UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

2024

Digital economy report

Shaping an environmentally sustainable and inclusive digital future

A very resumed reading
by Laércio Lima Pilla

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.

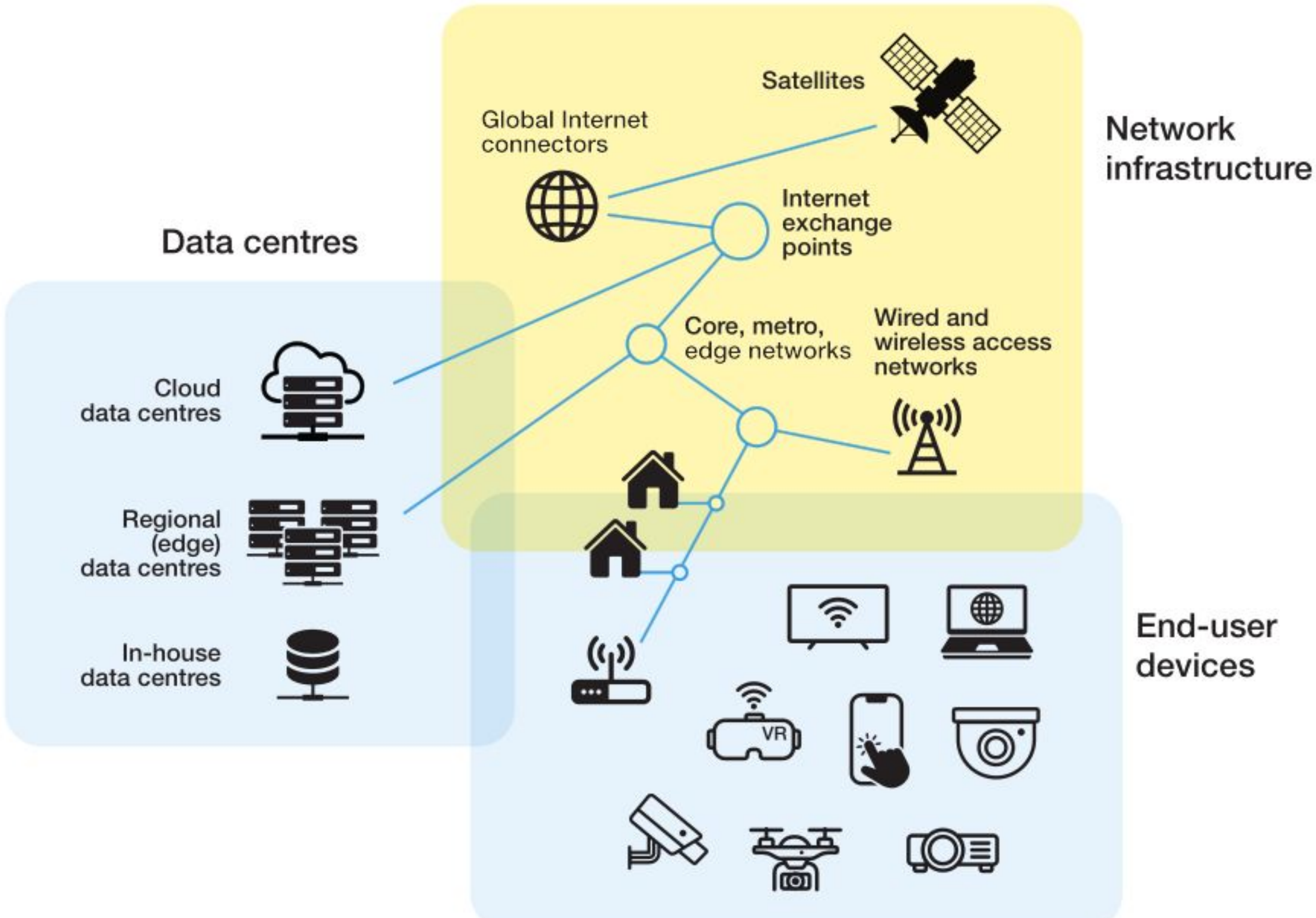
Against a backdrop of multiple environmental crises and the digital solutions leveraged to tackle them, it is increasingly important to consider how to reduce the environmental footprint of digitalization itself.

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.

to identify stages with important   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).

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;

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.

