Internet Sectoral Overview
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Technologies for sustainability

Green computing

By Tereza Cristina Melo de Brito Carvalho[1]

Introduction

There has been much discussion about the challenges posed by technological advances and their impact on society and the environment. The volume of equipment used by both organizations and individuals has been growing, which has generated an increasing demand for natural resources to produce this equipment and its operation. Additionally, the obsolescence of this equipment is becoming increasingly rapid, generating electronic waste that is often not properly treated.

MOTIVATION

Against this backdrop, the impact of the use of information and communication technologies (ICT) on climate change has been questioned. According to Freitag et al. (2021), in 2020, ICT accounted for between 1.8% and 3.9% of global greenhouse gas (GHG) emissions. A more pessimistic view by Andrae (2020) argued that this figure was around 6.3% in 2020 and estimated that it could reach 23% in 2030. This is mainly due to the growth in energy consumption and the use of non-renewable and dirty energy sources.

According to Meirelles (2024), the active computer base worldwide and in Brazil has grown steadily. Chart 1 below presents the market data in Brazil. In May 2024, each Brazilian owned an average of 2.2 digital devices, including computers and smartphones, which implies a potential rise in energy consumption and other resources used to keep this base active. In addition, such post-consumer devices contribute to the increase in the volume of electronic waste generated from obsolete computers or those that are poorly functioning in subsequent years.

It is, therefore, possible to identify distinct challenges at different stages of the equipment's life cycle. During the operational phase, the sustainability of digital infrastructures must be ensured through the rational use of various resources, including the computing resources themselves (e.g., machine virtualization), the electricity used to power equipment and the physical infrastructure that houses it (e.g., air conditioning), the water used for cooling cyber environments, among others. In the post-consumer

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Photo: NIC.br

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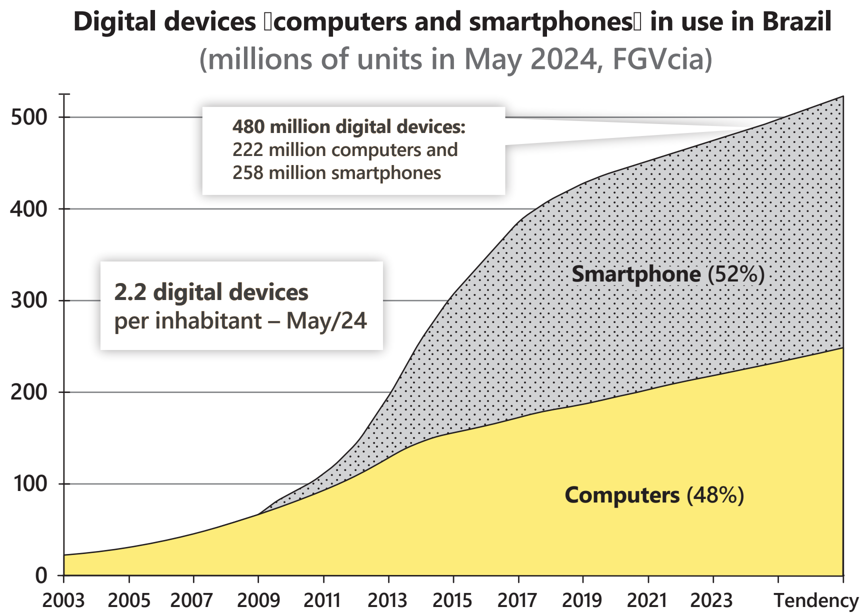
phase, i.e., at the end of its life cycle, it is necessary to guarantee the sustainable disposal of equipment, which can be sent for reuse, remanufacturing, or recycling.

Chart 1 – EVOLUTION OF THE NUMBER OF DIGITAL DEVICES PER BRAZILIAN FROM 2003 TO MAY 2024



Source: Meirelles (2024).

OBJECTIVES

This article aims to provide an overview of how the premises of "green computing" have permeated the selection, deployment, operation, and disposal of equipment used in digital infrastructures.

ORGANIZATION

This article is organized into seven sections. The first section ("Introduction") discusses the motivation for adopting green computing and defines the objectives of this article. The second section ("Characteristics of green computing") conceptualizes "green computing". The third section ("ICT equipment life cycle") describes the main life cycle phases of electronic equipment and the sustainable practices to be adopted during these phases. In the operating phase, energy consumption is a critical factor in reducing the carbon footprint. The fourth section ("Renewable and clean energy sources") conceptualizes clean and renewable energy and presents Brazil's electricity matrix. The fifth section ("Energy efficiency challenges") discusses the main challenges related to increasing the energy efficiency of ICT systems. The sixth section ("Challenges of electronic equipment waste") presents the main challenges related to the proper treatment of electronic equipment waste. Finally, the seventh section ("Final considerations") brings the article to a close and summarizes the key points of green computing.

Characteristics of green computing

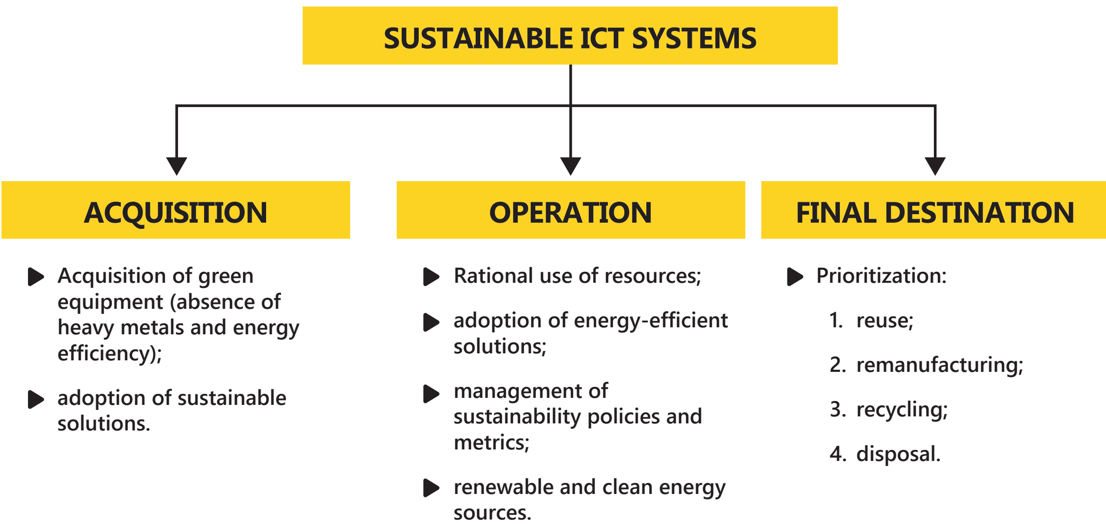
Green computing is characterized by the adoption of computing equipment that does not contain heavy metals (e.g., lead), whose operation presupposes the rational use of resources (e.g., electricity) and, at the end of its life cycle, its disposal is done according to circular economy premises, prioritizing reuse, remanufacturing, and recycling.

Two main standards specify the characteristics of "green systems": The Restriction of Hazardous Substances (RoHS), of European origin (European Commission, 2023), and the Electronic Product Environmental Assessment Tool (Epeat), of American origin (Global Electronics Council [GEC], 2025). Both specify limits on the quantities of heavy metals allowed in the manufacture of this equipment and energy consumption levels. In the case of the European Union (EU), the RoHS standard was adopted in 2002 both for manufacturing equipment in EU countries and for importing equipment into these countries.

ICT equipment life cycle

ICT equipment goes through several stages in its life cycle, covering everything from its acquisition to its final disposal when it becomes obsolete or dysfunctional. This section discusses each of these stages (Figure 1).

Figure 1 - STAGES IN THE LIFE CYCLE OF ICT EQUIPMENT



Source: Prepared by the authors.

ACQUISITION OF GREEN SYSTEMS

The acquisition of equipment can be done through a direct purchase or a Request for Proposal (RFP), in the case of private enterprises, or a public tender, in the case of public sector purchases.

One of the main elements of sustainable digital infrastructures is green data centers: ICT facilities that involve storing, processing, and transmitting data.

The purchase specification for a piece of equipment must contain a specification of its characteristics and the manufacturing standards to be met. In terms of sustainability, RoHS and Epeat may be adopted. In addition to these standards, others may be required, such as ISO 9001 (Quality Control) and ISO 14.001 (Environmental Management) (European Commission, 2023; Epeat, 2025; International Organization for Standardization [ISO], 2015).

OPERATION

The operation of electronic equipment occurs in different scopes, including end-user equipment, data centers, and telecommunication and computer network infrastructures.

According to some statistics (Ardito & Morisio, 2014), the sector's expected energy consumption in 2020 was 10% to 12% of global electricity consumption. That same year, the estimate of this consumption corresponded to the following distribution of GHG emissions: 50% from end-user equipment (computers, mobile phones, and other devices), 29% from data centers, and 21% from telecommunication infrastructures and computer networks.

