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AI, Biodiversity and Energy in Latin America and the Caribbean: From a Resource Intensive to Symbiotic Tech

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Abstract

This paper explores the intersection of AI, biodiversity and energy, emphasizing the need for a sustainable approach to tech developments. AI has the potential to boost economic growth, but its resource-intensive nature poses environmental risks, particularly due to energy and water consumption. We argue for a shift from a resource-intensive AI model to a symbiotic one, where biodiversity inspires sustainable energy solutions. Latin America and the Caribbean (LAC), rich in biodiversity and critical minerals, is well-positioned to lead this transition. Specifically, the paper highlights the potential of *biomimicry*, where nature-inspired innovations can enhance energy efficiency and sustainability in AI systems. Examples include using biological forms, processes and systems to optimize energy use and diversify sources to generate AI. Policy frameworks that support bio-innovation, interdisciplinary collaboration and sustainable AI practices are needed, particularly to foster transparency and incentives for investment in renewable energies. By integrating AI, biodiversity and energy, LAC can foster resilient, sustainable growth and become a global leader in green innovation.

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I. Motivation

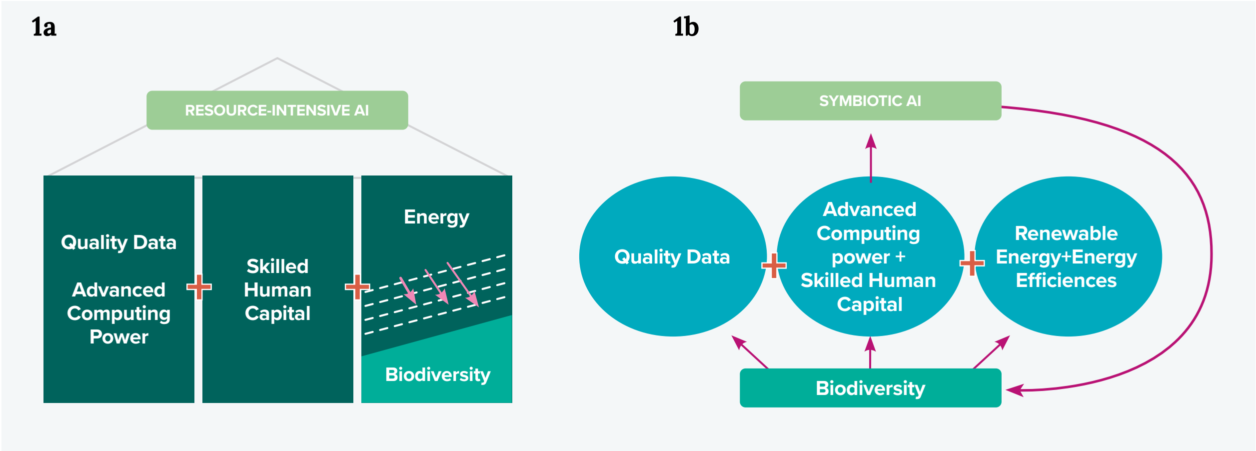
Artificial Intelligence (AI) is the revolution of our times. Generative AI could add up to US$ 4.4 trillion to the global economy, a positive shock not just for productivity in the technology and telecommunication industry, but also in finance, retail and the life sciences (McKinsey, 2023). These remarkable effects stem both from labour productivity and automation, and from a generalized acceleration of innovation, in a scenario where AI spreads all across the economy (Baily et al., 2024).

True, many caveats are in order. This potential is still untapped. Some authors argue that at least in the next decade, AI impact would only involve automation of tasks and some task complementarity, with no impact on capital productivity nor generation of new tasks (see Acemoglu, 2024). Also, as it stands in absence of global governance and with significant human capital and technology gaps, AI development can reproduce and even amplify socioeconomic and environmental risks. Indeed, the macroeconomic productivity impact from AI can be influenced through several policy areas, such as data regulation, digital trade and labour policies (OECD, 2024b). Connectivity gaps and a lack of digital skills limit the capacity to harness AI's full potential, possibly affecting half of the positions that could potentially benefit from augmentation in Latin America and the Caribbean (LAC), for example. Socially, AI can exacerbate inequalities and biases, particularly in already marginalized groups, such as women, ethnic minorities, rural populations and economically disadvantaged segments. Environmentally, AI's resource-intensive processes can strain local ecosystems (UN, 2024, UNESCO, 2024 and Gmyrek et al., 2024). Overall, AI is believed to be the first technological revolution that can become "self-directed, self-replicating and self-improving beyond human control" (Bremmer and Suleyman, 2023), urging the need to establish a right governance to make sure economic, social and environmental risks do not materialize.