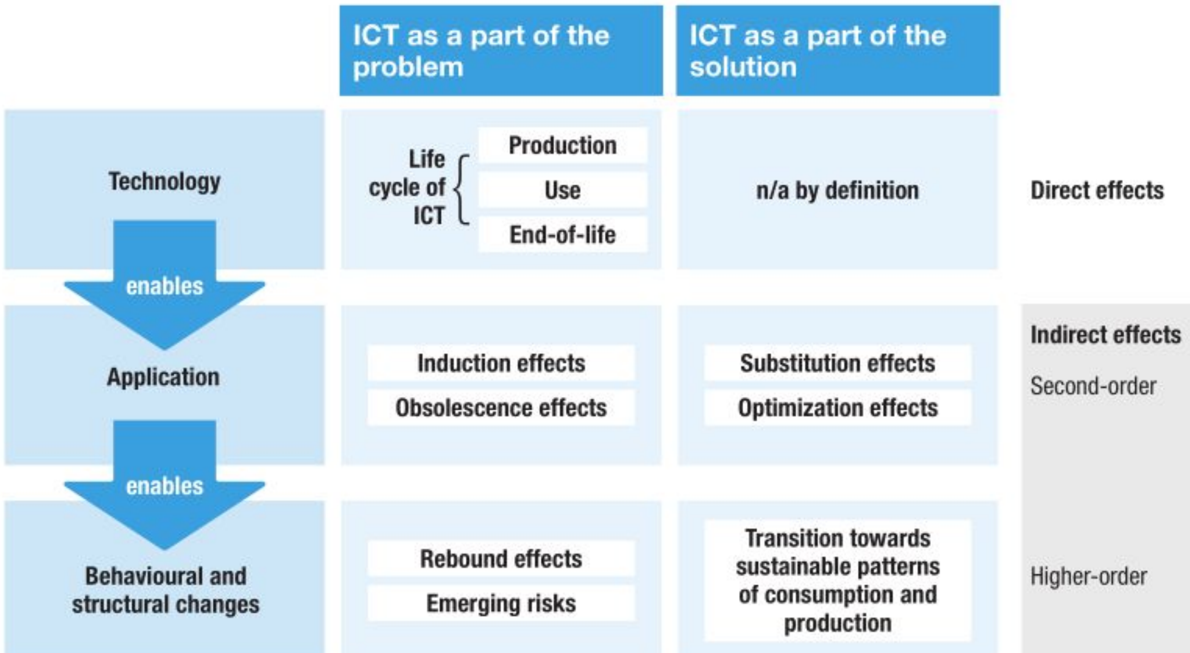
Table I.2
Indirect environmental effects from the use of digital devices and infrastructure

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 behavioural and lifestyle changes ("structural effects and economic changes" and "systemic and societal-level effects and 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



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

[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

Extras

- Comprehensive assessments of the environmental footprint of digitalization are scarce
- Measurement challenges (what to include and exclude, changes in time, …)
- Environmental footprint beyond emissions and energy (water, air quality, biodiversity, …)
- Adverse effects often impact regions far from where the devices are mainly used

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.

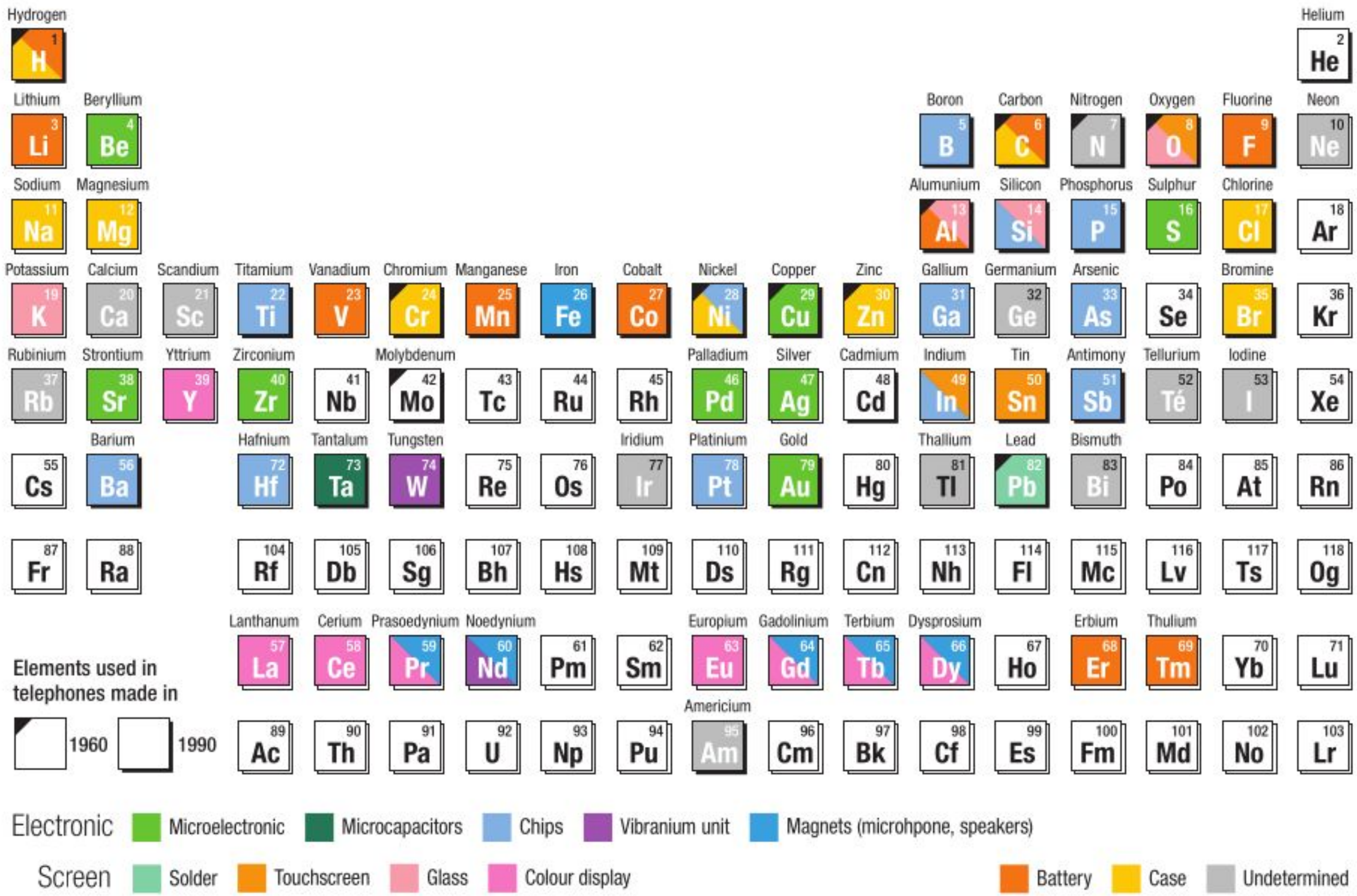
There is growing demand for minerals and metals needed for the shift to low-carbon and digital technologies, which is part of a broad transformation in the world economy.