EQUIPMENT FOR END-USERS

The end-user equipment makes a significant contribution to the ICT carbon footprint, on the order of 50%. To mitigate these effects, it is very important to acquire equipment considered "green", as there are the benefits of greater energy efficiency in its operation and, at the end of its life cycle, a reduction in the disposal of material containing heavy metals. In addition, proper management of active equipment is very important, and it is recommended that this equipment be put into low-energy consumption mode when not in use. In enterprises, this can be done automatically through pre-established energy-saving policies.

DATA CENTERS

One of the main elements of sustainable digital infrastructures is green data centers: ICT facilities that involve storing, processing, and transmitting data. They are designed and built considering energy efficiency requirements, low GHG emissions, resource optimization, waste management, and the adoption of a renewable and clean energy matrix.

In data centers, energy consumption from cooling systems is critical. Thus, the big players in the market have been researching and investing in disruptive solutions that consider, for example, the immersion of containerized data center in the ocean (such as Microsoft's Project Natick)[2], and building data centers near rivers, lakes and seas (for example, Google)[3] or in regions close to the Arctic poles (such as Facebook's Arctic Data Center)[4]. In Brazil, some banks have also invested in green data centers, such as Banco Itaú, which in 2015 created its first green data center in the city of Mogi Mirim (São Paulo). Other banks have likewise invested in creating increasingly green data center infrastructures.

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[2] Find out more: https://natick.research.microsoft.com/
[3] Find out more: https://datacenters.google/
[4] Find out more: https://web.facebook.com/reel/745326888869335

It is worth mentioning that the market for green data centers has been growing strongly and is expected to have quadrupled in 2032 compared to 2023, reaching a value of US$307.52 billion due to the urgent need to reduce energy consumption and GHG emissions (Fortune Business Insights, 2025).

TELECOMMUNICATION INFRASTRUCTURE AND COMPUTER NETWORKS

Telecommunication and computer network infrastructures account for around 21% of the total GHG emissions from ICT. Considering that society is increasingly connected, encompassing various sectors of the economy at a global level, this contribution is expected to grow over time.

Increasing the energy efficiency of telecommunication and computer networks infrastructures depends on their operating policies, which can leverage numerous mechanisms, such as the adoption of green routing and the use of different operating states for the equipment itself.

Green routing uses energy consumption as a metric when establishing routes and adopts the most energy-efficient routes, not necessarily the fastest. As far as operating states are concerned, some devices allow their communication interfaces to be placed in dormant or active mode, and in active mode, it is possible to program the interface to operate at different transmission rates. This enables the allocation of an interface to different operating modes depending on the volume of traffic, in order to save energy. In addition, energy efficiency mechanisms can be configured to operate either natively or through a network management system.

DISPOSAL OF LEGACY SYSTEMS

Considering that the amount of electrical and electronic equipment purchased has been increasing year on year (Chart 1), it is expected that the number of discarded equipment will increase. According to the United Nations (UN) (Baldé et al., 2024), the volume of electronic waste generated worldwide rose from 53.6 million tons in 2019 to 62.0 million tons in 2022. In Brazil, this volume was around 2.4 million tons in 2022, with 10% of that total being green line equipment (Baldé et al., 2024).

One of the issues to be addressed is that the percentage of waste collected and treated properly is very low. Worldwide, this figure is around 22.3% (Baldé et al., 2024) while in Brazil it is less than 4%. Thus, it is worth noting that electronic waste is considered hazardous due to the variety and volume of heavy metals found on printed circuit boards. This requires training of professionals who handle this type of waste and obtaining environmental licenses from companies operating in the area.

According to the Brazilian National Policy on Solid Waste (PNRS) (Decree No. 7.404/2010), recyclable material collectors must be included in the reverse logistics chain of electronic equipment waste. To this end, they must be trained, and the cooperatives must hold environmental licenses. Furthermore, the treatment of electronic waste must follow the premises of the Circular Economy, prioritizing reuse, remanufacturing, and recycling (Carvalho, 2018).

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Brazil's electricity matrix is considered one of the cleanest in the world. (...) Electricity from renewable sources accounts for 84%, including hydro, wind, solar, and biomass from sugarcane bagasse.

Renewable and clean energy sources

Clean energy is understood as "any renewable energy that does not emit polluting substances into the environment" (WebTV CREA-RJ, 2021). Examples include hydro, solar, wind, and tidal energy.

Brazil's electricity matrix is considered one of the cleanest in the world. Table 1 shows how it is segmented, considering renewable and non-renewable sources. Electricity from renewable sources accounts for 84%, including hydro, wind, solar, and biomass from sugarcane bagasse.

Table 1 - BRAZILIAN ELECTRICITY MATRIX 2023

Energy source	Participation
Hydro	58.9%
Wind	13.2%
Solar	7%
Natural gas	5.3%
Sugarcane bagasse	5.1%
Lixivium or black liquor	2.1%
Net imports	2.1%
Nuclear	2%
Other non-renewables	1.6%
Coal	1.2%
Other renewables	0.8%
Diesel oil	0.6%

Source: Prepared by authors based on Ben (2024) as cited in Energy Research Enterprise (Empresa de Pesquisa Energética [EPE]) (2025).

However, some types of energy generation are known to cause other environmental problems. This is the case with wind energy, which produces a lot of noise pollution and introduces problems for both people and animals in the areas where the stations are installed.

Energy efficiency challenges

One of the main challenges to reducing the carbon footprint is to reduce energy consumption. To this end, it is necessary to:

IDENTIFY ENERGY EFFICIENCY METRICS AND INDICATORS

One of the best-known energy efficiency indicators is Power Usage Effectiveness (PUE).

PUE = Total installation load/ICT load, where:

- **ICT load:** Corresponds to the energy consumption of all the ICT components in the installation.
- **Total installation load:** Corresponds to the energy consumption of all the systems that support the ICT infrastructure, including cooling systems, power distribution, lighting, security systems, and the ICT systems themselves.

The PUE value for data centers considered very efficient is <=1.2. Facebook, with its data center immersed in snow, declares a PUE equal to 1.06. Google operates data centers with a PUE of 1.12. According to the Uptime Institute (Davis, 2024), the average PUE in data centers in 2023 was 1.58.

IDENTIFY AND EVALUATE ENERGY EFFICIENCY MECHANISMS

The existing energy efficiency mechanisms are numerous, and their application depends on the setting.

In the case of data centers, the most critical element is the cooling system, which accounts for around 38% of energy consumption (Table 2). In this way, strategies for minimizing energy consumption with cooling have generated significant innovation, as pointed out in the section "ICT equipment life cycle," which mentioned the case of Facebook's data center immersed in snow, or even data centers built near water flows (rivers, lakes, seas). Another energy drain is servers, which has led to server consolidation practices through the virtualization of computing resources.

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In the case of data centers, the most critical element is the cooling system, which accounts for around 38% of energy consumption (...).

In the case of telecommunication infrastructures and computer networks, there are simpler and more common practices, such as disabling equipment or even interfaces with low workload, or changing the operating frequency of interfaces or the equipment as a whole, which result in reduced energy expenditure.

Table 2 - ENERGY CONSUMPTION IN DATA CENTERS

Energy efficiency mechanisms	Energy consumption
Cooling	38%
Processor	15%
Other server	15%
Server power supply	14%
Uninterruptible Power Supply (UPS)	5%
Storage	4%
Communication equipment	4%
Switchgear and transformers	3%
Lighting	1%
Power Distribution Unit (PDU)	1%

Source: Prepared by authors based on Clarke Energy (2025).

In the case of telecommunication infrastructures and computer networks, there are simpler and more common practices, such as disabling equipment or even interfaces with low workload, or changing the operating frequency of interfaces or the equipment as a whole, which result in reduced energy expenditure. Other more sophisticated practices include green routing (choosing the most energy-efficient routes) or defining the positioning of Virtual Network Functions (VNF) in network elements, based on the greatest energy efficiency.

EVALUATE THE RELATIONSHIP BETWEEN ENERGY EFFICIENCY AND QUALITY OF SERVICE PARAMETERS

The adoption of energy efficiency mechanisms can result in a loss of performance. For example, when a Control Process Unit (CPU) has a low workload and it is decided to reduce its operating frequency to reduce energy consumption, there is a loss of performance. This can impact the quality of service (QoS) of the service offered. This relationship between energy efficiency and QoS parameters must therefore always be evaluated and can even be monetized. Users can, for example, opt for a "green" service that is more energy-efficient, compromising on QoS parameters in exchange for cost reduction for users.

ALIGNING ENERGY EFFICIENCY ACTIONS WITH SUSTAINABILITY AND PERFORMANCE POLICIES

The evaluation of the relationship between energy efficiency and QoS parameters presented in the previous section can result in the specification of sustainability and performance policies. Such policies can define different classes of ICT services according to this assessment, specifying various gradations of "green" services associated with different levels of energy efficiency, quality of service parameters, and costs.

