different consumer needs and online purchase behaviours can have a negative environmental effect, including in relation to shopping frenzies and impulse buying. Events such as Black Friday, Cyber Monday and Singles' Day boost shopping online, as consumers rush to take advantage of discounts and promotions. Concerns have grown about the development of a "hyper-discount culture". It encourages companies to produce surplus stock in the hope of capturing every possible customer and subsequently getting rid of excess stock by trashing, donating or selling it at greatly reduced prices (Symons, 2023). In addition to fuelling excessive consumerism and overconsumption, such trends can contribute to increased GHG emissions and waste generation, with additional plastic packaging often ending up in landfills, incineration or low-quality recycling (University of Leeds, 2019). High return rates from impulse buying also contribute to environmental costs.

The ease and convenience of online shopping, coupled with persuasive advertising and marketing play a significant role in promoting overconsumption.

In order to mitigate these trends, it is relevant to consider how to encourage more responsible online consumption. For example, persuasive technologies and digital applications embedded in e-commerce platforms, such as ethical nudging, gamification, carbon footprint calculators, positive feedback loops and green activations, can support a shift in awareness and steer consumers towards more environmentally sustainable products and services (CODES, 2022). Providing consumers with sustainability information at the time of purchase can positively shape the environmental impact of e-commerce. The way in which digital nudges are applied should also take into consideration human rights, including with regard to privacy and data protection (box V.6).

When used effectively, digital nudges can help buyers make environmentally conscious purchase decisions by providing relevant information (Mirbabaie et al., 2022). E-commerce platforms, however, must employ these tools responsibly and ethically and avoid the use of so-called "dark nudges" that exploit cognitive biases, potentially leading to overconsumption. For example, dark nudges may involve obscure price changes at checkout, website

Box V.6
Digital nudges and human rights

Some digital nudges can raise human rights concerns. First, the use of behavioural science techniques to influence decision-making in digital environments may compromise individuals' autonomy and freedom of choice. Such nudges can subtly manipulate users without their full awareness or consent, potentially undermining their ability to make independent decisions.

Second, extensive data collection and personalized targeting used in digital nudges can give rise to privacy and data protection concerns. Users may not be fully aware of how their data are used, risking potential misuse or unauthorized sharing with third parties, violating their right to privacy.

Third, there is a risk of perpetuating discrimination and biases if algorithms behind the nudges are biased or trained on data reflecting societal inequalities, thereby compromising the right to equality and non-discrimination. Digital nudges that rely on gender stereotypes perpetuate harmful societal gender roles and reinforce gender-based inequalities.

Ensuring the protection of human rights in the design of digital nudges requires addressing these and other related implications as part of an inclusive digital ecosystem.

Sources: UNCTAD, based on Scott (2023a, 2023b).

designs that subtly push users towards more expensive options or preselected additional products that users must opt out of to avoid unexpected charges (Davis, 2017). E-commerce companies should facilitate more informed decision-making and foster more sustainable consumption.

Shopify's carbon calculator and carbon offset tool, for instance, estimates the carbon emissions generated by shipping orders. It allows merchants to purchase carbon offsets to neutralize the impact of emissions, while consumers are shown how their purchases get matched with carbon offsets. All offset payments are donated to forest protection efforts (Reed, 2020). Similarly, the GoTo Group in Indonesia charges a fixed amount to consumers who have activated the GoGreener Tree Collective app when ordering a GoRide or GoCar. The amount calculated is based on the number of trees needed to absorb the average CO_2 emissions from a ride (GoTo Group, 2021). Smartdrop in Belgium is another example of a digital initiative aimed at promoting sustainable consumer choices, specifically in the context of delivery. This innovative tool enables retailers to input customer, store and logistics information, providing insights into the environmental impact of different delivery options and allowing consumers to select the most sustainable delivery method. Its design facilitates informed decision-making, thereby encouraging eco-friendly practices in e-commerce logistics.[13]

Despite its potential for steering online purchasing decisions towards more environmentally sustainable outcomes, nudging can also undermine the broader goals of sustainable consumption. For instance, displaying “buy one, get one free” offers, “one-click buy” options or suggesting additional items at checkout can lead consumers to purchase items they may not need, thereby contributing to excess consumption. Striking the right balance between encouraging individuals to make sustainable choices and preventing overconsumption is needed to promote responsible use of digital technology.

At the same time, to foster more environmentally conscious consumer behaviour and ensure adequate protection against greenwashing, consumers need reliable information on the environmental sustainability of different products. Better

> Striking the right balance between encouraging individuals to make sustainable choices and preventing overconsumption is needed to promote responsible use of digital technology

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[13] See https://smart-drop.be/en.

access to comprehensive data on the LCA of products available in the marketplace is desirable in this context. LCA data provides critical insights into the environmental impact of a product throughout its life cycle, from raw material extraction and manufacturing to distribution, usage and disposal. This information can empower consumers to compare products not just based on price and quality, but also on their environmental footprint. Moreover, expanding the availability of LCA data for all products would encourage manufacturers to adopt more sustainable practices, as consumer demand for eco-friendly products could significantly influence market trends (UNEP, 2012; UNCTAD, 2023b). Moreover, environmental claims made by e-commerce platforms and retailers should be based on verifiable and reliable information.

6. Legal and regulatory measures

Together with persuasive technologies and digital applications, legislation, regulations and non-binding guidelines that address misleading and deceptive environmental claims can be effective in this context and influence the environmental impact of e-commerce. Exponential growth in the use of green claims in e-commerce as part of advertising strategies by traders presents challenges to consumers and consumer protection authorities (UNCTAD and Superintendence of Industry and Commerce of Colombia, 2022).The use of the term “sustainability” in various corporate communications can also at times be confusing and amount to greenwashing or a misuse of green claims (UNEP, 2022a).

The United Nations guidelines for consumer protection do not explicitly mention greenwashing in the context of e-commerce. However, paragraph 63 on e-commerce recommends that Member States should, where appropriate, “review existing consumer protection policies to accommodate the special features of electronic commerce and ensure that consumers and businesses are informed and aware of their rights and obligations in the digital marketplace” (United Nations, 2016).

To gain a better understanding of the existing legal landscape and regulatory measures related to environmental claims, including in the context of e-commerce, an online questionnaire on green claims was distributed to all members of the e-commerce working group under the Intergovernmental Group of Experts on Consumer Protection Law and Policy (UNCTAD and Superintendence of Industry and Commerce of Colombia, 2022). While the majority of respondents (82 per cent) reported not having specific legislation or regulations in place to address environmental claims made through e-commerce or digital means, 63 per cent confirmed having developed, or that they were in the process of developing, educational material on the subject in order to raise awareness among consumers, businesses and marketers.

Countries that reported having specific legislation and guidelines in place in this area included Peru, Sweden and the United States (UNCTAD and Superintendence of Industry and Commerce of Colombia, 2022):

- Peru enforces certain general provisions contained in the Legislative Decree 1044 – Law on the Repression of Unfair Competition. Although this legislation is not strictly related to e-commerce, article 8 considers acts which have “the effect, actual or potential, of misleading other market players as to the nature, method of manufacture or distribution, characteristics and attributes, fitness for use, quality, quantity, price, conditions of sale or purchase” to constitute acts of deception. This includes advertising with environmental claims that could end up being misleading.
- Sweden assesses environmental claims based on general provisions in the Swedish Marketing Act, which implements the Unfair Commercial Practices Directive from the European Union. Sweden has also produced non-binding guidance on the application of the Directive, which

includes a section on environmental claims. The Swedish courts and the Swedish Consumer Agency refer to the Consolidated Code of Advertising and Marketing Communications Practice from the International Chamber of Commerce (ICC), which has a chapter on environmental claims.

- In the United States, the "Guides for the use of environmental marketing claims" from the Federal Trade Commission help marketers ensure that their claims are truthful and supported by evidence.

On 22 March 2023, the European Commission published its proposal for a European Union Directive on substantiation and communication of explicit environmental claims, the Green Claims Directive (European Commission, 2023b). It proposes new rules on the evidence that companies will have to produce to substantiate their green claims, together with a requirement that such claims be verified and certified to be reliable and trustworthy by a third party. European Union countries are required to designate the most efficient competent authority to carry out the enforcement, including inspections, sanctions and judicial pursuits. If adopted, the proposed Directive would impact all businesses, including e-commerce businesses, selling products in the European Union.

Green and environmental labels offer transformative opportunities to mitigate environmental impacts, marking a crucial step towards more sustainable practices. For instance, the Nordic Swan Ecolabel for e-commerce logistics endorses reduced climate impact and upholds good labour standards.[14] Additionally, an initiative by the Dutch e-commerce federation is partnering with the e-commerce sector, environmental organizations and other stakeholders to discuss what should be included in an ideal environmental e-commerce label.[15] This initiative would result in a certification based on six pillars: strategy, delivery, packaging, returns, product offering and circular economy.

International organizations are supporting efforts to advance the credibility of environmental claims and prevent misleading practices and greenwashing. In November 2022, UNEP and adelphi, as part of the One Planet Network, published "Guidelines for providing product sustainability information in e-commerce" (box V.7).

Box V.7
Guidelines for product sustainability information in e-commerce

To prevent greenwashing and misuse of green claims, UNEP and adelphi, as part of the One Planet Network, have developed guidelines for providing product sustainability information in e-commerce.

These guidelines are voluntary and contain recommendations and good practice on how to communicate product sustainability information and encourage conscious consumer decisions based on transparent and reliable claims.

The guidelines are based on five fundamental principles (reliability, relevance, clarity, transparency, and accessibility) and five aspirational principles (sustainability dimensions, behaviour change, multichannel communication, collaboration and comparability).

The target audience includes e-commerce platforms, online sellers, policymakers, consumer organizations and other NGOs.

Source: UNCTAD, based on One Planet Network and adelphi (2022).

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[14] See https://www.nordic-swan-ecolabel.org/criteria/e-commerce-logistics-111/.

[15] See https://www.thuiswinkel.org/webshops/kennisbank/kennisartikelen/dit-zijn-de-trends-voor-duurzame-e-commerce/.

E. Opportunities for contributing to the circular economy and fostering a sharing economy

Platform business models used for e-commerce can help to promote greater resource efficiency and waste reduction by enabling the reuse, reselling, lending, giving, swapping and renting of products and services directly between individuals. This can facilitate the transition to circular and sharing economies, which helps to reduce pressure on scarce resources such as water, non-renewable energy and raw materials, increasing the efficiency of production (United Nations, 2021b). For instance, consumers trading used electronics, furniture, clothes and other items on third-party platforms can help to lessen the demand for new products and the resources required to produce them. In facilitating trade in second-hand goods, goods for refurbishment and the repair of existing products that might otherwise be discarded or left unused, e-commerce may extend the lifespan of products and encourage a shift towards more responsible consumption and production.

Another opportunity for fostering circularity can be found in peer-to-peer activity whereby goods and services are shared among consumers, often facilitated by a third-party online platform (Collini et al., 2023). Applications that allow users to share vehicles can help to reduce the number of vehicles on the road and vehicle kilometres driven, encouraging more sustainable transportation systems (Transport and Environment, 2017). Such applications have become popular in both developed and developing countries. For instance, Didi, a taxi-hailing application in China enables users to share taxis and bikes; Rapido is the first bike taxi application in India; and the Lyft ride share application enables different passengers traveling along similar routes to share a ride in the same vehicle. “Slow fashion” applications, like Nuw in Ireland and Swopped in the United Kingdom, allow users to swap items from high-street to designer goods, through their mobile phones, and inch closer to circular economy objectives. Nuw includes an impact calculator that lets users track the carbon, waste and water offset created every time they swap (*The Guardian*, 2021).

Another way of improving sustainability is through business models that prioritize environmental and social responsibility solutions and circular economy infrastructure. For example, OLX India, an online classified marketplace, reported a reduction of eight million tons of CO_2 in one year by facilitating product resale and reducing the need to produce new goods.[16] Similarly, Taragram, a social enterprise in India, collects and converts waste material into eco-friendly, high-quality paper which it sells online, while creating sustainable employment and support to communities in rural areas (Taragram, 2020).

Although sharing systems may promote sustainable consumption and production, there is the risk of circular economy “rebound” effects, which partially or fully cancel out the benefits. This occurs when circular economy activities, despite having lower per-unit-production impacts, lead to increased consumption and production levels. This can have negative implications for natural resource consumption and the environment (Zink and Geyer, 2017). For example, while promoting sharing of bicycles and taxis on the Didi platforms in

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[16] See https://www.thehindubusinessline.com/news/how-olx-india-users-helped-reduce-their-carbon-footprint/article24078672.ece.

China, it may have inadvertently increased China’s carbon emissions by enabling a shift from public transport to private taxis.[17]

Mitigating the risk of such rebound effects requires a collective effort from all stakeholders. Governments could provide financial incentives to e-commerce platforms and businesses that promote pro-social sharing models and facilitate sustainable consumption and production patterns, while platforms and businesses could partner with organizations on circular economy initiatives that advocate sharing services or reducing waste. Moreover, consumers can be encouraged to consume in a more sustainable manner, for example by using sharing systems and repairing products instead of buying new ones and by supporting policies that promote circularity.

F. An agenda for action

This chapter has explored the different environmental impacts of e-commerce, as well as actions and measures for more sustainable practices. As e-commerce continues to expand, understanding its various sustainability challenges, especially for goods, is crucial. E-commerce has reshaped consumption patterns and logistics, with multiple environmental effects. Precise impact assessments are hindered by data limitations. But e-commerce presents both opportunities and risks – from warehousing and storage to transportation and logistics, packaging, returns, and consumer behaviour.

Making e-commerce more environmentally sustainable requires collaborative efforts from governments, businesses, platforms, logistics providers and consumers. Initiatives could focus on responsible and sustainable sourcing, energy-efficient logistics and production processes, adopting renewable energy, eco-friendly packaging and delivery solutions as well as sustainable consumption. Policymakers need to create the right mix of legislative and regulatory instruments and tax incentives to reduce CO_2 emissions in transportation and minimize plastic waste generated by e-commerce. Consumers also have a central role to play, including by adapting their behaviour towards more conscious and sustainable consumption and encouraging businesses to prioritize sustainability in e-commerce. Likewise, international organizations can promote an environmentally sustainable e-commerce sector, including through research, capacity-building and training.

Drawing from the discussion in this chapter, including examples of good practice, the following recommendations for different stakeholders are proposed.

1. Promoting better e-commerce practices

Governments and businesses have complementary roles in advancing environmental sustainability. Governments can establish regulatory frameworks, provide incentives and engage in international cooperation. Businesses can drive innovation, adopt sustainable practices and engage with stakeholders to integrate sustainability considerations into their operations and strategies.

Sustainable *warehouse* practices are essential for reducing environmental impact and promoting resource efficiency within e-commerce. Governments can adopt economic incentives, such as tax rebates and reduced VAT, to encourage

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[17] Based on written inputs from Ying Tung Chan, Associate Professor, Bay Area International Business School, Beijing Normal University, 23 November 2023.

e-commerce companies to invest in resource-efficient infrastructure and effective waste management in warehouses. Meanwhile, businesses should invest in energy-efficient solutions. This may involve installing energy-efficient lighting and opting for renewable energy sources, such as solar or wind power, to power warehouse operations. Businesses should also implement good practices to effectively manage waste, for example by optimizing inventory management to minimize overstocking or reducing packaging waste. They should also seek to separate different types of waste to facilitate recycling and proper disposal, and regularly monitor waste generation and disposal practices to identify opportunities for improvement. For both governments and businesses, it is essential to address employment, safety, and working conditions for warehouse workers to ensure social sustainability across the supply chain.