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.

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.

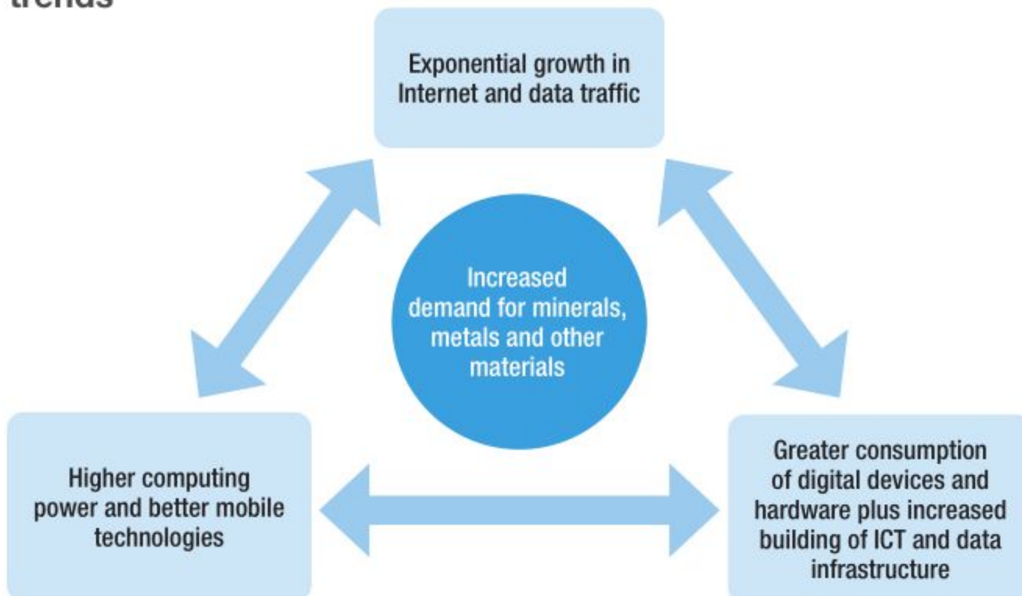
On average, over the past four decades,

purposes, the less efficient it becomes in terms of material use (Valero et al., 2021).

While minerals and metals are essential for

The more

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

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

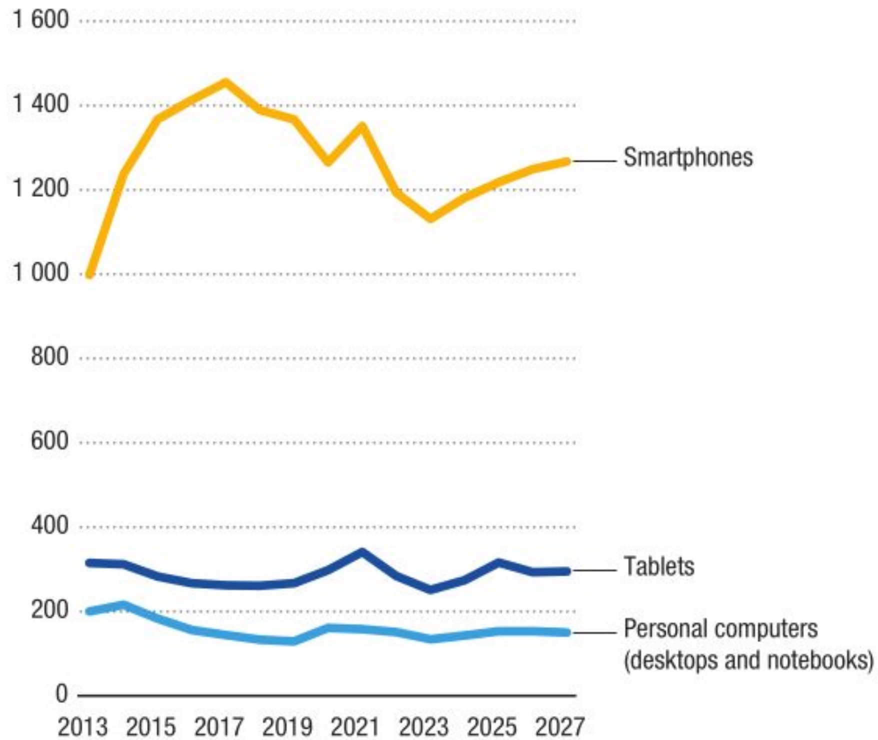
Source: UNCTAD, based on Ericsson (2023b).
Note: Country groupings are as defined in the source.