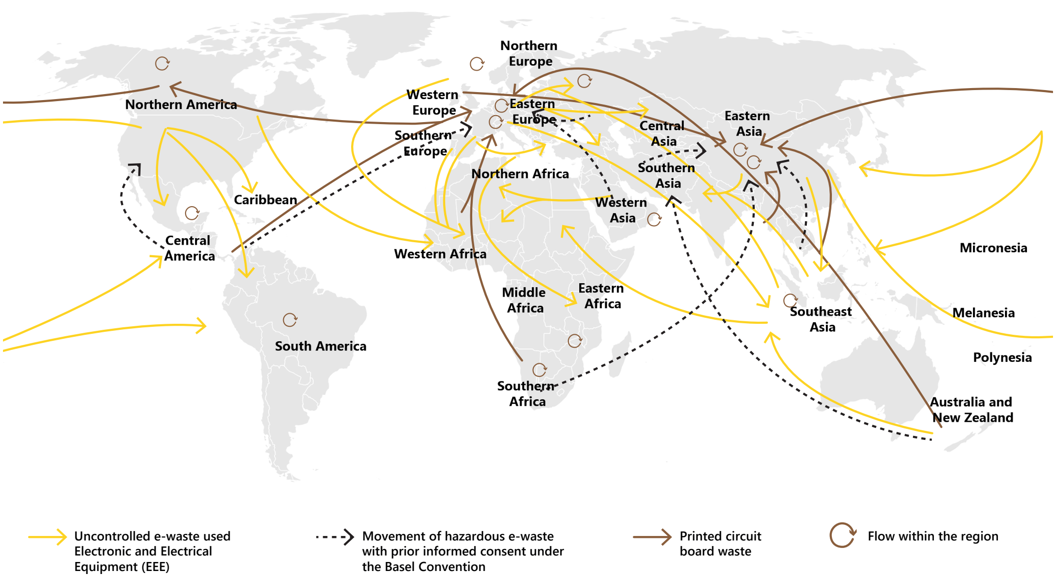
Challenges of electronic equipment waste

(...) only 22.3% of electronic equipment waste is treated properly worldwide (and around 4% in Brazil).

As mentioned in the section "ICT equipment life cycle", only 22.3% of electronic equipment waste is treated properly worldwide (and around 4% in Brazil). This is primarily due to the lack of adequate legislation regarding this type of waste. Brazil stands out for having robust legislation that includes electronic waste, incorporating the concepts of shared responsibility and extended manufacturer responsibility. Although each Brazilian state has its own legislation and environmental licenses, there is a lack of adequate enforcement, and many enterprises are operating in the market without valid environmental licenses.

In addition, there are various international agreements, such as the Basel agreement, to which many countries are not signatories. This has resulted in the illegal migration of waste between countries, with the main flows coming from developed countries and destined for underdeveloped countries. In this scenario, Africa is the main continent receiving this waste, but Brazil has also been the target of waste imports. Figure 2 shows the migratory flows of electronic waste mapped by the UN.

Figure 2 - MIGRATION OF ELECTRONIC EQUIPMENT WASTE



Source: Baldé et al. (2024).

(...) regardless of the energy efficiency mechanisms used, it is important to rely on renewable and clean energy sources. In this respect, Brazil is a privileged country, as it has one of the cleanest electricity matrices in the world.

Another important point is the treatment of waste by the informal sector (e.g., waste pickers) under precarious conditions. According to the PNRS (Decree No. 7.404/2010), waste pickers should be included in the reverse logistics chain for waste, including electronic waste. To do so, waste pickers need to be trained in the practices of sorting, separating, and handling this type of waste and have the appropriate environmental licenses. However, despite several projects to train waste picker cooperatives, the question of licenses remains open, as the costs are prohibitive for this population.

Final considerations

The starting point for this article was the impact of ICT use on GHG generation and, consequently, on climate change. It is well known that the volume of electronic equipment and devices in use is growing, generating increasingly higher electricity expenditures and waste at the end of their life cycle.

Practices were presented for the acquisition, operation, and disposal of this equipment. At the acquisition stage, it is important to select "green equipment" that is free of heavy metals and features energy-efficient functionality. In the operation stage, the most critical aspect is reducing energy consumption. Examples of energy efficiency mechanisms were presented, such as the consolidation of servers in data centers or the adoption of green routing in communication networks, prioritizing routes with greater energy efficiency. Finally, at the disposal stage, circular economy premises should serve as a base, prioritizing reuse, followed by remanufacturing and recycling.

It is also worth noting that, regardless of the energy efficiency mechanisms used, it is important to rely on renewable and clean energy sources. In this respect, Brazil is a privileged country, as it has one of the cleanest electricity matrices in the world.

Therefore, although ICT has increased GHG emissions, it is important to remember that ICT solutions have significantly contributed to ensuring the sustainability of various sectors of the economy. The example of ICT use in medicine illustrates this contribution.

References

Andrae, A. (2020). New perspectives on internet electricity use in 2030. *Engineering and Applied Science Letters, 3*(2), 19-31. https://pisrt.org/psr-press/journals/easl/05-vol-3-2020-issue-2/new-perspectives-on-internet-electricity-use-in-2030/

Ardito, L., & Morisio, M. (2014). Green IT - Available data and guidelines for reducing energy consumption in IT systems. *Sustainable Computing: Informatics and Systems, 4*(1), 24-32. https://doi.org/10.1016/j.suscom.2013.09.001

Baldé, C. P., D'angelo, E., Kuehr, R., Yamamoto, T., Mcdonald, R., D'angelo, E., Althaf, S., Bel, G., Deubzer, O., Fernandez-Cubillo, E., Forti, V., Gray, V., Herat, S., Honda, S., Iattoni, G., Khetriwal, D. S., Cortemiglia, V. L., Lobuntsova, Y., Nnorom, I., Pralat, N., & Wagner, M. (2024). *The Global E-waste Monitor 2024*. ITU and UNITAR. https://ewastemonitor.info/the-global-e-waste-monitor-2024/

Carvalho, T. C. M. B. (2018). Os benefícios e os desafios de Economia Circular aplicada ao setor de equipamentos eletroeletrônicos. In C. Ohde (Org.), *Economia Circular: um modelo que dá impulso à economia, gera empregos e protege o meio ambiente* (Part. 4, Art. 2, pp. 169-190). NetPress Books.

Clarke Energy. (2025). *Data Centre*. https://www.clarke-energy.com/applicat.ions/data-centre-chp-trigeneration/

Davis, J. (2024). *Large data centers are mostly more efficient, analysis confirms*. Uptime Institute. https://journal.uptimeinstitute.com/large-data-centers-are-mostly-more-efficient-analysis-confirms/

Decree No. 7.404, of December 23, 2010. (2010). Regulates Law No. 12.305, of August 2, 2010, which establishes the National Solid Waste Policy, creates the Interministerial Committee for the National Solid Waste Policy and the Guidance Committee for the Implementation of Reverse Logistics Systems, and makes other provisions. https://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/decreto/d7404.htm

Empresa de Pesquisa Energética. (2025). *Matriz Energética e Elétrica*. ABCD Energia. https://www.epe.gov.br/pt/abcdenergia/matriz-energetica-e-eletrica

European Commission. (2023). *Restriction of Hazardous Substances in Electrical and Electronic Equipment*. https://environment.ec.europa.eu/topics/waste-and-recycling/rohs-directive_en

Fortune Business Insights. (2025). *Tamanho do mercado de data center verde, análise de participação e indústria, por componente (soluções e serviços), por usuário (provedores de colocation, provedores de serviços em nuvem (CSPs) e empresas) e previsão regional, 2024-2032.* https://www.fortunebusinessinsights.com/pt/green-data-center-market-105173

Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G. S., & Friday, A. (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. *Patterns, 2*(9), Article 100340. https://doi.org/10.1016/j.patter.2021.100340

Global Electronics Council. (n.d.). *Electronic Product Environmental Assessment Tool*. https://globalelectronicscouncil.org/epeat-registry/

International Organization for Standardization. (2021). ISO 14001:2015. *Sistemas de gestão ambiental – Requisitos com orientação para uso* (review).

Meirelles, F. S. (2024). *Pesquisa Anual do Uso de TI (Tecnologia da Informação) nas Empresas*. EAESP/FGV. https://eaesp.fgv.br/sites/eaesp.fgv.br/files/u68/pesti-fgvcia-2024_0.pdf

WebTV CREA-RJ. (2021). *O que é energia limpa?* [Video]. YouTube. https://youtu.be/MYvpH_1rAkw?si=wqw82uHUp9KEr9LB

Interview I

Photo: MIMA

Ana Toni
Executive director of COP30

COP30 in Brazil: Inclusive digital technologies for climate justice

In this interview, Ana Toni, executive director of the 30th Conference of the Parties (COP30)[5] highlights Brazil's role in tackling climate change, focusing on preserving the Amazon and strengthening local communities. She also addresses the challenges and advances in using digital technologies for environmental monitoring, highlighting the need for socio-environmental responsibility and inclusion in climate solutions.