In terms of sustainable *transportation and delivery*, Governments can introduce fiscal incentives to encourage e-commerce businesses to adopt eco-friendly delivery practices. This could include subsidies or tax breaks for investments in electric delivery vehicles and bikes, as well as support for low- and zero-emission zones. Exploring opportunities for integrating e-commerce deliveries with existing public transport networks or using public transport hubs as pick-up and drop-off points can help reduce vehicle miles travelled and promote sustainable transportation options. Furthermore, developing credible sustainability labelling (eco-labelling) can help reduce negative environmental impacts and uphold good labour standards in e-commerce logistics.

Efforts by businesses in this area are also important. These could include investing in electric delivery vehicles, cargo bikes, tricycles and scooters, alongside establishing charging infrastructure to support these eco-friendly alternatives. Businesses can incentivize more environmentally sensitive delivery methods, by encouraging consumers to choose slower and consolidated shipments to reduce emissions, optimize delivery routes, and offer click-and-collect options.

In terms of *packaging*, Governments should introduce legislations to regulate excessive e-commerce packaging, particularly focusing on reducing single-use packaging and cardboard boxes. A shift to more reusable, recyclable or biodegradable packaging can help to minimize waste and environmental harm. Initiatives promoting reusable containers, envelopes and capsules for product delivery are also recommended. E-commerce platforms and businesses have a key role in this context. They should seek to eliminate the use of single-use plastics and instead use, for example, carton boxes and recycled shredded paper instead of plastic fillers, thereby reducing the reliance on non-biodegradable materials. Additionally, unnecessary packaging should be avoided by removing extra boxes when the original product packaging adequately protects the item.

Mitigating excessive rates of *returns* is also needed to improve the sustainability of e-commerce. Prohibiting the use of free returns can help discourage unnecessary returns and reduce associated environmental costs. Governments should consider banning the destruction of returned, unsold and overproduced products, promoting reuse, repair and refurbishment. There should also be mandatory reporting requirements for e-commerce platforms and businesses to disclose sustainability-related information, including details on the quantity, types, location and volumes of products being destroyed, facilitating transparency and greater accountability of the industry.

E-commerce platforms and businesses can adopt various strategies to reduce the environmental impact of returns. First, they can charge a nominal fee for all returns and introduce fair use policies with limits on returns within specific time periods. Second, they can provide comprehensive product information and invest in technology such as augmented reality virtual try-on and product visualization applications to prevent early stage returns by enabling customers to make more informed purchasing decisions. Third, businesses should establish environmental sustainability frameworks for product returns and collaborating with organizations on circular economy initiatives to refurbish returned products for reuse.

2. Encouraging more environmentally conscious consumer behaviour

More sustainable consumer behaviour online can help to enable the demand for sustainable and ethically sourced products, minimize waste, conserve resources and enable a more sustainable lifestyle.

To this end, Governments can consider using legislation, regulations and guidelines that align with international standards to prevent false or misleading claims and greenwashing in online transactions. They can also mandate the adoption by e-commerce platforms and businesses of environmental or labels certified by reputable institutions, ensuring the credibility and reliability of sustainability information provided to online consumers.

Collaborating with e-commerce platforms, businesses and international organizations, governments can raise consumer awareness about the environmental impacts of consumption patterns and purchasing behaviour. Additionally, they should require e-commerce sellers to transparently disclose the environmental cost of their products, promoting greater accountability and informed decision-making among consumers.

Businesses should encourage environmentally conscious consumer behaviour in their buying decisions through targeted awareness campaigns to address negative omnichannel behaviours and highlight sustainable options. Discounts for sustainable packaging or slower shipping options could further encourage eco-friendly choices. For, transparency, businesses should present their sustainability attributes clearly and verifiably, potentially through recognized eco-labels.

3. Improving the evidence base for informed policymaking

Evidence is crucial for Governments. To make informed policy decisions, set realistic targets, and monitor progress, they require reliable evidence. Research-oriented initiatives should focus on innovative solutions along the entire e-commerce value chain. Policymakers could also establish mechanisms to collect relevant data on the environmental impact of e-commerce. This may be achieved by requiring companies to disclose information on their sustainability performance. Such data collection efforts would help to identify areas requiring improvement and track progress over time.

International organizations can also play an important role in this context. They can advance the understanding of the environmental impact of e-commerce and craft a comprehensive research agenda, tailored to countries at various stages of development. Collaboration among international organizations, academia, and industry stakeholders is also important for sharing data, research findings and successful strategies for integrating sustainability into e-commerce practices. Furthermore, partnerships with financial technology, e-commerce and digital companies should be fostered to drive investment in digital innovations that prioritize environmental and social sustainability, thereby advancing a more responsible and sustainable e-commerce ecosystem.

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The objective of any policy action taken should be to maximize the positive contribution of digitalization to sustainability and minimize its negative impacts, while ensuring inclusive development outcomes

Chapter VI

Towards environmentally sustainable digitalization that works for inclusive development

This chapter turns to the policy challenge of fostering environmentally sustainable digitalization that works for inclusive development. It stresses that policy responses at the national, regional and international levels are more likely to prove successful if they reflect the involvement of all stakeholders and address digital, socioeconomic and environmental goals holistically, across the entire life cycle of digital devices and ICT infrastructure.

Government strategies to mitigate GHG emissions, conserve water resources and reduce waste generation should also pay adequate attention to the environmental footprint of digitalization, as well as to how digital technologies can offer solutions to environmental concerns. Given the asymmetrical distribution of capabilities and resources, development partners are called upon to offer adequate support to low-income countries to strengthen their ability to participate effectively in a more circular global digital economy that is also environmentally sustainable.

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A. The need for a new policy mindset

This report has explored the relationship between digitalization and environmental sustainability, from the perspective of trade and development, with a view to moving towards a digital economy that leads to both environmental sustainability and inclusive development. The relationship between digitalization and environmental impact is bidirectional, in that digitalization has a significant and growing environmental footprint, yet digital solutions can also play a role in addressing environmental challenges. The report has mainly focused on the direct impacts of digitalization on environmental sustainability. Achieving environmentally sustainable digitalization requires government policies and consumer and business decisions that help to reduce unsustainable practices along the life cycle of digitalization, including production, use and end-of-life.

Digital and data divides are still widening, and various environmental costs associated with digitalization continue to rise. The new and complex interplay between digitalization, development and environmental sustainability points to the need for integrated policy responses that can help to bridge digital divides and ensure that technological progress contributes to socioeconomic equity while respecting planetary boundaries. At present, the world is not on track for achieving either inclusivity or sustainability.

For change to become a reality, a shift in mindset is needed. Business as usual is not an option. Exponential growth in digitalization and the associated demand for transition minerals cannot be sustained, as the reality of a finite planet is increasingly evident. The current linear economy model, based on extract-make-use-dispose, is exhausting its resources. This calls for a move towards a circular economy model based on the principles of reducing, reusing and recycling – approaches that favour reduced consumption and greater material recovery. Such a shift could also stimulate new economic activities and job opportunities, supporting inclusive development. Moving towards a circular digital economy would require changes in consumer behaviour and business models, as envisaged in Sustainable Development Goal 12.

This chapter explores actions by relevant stakeholders and options for policymaking to foster environmentally sustainable digitalization that works for inclusive development. Section B discusses the case for the integrated treatment of digitalization, environmental sustainability and inclusive development, as a key objective. Section C argues that this can be achieved through sustainable consumption and production, as well as moving towards a circular approach, which will require proactive policy support. Preconditions and fundamentals for better policymaking are discussed in section D, notably with regard to improving the understanding and evidence base of how to achieve environmentally sustainable digitalization that works for inclusive development. Section E summarizes policy options at different levels and stages of the digitalization life cycle. The final section discusses the role of international cooperation for collective action.

> The new and **complex interplay** between **digitalization, development and environmental sustainability** points to the need for integrated policy responses

B. Aligning digitalization, environmental sustainability and inclusive development

1. Complex and interconnected global challenges

The world is undergoing a deep transformation driven by many global forces, notably the rapid progress in digital technologies and the need to move towards environmental sustainability and low-carbon technologies. These two interrelated drivers are mutually reinforcing, with key implications for inclusive development. In light of the strong interface between digitalization and environmental sustainability, associated challenges therefore need to be assessed and addressed in an integrated manner.

A continuation of the current trajectories is not consistent with the need to comply with the **“planetary guardrails”**

The growing urgency to tackle these challenges has not yet been matched by a sufficiently integrated and overarching aim towards an inclusive and environmentally sustainable digital future. In fact, trends reviewed in this report leave little room for optimism:

- Many digital and data-related divides keep widening;
- Concentration of market power continues to grow in the digital economy and is expected to be further accentuated by increased reliance on AI;
- More digital devices are sold globally, and new digital networks and data centres are being built, increasing the demand and competition for raw materials, including minerals and metals, some of which are in scarce supply and environmentally and socially unsustainable practices persist in mining, processing and manufacturing for digitalization;
- The ICT sector is consuming increasing amounts of energy and water, contributing to GHG emissions and threatening water availability, including in locations where water resources are under significant stress;
- Digitalization-related waste is growing in volume, while levels of reuse, repair and recycling remain insufficient, contributing to pollution and environmental degradation, especially in developing countries;
- Major applications of digital innovations, such as e-commerce, while adding convenience for consumers and businesses, also contribute to unsustainable levels of consumption and negative environmental impacts.

A continuation of the current trajectories is not consistent with the need to comply with the “planetary guardrails” related to climate, biodiversity, soils and oceans. Many more people around the world are expected to come online, adding demand for digital devices and services. Furthermore, AI, IoT and augmented and virtual reality, among other emerging technologies, are only in their infancy. This makes it all the more important to consider how to reduce the direct environmental footprint of the ICT sector.

2. Towards a holistic, whole of life cycle and multi-stakeholder approach

Achieving environmentally sustainable digitalization that works for inclusive development requires international cooperation, with the engagement of many stakeholders. Digital transformation and environmental sustainability need to be considered jointly and holistically, to move humanity towards the sustainable development future envisaged by the United Nations Conference on Environment and Development in 1992, also known as the "Earth Summit", and in the 2030 Agenda for Sustainable Development. The transformation that the world is undergoing affects many spheres and is driven by several interconnected global forces.

Shaping an environmentally sustainable digital economy that is also inclusive is complex and requires the consideration of a range of dimensions, as follows:

- Digitalization can have positive and negative impacts on the environment. Environmentally sustainable digitalization involves direct effects from the production and use of digital technologies and indirect effects from changes enabled by digitalization in economic and social behaviour (complicated by rebound effects). Indirect effects also include societal impacts resulting from the ways in which those changes affect underlying economic and social structures. To date, measures to assess the net effect have not been available;
- Impacts occur at all stages in the life cycle of digital devices and infrastructure;
- Several environmental challenges emerge from digitalization, including in relation to the extraction and processing of natural resources, energy and water use and waste generation;
- Addressing these challenges requires the involvement and collaboration of diverse stakeholders, such as academia and civil society organizations that contribute research and insights into the effects of digitalization on environmental sustainability; Governments and international organizations that can set policies, standards and regulations in order to ensure the environmental and social sustainability of the digital economy; scientists and developers who can design products and services with the purpose of sustainability in mind; businesses throughout the digital life cycle that can produce goods and provide services on the basis of sustainability criteria; and consumers, whose choices both create and respond to market signals that affect the environment;
- Policy responses need to reflect the perspectives and priorities of countries at all levels of development.

Multi-stakeholder engagement for the necessary actions and policymaking has become increasingly important in both the environmental and digital domains in recent years. Enabling relevant actions and policies along the life cycle of digitalization is a joint responsibility for all stakeholders and all countries.

Enabling relevant actions and policies along the life cycle of digitalization is a joint responsibility for all stakeholders

The objective of any action taken should be to maximize the positive contribution of digitalization to sustainability and minimize its negative impacts, while ensuring inclusive development outcomes. Achieving this will require a new culture of sustainable digitalization and a change in mindsets and behaviours. It should be built on shared principles of sustainable consumption and production, and based on a circular economy approach. Uncertainties related to the severity of environmental challenges (including raw materials depletion, climate change and water scarcity), as well as the rapid evolution of digital technologies, will require all stakeholders to adjust to evolving circumstances. There is no time to waste. Decisions taken in the next few years will profoundly affect the digital economy and its environmental impact long into the future.

3. Harnessing the principle of common but differentiated responsibilities in the digital economy

The 2030 Agenda for Sustainable Development committed the global community to ensuring that no one, and no country, is left behind in the pursuit of sustainable development. Currently, benefits and costs from digitalization are asymmetrically distributed. Developed countries have gained much more from industrial development, including digitalization, than most developing countries. Most of the added value created in the digital economy is captured by developed and digitally advanced developing countries. They have also contributed far more to its environmental footprint. Conversely, many of the costs related to this footprint are incurred in lower-income countries. Developing countries are often locations of mining operations and the destination for digitalization-related waste and are particularly vulnerable to the impacts of climate change. There are risks that LDCs, in particular, will fall further behind in terms of inclusive digital development and environmental welfare. Policy responses will have to take into account the unequal ecological exchange and the situation of countries that are only at an early stage of digitalization.

> Policy responses will have to take into account the unequal ecological exchange and the situation of countries that are only at an early stage of digitalization

For the digital economy to be inclusive and environmentally sustainable, it must provide opportunities for Governments, businesses and citizens in developing countries to participate effectively in increasingly digitalized domestic markets, global value chains and trade. While there is a need at the global level to reduce the overconsumption of ICT goods and services, especially in developed countries and higher-income parts of society, bridging the digital divide and raising digitalization levels above the social floor remain critical preconditions for achieving equitable growth and prosperity.

Efforts to foster environmentally sustainable digitalization need to recognize that economies differ in their characteristics and abilities to engage in and benefit from the digital economy. Countries at different levels of development do not have the same capacities to address the challenges of digitalization and environmental sustainability. They also have specific needs to fulfil in order to meet their development objectives.

Worldwide, the digital economy is dominated by large digital corporations based in developed countries and in some developing countries in Asia. While the extraction of many essential minerals is concentrated in developing countries, including several LDCs, processing activities and manufacturing of ICT goods with higher value addition are overwhelmingly performed elsewhere. Similarly, global corporations that dominate the entire global data value chain, including data collection, storage and analysis, and related digital intelligence, are mainly concentrated in China and the United States (UNCTAD, 2021a).

Some developing countries have succeeded in nurturing dynamic digital sectors, generating growth and jobs by leveraging local expertise and lower costs. However, many developing countries may lack the resources and capabilities to compete directly with global manufacturers, network providers and platforms, and are vulnerable to international competitors that harness global reach and scale. Most developing countries remain involved in lower value addition activities and experience the related environmental consequences.

This situation raises concerns for developing countries, including the following:

- Developing countries rich in natural resources are often suppliers of unprocessed raw materials needed for digitalization, generating little domestic value addition while having to pay for imported digital equipment and services to meet digitalization needs;
- As connectivity and the use of digital technologies grow in developing countries, the digital data that are generated domestically provide opportunities for international digital platforms to produce digital intelligence that can be monetized, rather than for local businesses (UNCTAD, 2021a);
- Policies, regulations and standards adopted for the digital economy are often being shaped by and for developed countries. Norms and standards, which may become global in spite of the marginal participation of low-income countries in their development, risk being ill-adapted to their needs and capabilities;

- The digital divide between low-income and more advanced countries continues to widen.