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.

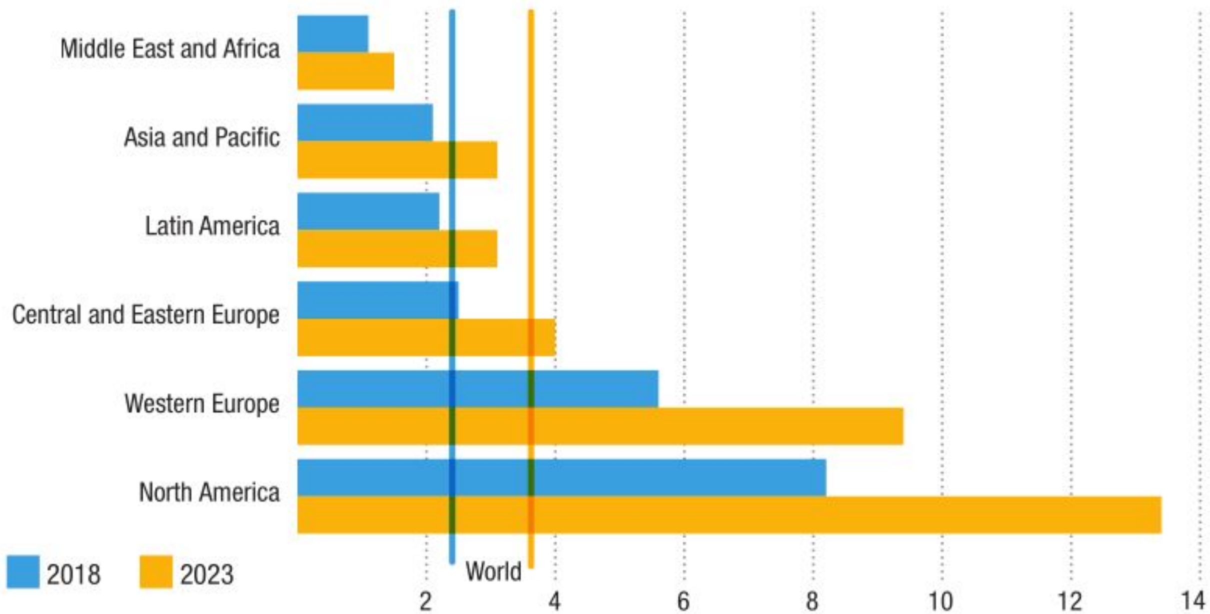
The trend in personal computers (desktops and notebooks) has followed a different trajectory, declining until 2018 and then increasing, although recording a similar decline in 2022–2023. Worldwide tablet shipments also fell until 2019, followed by a rebound in 2020. Shipments of both

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



Source: UNCTAD, based on data provided by Canalys.