Internet Sectoral Overview (I.S.O.)_ COP30 will take place at a critical moment for the global climate agenda and will be hosted in the Amazon. What goals does Brazil aim to achieve, and what role can it play in driving more ambitious and fair commitments?

Ana Toni (A.T.)_ COP30 will be a concrete opportunity to take a step forward in the implementation of the Paris Agreement. Our commitment is to help accelerate this process, strengthen climate multilateralism, and support a transformation that places the climate crisis at the heart of economic and financial decision-making.

Brazil has both the legitimacy and responsibility to lead this process. We are a highly diverse country, with one of the cleanest energy matrices in the world, an active civil society, and a territorial base that is home to extremely rich and vital biomes that are essential for climate regulation, biodiversity conservation, and the way of life of millions of Brazilians.

Due to this unique condition, which entails significant responsibilities, the Lula administration has focused efforts on strengthening the strategic planning of public policies aligned with the new reality imposed by the climate crisis. We are finalizing the Climate Plan (Plano Clima)[6] update, an intrinsically cross-cutting strategy, developed in collaboration with 23 sectoral ministries. This plan coordinates mitigation and adaptation actions, five cross-cutting strategies, and several sectoral plans. We have also made a public commitment to achieve zero deforestation by 2030—a goal reflected in our Nationally Determined Contribution (NDC),[7] the second to be submitted in this new round, reaffirming our commitment to climate ambition.

The COP30 Presidency is committed to this vision: To drive an equitable climate transition, with adequate funding, support for adaptation, accessible technological solutions, and a leading role for local peoples and communities. Brazilian leadership is based on listening, cooperation, and concrete action—principles that will guide the work in Belém and beyond.

[5] Find out more: https://cop30.br/en
[6] Find out more: https://www.gov.br/mma/pt-br/composicao/smc/plano-clima
[7] Find out more: https://cop30.br/en/about-cop30/nationally-determined-contributions-ndcs

I.S.O._ Information and communication technologies (ICT) have increasingly gained ground in climate debates. How do you assess the historical relationship between digital technologies and climate debates at previous COP, and what paths do you see for the issue to be addressed more strategically?

A.T._ Historically, the role of digital technologies in the climate spaces of the United Nations Framework Convention on Climate Change (UNFCCC) has been on the margins of the decision-making center. However, this reality is changing. The Declaration on Green Digital Action,[8] launched at COP29,[9] was an important step forward, and COP30 may consolidate this movement.
Digital technologies are essential for addressing the climate crisis. They enable everything from remote forest monitoring to Artificial Intelligence (AI) usage to predict extreme events or optimize production chains with lower emissions. However, this potential needs to be harnessed with responsibility, also considering the environmental and social risks, such as the energy consumption of data centers and the widening of technological inequalities.

I.S.O._ The Declaration on Green Digital Action, launched at COP29, established common goals to make digital systems more sustainable and strategic in climate action. What progress and obstacles have you identified since then, and how can COP30 push this agenda forward, especially in developing countries?

A.T._ The Declaration on Green Digital Action was an important milestone in recognizing that digital transformation can—and must—be at the service of more efficient, inclusive, and sustainable climate action. The document established commitments across various areas, such as mitigating the environmental impacts of digitalization, promoting digital inclusion, building resilient infrastructures, using data to support decision-making, and fostering green innovation.
Since then, we have seen growing political and technical recognition of digital technologies' role in accelerating the Paris Agreement's implementation. However, significant obstacles remain, such as the increasing data centers' energy consumption, data governance challenges, and the persistent digital exclusion of countries and populations that most need these solutions. These risks must be addressed with responsibility, transparency, and international cooperation.
COP30 could be an important space to continue the implementation of the declaration, particularly regarding the priorities of developing countries. There is an opportunity to broaden the debate on institutional training, financing sustainable digital solutions, and building bridges among governments, the private sector, academia, and civil society. Digitalization, in itself, is not neutral—its impacts depend on the political choices that guide its use. These choices must be guided by principles of justice, inclusion, and effective contribution to climate action.

"Historically, the role of digital technologies in the climate spaces of the United Nations Framework Convention on Climate Change (UNFCCC) has been on the margins of the decision-making center. However, this reality is changing. The Declaration on Green Digital Action, launched at COP29, was an important step forward, and COP30 may consolidate this movement."

[8] Find out more: https://cop29.az/en/pages/cop29-declaration-on-green-digital-action
[9] Find out more: https://cop29.az/en/home

"Tools such as AI, remote sensing, connectivity, and open data platforms have the potential to monitor, protect, and enhance territories, strengthen sustainable production chains, and expand access to public policies."

I.S.O._ How can digital technologies support an ecological transition that is inclusive for local and traditional populations?

A.T._ The ecological transformation we need requires more than technological innovation: It demands inclusion, justice, and permanent dialogue with the territories. I often emphasize that the economic transition will occur, whether at a slower or faster pace; the just transition is a political choice that needs to be reaffirmed at every moment.

Digital technologies can be great allies in this choice. Tools such as AI, remote sensing, connectivity, and open data platforms have the potential to monitor, protect, and enhance territories, strengthen sustainable production chains, and expand access to public policies. However, this potential can only be fully realized when it is created *with* and *for* the people who live in and care for these territories.

Digital inclusion is, therefore, an essential part of climate justice. This entails ensuring access to connectivity, providing adequate technical training, implementing data governance mechanisms, and securing funding for locally developed solutions. Promoting an inclusive ecological transition requires investing in technologies that respect cultural diversity, strengthen the autonomy of territories, and expand the capacities of communities. In this way, digitalization can cease to be a vector of exclusion and become an instrument of empowerment and equity.

Article II

Artificial Intelligence for climate action in developing countries: Opportunities, challenges, and risks[10]

By United Nations Climate Change Technology Executive Committee

AI systems that use machine learning techniques are rapidly emerging as transformative technologies, with climate change standing out as an area where these innovations can drive impactful changes.

Introduction

This information note is intended to serve as an accessible introduction to the relationship between Artificial Intelligence (AI) and climate action. The Technology Executive Committee (TEC)[11] has prepared this publication as part of the Technology Mechanism Initiative on AI for Climate Action (#AI4ClimateAction)[12] to provide an overview of the opportunities, risks, and challenges of using AI for climate action in developing countries, with a focus on least developed countries (LDC) and small island developing States (SIDS). The Technology Mechanism consists of a policy arm, the TEC, and an implementation arm, the Climate Technology Centre and Network (CTCN),[13] to advance the development and transfer of climate technologies under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement.

AI and machine learning

AI systems that use machine learning techniques are rapidly emerging as transformative technologies, with climate change standing out as an area where these innovations can drive impactful changes. Research has shown that AI can act as an enabler and inhibitor in addressing climate change challenges (Vinuesa et al., 2020). The #AI4ClimateAction is exploring how AI can help address climate change in developing countries, in particular in LDC and SIDS, including through the use of AI for monitoring and data collection; climate modelling and prediction;

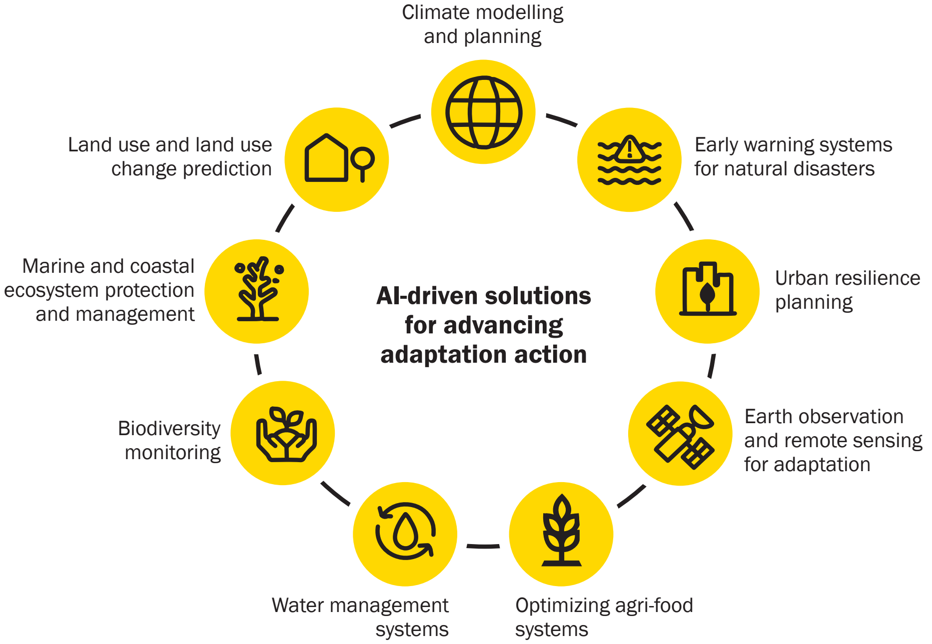
[10] Edited version of the homonymous work published by the United Nations Climate Change Technology Executive Committee. The original version is available at: https://unfccc.int/ttclear/tec/AI4climate.html#infonote
[11] Find out more: https://unfccc.int/ttclear/tec
[12] Find out more: https://unfccc.int/ttclear/artificial_intelligence
[13] Find out more: https://www.ctc-n.org/

AI systems are playing a role in climate modelling and planning, data analysis, and prediction of sea-level rise, deforestation, and other climate impacts.

resource, energy, and transport management; disaster risk reduction; and education and community engagement. The aim is to assess how these technologies can contribute to climate action, while addressing the challenges and risks of their use.