Requirements related to more environmentally sustainable digitalization should not favour international corporations or businesses that may find it easier to finance or demonstrate environmental responsibility than businesses in developing countries. A more level playing field needs to be established for developing-country businesses to engage in global markets. This would imply improving the value they derive from low-value sectors, such as mining and digitalization-related waste management, as well as increasing their engagement in higher-value domestic and regional markets for digital products and services.

The principle of "common but differentiated responsibilities" is highly relevant in this context. It acknowledges that while all countries share a responsibility to address global environmental challenges, the extent and nature of that responsibility vary according to each country's past responsibilities, capabilities and level of development. Some international environmental agreements recognize that, while all countries have a common interest and responsibility to address environmental problems, the historic contribution of developing countries is significantly lower.[1] Regulatory powers and policy institutions are frequently much stronger in countries with large markets compared to those with smaller markets; this reduces the bargaining power of the latter in negotiations with global companies, reinforcing existing asymmetries.

Actions by relevant stakeholders and policymaking at all levels should be founded on the basis of this principle. The steps taken should factor in digitalization needs in less advanced economies and ways to achieve economic development and social welfare within the framework of the Sustainable Development Goals, while considering the constraints that Governments may face in implementing environmental sustainability policies.

> The principle of **"common but differentiated responsibilities"** is highly relevant

C. Fostering sustainable consumption and production in the digital economy

1. Applying the concept of sustainable consumption and production

Rapid digitalization has led to growing concerns about its environmental impacts, suggesting an urgent need to move towards more sustainable consumption and production. As stressed in *Global Resources Outlook 2024*, "it is no longer whether a transformation towards global sustainable resource consumption and production is necessary, but how to urgently make it happen" (UNEP and IRP, 2024).

The second United Nations Conference on Sustainable Development (Rio+20) in 2012 adopted a framework for sustainable consumption and production,[2] which was referred to in the 2030 Agenda for

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[1] See, for instance, principle 7 of the Rio Declaration on Environment and Development and article 3 of the United Nations Framework Convention on Climate Change.

[2] See https://sustainabledevelopment.un.org/content/documents/944brochure10yfp.pdf.

Sustainable Development.[3] Accordingly, targets for sustainable consumption and production under Goal 12 link these to economic prosperity, social welfare and human rights, but there is no explicit link within that context to digitalization.[4] However, the targets can usefully be applied in the digital context (box VI.1).

Environmental considerations have to date been given insufficient attention in relation to the consumption and production of digital products

Sustainable digitalization and sustainability by design should be at the core of any emerging global governance framework for digital technologies (UNEP, 2023b). Sustainable consumption and production are inherent in this approach. Governments and the wider stakeholder community should be encouraged to proactively shape the digital future, integrating digital and non-digital ways of achieving digital sufficiency and circularity rather than merely maximizing the reach of digital innovation (Digitalization for Sustainability, 2022).

The impacts of the digital economy depend significantly on the relationship between the consumers and producers of digital products and infrastructure, i.e. the individuals and organizations that buy goods and services and the businesses that design, make, sell and, ultimately, dispose of them. Governments can enable, promote, incentivize and regulate their behaviours to encourage environmentally sustainable practices and discourage those that are unsustainable. This can also be supported by actions by civil society.

Consumers and businesses are the principal actors in the growing digital economy and, consequently, play an important role in influencing sustainability

Consumers and businesses, including digital platforms, are the principal actors in the growing digital economy and, consequently, play an important role in influencing sustainability. Consumers have embraced new digital technologies, driven by the potential for improvements in their quality of life, leading to evolving lifestyles in response to digitalization. Businesses have prioritized the development of new digital products and services, and have sometimes made use of regulatory grey areas, to create new business models and markets to seize profit-making opportunities. Technology experts and developers have focused on innovations in response to such priorities. Governments, especially in digitally advanced economies, aim to maximize potential gains for national economies that can benefit their citizens and business communities.

In this context, environmental considerations have to date been given insufficient attention. Sustainable consumption and production should be placed at the centre of efforts to foster a sustainable digital economy. This will imply modifying modes of consumption and production, as well as adapting existing economic models. Discussions in this context are increasingly focusing on the need to achieve a more circular digital economy, moving away from the linear economy model of extract-make-use-dispose or the throw-away economy.

2. Fostering more sustainable consumption of digital products

Consumers of ICT goods and services are diverse, with different needs and priorities. Growing prosperity over many decades has led to increased consumption, and digitalization has exacerbated trends towards consumerism through digital advertising, e-commerce and digital delivery channels. Digitalization has increased the choice, convenience and availability of goods and services, often at reduced prices. Meanwhile, unsustainable practices by consumers relate, for example, to the frequent replacement of digital devices, although they may remain functional.

Consumer choices are driven by a number of factors, including cost, value for money, longevity, efficiency, convenience, capability and performance, as well as personal skills. Beyond these more objective factors, consumers may also be swayed by "perception", related to what ownership and use of a digital product represents and how

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[3] See https://www.un.org/sustainabledevelopment/sustainable-consumption-production/.

[4] See https://sdgs.un.org/2030agenda.

the consumer may be perceived in terms of status, fashion or identity. These drivers are primarily associated with cost and perceived enhancements in quality of life. While ethical and environmental considerations have resonance with some consumers, they do not yet substantially affect most individuals' consumption patterns. In order to increase the incentives for consumers to make more environmentally responsible choices, it will be important to ensure that such choices are attractive on the basis of affordability, efficiency convenience and style.

There appears to be new interest among some consumers in products that are environmentally friendly. As discussed in this report, a few recent surveys point to growing demand for more sustainable electronic products, especially among younger people. Consumers can and should be encouraged to take more responsibility for the environmental footprint of their own behaviour and lifestyles, but to do so they need awareness of the environmental impact of their consumption and its implications. Consumers also need information that enables them to make

> Ethical and environmental considerations do not yet substantially affect most individuals' consumption patterns

Box VI.1
Relevant targets of Sustainable Development Goal 12 on sustainable consumption and production for digitalization

Sustainable Development Goal 12 is particularly relevant to minimizing the environmental footprint of the digital economy. It points to the importance of utilizing the planet's scarce natural resources more responsibly, producing more sustainably and keeping consumption within the limits of planetary guardrails. Seven of its 11 targets are highly pertinent in relation to digitalization, as follows:

Achieve the sustainable management and efficient use of natural resources (target 12.2). For the digital economy, this requires measures to mitigate overconsumption and for sustainable mining, responsible production, effective waste management and a more circular digital economy.

Achieve the environmentally sound management of chemicals and all wastes (target 12.4). This concerns the management of waste related to digitalization.

Substantially reduce waste generation (target 12.5). This involves preventing, reducing, reusing and recycling digital devices and infrastructure, but can also extend to digitally enabled services that promote waste reduction.

Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle (target 12.6). This target relates to the need to develop a stronger evidence base on which to inform policymaking. Throughout the life cycle of digital products, there is a need for more standardized reporting, especially by the largest corporate players in the digital economy.

Promote public procurement practices that are sustainable (target 12.7). Governments can lead by example to ensure that the procurement of ICT goods and services takes into account their environmental footprints.

Ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles (target 12.8). This target underscores the importance of raising awareness about the environmental implications of the choices of consumers and of enabling a more circular digital economy. It could involve measures such as digital product passports.

Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production (target 12.a). This target involves strengthening international cooperation in areas that can enable developing countries to achieve more sustainable production of ICT goods and services.

Source: UNCTAD.

environmentally responsible decisions, and increased availability of environmentally sustainable goods and services.

One aim of sustainable consumption is to mitigate overconsumption and move away from an instinctive or compulsive use of digital technologies to a more controlled use that factors in both associated risks and opportunities. The concept of "digital sufficiency" includes the following four dimensions (Santarius et al., 2023): *hardware sufficiency*, aiming for lower demand and production of fewer devices, and keeping energy demand as low as possible to perform the desired task; *software sufficiency*, keeping data traffic and hardware utilization as low as possible; *user sufficiency*, with users applying digital devices frugally and using ICTs in a way that promotes sustainable lifestyles; and *economic sufficiency*, with digitalization supporting a transition to an economy characterized not by economic growth as the primary goal but by sufficient consumption and production within planetary boundaries. Changes of consumer behaviour in this direction may relate to the availability of, among others:

- Environmentally sustainable digital devices and services;
- Easier ways to acquire digital products responsibly and sustainably, aligning environmental sustainability with consumer preferences in terms of cost, convenience, capacity and image;
- Information that helps consumers understand environmental impacts regarding how different digital products are used, and how their environmental footprint could be reduced. This could lead to a more frugal use of connectivity, fewer connected IoT devices and less use of standby mode. In some contexts, it could involve using less sophisticated devices, such as those with smaller screens, or favouring standard telephone calls over video calls (Bordage, 2019);
- Possibilities for consumers to extend the lifespan of devices rather than frequently replacing them with newer, only marginally upgraded, models. This would require more opportunities to upgrade device components, replace batteries and reuse, repair, refurbish, resell and recycle devices. It would need to be supported by well-developed second-hand markets, the ability to obtain digital products as a service, convenient channels for collecting devices at end of use and appropriate information on how to dispose of them in an environmentally sound manner;
- More environmentally friendly online shopping practices, for example through ecofriendly delivery options and limiting free returns.
- Extending the lifetime of digital products can allow consumers to make monetary savings, restore efficiency and possibly add value. Consumers can also be empowered by their ability to contribute directly to environmental sustainability.[5]

Businesses and business associations are more likely to move towards more environmentally responsible digitalization business models if consumers demand more sustainable digital product options. Meanwhile, consumers may be interested in maintaining and protecting their devices, giving items a second life, valuing used items, engaging with reverse logistics (whereby a product is returned from the point of sale to the manufacturer or distributor for recovery, repair, recycling or disposal), valuing easy-to-repair products, repairing products and replacing batteries. Renting or sharing options could give users access to items, when necessary, without owning them.[6]

It is important for consumers to understand potential environmental impacts before

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[5] See https://www.oneplanetnetwork.org/sites/default/files/2023-02/23_02_02_PLE_Infographic_One%20Way.pdf.

[6] See https://www.oneplanetnetwork.org/sites/default/files/2023-02/23_02_02_PLE_Infographic_Players.pdf and https://www.oneplanetnetwork.org/sites/default/files/2023-02/23_02_02_PLE_Infographic_Eletronic.pdf.

buying, be informed about proper recycling and disposal at end of use and be aware of the environmental and human rights impacts of products over an entire supply chain. Consumers should also have the necessary information on how to opt for more rational, productive and environmentally sustainable ways of using the Internet, for example in terms of data storage involving pictures, streaming videos and sending messages.[7]

Individual consumers may think that their contribution to environmental impacts through digitalization is relatively small, and that individual actions or behaviours in this context do not matter, particularly if others do not act. Therefore, actions towards environmentally sustainable digitalization need to be a joint responsibility between Governments, producers and consumers, as discussed in the rest of this section.

3. Fostering sustainable production in the digital economy

In general, businesses in the ICT sector, as elsewhere, are mainly driven by the maximization of profits. In most cases this leads to a focus on market growth and innovations that will lead to creation of new products and improve economic efficiency and productivity in meeting consumer demand, encouraging the rapid roll-out of innovations without a detailed scrutiny of potential impacts on society or the environment. In the digital economy, network effects, which intensify value to users when networks are used by large numbers of people, have added pressure to bring new products and services to market early and helped to concentrate market power (UNCTAD, 2019a).

Some business models in the digital economy are distinct from those in other sectors in that they are modelled on the following two trends that actively work against sustainable consumption and production:

- Rapid technological change, which requires the frequent upgrading of infrastructure for digitalization and has sometimes encouraged obsolescence in digital products. The average lifetime of digital devices is often very short. This is of concern, as most of the environmental footprint of such devices is generated at the production stage;
- The revenue model for many digital platforms, particularly social media, is based on advertising revenue and on exploiting data gathered from customer interactions. This incentivizes platforms to maximize such interactions and, thereby, maximize exposure to advertising, which encourages excess consumption. Recommendation algorithms on e-commerce platforms can exacerbate this trend.

These business models lack strong incentives to economize on scarce resources and energy consumption or to facilitate environmental sustainability. There is, however, an alternative to this model. The Coalition for Digital Environmental Sustainability (CODES) Action Plan calls for the “mindset of maximizing shareholder value [to] evolve to a new set of values focusing on transparency, accountability and inclusive stakeholder engagement”, in which a “shared set of sustainability values and standards [is] encoded into the design, development and deployment of digital products, services, practices and business models” (CODES, 2022: 13). As argued by some scholars, there is a need to go even further in considering the social and environmental context, as “business models must profoundly change to foster the common good and overcome the existing growth fixation of the fossil and linear economy” (Digitalization for Sustainability, 2022: 82).

Actions towards environmentally sustainable digitalization need to be a joint responsibility between Governments, producers and consumers

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[7] For more detailed discussions on actions for sustainable consumption in the digitalization context see, for instance, Zibell et al. (2021) and Green IT (2022).

A new culture that recognizes the significance of environmental outcomes during the design phase of digital products could have a substantial impact over the entire digitalization life cycle. Platform service providers, for instance, could refocus algorithms and data management to optimize through efficient use of (environmental) resources rather than maximize potential business opportunities. Devices could be designed on the basis of environmental sustainability considerations. The modularization of devices would allow for their repair, reuse and refurbishment and make it easier, and more economically attractive, to recover components and scarce resources through recycling.

Most digital devices are not designed with environmental sustainability in mind

Most digital devices are not designed with environmental sustainability in mind. Standard-setting bodies in the digital sector have generally prioritized technical and economic efficiency, paying less attention to environmental impacts and externalities. This has stimulated innovation and benefited businesses developing new markets, but has led to outcomes that are often environmentally suboptimal. The digital economy encourages programmed obsolescence, as businesses upgrade digital products frequently rather than extending their lifespans. For much hardware, business models prioritize replacement rather than software upgrades or refurbishment, which would be more environmentally sustainable.

Similar issues relate to the design of online services, both those that are entirely digital and those that use digital resources to deliver non-digital goods and services. The ways in which these are configured and interface with customers affect the kinds of devices that end users require, the amount of energy they use and the environmental costs of delivering consumer goods that have been ordered. In addition, digital ecosystems that tend to lock in users not only stifle competition (Jacobides and Lianos, 2021; UNCTAD, 2021h), but can also limit consumer choices for more sustainable hardware and software solutions.

With encouragement or requirements from Governments, digital businesses could contribute towards a more environmentally sustainable digital economy by:

- Undertaking impact assessments of existing and new digital products with a view to optimizing environmental efficiency in their design, deployment and disposal. These should pay attention to the entire supply chain, from the sourcing of components through to marketing and data management and disposal;
- Collecting detailed information on environmental performance and impacts, and reporting them transparently. Ideally, technologies would include detailed manufacturing information, enabling an independent evaluation of the environmental footprint based on the provided input data. Independent scrutiny should ensure that data are not selected in such a way as to present companies in a more favourable light; ensure that greenwashing does not take place; and ensure a fair reflection of reality;
- Partnering with other businesses in supply chains and, where necessary with competitors, to minimize the use of scarce resources and optimize the use of data centres and of networks. For instance, in the case of the roll out of 5G mobile networks, competing network and service providers could be required to share the use of base stations (Pohl and Hinterholzer, 2023);
- Developing better systems for reuse and recycling, including collection and handling of waste, as well as separating different types of material, particularly plastics and transition minerals (Handke et al., 2019);
- Developing software with energy and resource efficiency in mind. This includes optimizing software applications for reduced power consumption and minimizing the computational resources required, thereby extending the life span of devices and lowering the overall environmental footprint (Atadoga et al., 2024).