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

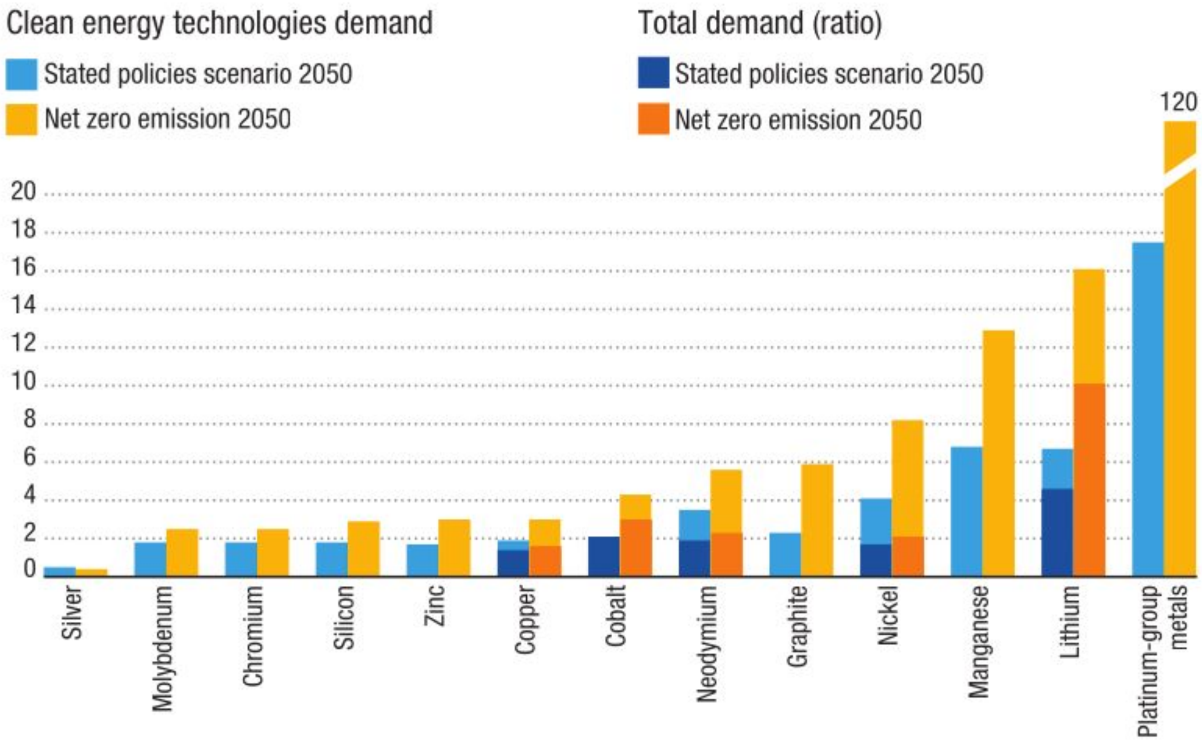


Source: UNCTAD, based on Cisco (2020).
Note: Country groupings are as defined in the source.

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).

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

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,

use of transition minerals and move towards

A crucial

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.

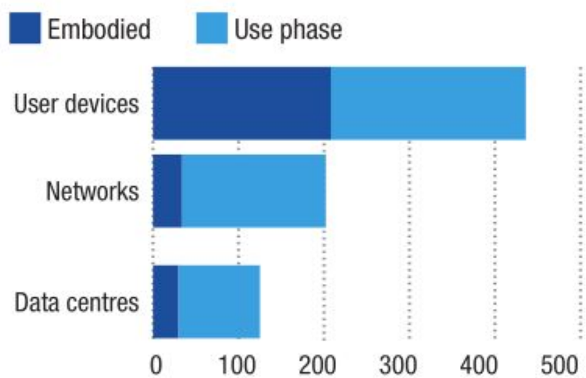
This chapter explores the primary environmental impacts stemming from the utilization of end-user devices, data transmission networks and data centres in light of current trends and developments.

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.

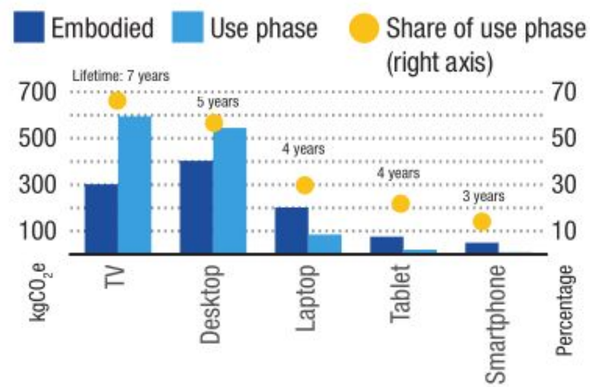
With the adoption of ever more sophisticated, compute-intensive digital services, there is a need to give greater attention to the environmental footprint of digitalization and develop targeted policies to mitigate local and global impacts.

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)



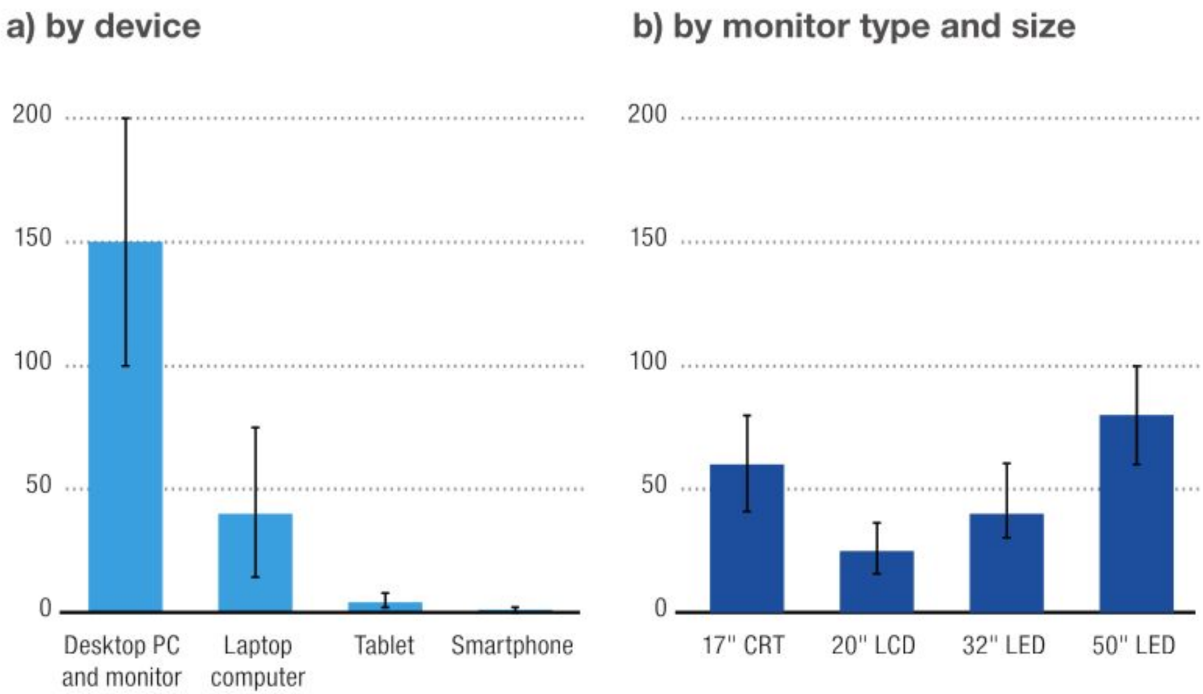
Source: Malmodin et al. (2024, left) and Malmodin and Lundén (2018, right).