AI-driven solutions for advancing adaptation action

Figure 1 – AI APPLICATIONS FOR CLIMATE CHANGE ADAPTATION



Source: Prepared by the authors.

CLIMATE MODELLING AND PLANNING

AI systems are playing a role in climate modelling and planning, data analysis, and prediction of sea-level rise, deforestation, and other climate impacts. These models can help governments and organizations develop more tailored and efficient adaptation responses, improve disaster preparedness, and include resilience in infrastructure planning. AI can also be used to enhance the ability to forecast long-term climate trends and identify the areas that are most vulnerable to climate risks, enabling data-driven decisions that strengthen resilience.

EARLY WARNING SYSTEMS FOR NATURAL DISASTERS

AI models are increasingly deployed in developing countries, including LDC and SIDS, to support analysis of weather patterns and provide more accurate forecasts for hurricanes, floods, and droughts, allowing for timely alerts and preparedness measures and helping to mitigate the impacts of these events on vulnerable communities.

URBAN RESILIENCE PLANNING

AI is increasingly being utilized to map housing stock characteristics in countries vulnerable to natural disasters, such as LDC and SIDS. It automates the creation of detailed maps that identify building footprints, material types, and structural conditions, leveraging high-resolution aerial imagery and machine learning techniques, including advanced computer vision models. These AI-driven tools are beneficial for conducting effective vulnerability assessments and enhancing disaster risk management and urban resilience planning. In areas prone to natural hazards, AI systems can enable rapid assessment of damage following a disaster and can help to identify at-risk structures before such events occur. This supports more resilient urban planning and disaster preparedness efforts.

In areas prone to natural hazards, AI systems can enable rapid assessment of damage following a disaster and can help to identify at-risk structures before such events occur.

EARTH OBSERVATION AND REMOTE SENSING FOR ADAPTATION

AI-driven Earth observation and remote sensing technologies are supporting adaptation efforts in sectors like agriculture, water management, and ecosystem conservation. These systems provide real-time information on soil health, water levels, and land degradation, helping countries monitor environmental conditions that are critical to adaptation. By using AI systems that include satellite data, governments and communities can be supported in implementing timely interventions, adjusting farming practices, and managing natural resources more effectively, supporting food security and sustainable development.

OPTIMIZING AGRI-FOOD SYSTEMS

In agriculture, AI can assist in optimizing planting schedules, monitoring crop health, and predicting pest outbreaks. This is particularly relevant for LDC and SIDS, where food security is often threatened by changing climate conditions. AI-driven precision agriculture has shown potential in improving yields and reducing resource use. In sub-Saharan Africa, AI has been used to optimize irrigation and farming practices, improving crop yields in regions affected by unpredictable climate conditions. The machine learning models have been used to support the analysis of weather patterns and soil data to provide guidance to farmers, enhancing food security.

AI-driven solutions have been employed to automate irrigation systems, predict droughts, and manage reservoirs to maintain optimal water levels, ensuring a reliable supply for agriculture, industry, and domestic use.

WATER MANAGEMENT SYSTEMS

AI technologies can play a key role in monitoring water resources, predicting water demand, and optimizing distribution systems to improve water use efficiency. AI can help forecast water needs and allocate resources more effectively by leveraging correlations on vast datasets on weather patterns, soil moisture, and water consumption trends. This is particularly important in LDC and SIDS, where access to clean water is often limited, and climate change exacerbates water scarcity. AI-driven solutions have been employed to automate irrigation systems, predict droughts, and manage reservoirs to maintain optimal water levels, ensuring a reliable supply for agriculture, industry, and domestic use. These solutions are relevant in ensuring sustainable water management in countries and states that are vulnerable to both climate variability and increasing water stress.

BIODIVERSITY MONITORING

AI is advancing biodiversity monitoring, allowing for the real-time tracking of ecosystems and species affected by climate change. AI systems are used to process data from drones, remote cameras, and acoustic sensors to monitor wildlife populations and assess ecosystem health. These systems have helped conservationists and governments to monitor the impacts of climate change on biodiversity, implement protective measures, and address the challenges of habitat loss.

MARINE AND COASTAL ECOSYSTEM PROTECTION AND MANAGEMENT

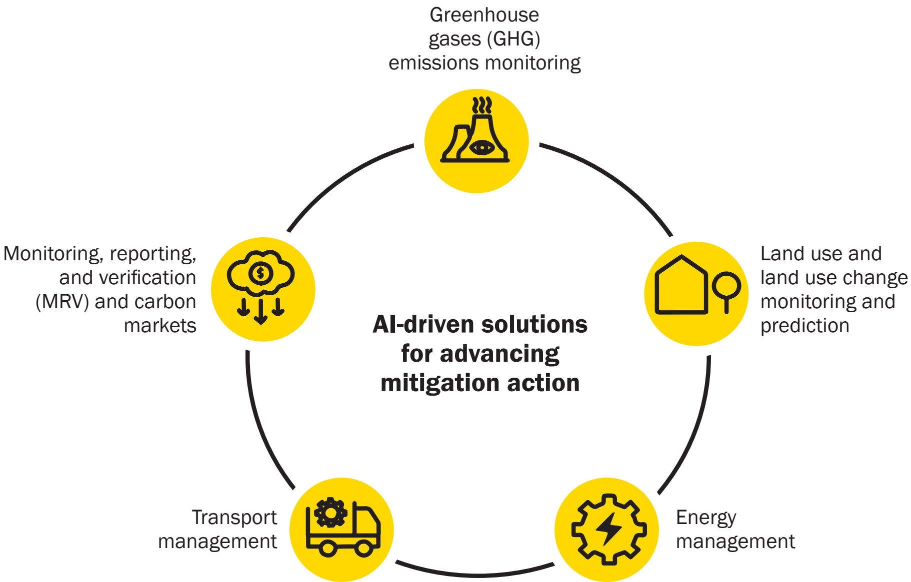
AI is increasingly being used to monitor and protect coastal and marine ecosystems by tracking changes in coral reefs, fish populations, and other vital resources. These ecosystems are essential for biodiversity and provide critical services, such as food security, livelihoods, and protection from natural disasters. In SIDS, where many communities rely on the health of marine environments for their economic well-being, AI technologies, combined with satellite imagery, are being deployed to track illegal fishing activities, monitor coastal erosion, and assess changes in marine habitats. Moreover, AI-powered remote sensing and drones are used to survey hard-to-reach areas, providing real-time data on ecosystem health. However, despite the potential of these technologies, large-scale implementation across all SIDS is not yet uniform, with varying levels of access to AI tools and resources. Efforts are ongoing to scale up the use of AI in marine conservation, contributing to more effective management and protection of these ecosystems.

LAND USE AND LAND USE CHANGE PREDICTION

AI models are being used to predict land use and land cover changes using spatial data related to soil type, altitude, and proximity to infrastructure, among other features. These predictions help forecast shifts in land use patterns, enabling policymakers to better manage resources and plan for sustainable land use.

AI-driven solutions for advancing mitigation action

Figure 2 – AI APPLICATIONS FOR CLIMATE CHANGE MITIGATION



Source: Prepared by the authors.

> (...) AI systems can help pinpoint methane emissions with greater precision. These systems enable real-time detection, allowing for faster interventions in sectors such as oil and gas, agriculture, and waste management, where methane leaks are prevalent.

GHG EMISSIONS MONITORING

AI has become a tool in GHG emissions monitoring, particularly for methane, one of the main GHG, making its detection and reduction critical for climate mitigation efforts. By leveraging vast datasets from satellite imagery, remote sensors, and ground-based monitors, AI systems can help pinpoint methane emissions with greater precision. These systems enable real-time detection, allowing for faster interventions in sectors such as oil and gas, agriculture, and waste management, where methane leaks are prevalent. Moreover, the prediction of potential leaks based on historical data patterns is transforming methane management strategies, better equipping governments and industries to address these emissions before they escalate, in line with global efforts, such as the Global Methane Pledge, where countries have committed to reducing global methane emissions at least 30% by 2030.