High market concentration in the context of digitalization, for example, in the manufacturing of semiconductors and digital devices, the ownership of social media and e-commerce platforms and the provision of infrastructure networks and hyperscale data centres, give a small number of large companies huge influence over the options available to businesses throughout the supply chain. Changes in business models significantly affect their direct environmental footprints, as well as those of their suppliers, customers and other businesses dependent on the infrastructure, hardware and services that they provide. Improvements in the carbon efficiency of data centres, for instance, would have knock-on effects on the carbon efficiency of all businesses that rely on them.

Businesses may pay more attention to environmental impacts and adopt more sustainable business models if environmental issues become a more decisive consumer preference, and if consumers seek to influence choices in ways that are both commercially and environmentally sustainable. Business associations can encourage collaboration on more sustainable innovation and production by building consensus and establishing self-regulatory mechanisms, for instance concerning advertising.[8]

More broadly, sustainable innovation in the digital economy requires integrating environmental considerations into the development of new technologies. These include standard setting and the design, development and deployment of infrastructure, products and services by digital businesses, from the largest manufacturers and data corporations to start-up enterprises entering niche markets. Standards-setting bodies and product and service designers should consider and seek to mitigate potential negative environmental impacts. In particular, developers should be encouraged to apply designs that help economize on scarce resources, optimize energy and data storage or reduce the power requirements of consumer devices. Design for environmental sustainability should also help minimize the use of hazardous substances, enable more substantial recycling (for example, through more modular design) and the greater use of recycled materials and to the greatest extent allow digital products to be disassembled into their initial components.[9]

Producers can benefit from extending the lifetime of digital products, for example, in terms of reduced production costs and a smaller environmental footprint; increasing their product portfolio to include both new products and services such as repairing or remanufacturing; developing new business models; identifying ways to improve the design of future products; seizing opportunities to increase profitability by offering higher value added materials and products; contributing to corporate social responsibility and generating more job opportunities; and achieving customer loyalty.[10]

Businesses may pay more attention to environmental impacts and sustainable business models if environmental issues become a more decisive consumer preference

4. Moving towards circularity

Circular economy activities can offer a sustainable foundation for business models aimed at enhancing the longevity, utilization and overall lifetime of products, particularly in the context of digitalization and electronic devices. By prioritizing product life extension strategies, such as maintenance, repair, refurbishing and recycling, they reduce the need for new products and the corresponding extraction of raw materials, thereby cutting down

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[8] Examples of business initiatives in the context of environmentally sustainable digitalization include the Global Enabling Sustainability Initiative, the European Green Digital Coalition, the Global Electronics Council and the Circular Electronics Partnership.

[9] For a more detailed discussion of the role of businesses in moving from linear to circular economies, including in the electronics value chain, see UNEP (2021b).

[10] See footnotes 5 and 6.

on waste. They can also create valuable opportunities for economic growth and job creation within these areas. Thus, there is a business case for the move towards circularity,[11] which can contribute to inclusive development. Entrepreneurs can play a catalytical role in such a transition (UNCTAD, 2024b). The economic potential is reflected in the expected expansion of circular economy practices related to the electronics industry (see chapter IV).

Circularity needs to be already factored in at the innovation and design stage

In order to enable a more environmentally sustainable digital economy, circularity needs to be already factored in at the innovation and design stage. Progress towards a more circular digital economy could lead to the optimization of economic and environmental impacts of digitalization by:

- Reducing waste and pollution in extraction and processing;
- Encouraging the more frugal use of scarce resources in manufacturing;
- Increasing the use of renewable energy and reducing water use by data centres and network operators;
- Ensuring sufficient, adaptive and resilient infrastructure without excess capacity;
- Ensuring the repair, reuse, refurbishment and recycling of devices;
- Maximizing the recovery of material resources from digitalization-related waste.

While no economic process can be entirely circular, approaching business and digital product design in this way can embed more sustainable processes that encourage positive impacts and reduce adverse environmental effects. Circular economic thinking needs to be approached holistically, as reductions in environmental impacts at one stage of the digital life cycle may generate increased impacts at other stages. Attention must be paid to both the direct and indirect impacts of products and services.

Achieving greater circularity will require concerted action at all levels by Governments, businesses and consumers throughout the digital life cycle, including in designing digital platforms, products and services in ways that foster sustainable consumption by default and by encouraging sufficiency in the use of resources, promoting behavioural change among consumers and facilitating the recovery and reuse of resources to maximize their value.

All of this requires a reconsideration of how digital products make use of hardware and software and how to manage these components at the end of their life. Such an approach could provide new environmental, social and economic benefits. Value retention processes that can be adopted in this context could offer win-win opportunities for relevant stakeholders. Governments could benefit from having to deal with less waste while generating new environmentally sustainable jobs and stimulating economic growth. Producers could lower production costs, avoid resource constraints on business growth and open new markets, while customers could benefit from lower prices for refurbished products (UNEP, 2017).

5. The growing need for integrated policymaking

Self-regulation through corporate governance and voluntary agreements between digital businesses can contribute to a culture of environmentally sustainable digitalization among producers. However, relying solely on the free play of market forces is unlikely to be enough to prompt shifts in consumer or producer behaviour towards sustainability in the digital economy.

Significant policymaking efforts are needed to enable collective action, align with circular economy goals and promote the transition towards sustainability among consumers and producers. This will require a combination of policies, legislation, regulations, licences, mandatory requirements and fiscal incentives. Environmentally responsible behaviour can

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[11] The case for circular business models in the electronics industry is discussed in PwC Sweden (2023).

be encouraged through incentives and information campaigns, and unsustainable behaviours should be discouraged or halted.

Many Governments have adopted national strategies for digital development. These relate to national goals such as digital inclusion, promotion of digital sectors, digital trade that contributes to economic development and regulatory oversight of data protection and cybersecurity. In parallel, most Governments have also established strategies for environmental sustainability, in response to the Sustainable Development Goals, including multilateral agreements related to climate change, water, pollution and biodiversity, such as the nationally determined contributions under the Paris Agreement,[12] as well as various national priorities. These play a similar role in focusing government and stakeholder attention on environmental goals and how these relate to economic and social development.

To date, however, Governments have tended to address digitalization and environmental sustainability in silos. Digital strategies, where they have been adopted, typically focus on leveraging the digital economy to benefit national competitiveness, export markets and employment, and pay little attention to the environmental dimension. Environmental strategies, meanwhile, generally underestimate and fail to address the negative effects of digitalization. This needs to change.

Developing a stronger understanding of the relationship between the two areas, as discussed in the next section, and integrating policies for the transition to digital and low-carbon technologies, is critical to building environmentally sustainable digitalization that works for inclusive development. Digitalization and environmental sustainability strategies should be coherently considered as part of national development strategies.

Governments are responsible for overseeing and shaping economic relations, including digitalization and environmental sustainability developments, in the general interest of the societies they govern. This includes translating international and regional agreements and standards into national regulation. Policymakers can provide strategic leadership and shape public opinion. They can build environmental awareness within the business community and among consumers to encourage the adoption of environmentally responsible digital business models and consumer behaviour. Moreover, as major purchasers of digital products, Governments can set an example through public procurement. Governments and public service providers are high-volume consumers of digital products, wielding considerable procurement power as they seek value for money (box VI.2).

Several policy enablers could promote the objective of inclusive and environmentally sustainable digitalization in practice through the following:

- Broad-based and stronger understanding and awareness of the complex and varied impact of digitalization on the development of different countries, industries and communities, as well as on environmental sustainability;
- An underlying commitment from relevant stakeholders to the objectives of environmental sustainability, including a more circular economy;
- Willingness on the part of Governments, in close collaboration with the business community and civil society, to develop legal and regulatory frameworks that facilitate sustainable innovation and business development and promote sustainable consumption; and
- Institutional arrangements that embed a culture of environmentally sustainable digitalization into policymaking, design standards and business decision-making at a time of rapid technological and economic change.

> To date, Governments have tended to address digitalization and environmental sustainability in silos

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[12] See https://www.un.org/en/climatechange/all-about-ndcs.

Box VI.2

Towards environmentally sustainable procurement of digital products

The promotion of sustainable public procurement practices is one of the targets under Goal 12. Governments are increasingly moving public services online as complements to, or substitutes for, offline services. Digital products are also procured in large quantities in the private sector. Digitally enabled businesses (such as e-commerce retailers) would be unviable without digital devices and services. Other businesses that are highly dependent on digital transactions and data management, such as banks, acquire high-quality equipment in bulk and require reliable infrastructure, while all large businesses rely on digital resources to undertake transactions, manage operations and serve clients. A growing number of office workplaces make extensive use of telecommuting, teleconferencing and cloud storage.

Governments, as well as corporate consumers, should consider the environmental impacts of their activities. For example, they could undertake environmental audits of the ways in which they interact with suppliers and clients, with the aim of reducing environmental footprints. In particular, they should include environmental impacts in procurement policies and strategies along the same lines as public services and foster a culture of sustainability among employees throughout business operations.

Procurement practices can promote sustainability both directly, by including environmental goals within procurement decisions, and indirectly, by acting as an example to other decision makers. Environmentally sustainable procurement can have economic benefits if equipment with a longer active life proves cheaper over its life cycle than alternatives.

Procurement policies should favour products and services that minimize impacts related to energy and water use, and waste across the digital life cycle. For example, in Argentina, the National Information Technology Office and the National Procurement Office work jointly to promote circular and sustainable ICT procurement by public administrations. In India, the Government e-market place for digital procurement promotes sustainable procurement by targeting and prioritizing the listing and availability of environmentally sustainable products and services, with filters to help government buyers identify sustainable options (ITU, 2023b). In Spain, the Barcelona City Council is working towards minimizing the environmental impact of the use of ICT equipment needed for municipal services.[a]

Tender requirements that prioritize or incentivize environmental responsibility can have a significant impact on businesses seeking public sector contracts, particularly if these require compliance with internationally agreed norms, as well as national priorities. Governments should include environmental impact assessments in tender criteria and evaluation, encourage contracted suppliers to include similar assessments in their procurement processes and require them to report regularly on the environmental impacts of their public service work.

United Nations agencies should adopt similar criteria in order that their procurement efforts integrate sustainability across the board (UNEP, 2023b). Criteria and good practices for sustainable procurement should be consolidated and shared among Member States and United Nations agencies. The CODES Action Plan calls for the establishment of an international framework to enable standardization and harmonization of sustainable procurement principles and green digital infrastructure across Governments and corporations (CODES, 2022).

To this end, ITU, in a circular on the sustainable procurement of ICT equipment, offers comprehensive guidance on embedding sustainability and circular economy principles into public sector procurement practices, emphasizing the importance of developing policies and strategies that not only align with international sustainability standards but actively promote innovation and sustainability in the ICT sector (ITU, 2023b). This approach is important for reducing environmental footprints and fostering a culture of sustainability within public procurement processes. UNEP has also launched the Circular and Fair ICT Pact, a procurement-led partnership to accelerate the transition to a sustainable ICT sector.[b]

Source: UNCTAD, based on sources cited.

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[a] See https://www.ajsosteniblebcn.cat/ins_eng_c_ict_maq_68272.pdf.
[b] For more information, see van Geet et al. (2022).

Proactive policy frameworks are needed to achieve significant and sustainable changes in consumer behaviour, particularly where lifestyle choices are affected (UNEP, 2023b). Governments have the capacity to influence, or nudge, consumer behaviour towards more environmentally responsible practices. Importantly, they are also uniquely positioned to address collective action problems and facilitate coordinated efforts that individual actions alone cannot achieve. This can be done through a variety of mechanisms, including those that are designed to make environmentally responsible behaviour more attractive (Digitalization for Sustainability, 2022). Choices available to consumers in the digital economy are greatly influenced by businesses. The most powerful levers that Governments and international organizations can apply towards an environmentally sustainable digital economy that works for development are therefore those aimed at shaping and, when necessary, regulating business models towards sustainability.[13]

> Governments have the capacity to influence consumer behaviour towards more environmentally responsible practices

D. Preconditions for policymaking

The challenges at the digitalization and environmental sustainability nexus are complex and interdependent. Overall, actions by stakeholders and policymaking at all levels in pursuit of the common goal of an environmentally sustainable digital future that works for inclusive development should be based on various fundamentals, as presented in box VI.3. These fundamentals should inform the work of all stakeholders concerned. Two enabling factors can be seen as preconditions for the effective implementation of actions in this area: first, an enhanced understanding of the impacts of digitalization on the environment, founded on a robust evidence base, to inform policymaking and decisions by other stakeholders; and second, broad-based awareness of the critical issues.

1. Improving the understanding of how digitalization impacts the environment

Understanding of the impacts of digitalization on environmental sustainability remains limited. More research and analysis are needed to build the evidence base. Extensive, reliable and timely information is required to raise awareness and enable Governments, businesses and consumers to gain confidence that their actions will bring economic, social and environmental gains.

As shown in this report, while there is a considerable amount of data gathering and modelling of digitalization and environmental impacts, this evidence base has several weaknesses:

- Some environmental concerns (notably related to carbon emissions) are more extensively researched than others (such as water use and digitalization-related waste) and this risks that processes are optimized only in these domains, potentially leading to “greenwashing”;
- In certain areas, such as digitalization-related waste, data-related challenges include incomplete reporting, ambiguous definitions, incorrect categorizations and inaccuracies; lack of data is particularly acute in the case of waste because a significant part is managed in informal settings and through illegal channels, particularly in transboundary flows;
- Much of the information available draws on data predominantly from developed countries;
- Some oft-cited results have been derived using models of data collection and

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[13] For a detailed discussion of how sustainability is governed throughout the electronics value chain, see Evans and Vermeulen (2021).

Box VI.3
Fundamentals for informed policymaking

Establishing a commonly agreed understanding of the need for new policies is vital to ensure that the development of the digital economy aligns with broader goals of environmental sustainability, inclusivity and equity. Public policy to bolster development gains from the growth of a national digital economy is more likely to succeed if it is part of an overarching strategy designed with economic inclusion and environmental sustainability in mind.

Drawing on the analysis in this report, eight broad fundamentals are proposed that could serve as the basis of an inclusive and environmentally sustainable digital economy that contributes both to prosperity for all and to improved environmental outcomes.

Policies and practices to promote the digital economy should:

1. Integrate economic, environmental and other goals related to sustainable development, including principles of geographical and social inclusion, intergenerational equity and the protection of planetary boundaries, which were established as global priorities at the United Nations Conference on Environment and Development in 1992 and reinforced in the 2030 Agenda for Sustainable Development;
2. Recognize disparities in living standards and resource use within and between countries at different levels of development and the need to expand opportunities for disadvantaged groups, including women, youth and marginalized communities, in line with the pledge in the 2030 Agenda that no one will be left behind;
3. Understand that economic development that is not environmentally sustainable will be economically unsustainable, that responsible innovation and the deployment of technology should optimize rather than maximize the use of digital devices and services and that environmental considerations should be incorporated into national strategies for digital development and in the design, development and delivery of products and services, as part of national development strategies;
4. Consider the whole life cycle of digital equipment and infrastructure, including the extraction and processing of material resources and the manufacturing, distribution, use and disposal of devices, identifying ways to minimize and mitigate negative environmental impacts at each stage and facilitate a more circular digital economy;
5. Consider the full range of environmental impacts, including direct, indirect, rebound and societal effects, identify ways to optimize beneficial applications and minimize those that are inequitable or environmentally harmful and pay attention to the interface between policies concerned directly with the digital economy and those concerned with other social and economic domains affected by it (such as transport, energy, housing and urban development);
6. Involve all stakeholders in the shared endeavour to achieve a sustainable digital economy, reflecting the views and needs of consumers alongside those of policymakers, businesses and civil society in general, and building environmental expertise into the development of policies, standards and business models from the outset and develop relevant statistics to inform policymaking;
7. Be consistent with relevant United Nations and international goals, including those concerned with human rights, gender equity, poverty reduction and consumer welfare, particularly the targets under the Sustainable Development Goals and relevant international digital and environmental agreements;
8. Be agile, capable of responding and adapting to changes in the context of the digital economy, including technological developments (such as new opportunities to address environmental problems emerging through the use of AI) and trade-related, environmental and social developments.