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

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 past decade, overall energy consumption associated with their use has been found to be relatively flat (Malmodin and Lundén, 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)

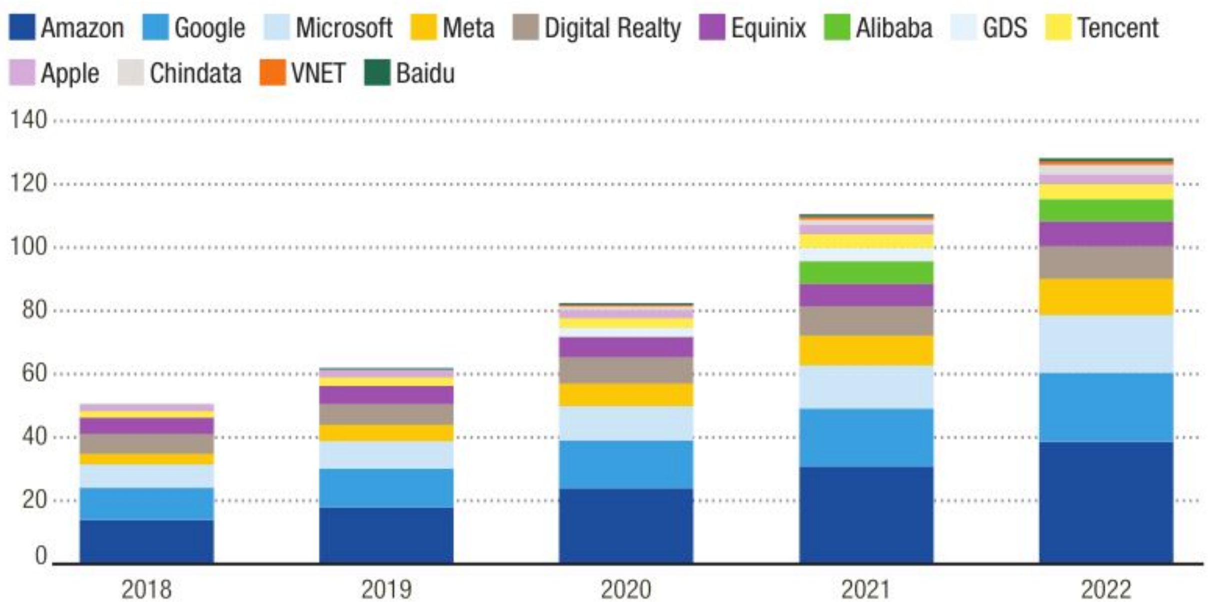


Source: UNCTAD, based on Urban et al. (2017) and Kamiya (2020a).

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.

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).

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

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

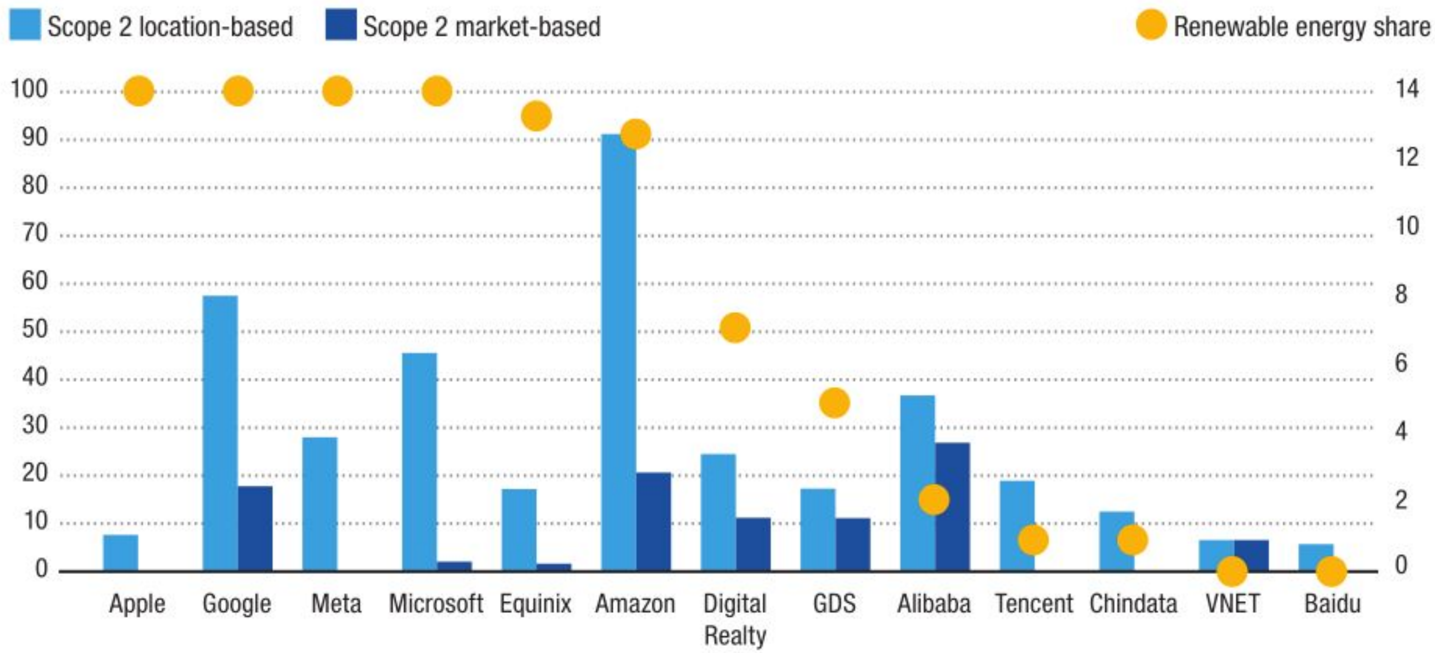
Data centre energy use is likely to continue to **grow significantly** over the next few years commitments between the buyer and renewable electricity generators. They seek to reduce risks for new projects and allow access to project finance, while locking in a low and stable price for the buyer.