LAND USE AND LAND USE CHANGE MONITORING AND PREDICTION

AI-powered Earth observation and remote sensing technologies may be important for tracking land-use changes that impact GHG emissions. By processing satellite data, AI systems can support the detection of environmental changes in real time,

> AI algorithms, leveraging extensive data on traffic patterns, passenger demand, and weather conditions, can significantly reduce emissions and enhance efficiency in transportation systems (...).

monitoring deforestation and land use changes, along with urban expansion, and industrial activity, all of which are significant sources of GHG emissions, enabling governments to identify emission hotspots and implement targeted mitigation efforts.

ENERGY MANAGEMENT

AI is increasingly being used to optimize the development and operation of renewable energy systems, such as batteries, solar, and wind power, by predicting energy demand and supply based on weather patterns, grid data, and consumption habits, and adjusting supply to ensure reliable energy access despite fluctuations in renewable energy sources. AI can also be utilized in demand-side management, where it optimizes energy consumption through smart grids and connected devices, allowing for more dynamic pricing models and real-time demand response. Furthermore, AI can play a role in grid optimization, improving energy dispatching processes, and ensuring efficient use of resources during high-demand periods. AI also has the potential to reduce energy use in residential and commercial buildings, such as through the optimization of building orientation for solar heat gains, accurate prediction of power and heat needs, and maximizing renewable energy integration. AI can also contribute to energy savings in the industrial sector by supporting analyses of operational data, optimizing production processes, and improving overall energy efficiency. Lastly, AI can improve power grid reliability by rapidly identifying maintenance needs. In Barbados, Mauritius, and Seychelles, AI already plays a role in managing microgrids that distribute energy efficiently across local networks. Embedding AI in these systems enabled these countries to optimize energy flows, reducing the need for fossil fuel-based energy and supporting the transition to clean energy sources.

TRANSPORT MANAGEMENT

AI offers a range of solutions to optimize transportation systems and diminish their carbon footprints. AI-powered traffic management systems and personal route planners use real-time data from sensors, cameras, and Global Positioning System (GPS) devices to monitor traffic flow and adjust traffic signals dynamically. For example, AI can enhance traffic flow, predict congestion, and optimize routes, thereby reducing emissions from idling and unnecessary detours. AI algorithms, leveraging extensive data on traffic patterns, passenger demand, and weather conditions, can significantly reduce emissions and enhance efficiency in transportation systems, resulting in substantial cost savings, decreased GHG emissions, and a more sustainable transportation sector.

MRV AND CARBON MARKETS

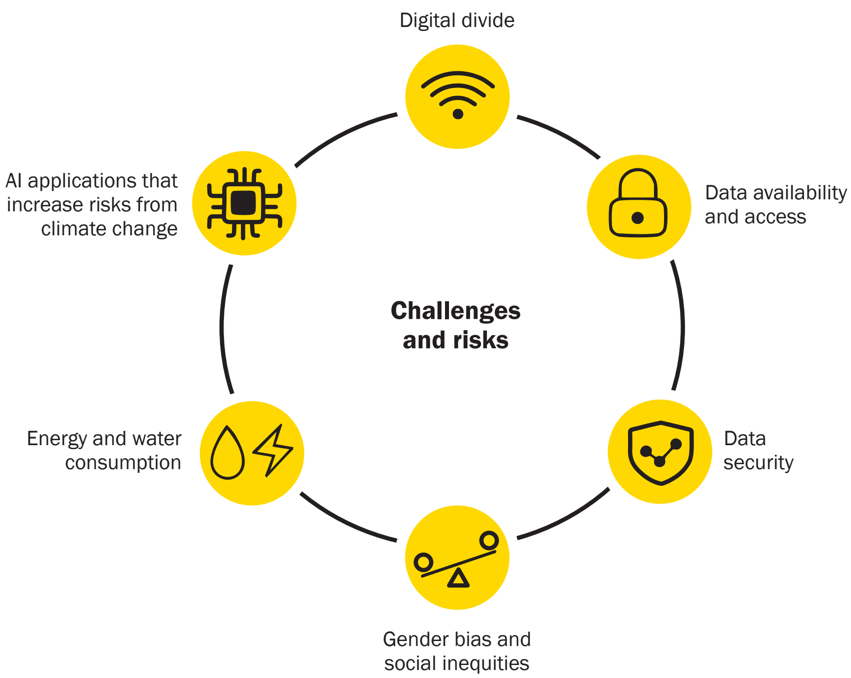
AI can play a role in enhancing the implementation of robust carbon credit certification standards by automating the MRV of carbon sequestration projects, such as reforestation and land-use change initiatives. AI-powered systems analyze satellite data and assess land-use practices to support accurate quantification of carbon storage. This can reinforce transparency and efficiency in carbon markets by providing information about results in real time. AI's ability to streamline MRV processes can help countries participate in global carbon trading and potentially increase their access to climate finance. While some uses have been tested in relation to carbon markets, the extent that AI-powered systems can be used for carbon markets is dependent on the requirements of the laws, regulations, and standards of each market.

While these examples showcase the potential of AI in supporting climate action, some of them also offer insights regarding the importance of ensuring that AI technologies are accessible, contextually relevant, and implemented in a way that considers local conditions and capacities.

The persistent digital divide remains a substantial gap between the developing and developed countries, but also within countries between vulnerable and rural communities and well-connected hubs.

Challenges and risks

Figure 3 – CHALLENGES AND RISKS ASSOCIATED WITH AI



Source: Prepared by the authors.

THE DIGITAL DIVIDE

The persistent digital divide remains a substantial gap between the developing and developed countries, but also within countries between vulnerable and rural communities and well-connected hubs. In particular, the lack of access to energy and digital infrastructure, such as reliable electric grids, internet, data storage, and computing power, severely limits the use of AI for climate action in remote and underserved areas. Also, a shortage of technical expertise and the absence of robust

> AI systems, if not designed with inclusivity in mind, can unintentionally perpetuate existing biases and social inequities in climate action. For example, AI models trained on biased datasets may overlook or misrepresent the climate needs of women and marginalized communities (…).

data management systems and national policies that promote endogenous innovation could be factors that can further hinder the development, deployment, and effectiveness of AI solutions in these countries.

DATA AVAILABILITY AND ACCESS

AI solutions are heavily dependent on high-quality, comprehensive data. However, many LDC and SIDS face significant gaps in data infrastructure, leading to a scarcity of reliable climate-relevant data. Limited data collection systems, inability to digitalize hardcopy data, inadequate data-sharing frameworks, and poor integration between local and global datasets further compound this issue. Also, the availability of data can correlate with demographic and socioeconomic status, creating a compounding effect with other sources of bias. In addition, developing countries may lack financial resources for access to satellites or high-resolution hyperspectral imaging, which are essential for building accurate AI models for some purposes.

DATA SECURITY

This is a growing concern as AI becomes widespread. The vast and complex datasets used in AI-driven climate-relevant models, including sensitive information about environmental conditions, national resources, and vulnerable communities, are increasingly at risk of cyberattacks and unauthorized access. Protecting these datasets is essential, as any breach or tampering could lead to the misuse of information, potentially undermining climate action efforts.

GENDER BIAS AND SOCIAL INEQUITIES

AI systems, if not designed with inclusivity in mind, can unintentionally perpetuate existing biases and social inequities in climate action. For example, AI models trained on biased datasets may overlook or misrepresent the climate needs of women and marginalized communities, resulting in solutions that fail to address their specific climate-related challenges, such as access to resources or disaster preparedness. This can exacerbate existing vulnerabilities in climate-sensitive regions or communities, where these groups often bear the brunt of climate impacts. As AI becomes more integrated into disaster response, resource management, and environmental monitoring, there is a risk that such systems may deepen existing social divides if not carefully monitored and adapted.

ENERGY AND WATER CONSUMPTION

AI systems, especially those powered by deep learning and large language models (LLM), are highly energy-intensive. While some studies highlight the increasing resource demands of AI, its current contribution to global GHG emissions is minimal, at around 0.01%, and even with rapid growth, AI's operational footprint is not expected to significantly impact GHG emissions in the near future (Luers et al., 2024). Predicting the long-term energy and resource use of AI is challenging due to the sector's fast evolution, and simple projections based on past trends often miss important social, economic, and technological factors, leading to inaccurate forecasts (Masanet et al., 2020) (Chen et al.,2024). Moreover, focusing solely on AI's indirect emissions may overlook its potential to drive climate solutions. Regardless, it is important to acknowledge the degree of uncertainty when separating AI emissions from those produced by data centers and data transmission.

The emissions from data centers and data transmission are currently estimated to account for approximately 0.6% of global emissions (International Energy Agency [IEA], n.d.). While AI is unlikely to result in significant near-term increases in GHG emissions, policy development could benefit from scenarios that quantify the potential long-term climate effects of AI expansion under various assumptions. This would help ensure that AI's future growth is managed in a sustainable and climate-conscious manner.