Source: UNCTAD.

analysis that reflect the interests of those funding and publishing the research; and

- Methodology and models are frequently inconsistent in terms of assumptions, scope and definitions, leading to widely different estimates of impacts and potential outcomes (see assessments of GHG emissions and energy consumption in previous chapters).

Reliable and comparable information on the environmental impacts of digital products can be provided by both Governments and businesses, for example, through product labels and in marketing literature. Independent information and trustworthy, consumer-friendly digital product reviews and ratings are desirable, as well as search filters that make it easier for consumers to identify environmentally positive options.

Addressing information and research deficits will help focus efforts towards building a more reliable, comprehensive picture of the environmental impacts of the digital economy. There are important responsibilities for Governments, businesses and the research community. Major objectives in this context include:

- *Developing standardized assessment methodologies and indicators* that enable comparisons between different companies and countries, as well as aggregation at the business sector, national and global levels. It is important to incorporate multiple criteria into these methodologies, to consider the broad spectrum of environmental indicators across the life cycle of digital products. Such an approach can help ensure a holistic assessment of the digitalization footprint, encompassing not only energy consumption and GHG emissions but also factors such as water use, resource depletion and pollution. This is crucial for developing targeted, effective policies that address the multifaceted environmental implications of digitalization and for preventing greenwashing. The life-cycle assessment standards developed by the International Organization for Standardization (ISO), such as ISO 14040 and ISO 14044, can be particularly useful in this context as they provide a comprehensive framework for evaluating multiple direct environmental impacts of digital products throughout their life cycles.

  Similarly, increased standardization in assessing indirect environmental impacts from digitalization in other sectors will be necessary. An initial, single-criteria framework has been proposed by ITU in a recommendation on assessing the impacts of ICT on GHG emissions in other sectors (ITU, 2022). Digital standard-setting agencies and environmental organizations, including those concerned with sectors that are particularly affected by digitalization such as energy and transport, should be strengthened. This would enable more environmentally sustainable frameworks to arise for the design of networks and infrastructure, especially where standards are likely to become universal (as, for example, with the next generation of infrastructure for mobile communications and those concerned with innovations in AI).

  The CODES Action Plan proposes an impact initiative aimed at developing a new, multi-stakeholder and globally representative platform to co-define key standards for sustainable digitalization and economic circularity. This “clearing house” would seek to create an up-to-date, authoritative overview of global digital standards, to address key gaps, and conduct outreach to enable effective implementation by all concerned parties (CODES, 2022). While it will take time to reach agreement on relevant methodologies in all areas, Governments, researchers and businesses can work with international agencies, including ISO, the International Electrotechnical Commission, the Institute of Electrical and Electronics Engineers and the ITU Telecommunication Standardization Sector to agree on assessment approaches for particular aspects of environmental sustainability in the digital economy, including under-researched areas such as water use and waste.[14] International organizations should work with business associations and consumer bodies to develop standardized data sets and indicators that are consistent with relevant global goals, to establish norms for data transparency applicable to global corporations, promote the use of internationally comparable data and support enhanced analytical capacity in national statistical networks.

- *Promoting effective data collection in all jurisdictions*. At present, data collection on the digital economy and its environmental impacts is concentrated in developed countries. Their experiences often differ substantially from those of the majority of developing countries, especially low-income countries. Effective policymaking requires more data and analysis in developing countries, reflecting local circumstances and priorities;
- *Fostering greater transparency among businesses* throughout the life cycle of digital devices and infrastructure, particularly corporations whose activities have a global reach (such as those that manufacture semiconductors and end-user digital devices, manage hyperscale data centres or develop AI applications). Their environmental performance should be reported transparently and comprehensively, in ways that enhance understanding and policy development rather than seeking to manage public opinion or regulatory outcomes. Transparency requirements can be established through normative agreements between government and business or mandated through legislation and regulation. This would be valuable for policymakers and consumers, as well as for businesses, and help to identify improvements to business models that would be commercially as well as environmentally beneficial. Another way to enhance the global evidence base on the interface between digitalization and climate change would be for the UNFCCC to extend its emissions monitoring to encompass the ICT sector. Monitoring is focused on the energy sector, industrial processes and products, agriculture and waste (UNFCCC, 2018); the inclusion of the ICT sector in monitoring efforts would provide valuable data, to inform sustainable practices within the sector. However, this would require a sufficiently wide definition of the ICT sector and systematic tracking of the carbon footprint;
- *Improving data collection and assessment methodologies* with regard to emerging technologies and services, including AI and cryptocurrencies. In the case of AI, recent research points to the need for more granular data to assess the environmental impacts of different stages of the life cycle of machine learning (Kneese, 2024; Luccioni et al., 2023). In addition, developers of AI could be obliged to report on the energy demand and carbon emissions of their models. There are already software tools and metrics available for reporting on model accuracy (Anthony et al., 2020). In the case of cryptocurrencies, the United States Energy Information Administration aims to estimate and manage the electricity consumption of cryptocurrency mining operations more accurately. This research involves both top-down and bottom-up methodologies for estimating energy use, with data sourced from the Cambridge Centre for Alternative Finance and directly from mining facilities (United States, Energy Information Administration, 2024). While such innovations can greatly influence the development of the digital economy during the next decade, they can also substantially contribute to its environmental footprint. Associated environmental impacts need to be carefully monitored so that businesses can identify ways of maximizing energy efficiency at an early stage and Governments can take necessary

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[14] For example, the 2022 Harmonized System amendments by the World Customs Organization (WCO) include classification provisions for e-waste, which simplify identification (WCO, 2019).

action to manage energy and water markets in the face of rising demand;

- *Increasing independent research and data analysis* by institutions concerned primarily with public interest outcomes. Much of the current data analysis comes from businesses and business associations that have privileged access to data and may wish to emphasize positive outcomes. Independent data analysis is essential if policymaking is to avoid capture by vested interests. It should include consumer bodies, academia, independent research institutions and think tanks, and should draw on both environmental and digital expertise. Findings should be widely publicized in order to build awareness, inform policymaking and facilitate consumer choice.

Governments should enforce transparency and accountability to combat greenwashing, ensuring that businesses substantiate environmental claims, to support informed and sustainable consumer choices (box VI.4).

The need to improve the evidence base should not be used as an excuse for inaction today. The underlying evidence that is currently available is sufficiently clear to establish the need for urgent action to reduce the environmental impacts of digital technology, build awareness and put policies in place to enhance sustainability.

2. Raising awareness of the environmental footprint of digitalization

Only recently has increasing attention been given to the environmental footprint of digitalization. As a result, there is limited awareness among most stakeholders of how different digital products and their use may impact the environment. Greater awareness is needed to foster more sustainable consumption and production in this area.

As noted, stakeholders in the digital economy are primarily driven by priorities other than environmental considerations. Addressing the goal of environmentally sustainable digitalization that works for inclusive development requires shared awareness and understanding by all stakeholders. In an ideal scenario, improved consumer awareness of the implications of their choices leads to changes in buying behaviour as well as foster greater political awareness and action, creating a virtuous circle through which increased public pressure encourages businesses to adopt more sustainable practices. Civil society plays a significant role in raising awareness and influencing public opinion on these issues, providing the necessary impetus for businesses and policymakers to take action.[15]

While understanding has been growing in recent years, achieving greater comprehension and appreciation of the importance of the environmental footprint of digitalization is not straightforward, for several reasons:

- Some of the impacts that threaten future generations (such as those related to climate change) include gradual, long-term processes that can be easily sidelined by short-term economic or political objectives. It is important to ensure a long-term recognition that economic and environmental goals are interdependent and central to policymaking. Over time, gains in economic value can become economically unsustainable if they are not also environmentally sustainable;
- The relationship between positive and negative environmental impacts is often presented as a trade-off, that is, increased energy consumption for digitalization can be tolerated, for instance, if it enables decreased energy consumption through energy efficiency in other sectors. While such trade-offs are valid, there may be rebound effects, as greater

There is limited awareness among most stakeholders of how digital products and their use may impact the environment

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[15] For example, civil society organizations such as Stop Planned Obsolescence and the Right to Repair Movement are important in raising awareness about unsustainable business practices with regard to digital products.

efficiency tends to induce consumption. Environmental impacts are also complex and interrelated. Relevant impacts for society arise from the production, distribution, consumption and disposal of digital devices and infrastructure. They also include broader impacts on the future of urban centres, public transport, workplaces, employment, taxation and overall national economic development. Thinking about trade-offs may encourage complacency. Potential environmental

Box VI.4
Protecting consumers against greenwashing

The rapid expansion of digital retail has drawn attention to the issue of “greenwashing”, where businesses inaccurately claim that their products are environmentally sustainable, exploiting consumer interest in “green outcomes” (United Nations, 2023c). This practice not only misleads eco-conscious consumers but adds to traditional consumer protection concerns regarding data privacy, misleading marketing and fraud. To mitigate greenwashing and promote genuinely sustainable consumer choices requires a multifaceted approach, combining government regulation, industry standards and consumer education.

Governments can address greenwashing by mandating standardized environmental reporting by businesses, including for product comparison, exposing false claims through published data and holding non-compliant companies accountable. This requires establishing clear regulations and guidance to limit and verify green marketing claims, possibly through a pre-market control mechanism, to ensure claims are substantiated (Consumers International and International Institute for Sustainable Development, 2023).

Industry self-regulation, guided by advertising standards set by organizations such as the International Chamber of Commerce and the World Federation of Advertisers, can also play a crucial role in curbing false claims and facilitating consumer complaint resolution (ICC, 2021; World Federation of Advertisers, 2022). The United Nations Guidelines for Consumer Protection do not explicitly mention greenwashing, but recommend updating consumer protection policies for the digital marketplace (United Nations, 2016). The United Nations High-Level Expert Group on the Net-Zero Emissions Commitments of Non-State Entities (2022) has called for an end to greenwashing and for regulation starting with large corporate emitters, including assurance on their net zero pledges and mandatory annual progress reporting.

Despite such efforts, dedicated legislation targeting environmental claims in e-commerce remains limited. In 2022, over 80 per cent of respondents to a questionnaire on green claims reported a lack of specific laws or regulations for addressing environmental claims in e-commerce. These respondents were from consumer protection agencies in countries that are members of a working group on consumer protection in e-commerce, under the UNCTAD Intergovernmental Group of Experts on Consumer Protection Law and Policy. However, almost two thirds said that educational materials to raise awareness among consumers and businesses in this area had been or were being developed (UNCTAD and Superintendence of Industry and Commerce of Colombia, 2022).

Notable efforts to address greenwashing include UNEP guidelines on regulatory frameworks (UNEP, 2023c) and proposed rules by the European Commission for substantiating green claims (European Commission, 2023b). On the national level, for example, the United Kingdom and the United States introduced the green claims code in the former (United Kingdom, Competition and Markets Authority, 2021) and the guides for environmental marketing claims in the latter (United States, Federal Trade Commission, 2012). In Asia, important steps to mitigate greenwashing have been taken by China, India, Malaysia and Singapore.[a]

Source: UNCTAD, based on sources cited.

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[a] See, for example, File (2023).

benefits from digitalization should not undermine the need to minimize its environmental costs, for example, by designing more energy-efficient devices and services. On the contrary, policies should be complementary, focusing innovation on approaches that optimize both digital and environmental outcomes;

- Some Governments, businesses and individuals may see their contributions to global environmental impacts as marginal. Individual consumers, in particular, may feel that adjusting their behaviour (at a personal cost) will have little or no effect unless everyone else does likewise. This suggests that awareness and exhortation alone are unlikely to change the behaviour of most businesses or consumers on their own. Incentives and regulations will also be required;
- Governments should take steps to build knowledge and understanding of environmental impacts, and of the role that individuals and businesses can play in mitigation. This can be achieved through public education and information campaigns, and by requiring businesses to be transparent about their impacts in marketing and packaging. For example, digital applications embedded in social media and e-commerce platforms, which involve product comparability, ethical nudging, gamification, carbon footprint calculators and positive feedback loops, can be used to raise awareness (CODES, 2022). One example is providing information that allows for the circularity of a product to be traced, which would also enable consumers to be aware of the composition of products (box VI.5).

Box VI.5
Towards better tracing of the circularity of digital products

Currently there is no international agreement on the product information needed to facilitate digital circularity, but steps in this direction are being taken. A variety of approaches exist or are in development, to introduce digital product passports in corporate, policy and research activities, as reviewed by Jansen et al. (2022).

The European Commission is consulting on proposals to trace digital products throughout their life cycle in order to facilitate decarbonization, recycling and a more circular economy. The proposed digital product passport will bring together information about the components, materials and chemical substances, repairability, spare parts and professional disposal requirements of a product with the aim of improving durability, repairability and upgradability. The legislation will be introduced as part of the European Commission Circular Economy Action Plan, adopted in 2020, and will require companies to create passports for certain products (European Commission, 2022b; University of Cambridge Institute for Sustainability Leadership and Wuppertal Institute, 2022).

Similar principles can be applied to software. In Germany, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2020) has initiated the “blue angel” label for software with the aim of encouraging applications that are more power- and resource-efficient during use.

ITU is also working on developing standards to describe the information that should be contained in a sustainability passport for digital products (ITU, 2021b). Measures such as these offer a potential way for Governments with sufficient regulatory capacity to improve the circularity of digital product markets.

Source: UNCTAD, based on sources cited.

E. Policy options

The need for a holistic, whole of life cycle, multi-stakeholder and interdisciplinary approach to environmentally sustainable digitalization implies that multiple policy areas need to be considered in an integrated manner. Many of them have been discussed in this report. This section provides a summary of such policy options, then delves into some relevant aspects of policies in the three main phases of the digitalization life cycle.

1. Overview of policy options

The appropriate balance between different legislative, regulatory and collaborative instruments depends on the scale and nature of digitalization in each national economy, the extent to which policymakers can influence the behaviour of international businesses and the institutional capacity for data gathering, analysis and policy enforcement. Mandatory requirements, through legislation, licencing or regulation, are particularly important where service providers are virtual monopolies. These are also needed when competition between businesses acts as a disincentive to sustainable production, for example, when marketing strategies rely on frequently offering customers new features or service improvements.