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).

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.

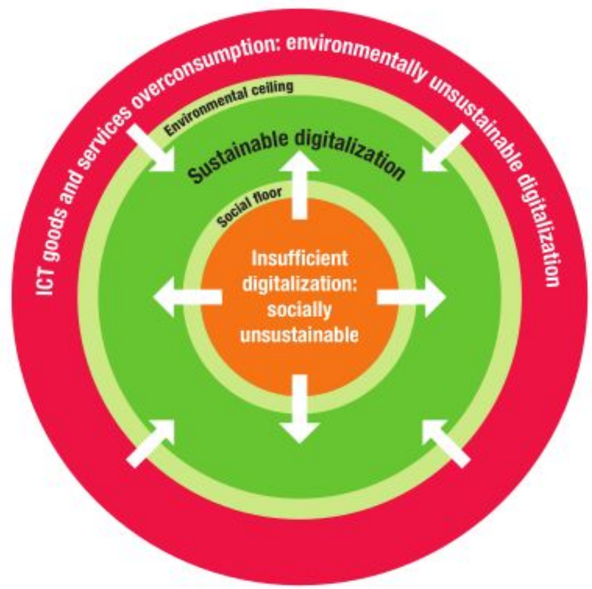
The chapter calls for a more circular digital economy, which would enable longer lifespans of devices and more efficient recycling, to reduce waste. This would not only help to alleviate pressure on raw material supplies but could also enable economic often have multiple devices per person.

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

(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

[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.

D. Factors driving the growth of digitalization-related waste

The linear model of production leads to a **throwaway culture without incentives to limit** the generation 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

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 that cannot easily be repurposed for other uses, as discussed above.

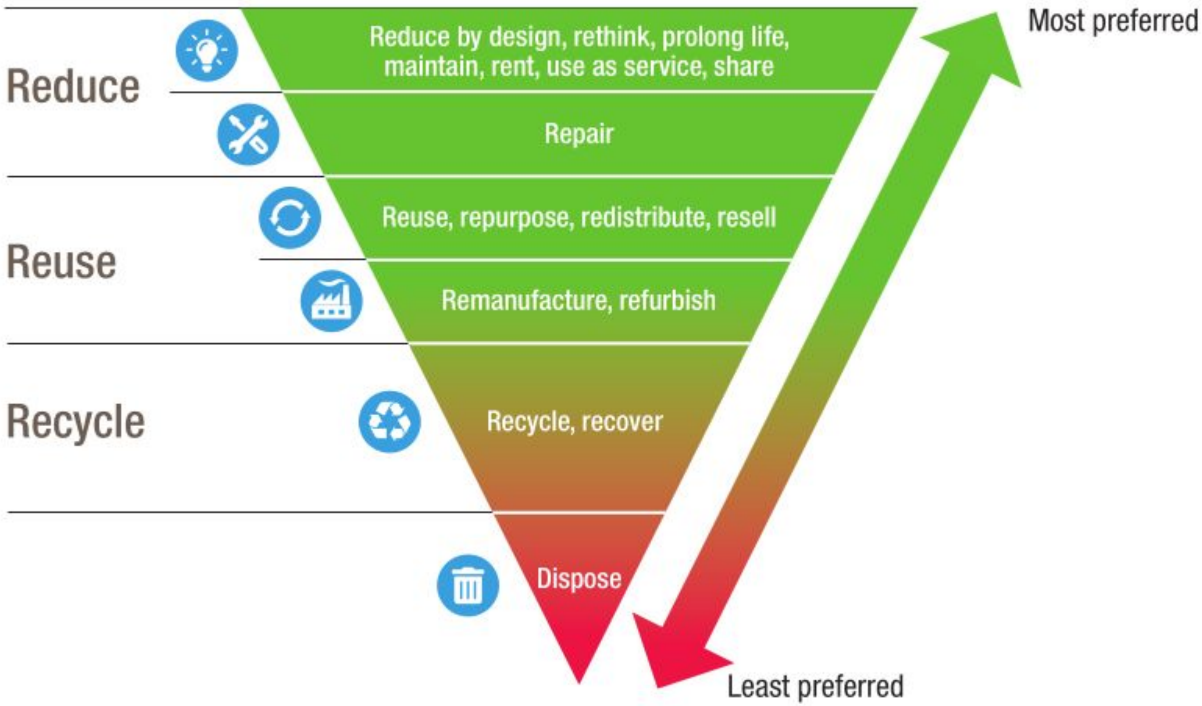
Overall, the lifespan of devices and equipment is linked to the concept of obsolescence. If this is intentionally integrated by the manufacturer, it is known as planned, programmed or built-in obsolescence, which is commonly used in the market of consumer electronics (Bisschop et al., 2022). This business 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