In addition to the energy demand, data center operations require significant quantities of water for cooling purposes. Some estimates, such as from the Organization for Economic Cooperation and Development (OECD), put water consumption by AI at 6.6 billion m^3 of water by the year 2027 (Ren, 2023). Due to the local nature of the impacts of water consumption and extraction, the location of the infrastructure and the source of the water used can add further pressure on water resources in vulnerable communities where water scarcity is, or will be in the future, a critical issue.

Efforts to address these challenges are underway. Energy-efficient AI algorithms are being developed to reduce the computational load required for AI models. Similarly, hardware has also become more efficient, with data centers increasingly turning to renewable energy sources to power their operations. Innovations in cooling technologies are also aiming to decrease water usage in data centers, such as using air-cooled systems or recycled water in place of freshwater. In addition, improving standardization in the measurement of AI energy consumption and promoting the disclosure of relevant information helps reduce uncertainty and increase accountability across the industry.

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AI APPLICATIONS THAT INCREASE RISKS FROM CLIMATE CHANGE

AI can be used for applications that benefit climate action; it can also be used for applications that increase risks from climate change. For example, AI is being leveraged to enhance fossil fuel exploration and extraction, directly contradicting global efforts to transition to renewable energy. Moreover, AI plays a central role in targeted advertising that perpetuates consumerism and encourages unsustainable behaviors, driving demand for products and services that contribute to climate change. Additionally, AI systems are increasingly used to amplify the spread of climate disinformation and misinformation, further complicating efforts to address climate change challenges.

References

Chen, C., Nguyen, D.T., Lee, S.J., Baker, N.A., Karakoti, A.S., Lauw, L., Owen, C., Mueller, K.T., Bilodeau, B.A., Murugesan, V., & Troyer, M. (2024). Accelerating computational materials discovery with artificial intelligence and cloud high-performance computing: From large-scale screening to experimental validation. *arXiv*. https://doi.org/10.48550/arXiv.2401.04070

International Energy Agency. (n.d.). *Data Centres and Data Transmission Networks* [CO2 emissions Indicators]. https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks

Luers, A., Koomey, J., Masanet, E., Gaffney, O., Creutzig, F., Lavista Ferres, J., & Horvitz, E. (2024). Will AI accelerate or delay the race to net-zero emissions? *Nature*, *628*, 718-720. https://www.nature.com/articles/d41586-024-01137-x

Masanet, E., Shehabi, A., Lei, N., Smith, S., & Koomey, J. (2020). Recalibrating global data center energy-use estimates: Growth in energy use has slowed owing to efficiency gains that smart policies can help maintain in the near term. *Science*, *367*(6481), 984–986. https://doi.org/10.1126/science.aba3758

Ren, S. (2023). *How much water does AI consume? The public deserves to know*. OECD.AI. https://oecd.ai/en/wonk/how-much-water-does-ai-consume

Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domish, S., Felländer, A., Langhans, S. D., Tegmark, M., & Nerini, F. F. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. *Nature Communications*, *11*(233). https://doi.org/10.1038/s41467-019-14108-y

Interview II

Climate models, Artificial Intelligence, and the Amazon

Photo: Ricardo Matsukawa

Paulo Artaxo
Professor at IFUSP

In this interview, Paulo Artaxo, professor at the Institute of Physics at the University of São Paulo (IFUSP), analyzes the role of Artificial Intelligence (AI) in climate issues and comments on the challenges and advances needed in climate models, as well as the strategic importance of the Amazon in global dynamics.

Internet Sectoral Overview (I.S.O.)_ In your opinion, are we close to a new revolution in the way we produce knowledge about the climate driven by AI? What future do you envision for climate change research in the coming years?

Paulo Artaxo (P.A.)_ No, we are not making a revolution with the entry of AI. AI is another aid in building climate models, interpreting observational data, and integrating models and measurements. It is not a revolution. You must look at AI the right way, as it is. It will not solve all of humanity's problems, as many people working with AI tend to suggest.
From the point of view of future transformations in climate change research, I believe the next step will be to have climate models that take into account not only the physics, chemistry, and biology of the climate, but also, in an integrated way, socioeconomic strategies, political issues, and issues around the decisions of each government concerning changes, particularly in the energy transition. It is also important to include the feedback from the general system, the system that maintains our planet's climate, to the climate itself. This feedback is very complex: It is not taken into account even today and will basically be at the heart of the new generation of models that should emerge in the next decade.

I.S.O._ Why is the Amazon a key locus for discussions on climate change?

P.A._ The Amazon truly is a key issue in climate change, for several reasons. First, Amazon is a massive carbon reservoir, on the order of 120 billion tons. The emission of this carbon—stored in the Amazon ecosystem—into the global atmosphere could significantly worsen climate scenarios. Additionally, Amazon is a gigantic feeder of water vapor for the global climate system. Much of the hydrological cycle depends on emissions from tropical forests such as the Amazon, and this is critical for the climate, including in South America and Central Brazil. Finally, the Amazon is also important because it contains a huge portion of our planet's biodiversity, and this biodiversity is essential for maintaining life on the planet as we know it. Therefore, Amazon is indeed absolutely strategic when it comes to global climate change.

"The difficulty of access to the Amazon region makes knowledge of the forest's basic functioning, the interaction between the forest and the atmosphere, and the hydrological cycle an enormous challenge. (...) We rely on remote sensing, which are very advanced satellite sensors, but it obviously cannot answer all the questions."

I.S.O._ What makes the Amazon Rainforest a particular challenge for scientific research, and how are digital technologies and, in particular, AI helping to overcome this challenge in the scientific field?

P.A._ The difficulty of access to the Amazon region makes knowledge of the forest's basic functioning, the interaction between the forest and the atmosphere, and the hydrological cycle an enormous challenge. In other words, most of the Amazon Rainforest is still inaccessible to instruments that can, for example, monitor the state of the forest itself. We rely on remote sensing, which are very advanced satellite sensors, but it obviously cannot answer all the questions. For example, the issue related to soil nutrients, the issue related to what happens below the forest canopy, and so on. Therefore, Amazon is indeed a challenge from a scientific research perspective.

On the matter of AI: It can help, but in a very limited way on this particular issue. Satellite Internet access, a relatively new development, is a significant advance because it provides access to the Internet and the Web as a whole for remote regions of the Amazon, which is incredibly beneficial.

I.S.O._ The rapid advance of AI brings enormous opportunities, but also new uncertainties. What are your biggest concerns regarding the future of climate science and environmental preservation?

P.A._ There is no doubt that AI also brings many uncertainties about the future of humanity as a whole. One of them is: Who will control the algorithms that are essentially at the heart of AI? In other words, today, large enterprises like Microsoft and Facebook dominate the primary mechanisms for accessing AI. This poses a significant risk to societies as a whole. It is a social, economic, and, in all respects, even a national security risk. Thus, I believe that until we solve the issue of democratizing access to AI, taking it out of the hands of a very few (as it is today), it will really continue to be much more of a threat to our society than a possibility for it to actually become an opportunity. We need to democratize this access, we have to make this access universal, and with good regulation by each State, perhaps it can truly stop being a threat and become a meaningful advance.

Domain Report

Domain registration dynamics in Brazil and around the world

The Regional Center for Studies on the Development of the Information Society (Cetic.br), department of the Brazilian Network Information Center (NIC.br), carries out monthly monitoring of the number of country code top-level domains (ccTLD) registered in countries that are part of the Organisation for Economic Co-operation and Development (OECD) and the G20.[14] Considering members from both blocs, the 20 nations with the highest activity sum more than 96.49 million registrations. In June 2025, domains registered under .de (Germany) reached 17.59 million, followed by China (.cn), United Kingdom (.uk), and Netherlands (.nl), with 11.97 million, 8.87 million, and 6.11 million registrations, respectively. Brazil had 5.47 million registrations under .br, occupying 6th place on the list, as shown in Table 1.[15]

[14] Group composed by the 19 largest economies in the world and the European Union. More information available at: https://g20.org/

[15] The table presents the number of ccTLD domains according to the indicated sources. The figures correspond to the record published by each country, considering members from the OECD and G20. For countries that do not provide official statistics supplied by the domain name registration authority, the figures were obtained from: https://research.domaintools.com/statistics/tld-counts. It is important to note that there are variations among the date of reference, although the most up-to-date data for each country is compiled. The comparative analysis for domain name performance should also consider the different management models for ccTLD registration. In addition, when observing rankings, it is important to consider the diversity of existing business models.