Digitalization and environmental sustainability policies should be updated and integrated into national development strategies

Digitalization and environmental sustainability policies should be updated to achieve an integrated treatment of their interdependent goals, as part of coherent national development strategies. For example, with regard to integrating digitalization and environmental sustainability, in 2020, the Government of France created an Interministerial Mission for an Eco-Responsible Digitalization and a policy framework that comprises of various regulations related to eco-responsible public services, digitalization-related waste and the circular economy and reducing the environmental footprint of digitalization. This includes banning programmed obsolescence and reducing energy consumption in data centres.[16] The Government of Germany has been moving in this direction through the Digital Policy Agenda for the Environment (Germany, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2020). These trends have extended to the European Union, which has been integrating various policies in relation to digitalization and environmental sustainability, as discussed in this report. The European Union states that "Europe's digital transition goes hand in hand with the European Green Deal".[17] Outside of Europe, the Republic of Korea is introducing a green agenda for national policy initiatives and aligning its green ICT strategy with national GHG reduction targets.[18]

Coordinated strategies should draw on expertise from policymakers, business and civil society in economic, digital and environmental domains. A holistic, interdisciplinary policy approach is key. Policy options should include realistic and achievable goals with targets and indicators for monitoring progress, mechanisms for data gathering and analysis and clarification of how different instruments of governance can be applied to support sustainable consumption and production, including by promoting a more circular digital economy. Countries have already designed and adopted a number of policy initiatives, which point to progress in this direction, but there are significant

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[16] See https://ecoresponsable.numerique.gouv.fr/r%C3%A9glementations/ and https://www.ecologie.gouv.fr/politiques/consommation-et-production-responsables.

[17] See https://digital-strategy.ec.europa.eu/en/policies/green-digital.

[18] See https://www.wbgkggtf.org/node/3560.

challenges when it comes to implementation and enforcement. It is also important to strengthen accountability channels and capacity-building for enforcement.

A summary of policy options discussed in this report, at the national, regional and international levels and in the different phases of the digitalization life cycle, to enable a circular digital economy and to promote the more sustainable consumption and production of digital products and ICT infrastructure, is presented in table VI.1.

There is no one-size-fits-all approach that can be applied, and a plethora of policy options are presented in the table. As countries are at different stages of economic and digital development, the impact of digitalization on the environment varies, as do development priorities. Countries need to prioritize policy options, domestically and internationally, according to their environmental sustainability, digitalization and socioeconomic development needs. Any international approach should be based on the principle of common but differential responsibilities and consider respective capacities and needs. A wide range of instruments is available for policymakers to consider (see table VI.2). The effectiveness of different instruments, and the balance between them, will vary between national contexts, not least because of the different capacities of Governments to influence or enforce other stakeholders' compliance.

2. Managing growing demand for transition minerals sustainably and inclusively

The demand for transition minerals, required for both digitalization and low-carbon technologies, is expected to rise rapidly, regardless of improvements in environmental efficiency. This is due to increased capabilities and deployment of infrastructure, hardware and data analysis. Surging demand puts pressure on the production process, especially as there is a finite supply of transition minerals, and some may be approaching scarcity (see chapter II). Mining activities can often have direct negative impacts on local environments, including through the exploitation of limited water resources, pollution, deforestation and other adverse ecosystem effects. Poor employment practices and violations of human rights, including child labour, are widespread. This underlines the need to foster sustainable mining practices.

Policies and business practices need improvement at all stages of the digitalization life cycle to maximize the efficiency with which scarce resources are exploited and used. These should aim to strike a better balance between the interests of producing and processing countries and businesses, local communities and the local environment. Mining and processing companies need to apply more sustainable practices. Manufacturers need to develop ways of using resources in smaller quantities and make products that are easier to maintain, disassemble and recycle, thereby reducing consumption and improving the recovery of components at the disposal stage. Greater investment is required in recycling and recovery capacity, including for urban mining, worldwide, notably in developing countries.

Market forces alone cannot create the conditions for transition mineral to become a source of development and benefit everyone

Market forces alone cannot generate the conditions for transition mineral resources to become a source of development and benefit everyone.While there is no universally applicable approach, Governments in transition mineral-producing countries could pay attention to the following issues.

Ensuring a fair distribution of the rents from mining activities. This implies addressing inequality with foreign investors, reviewing fiscal regimes to improve fiscal linkages and transparency and increasing domestic resource mobilization. Given that other linkages in mineral extraction, for example in terms of job creation, are relatively weak, fiscal linkages are key for development. Developing countries have often not obtained a fair share of the rents from extractive industries, mostly due to limited bargaining power to negotiate mining agreements (UNCTAD, 2010, 2014). Doing so may require efforts to bolster institutional capacity to engage in contract negotiations

Table VI.1
Summary of policy objectives and options at national, regional and international levels, by stage of the digitalization life cycle

Phase of digitalization life cycle		Policy options		
	Objective	**National**	**Regional**	**International**
Production	• Environmentally sustainable and responsible mining and electronics manufacturing, while enabling more domestic value addition for economic development in producing countries	• Improve information on mining resources for exploration • Promote mining contract negotiations for equitable distribution of rents from mining of transition minerals • Develop industrial policies to support value addition of raw materials extracted and move towards manufacturing • Develop technology policy for research on more sustainable substitute materials • Ban use of toxic materials • Incentivize and promote use of recycled materials, supporting development of secondary markets • Require producers to report transparently on their environmental footprints	• Foster regional cooperation to increase negotiating power in mining contracts and regional tax regimes • Develop regional industrial policies for value addition in developing countries	• Develop standards for responsible and sustainable mining and electronics manufacturing • Limit use of minerals that may be a source of conflict • Adopt and apply global transparency standards • Collaborate for improved geological and mining data • Establish sustainable development licences to operate mining activities • Negotiate international tax regime that works for equitable distribution of rents among producers and consumers • Enable international cooperation among consumer and producer countries of transition minerals and metals
Use	• Optimize data centre performance to minimize impacts on energy and water, as well as on local communities • Optimize software to reduce energy use • Reduce overconsumption • Incentivize and promote meaningful, effective and productive use of digital tools and equipment • Bridge digital and data divides	• Raise awareness of environmental implications of different kinds of use (e.g., AI) • Develop policies to counter and ban greenwashing • Require sharing of network infrastructure • Require data centres to report holistically on environmental impacts • Mitigate excessive data storage • Adopt technology policy to foster and meet requirements of energy and water use efficiency in data centres • Require investments by hyperscale data centres in renewable energy to feed local grids • Promote water conservation in data centres, minimizing use of water for cooling	• Consider regional data centres as a more efficient option for the environment • Undertake needs assessment and identification of locations for regional data centres based on potential environmental impact	• Develop global reporting standards on environmental impacts • Foster global data governance, including environmental sustainability considerations • Strengthen international cooperation on bridging digital and data divides and building digital and environmental capabilities in developing countries • Strengthen international cooperation on competition policies to address abuse of market power in the digital economy

Phase of digitalization life cycle		Policy options		
	Objective	National	Regional	International
End-of-life	• Prevent and minimize digitalization-related waste and increase recovery of resources and value from such waste	• Adopt and enforce e-waste policy, legislation and regulations, to improve collection and recycling rates • Improve data and information on digitalization-related waste • Build waste management infrastructure • Apply extended producer responsibility mechanisms • Improve working conditions in waste management sector, moving towards formalization	• Develop regional recycling facilities, particularly in developing countries, to enable shift to higher value addition in digitalization-related waste value chain and better recovery of valuable resources • Facilitate collaboration in waste management, sharing technology and best practices	• Improve data and information on digitalization-related waste • Develop global standards for circularity • Ensure compliance with rules of Basel Convention for transboundary flows, to prevent illegal exports of digitalization-related waste • Consider transferring extended producer responsibility in transboundary flows of used equipment and/or extending geographical scope
All phases	• Enable, promote and regulate sustainable consumption and production and the circular digital economy through policies for reducing, reusing and recycling	• Implement circular economy policy approaches throughout digitalization life cycle • Strengthen integration of environmental sustainability and digital development aspects, in a coherent manner, in national development strategies • Regulate to require the following: ICT products designed for circularity and sustainability; avoidance of programmed obsolescence; extended product durability; right to repair; traceability of products, including components and raw materials (e.g., through digital product/material passports); and higher levels of recycling • Incentivize and promote new sustainable business models (e.g., electronic products as a service) • Develop collaboration and partnerships among relevant stakeholders throughout digitalization cycle • Improve evidence base for policymaking • Raise awareness through targeted campaigns on environmental impacts of digitalization • Regulate advertising in the digital economy to prevent manipulation and control over consumers, including actions that encourage overconsumption	• Consider developing regional approaches to circular digital economy and digital trade • Develop regional approaches to tracing of digital products	• Strengthen international cooperation among relevant stakeholders throughout digitalization life cycle • Adapt policies to ensure that trade works for an inclusive and sustainable global digital economy and digital trade • Develop global standards of design for sustainable ICT products, as well as for reusing, repairing and recycling • Include ICT sector in international frameworks for assessing various environmental impacts

Source: UNCTAD.

Table VI.2
Policy instruments for environmentally sustainable digitalization that works for inclusive development

Policy instrument	Example
Legislation, enforceable through the courts	Statutory requirements to restrict pollution
Regulations, enforced by statutory regulators	Enforceable rules concerned with competition policy, communications, data protection, consumer rights and environmental outcomes
Mandatory requirements in licencing and other legal instruments	Requirements to provide accurate information on environmental impacts of devices and services; apply standards to enable consumers to repair digital devices and to provide means to recycle devices at the end of life
Encouragement and endorsement of voluntary agreements and self-regulatory mechanisms	Restrictions on advertising or on marketing practices such as free delivery and returns when buying online
Reporting requirements	Regular reporting by businesses that allows Governments to monitor the digital economy and assess impacts on sustainability, and enables consumers to make more environmentally responsible choices
Fiscal and financial incentives and deterrents	Tax incentives to encourage good environmental practices or higher taxes to mitigate negative externalities, such as CO_2 emissions
Other measures to facilitate environmentally positive behaviour by consumers	Provision of recycling facilities to enable better waste management
Public information	Campaigns outlining the benefits of more environmentally sustainable choices by consumers

Source: UNCTAD.

with large mining companies. In this context, Governments need to balance the need to attract foreign investment with the need to appropriate a fair share of rents. Moreover, the fair capture and distribution of rents for domestic development purposes requires avoiding illicit financial flows, corruption and rent-seeking practices.

Fostering local value addition, diversification and structural transformation. Proactive policies are needed to address constraints and build capacities to move up in the mining and related manufacturing value chains and to enhance revenue transparency. There is a need for long-term development policies for domestic value addition among the transition minerals extracted and to enable structural transformation towards higher productivity activities. Increased processing of minerals could boost the proportion of value added to local economies. Industrial policy should support building backward and forward linkages that increase and enhance domestic economic activity and job creation, allowing for progression up value chains (UNCTAD, 2016), including a focus on business regulation, skills development and investment attraction. Overall, there is increasing political awareness among countries of the need to benefit from mineral endowments for domestic resource mobilization, to finance development objectives, which often includes dealing with challenges related to external debt. It will be important to recognize the need for developing countries to use domestic policies to add value to transition minerals for developmental purposes, and for international support in this context (Nature, 2023).

Regional cooperation could enable producer countries to achieve better agreements with mining companies

Regional cooperation could play an important part, not least in enabling producer countries to achieve better agreements with mining companies. In Africa, for example, the Africa Mining Vision,[19] a policy framework created by the African Union, may provide a foundation to enable producer countries on the continent to speak with one voice

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[19] See https://unece.org/sed/documents/2023/04/presentations/african-mining-vision-tunde-arisekola-senior-advisor-geological.

to minimize geopolitical risk, strengthen negotiating power and reduce the risk of tax competition. This vision has been complemented more recently by the African Green Minerals Strategy, for countries to harness large deposits of minerals to foster domestic value addition (Kitaw, 2023).

From the perspective of mineral-consuming and importing countries, the surge in demand for minerals is driven by significant processing and manufacturing activities that rely heavily on mineral resources. This has led to increased competition to safeguard supply chains for the future. As highlighted in chapter II, some recent strategies to secure access to transition minerals have included efforts to make relevant value chains more resilient and achieve higher levels of self-sufficiency and sovereignty, as well as more control over production in critical sectors. There is also a trend towards creating alliances or partnerships with countries that may be considered “friends” or “like-minded”, to allow for the friendshoring of minerals production.

The implementation of such strategies is not without challenges. First, domestic mining requires having deposits of the desired minerals, and many countries do not have these minerals within their borders. In some cases, local communities may be resistant to the development of domestic mining. Second, decisions about the location of mining and processing activities are influenced not only by Governments but also by multinational mining companies, only some of which are government-owned (Ericsson et al., 2020). Third, domestic support for transition minerals and related sectors could lead to widening development divides. While developed countries can dedicate significant financial resources to support domestic industries, most developing countries, particularly LDCs, have much less fiscal space (Grynspan, 2023). Fourth, with regard to friendshoring, the implications for developing countries depend on whether they qualify as a friend or like-minded country.[20]

Partnerships between developed countries importing transition minerals and exporting developing countries in Africa, Asia or Latin America should seek to foster mutual benefits, allowing for domestic value addition and structural transformation in producing countries (Andreoni and Roberts, 2022; de Brier and Hoex, 2023). Developing countries that export transition minerals should be able to decide on the best agreement for them, based on their development interests.

Current policies focus heavily on the supply side of transition minerals and mainly aim to meet demand through primary production. Although they may also look to the secondary production of minerals from recycling, there is generally less emphasis on the need to reduce overall demand for minerals. Increasing levels of reusing, repairing or remanufacturing of devices and hardware could significantly contribute to reducing mineral consumption, and also reduce demand and supply deficits.

3. Minimizing the environmental footprint in the use phase

Rapidly increasing data traffic is placing growing demand on data transmission infrastructures, in particular on data centres. This trend is expected to persist, especially with the growth in the use of IoT devices and AI, both of which require additional storage and significant computational capacity. Data centres need highly reliable power to run servers, as well as water for cooling. Their operations involve other environmental challenges too, such as with regard to land use. Such impacts on local environments need to be considered in an integrated manner.

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[20] For example, the United States refers to countries that are part of a free trade agreement. Concerns were raised in Indonesia about the exclusion of the country’s critical minerals from subsidies for green technologies. For more details, see https://www.ft.com/content/814b453c-0001-4d81-a22a-41287e7147f3. In Africa, only Morocco has a free trade agreement with the United States; Schneidman and Songwe (2023) suggest amending the Inflation Reduction Act to include all African countries that participate in the African Growth and Opportunity Act.

Energy consumption represents a high proportion of data centre operating costs. Substantial improvements have been made in energy efficiency in recent years, as operators have sought to curtail costs, offsetting much of the increased energy demand resulting from growing data volumes. However, as the scope for further efficiency gains is likely to decelerate in coming years, while data volumes and computational demand will continue to grow sharply, both Governments and businesses should promote research and development into new technologies that could reduce energy consumption and minimize water stress.

Some hyperscale data centres have been making efforts to increase their use of renewable energy sources. This shift can contribute to overall carbon efficiency, especially if data centres add to the renewable energy capacity of the regions in which they operate. Increased data centre activity has placed considerable burden on energy and water supplies in certain locations, leading some Governments, for example in Ireland, the Kingdom of the Netherlands and Singapore, to restrict future data centre expansion. Corporations can minimize impacts by locating data centres in areas with sufficient renewable energy and water resources and reducing energy use by optimizing rather than maximizing the volumes of data retained.

There are opportunities for Governments to partner with data centre operators to develop power and water infrastructure that could add to local capacity. Data centres that generate their own renewable capacity can support local grids by providing demand-side flexibility, especially if they generate a surplus, while those that buy up local renewable capacity risk doing so at the expense of users in other sectors. Data centres can mitigate some of their local energy-related impacts by developing or investing in local renewable energy projects, participating in demand response programmes and providing waste heat to support local water and electricity infrastructure (IEA, 2023d; Kamiya and Kvarnström, 2019). In terms of infrastructure, one option would be for Governments and utilities in developing countries to co-develop local electricity and water infrastructure jointly with data centres, with the latter serving as "anchor customers" for both the water and electricity utilities, making investments in the infrastructure financially sustainable.