> The rapid evolution of digital technologies shortens the lifespan of

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, 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,

Figure IV.3
The digitalization-related waste hierarchy of options for reducing environmental impact



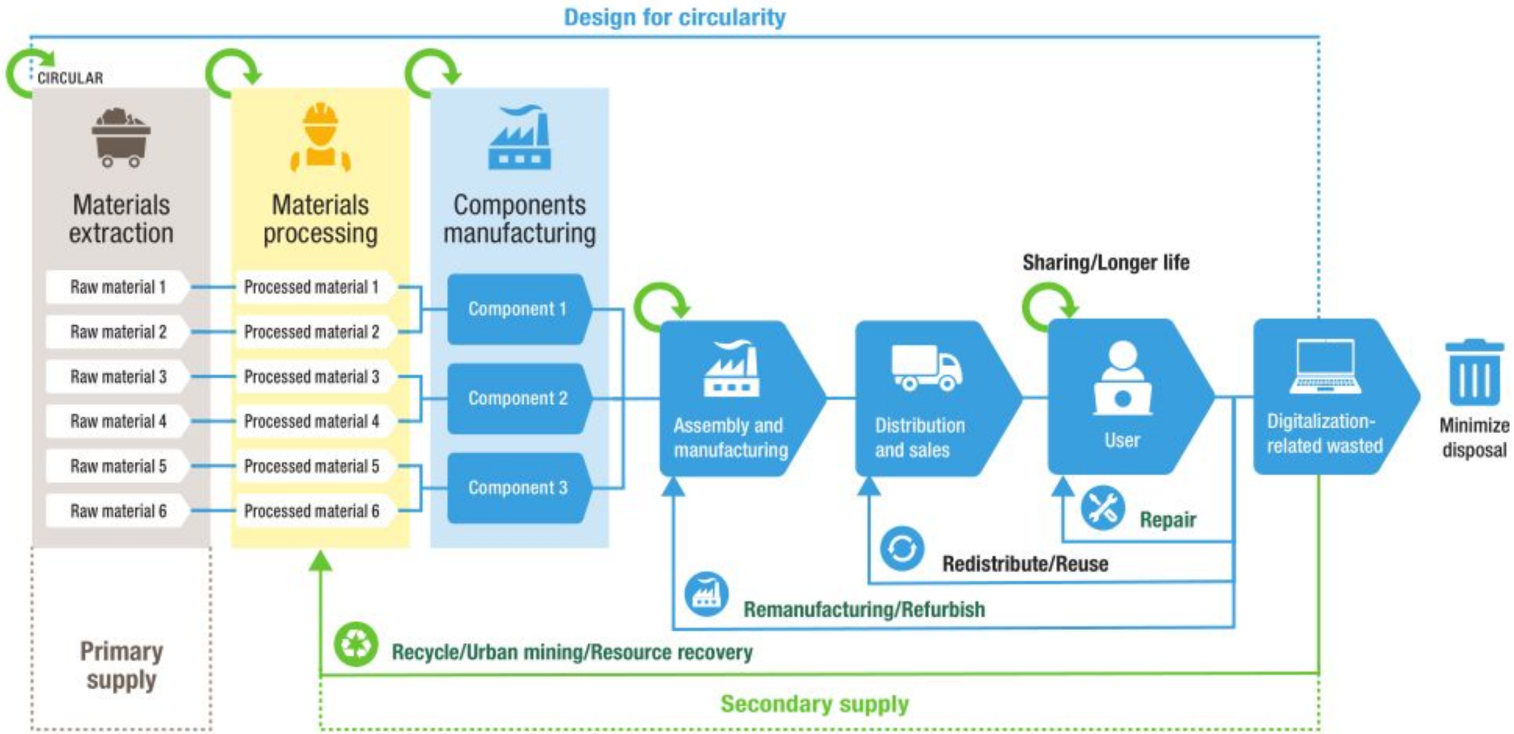
Source: UNCTAD.

[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.

shift towards the circular economy, to close the loop and either increase the supply of

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).

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).

Other chapters (that will not be covered today)

- E-commerce and environmental sustainability
- Towards environmentally sustainable digitalization that works for inclusive development

That's all, folks!