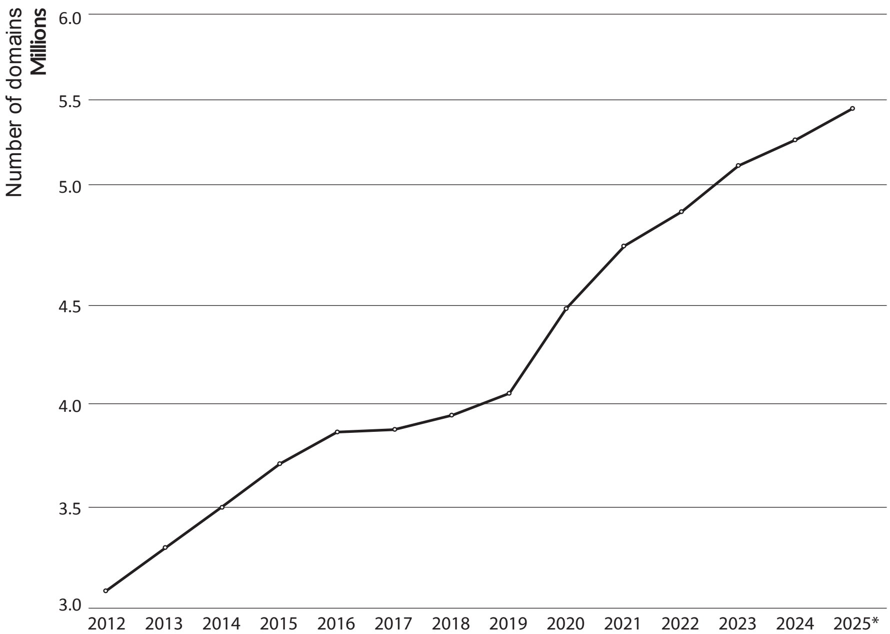
Table 1 – TOTAL REGISTRATION OF DOMAIN NAMES AMONG OECD AND G20 COUNTRIES

Position	Country	Number of domains	Date of reference	Source (website)
1	Germany (.de)	17,596,660	01/07/2025	https://www.denic.de
2	China (.cn)	11,972,389	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
3	United Kingdom (.uk)	8,873,968	30/06/2025	https://www.nominet.uk/news/reports-statistics/uk-register-s-tatistics-2025/
4	Netherlands (.nl)	6,112,072	01/07/2025	https://stats.sidnlabs.nl/en/registration.html
5	Russia (.ru)	5,937,740	01/07/2025	https://cctld.ru
6	**Brazil (.br)**	**5,474,691**	**30/06/2025**	**https://registro.br/dominio/estatisticas/**
7	France (.fr)	4,250,850	30/06/2025	https://www.afnic.fr/en/observatory-and-resources/statistics/
8	Australia (.au)	4,165,543	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
9	European Union (.eu)	3,613,990	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
10	Italy (.it)	3,512,779	30/06/2025	https://stats.nic.it/domain/growth
11	Canada (.ca)	3,440,744	01/07/2025	https://www.cira.ca
12	Colombia (.co)	3,380,580	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
13	India (.in)	3,156,984	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
14	Switzerland (.ch)	2,570,213	15/06/2025	https://www.nic.ch/statistics/domains/
15	Poland (.pl)	2,504,441	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
16	United States(.us)	2,368,858	01/07/2025	https://research.domaintools.com/statistics/tld-counts/
17	Spain (.es)	2,125,687	31/05/2025	https://www.dominios.es/es/sobre-dominios/estadisticas
18	Portugal (.pt)	2,008,878	01/07/2025	https://www.dns.pt/en/statistics/
19	Japan (.jp)	1,804,964	01/07/2025	https://jprs.co.jp/en/stat/
20	Belgium (.be)	1,626,638	01/07/2025	https://research.domaintools.com/statistics/tld-counts/

Collection date: July 1, 2025.

Chart 1 shows the performance of .br since 2012.

Chart 1 – TOTAL NUMBER OF DOMAIN REGISTRATIONS FOR .BR – 2012 to 2025*



*Collection date: June 30, 2025.
Source: Registro.br
Retrieved from: https://registro.br/dominio/estatisticas

In June 2025, the five generic Top-Level Domains (gTLD) totaled more than 188.07 million registrations. With 155.60 million registrations, .com ranked first, as shown in Table 2.

Table 2 – TOTAL NUMBER OF DOMAINS AMONG MAIN gTLD

Position	gTLD	Number of domains
1	.com	155,606,893
2	.net	12,346,211
3	.org	11,216,967
4	.xyz	4,582,843
5	.top	4,322,197

Collection date: July 1, 2025.
Source: DomainTools.com
Retrieved from: research.domaintools.com/statistics/tld-counts

WHERE DOES ELECTRONIC WASTE GO?

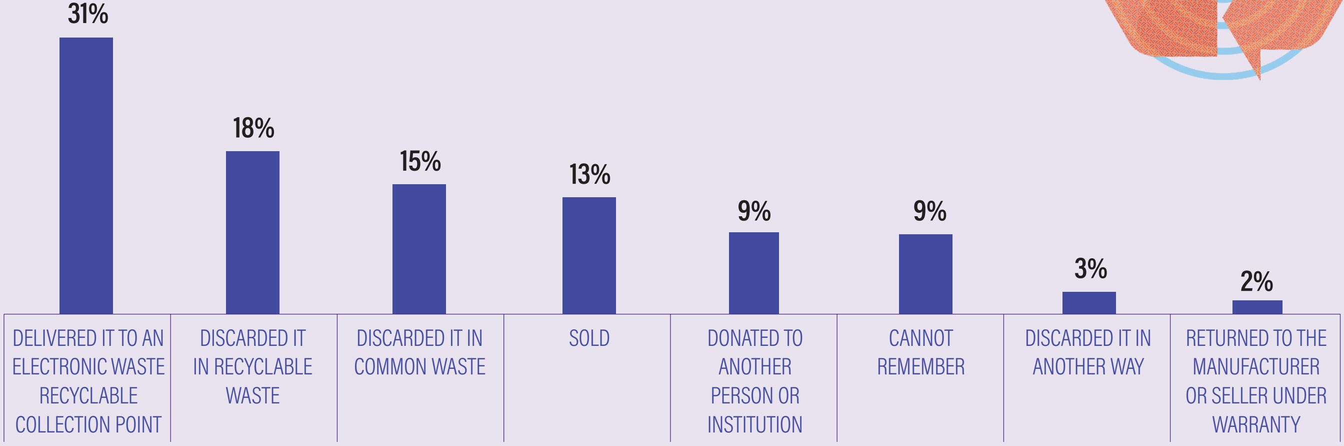
The *Global E-waste Monitor 2024*, published by the International Telecommunication Union (ITU) and the United Nations Institute for Training and Research, reveals that in 2022 the global volume of electronic waste reached a record 62 of billion kilograms. Of this total, only 22.3% was formally collected and recycled in an environmentally sound manner.[16]

In Brazil, the study *ICT: Web survey with Brazilian Internet users – Perspectives on the disposal of electronic waste*, conducted by the Regional Center for Studies on the Development of the Information Society (Cetic.br) of the Brazilian Network Information Center (NIC.br), indicated that 25% of Internet users aged 16 or older—more than 28 million people—disposed of a mobile phone in the 12 months prior to the survey. This rate of disposal reaches 38% among individuals with higher purchasing power (Class A).[17]

The study suggests that discussions and actions aimed at environmentally sound collection and recycling can be intensified. The chart below shows the destinations of mobile phones discarded in Brazil during this period.

Destination of disposed mobile phones in Brazil[18]

Total number of Internet users with 16 years or older who disposed of a mobile phone in the 12 months prior to the survey (%)



[16] Information adapted from the publication *Global E-waste Monitor 2024*, by ITU in partnership with Unitar. Available at: https://ewastemonitor.info/wp-content/uploads/2024/12/GEM_2024_EN_11_NOV-web.pdf

[17] Information adapted from the survey *ICT: Web survey with Brazilian Internet users – Perspectives on the disposal of electronic waste*, by Cetic.br|NIC.br. Available at: https://cetic.br/en/publicacao/ict-panel-web-survey-with-brazilian-internet-users-perspectives-on-the-disposal-of-electronic-waste/

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ABOUT CETIC.br

The Regional Center for Studies on the Development of the Information Society – Cetic.br (https://www.cetic.br/en/), a department of NIC.br, is responsible for producing studies and statistics on the access and use of the Internet in Brazil, disseminating analyzes and periodic information on the Internet development in the country. Cetic.br acts under the auspices of UNESCO.

ABOUT NIC.br

The Brazilian Network Information Center – NIC.br (http://www.nic.br/about-nic-br/) is a non-profit civil Entity in charge of operating the .br domain, distributing IP numbers, and registering Autonomous Systems in the country. It conducts initiatives and projects that bring benefits to the Internet infrastructure in Brazil.

ABOUT CGI.br

The Brazilian Internet Steering Committee – CGI.br (https://cgi.br/about/), responsible for establishing strategic guidelines related to the use and development of the Internet in Brazil, coordinates and integrates all Internet service initiatives in the country, promoting technical quality, innovation, and dissemination of the services offered.

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