Governments can also encourage data centres to invest in additional renewable energy. For example, the Climate Neutral Data Centre Pact, a self-regulatory initiative, calls for data centre electricity demand in Europe to be matched by 75 per cent renewable energy or hourly carbon-free energy by the end of 2025, rising to 100 per cent by the end of 2030.[21]

However, government subsidies and tax incentives aimed at attracting data centre investment to locations with unsuitable energy and water supplies should be avoided. These may generate significant environmental costs without apparent long-term gains to the local economy in terms of employment or downstream business opportunities. Moreover, the main development opportunity from data does not arise from storing data but from being able to leverage the data for the development of digital intelligence that can be used to create economic or social value (UNCTAD, 2021a).

Data governance also affects the location of data centres. As discussed in *Digital Economy Report 2021*, there has been growing international concern about data privacy, data protection, data security and data sovereignty, which has led to increased willingness on the part of some Governments, businesses and consumers to locate data within national jurisdictions. This points to the need for international governance that can build the necessary trust for Governments and stakeholders to feel comfortable with data that is generated locally being stored outside of their territories, while ensuring access and control over the data, regardless of location.

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[21] The pact includes pledges by data centre companies on energy efficiency, clean energy, water, the circular economy, circular energy systems and governance. See https://www.climateneutraldatacentre.net/.

Governments should make use of economy-wide policies, such as carbon and water pricing and renewable electricity mandates, to incentivize investments in renewable electricity and resource-saving technologies. They can use planning controls to ensure that new data centres are located in areas with adequate energy and water resources, and require operators to meet higher standards of operational efficiency (IEA, 2023d). Regulators should ensure that electricity market design provides clear price signals to data centres and other high-volume electricity consumers to participate in programmes to optimize supply and demand. In parallel, these should be balanced with the frequency of server turnover to limit equipment being disposed of earlier than necessary. Progress on demand response has recently been made in Australia, Brazil, the Republic of Korea, Singapore, the United States (in California) and the European Union (IEA, 2023g).

At the same time, switching to renewable energy is not enough to mitigate a negative environmental footprint from the growth of data centre activity. Greater use of AI, machine learning, IoT and cryptocurrency mining, for example, will require more mining and manufacturing to produce servers and specialized chips, and more water. These environmental impacts also have to be factored in when weighing the risks and benefits of using these new technologies. Regulators could consider introducing specific environmental disclosure requirements to enhance transparency across the supply chain of AI (de Vries, 2023). Further, encouraging pricing schemes that take into account the environmental cost of these innovations could contribute to the more informed and sustainable use of these emerging technologies by consumers and businesses.

4. Promoting a circular digital economy

The volume of digitalization-related waste is growing rapidly as the number of digital devices in use worldwide has grown, reinforced by programmed obsolescence in modes of production and limited awareness of waste issues among users. Digital components include materials that are toxic, require special treatment and are in short supply, making recovery and recycling both economically and environmentally desirable. While the volume of waste is rapidly expanding, and is expected to continue to do so, the rates of collection and recycling have not kept up. These rates are insufficient in developed countries and particularly low in developing countries, where recycling activity often takes place in informal settings, with minimal health safeguards and no formal regulation of material recovered. Moreover, large quantities of waste may be dumped in ways that are detrimental to local communities and the environment, with intrinsic resources being lost.

Addressing this situation will require multiple measures which would allow for waste to be transformed into resources and economic value. The potential for circularity, including recycling, needs to be considered throughout the digital life cycle. The main priority is to prevent or minimize the generation of waste.[22] This implies reducing the consumption of digital products and resources used to manufacture them. A major objective of policies in this context is to ensure that digital products are designed in such a way that they can be repaired, reused (in second-hand markets) and recycled, so that resources can be recovered. In this way, the secondary supply of raw materials can be increased, thereby reducing primary supply and its associated environmental impact. Policymakers also

> Regulators could consider introducing specific environmental disclosure requirements to enhance transparency across the supply chain of AI

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[22] The United Nations Secretary General announced the establishment of an Advisory Board of Eminent Persons on Zero Waste in 2023 (see http://unzerowaste.org/). The report *Towards Zero Waste: A Catalyst for Delivering the Sustainable Development Goals* sets out how improved resource efficiency and ensuring universal access to waste management services can improve lives worldwide, focussing on actions that Governments and municipalities in the Global South can take to provide cost-effective and inclusive programmes that will contribute to sustainable development, for the benefit of current and future generations (UNEP, 2023d).

need to strengthen the capacity to collect and manage the waste generated. Such efforts in many developing countries can benefit greatly from international support.

More efforts should be made to establish environmentally sound waste management in developing countries. Governments in these regions need to ensure that they have the necessary legislation and regulatory powers in place as well as the skills to implement any policies adopted. Institutional capacities are important, for example, when monitoring is needed to ensure that international flows of digitalization-related waste are not illegal.

At the national level, while most developed countries have adopted an e-waste policy, legislation or regulation, only 36 developing countries have done so (Baldé et al., 2024). National legislation in this area should be clear on the product scope, the stakeholders and their roles and responsibilities. Enforcement measures and penalties for non-compliance also need to be specified. Moreover, there should be clear stipulations on the organizational mechanism for electric and electronic equipment producers, together with clear terminology on who should cover the cost of the management of e-waste (Baldé et al., 2024).

Most developing countries are not yet prepared for circular international trade, as they rely on the informal sector and need to strengthen relevant institutional capacities

Digitalization-related waste management can hold promise for developing countries as it presents opportunities for added value. Some aspects of a circular economy are further along in developing countries, where new devices are less affordable and consumers are more reliant on repair, refurbishment and resale. However, many developing countries remain locked in at the low value part of the digitalization-related waste value chain, in addition to bearing the burden of environmental costs and risks, while developed economies capture the highest value. Most developing countries are not yet prepared to participate effectively in circular international trade, as they rely on the informal sector and often lack relevant legislation and institutional capacity.

Crucially, transitioning from the unregulated and informal treatment of digitalization-related waste to regulated, formal management would help maximize recycling and ensure the safe disposal of toxic materials. It could also help generate income from the sale of recycled materials and allow for the refurbishment and reuse of viable devices that could be resold in domestic markets and help bridge domestic digital divides.

Governments should work together with international organizations to facilitate recycling and regulate the disposal of digitalization-related waste, including related trade between developed and developing countries, in order to reduce risks from toxicity, recover scarce and valuable resources and protect the health and welfare of citizens living close to or working on dumped materials. This collaboration needs to be strengthened, notably to ensure compliance with and the enforcement of relevant legislation.

5. Enabling international trade in a circular digital economy

There is a case for promoting growth through a more circular digital economy. Various estimates suggest considerable economic prospects in second-hand markets for electronic products, as well as in sectors linked to repairing, remanufacturing, refurbishing and recycling (see chapter IV). In this context, there is a need for greater awareness of the nexus between trade and the circular economy. International trade has an important role in enabling more circularity in the digital economy. Different types of goods and services can be part of international trade related to circularity, including used goods that can be reused, repaired, remanufactured or recycled; refurbished and remanufactured goods and parts; secondary raw materials; waste and scrap for recovery and value creation; and goods, services and intellectual property that support the circular trade in goods (figure VI.1).

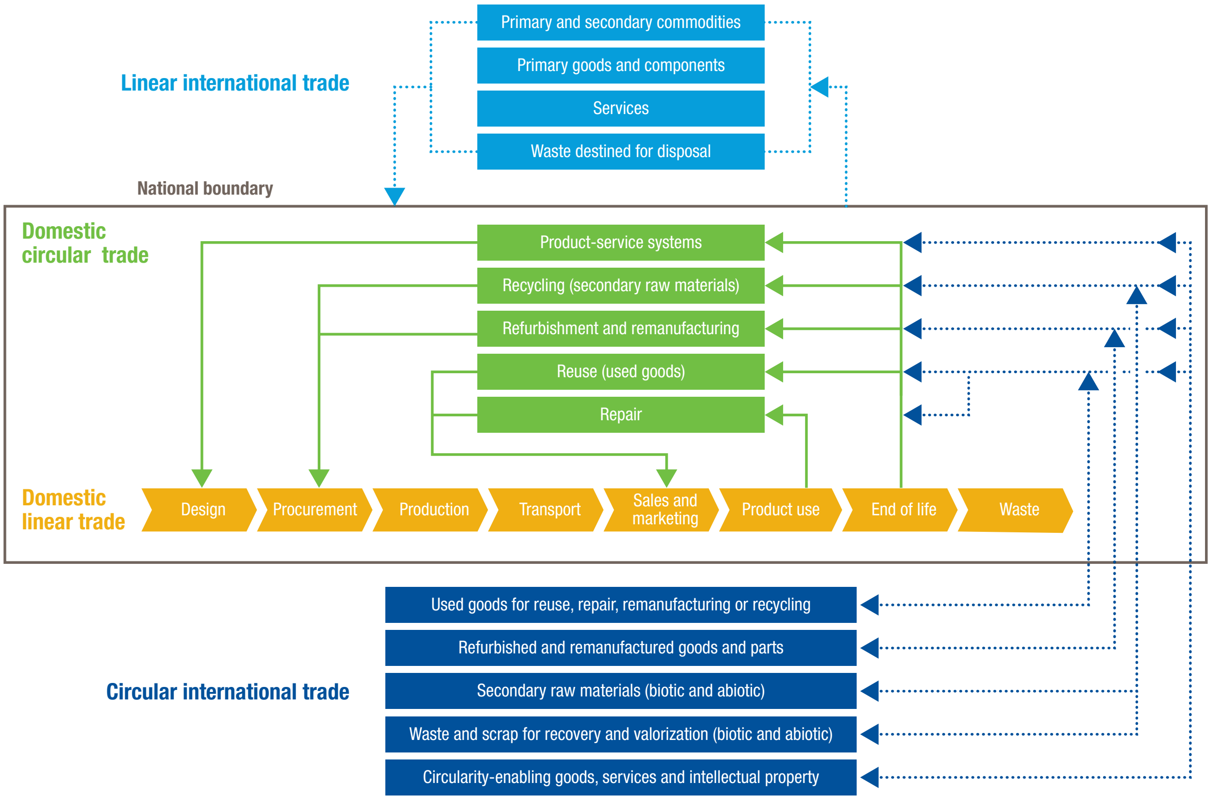
Despite growing commitment among both Governments and the private sector to facilitate the circular economy and trade in support of the Paris Agreement and the Sustainable Development Goals, levels of circular trade around the world remain limited. Moreover, achieving inclusive development in the context of circular trade related to digitalization means boosting opportunities for developing countries to move up the e-waste value chain, capturing more value and reducing their exposure to environmental costs and risks.

Circular trade is not always desirable. If poorly regulated, it can result in growing illicit trade, with pollution and negative impacts on people's health and safety (Barrie et al., 2022). In order to secure beneficial circular trade in the digital economy and to achieve more inclusive outcomes, a number of barriers need to be overcome through policy actions, as follows:

- There is a need for common standards, definitions and classifications of what constitutes hazardous waste, non-hazardous waste and non-waste goods destined for reuse, repair and refurbishment (WEF, 2020b). Progress in this area requires globally coordinated efforts to develop a shared language with a view to ensuring that a product traded is classified in the same way in both the exporting and importing countries. This work needs to involve relevant international organizations such as the Basel Convention Secretariat, ISO, WCO and WTO. Public–private dialogue, such as at the World Circular Economy Forum, a global initiative of the Government of Finland and the Finnish Innovation Fund, could play an important role in this process;
- There is a growing need to embrace circularity in trade and economic cooperation agreements. This is in contrast to trade policies of the past

> If poorly regulated, circular trade can result in high levels of illicit trade, with pollution and negative impacts on people's health and safety

Figure VI.1
Domestic linear and circular activities and international circular trade flows



Source: UNCTAD, based on Barrie et al. (2022).
Note: Domestic linear trade flows not included, to aid clarity.

that were developed with a linear model in mind (Barrie et al., 2022). Such agreements could include language that emphasizes sustainability, transparency and traceability requirements, as well as relevant provisions on trade facilitation. Comprehensive regional and bilateral trade agreements can support circularity and other environmental goals through binding commitments, mechanisms to stimulate cooperation on infrastructure and border controls. They could improve the efficiency of the supply of raw materials essential for the ICT industry, adding value for commodity producers and improving the security of supply for processors and manufacturers. Partners in agreements would be able to harmonize technical and environmental definitions, standards and regulations. It would also be desirable to integrate trade elements in national strategies aimed at promoting circularity (ECE, 2022b). Several forums are exploring how to make progress in this area and to make circular economy policies and trade policies mutually supportive. At WTO, the trade and environmental sustainability structured discussions have set up an informal working group on the circular economy and circularity. It has identified several areas for trade-related actions on the circular economy, including transparency, standards and regulations, trade facilitation, waste management, technical assistance and technology and other aspects for cooperation (WTO, 2023, 2024). The Global Alliance on Circular Economy and Resource Efficiency, which works on and advocates for a global just circular economy transition and the more sustainable management of natural resources at the political level and in multilateral forums, could give more attention to the trade and digital dimensions of the circular economy;

- Traceability needs to be improved in order to facilitate more circular trade, including by making use of digital solutions. In the context of international circular value chains, it is essential to have granular information on, for example, a product's material composition, methods of production, certification and standards compliance, quality and lifespan (Barrie, 2023). This is needed to mitigate illegal waste shipments while enabling the international distribution of secondary goods and materials. Having transparent access to relevant information also helps build trust among all actors along a supply chain and could prevent import bans and reduce trade frictions. There are currently no comprehensive data on trade in second-hand ICT goods and generally limited data related to circular trade in developing countries (OECD, 2018). Data gaps make it difficult to assess the challenges and opportunities associated with a more circular digital economy and the scope for services development in repair, reuse and recycling (WEF, 2020b). Various solutions have been proposed, including circularity transparency protocols, reporting tools and metrics and business support services (Barrie, 2023; WTO, 2024). Labelling, global trade item number (GTIN) systems and digital product passports are mechanisms that could facilitate the tracking of materials and products (WTO, 2024). As discussed, such digital product passports are being explored in the European Union. Digital technologies, such as digital watermarks, radio frequency identification (RFID) tags and blockchain technology can be leveraged to enable robust verification and certification over a product's life cycle (Barrie, 2023). In July 2023, ECE launched the Critical Minerals Traceability and Sustainability Initiative, which would develop a traceability and sustainability framework for critical raw materials in batteries and IT equipment;[23]
- Another area concerns trade procedures and trade facilitation. One factor delaying more widespread engagement with reverse logistics is that related trade

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[23] See https://uncefact.github.io/project-crm/docs/about/.

procedures are typically more costly, require more paperwork and result in border delays (WEF, 2020b). This shows the need for regulatory cooperation to fast track or streamline trade permit systems linked to circular trade. Cross-border cooperation on trade permits, pre-export checks and interoperable standards can facilitate efficient data management. Paperless trading and customs systems, such as UNCTAD's ASYCUDA, and the use of international digital standards can reduce paper waste, enable interoperability and strengthen risk management. In order to avoid waste being dumped in developing countries, under the Basel Convention, all e-waste will be subject to prior informed consent procedures as of 2025. Some concerns have been raised within the e-waste management industry that strict procedures may become cumbersome and discourage exports for legitimate recycling purposes. In this context, it will be important to foster coherent and transparent prior informed consent procedures, automated customs management and clear distinctions between waste and non-waste goods (Barrie, 2023; WTO, 2024). It has also been proposed that the WTO Agreement on Trade Facilitation be amended with a view to facilitating trade in reverse supply chains. The use of trusted "circular trader" schemes and special economic zones for circularity have also been highlighted as worthwhile initiatives to explore further (Barrie and Grooby, 2023);

- In order to achieve inclusive circular trade related to the digital economy, efforts are needed to avoid a worsening of the current unequal ecological exchange. For example, most controlled shipments under the Basel Convention occur either between high-income regions or into high-income regions. Countries are unequally prepared to engage in and benefit from circular transitions. In many developing countries, waste recovery operators are predominantly in the informal sector, with inadequate working conditions and limited capacity to undertake necessary reforms. There is a need for the international community to provide assistance to these countries. Areas where support is needed include investment in recycling and disposal facilities, the transfer of relevant technology, the formalization of circular economy activities and training and capacity-building related to trade facilitation and ensuring compliance with relevant global trade rules. The United Nations, Aid for Trade and international financing institutions will be important in this context.

There are concerns within the e-waste management industry that strict procedures may discourage exports for legitimate recycling purposes

6. Securing international support for capacity development

The capacities needed to move towards environmentally sustainable digitalization that works for inclusive development are asymmetrically distributed among countries. The required actions and policies involve substantial amounts of financial, human and institutional resources. While the design and implementation of policies are matters for Governments, support from the international community to complement national resources will be indispensable in many developing countries. Finance from multilateral and regional development banks can be helpful in this context.

In terms of human resources, skills need to be developed through education policies and targeted awareness campaigns, for example, by inviting stakeholders to learn how to manage digitalization-related waste in an environmentally sound manner. Moreover, improving the evidence base will require investment in skills and data-gathering capacity, with a focus on indicators that are most relevant for local and national policy and practice.

Low-income countries, in particular, will need adequate support from development partners to strengthen digital and environmental capabilities. At the same time, care must be taken to avoid transferring

Low-income countries will need adequate support from development partners to strengthen digital and environmental capabilities governance models from developed countries that may be inappropriate for developing countries in view of their different economic contexts, regulatory capabilities and national priorities. Countries need policy space to develop digital and environmental business sectors and achieve national development objectives.

F. Strengthening international cooperation and solidarity for collective action

The global challenges of environmental sustainability and digitalization require urgent action at the global level by all stakeholders. This should be anchored in global debates and agreements that can help to form consensus on how best to address them. To date, there has not been a comprehensive international process or agreement that addresses environmental impacts stemming from the life cycle of digital devices and infrastructure (Santarius et al., 2023). In the coming years, it will be essential to ensure that the digitalization and environmental sustainability nexus becomes fully and coherently addressed in relevant international forums and agreements. Digitalization needs to be as environmentally sustainable as possible to avoid adding to various environmental risks. At the same time, digital tools can make important contributions to support more environmentally sustainable socioeconomic activities so that they can become more efficient and resilient.

There is currently no inclusive, global governance framework in place to help catalyse collective action and facilitate knowledge-sharing among countries, foster consensus-building, set global standards and encourage the transparent reporting and monitoring of progress towards shared goals. An inclusive and integrated approach would be valuable for enabling policymakers to align their digital and environmental policies at all levels, thereby enhancing the ability of the global community to effectively tackle the complex and interdependent global challenges involved.

A number of international agreements include broad principles on the relationship between digitalization and the environment, including the outcome documents from the World Summit on the Information Society (WSIS) and the 2030 Agenda for Sustainable Development. However, most are concerned with particular issues, for example, with digital inclusion or cybersecurity or with climate change, biodiversity or hazardous waste. Dialogue between the digital and low-carbon policy communities should be more firmly established at the centre of discussions on sustainable development and embedded in the work of international standard-setting bodies. Strengthened cooperation between developed and developing countries will be important for successful international dialogue.

Greater coordination and strategic engagement will be required from intergovernmental and international business entities, within and beyond the United Nations, to secure digital development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987, paragraph 27). In this context, there may be a need to create or re-design existing multi-stakeholder forums that can bring the digital and environmental communities together and that also enable countries at different levels of development to participate.

Collaboration for collective action should involve multilateral agencies, as well as civil society and business associations concerned with relevant issues. Partnerships, such as CODES, that can draw on the capabilities and strengths of international agencies, Governments, businesses and research organizations, are likely to achieve better outcomes than Governments or multilateral agencies acting alone. More cross-fertilization between digital, economic and environmental perspectives should be fostered in forums such as those concerned with climate change, mineral extraction, waste disposal and recycling. Experts in the field and those with direct experience of environmental impacts should be at the centre of such cross-sectoral and interdisciplinary dialogues.

International processes and forums focusing on how to leverage digitalization for development, such as the WSIS Forum, the Internet Governance Forum, the Commission on Science and Technology for Development and processes related to the upcoming United Nations Summit of the Future should give adequate consideration to the environmental dimensions. Similarly, there is a need for processes related to global environmental challenges, such as the International Resource Panel, the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, to give more attention to the role of digitalization.

To protect the interests and well-being of all, including future generations, urgent and resolute actions have been called for to achieve systemic shifts in the areas of energy, food, mobility and the built environment. It is time to extend the calls for bold actions to the entire life cycle of digitalization and to start systematically tracking the environmental footprint of the ICT sector.

International organizations have a critical role to play. United Nations agencies, including DESA, ITU, the Office of the Special Envoy on Technology, UNCTAD and UNEP, coordinate multilateral activity in relevant policy areas and multilateral agreements, such as the United Nations Conference on Environment and Development, WSIS, the 2030 Agenda and the global digital compact. UNFCCC and the Basel Convention have established frameworks and goals for sustainability and digital development. Other multilateral organizations concerned with development and trade, such as the World Bank and WTO, also work towards progress on digital development, environmental sustainability and inclusive development. However, more needs to be done to align these goals with one another and elaborate them in key areas, including managing the trade and exploitation of scarce resources.

Multilateral organizations can also propel the development of a more reliable evidence base for a global understanding of digital sustainability. United Nations regional commissions and other relevant regional organizations could play a useful role by, for example, sharing experiences and expertise within the corresponding regions. At the global level, various entities of the United Nations can facilitate national experience-sharing, recognizing that governance approaches need to be adapted to regional and national circumstances and capacities. Within UNCTAD, the interface between digitalization and environmental sustainability could be a future topic for discussion at sessions of the Intergovernmental Group of Experts on E-commerce and the Digital Economy.

A number of international developments provide timely opportunities for change. WSIS, which first established global goals for digital development in the early years of this century, is to be reviewed by the United Nations General Assembly in 2025. The Sustainable Development Goals, which embedded environmental sustainability at the centre of the international community's agenda in 2015, will be reviewed in 2030. In 2024, the United Nations Summit of the Future is set to agree on an action-oriented

> International processes and forums focusing on how to leverage digitalization for development should give adequate consideration to the environmental dimensions

It is time to extend the calls for bold actions to the entire life cycle of digitalization and to systematically track its environmental footprint

pact for the future, showcasing global solidarity for current and future generations, including by emphasizing sustainable development and digital cooperation. This is expected to include a global digital compact setting out principles, objectives and actions for digital development that supports global development goals (United Nations, 2023d).[24]

As seen in the discussion on policy options, areas for international cooperation can be linked to the life cycle of digitalization.

At the production phase, which concerns the transition minerals and global value chains related to digital devices and ICT infrastructure, international dialogue may be needed to address complex issues related to security, sustainability, efficiency and economic development in a balanced way, taking into account the interests of developing-country producers as well as those of consumers, exporters and importers. Finding solutions will require increased and holistic cooperation that includes developed and developing countries, as well as stakeholders from the producer and consumer sides (Müller, Schulze, et al., 2023).[25]

The Group of Seven five-point plan for critical minerals security requested IEA to establish an internal task force and undertake analysis and verification in collaboration with the IEA working party on critical minerals.[26] This may focus on the perspective of mineral consumers or importing countries, and it is important to achieve a more holistic cooperative approach by, for example, involving global authorities with expertise related to mining activities, such as the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development.[27] International and regional efforts should seek to promote the more equitable sharing of the value derived from transition minerals.

Some steps have already been taken in this direction, as follows:

- At the global level, United Nations Member States have highlighted the need for greater international cooperation on the topic of mineral resource governance. Member States adopted a resolution on Mineral Resource Governance at the fourth session of the United Nations Environment Assembly in 2019.[28] At its sixth session in February 2024, the Assembly adopted a resolution on environmental aspects of minerals and metals, encouraging Member States and inviting relevant stakeholders to align their management practices with the 2030 Agenda for Sustainable Development and to promote sustainable consumption and production;[29]
- A study on mineral resource governance in the twenty-first century by UNEP and IRP (2020b), which maps more than 80 existing international governance frameworks and initiatives, calls for more coordination and integration and proposes building international consensus regarding the normative content and structure of the "sustainable development licence to operate", in a new governance framework for the extractive sector.
- In 2022, the United Nations Working Group on Transforming the Extractive Industries for Sustainable Development was established, to help ensure a more collaborative and impactful services delivery offer in this area. The aim is to coordinate extractives-related work across the United Nations and beyond through joint work, planning and collaboration;

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[24] See https://www.un.org/en/common-agenda/summit-of-the-future and https://www.un.org/techenvoy/global-digital-compact.

[25] See also https://www.ft.com/content/394dca37-ac50-4380-9b03-4fdfcef2ff7c.

[26] See Group of Seven (2023b) and https://www.iea.org/news/iea-critical-minerals-and-clean-energy-summit-delivers-six-key-actions-for-secure-sustainable-and-responsible-supply-chains.

[27] See https://www.igfmining.org/.

[28] See UNEP (2019b, 2022b).

[29] See https://www.unep.org/environmentassembly/unea6/outcomes.

providing an information and knowledge hub to scale up and replicate best practices and build synergies with existing initiatives; provide policy advice and technical assistance to stakeholders in the extractives sector; and assist with integrating work on the extractive industries into other initiatives across the United Nations. It highlights the need to address sustainability issues and for producer countries to be able to secure greater value for commodities, improve working conditions and address the challenges of informal mining. Stronger safeguards will be needed to prevent corruption and address illicit trade.[30] Its work offers an opportunity to address issues related to digitalization;

- In December 2023, during the twenty-eighth session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, the Secretary-General of the United Nations announced the establishment of the Panel on Critical Energy Transition Minerals.[31] As the Panel is expected to support and enhance the efforts of the Working Group, it should adequately factor in mineral needs resulting from digitalization.

Regarding the use phase of the life cycle of digitalization, given that concerns about the environmental impact of data centres have risen only recently, international cooperation is more limited. Most international cooperation in this area relates to issues of standardization and certification (ITU and World Bank, 2023). In order to enable the optimal geographical distribution of data centres, from an environmental sustainability perspective, an international framework regulating cross-border data flows would be needed.

At the end-of-life phase, dealing with digitalization-related waste is a worldwide concern that requires a globally coordinated approach. The main global governance framework is the Basel Convention, which regulates transboundary flows of electrical and electronic waste. However, significant challenges remain in its implementation and enforcement, which lead to continuous problematic international trade in such waste, mostly illegal, and flowing from developed to developing countries. There is currently no obligation to report on the international trade of used electronic equipment, although several international agreements address such trade. Recent amendments to the Convention may help prevent illegal trade flows of this kind of waste (see chapter IV).

Beyond trade issues, in response to the growing global challenges of e-waste, initiatives by international actors have been increasing, including under the auspices of the United Nations. In 2017, the United Nations Environment Management Group and the Issue Management Group on Tackling E-waste issued *United Nations System-Wide Response to Tackling E-waste*, a report highlighting the need for strengthened collaboration among United Nations organizations. More than 20 organizations are active in tackling e-waste and over 150 initiatives have been undertaken since 2004. The report offered recommendations on maximizing system-wide coherence towards a life-cycle approach to tackling e-waste. Subsequently, seven United Nations system organizations created the E-waste Coalition in 2018.[32] Moreover, the Global E-Waste Statistics Partnership plays a key role in monitoring e-waste developments and helping countries produce related statistics. While initiatives to increase international

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[30] See https://www.unep.org/events/working-group/transforming-extractive-industries-sustainable-development, United Nations (2021c) and Baptista (2023). A key output of the Working Group is the Critical Energy Transition Minerals Toolkit, available at https://www.unescap.org/our-work/energy/CETMToolkit.

[31] See https://news.un.org/en/story/2023/12/1144267 and https://www.unep.org/topics/energy/renewable-energy/critical-minerals.

[32] See https://unemg.org/our-work/emerging-issues/innter-agency-issue-management-group-on-tackling-e-waste/.

Stakeholder engagement and flexible policy frameworks are essential to ensure that technological change contributes positively to environmental and socioeconomic well-being

cooperation in this area represent welcome progress, there is a need for more global collaboration and coordination.

Closely linked to digitalization-related waste, and in order to close the loop and address the entire digitalization life cycle, is the need to promote a global circular digital economy. International cooperation is key for moving towards circularity at both the national and global levels. In 2019, a report titled *A New Circular Vision for Electronics: Time for a Global Reboot* was issued as part of a collaboration between the E-waste Coalition, WEF and the World Business Council for Sustainable Development (Platform for Accelerating the Circular Economy and WEF, 2019). The Platform for Accelerating the Circular Economy (2021) has produced a circular economy action agenda for the electronics sector.[33]

At the regional level, policy efforts in the direction of increased circularity are becoming more widespread, including with regard to digital technologies. In 2020, the European Commission (2020) issued a circular economy action plan. ASEAN (2021) has adopted a framework for the circular economy, and the AfDB (2023b) has established a multi-donor Africa Circular Economy Facility. The Economic Commission for Latin America and the Caribbean has commissioned studies towards a circular economy in its region.[34]

Rapid technological change will continue to present significant development challenges and opportunities at all policy levels, necessitating foresight and a proactive governance approach. The evolving nature of digital technologies and environmental risks highlights the importance of continuous research, dialogue and policy adaptation. While policymakers are the primary audience of this report, action is needed by many stakeholders, including consumers, producers and other relevant parties, to enable environmentally sustainable digitalization that works for inclusive development. Stakeholder engagement and flexible policy frameworks are essential for navigating future uncertainties, ensuring that technological advancements contribute positively to environmental and socioeconomic well-being.

Opportunities should arise as a result of more environmentally sustainable digital development. These are more likely to lead to success if they form part of national development strategies that include digitalization policies that have economic inclusion and environmental sustainability in mind. Such strategies should be supported by international agreements that recognize the importance of changing the dynamics of digital trade towards more balanced outcomes. This shows the need for a response that identifies policymaking at the national, regional and global levels and that addresses digital, socioeconomic and environmental goals holistically, across the entire life cycle of digital devices and ICT infrastructure. Solutions need to take into account the context and priorities of all countries, including opportunities for developing countries to benefit from the potential that digitalization offers.

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[33] The platform, hosted by the World Resources Institute, is a public–private collaboration platform "made up of global changemakers and their organizations working together to accelerate the transition to a circular economy". See https://www.wri.org/initiatives/platform-accelerating-circular-economy-pace.

[34] See, for example, https://www.cepal.org/en/publications/47604-conceptualizing-circular-economy-caribbean-perspectives-and-possibilities-policy.

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Printed at United Nations, Geneva
2411984 **(E)** – July 2024 – 1,820

UNCTAD/DER/2024

United Nations publication
Sales No. E.24.II.D.12

ISBN 978-92-1-003136-3