Particularly today, AI is on a challenging trajectory in terms of energy and resource consumption with companies increasing their environmental footprint by double digits annually. This might be generating an *AI-energy-biodiversity conflict* sooner rather than later: either AI keeps its extraordinary pace with energy and resource consumption pressing biodiversity; or biodiversity preservation is prioritized, limiting energy use and slowing down the AI boom. As proof of the magnitude of the challenge, the *Gartner Top Strategic Technology Trends for 2025* identified energy efficient computing in its top 10, at the level of quantum computing, neurotech or agents (Gartner, 2024).

In this context, is there a potential *virtuous AI-energy-biodiversity relationship*, where nature can inspire energy solutions that maintain AI momentum while also fostering resilient sustainable growth and contributing to biodiversity preservation? This exploratory paper argues that biodiversity can become an additional pillar for sustainable AI development, interacting with skilled human capital, advanced computing power, data and energy, rather than being depleted by technology developments, provided the right policies are in place (in other words, we can move from the 1a to 1b trajectory in Figure 1).

Figure 1. From a resource-intensive to a symbiotic AI



Source: Authors' elaboration

The relationship between AI, biodiversity and energy and this potential switch in trajectories is a particularly relevant topic for LAC. Global AI startups derive value primarily from technological ingenuity (OxValue.AI, 2024). In that sense, biodiversity – through bio-inspiration – can provide a bank of ideas on innovation, thanks to its 3.4 billion years of natural R&D (Benyus, 1994, and Lebdioui, 2022a). The region is one of the most biodiverse in the world and is particularly rich in the resources AI needs, such as minerals and rare earth elements for semiconductors, energy and water. At the same time, AI shows an untapped potential to introduce novel ways to fight the traditional regional development challenges, notably low productivity, inequality and poverty, and weak public services. Addressing how these resources can be leveraged sustainably to support data processing and AI infrastructure is an urgent task for the region and a potential new source of growth and development if LAC is able to provide solutions to the AI global value chains.

This paper deals with this frontier topic in four stages. Section II compiles general and specialized information on the relationship between AI and resources, particularly on energy. We reviewed the latest news and technical analysis of AI energy consumption in a *no-policy-change scenario* (which will place us close to the Figure-1.a path). Section III explores an alternative trajectory based on innovations by leading tech companies and responses to incentives and regulation. This section highlights how AI can help green various sectors (cities and industries, including mining), preserve environmental resources and even make itself more environmentally sustainable. Specific nature inspired innovations to generate, transmit, store or save energy – some already under exploration by innovation labs and leading global companies – are described in Section IV, where LAC potential is highlighted. Section V concludes by sketching policy recommendations on AI, energy and productive policies that can be included in a unified sustainable development strategy for LAC.

II. AI and natural resources, in search of a sustainable path

Artificial Intelligence is the defining revolution of our time, offering immense potential for economic development, particularly in regions like LAC. AI-driven solutions could address infrastructure gaps, modernize industries and foster digital entrepreneurship. Consequently, AI has the potential to be a *force for resilience*, driving sustainable growth and reducing vulnerabilities. AI is projected to contribute up to 5.4 percent of LAC's GDP by 2030, equivalent to approximately US$ 0.5 trillion, boosting productivity and innovation across key sectors (McKinsey Global Institute, 2018). This can be considered a lower bound, as they are pre-generative AI estimates (McKinsey (2023) calculated GenAI can increase the impact of AI by 15 to 40 percent). On a more conservative projection foreseeing a slowdown on AI adoption, Katz and Jung (2024) estimate AI could generate 1.03 percent of GDP by 2030.

The persistence of human capital and technology gaps and lack of a regional governance of AI mean AI could reproduce and even amplify LAC *development traps*, namely low productivity, high inequality, weak institutions and environmental risks (Muschett and Opp, 2024, Aguilar et al., 2023, ECLAC, 2022).

Focusing on the last point, one of the most pressing issues is the significant resources consumption associated with AI innovations, from minerals and rare earth extraction to manufacture semiconductors, to water and energy used in the large language models (LLMs) training and data centers' functioning. Reporting on this extraordinary surge of energy demand from AI developments and data centers' (where these LLMs are trained) consumption of electricity and water, and their contribution to greenhouse effects and climate change systematically appears in tech, economic and even general media (Crownhart,2024; Mehta, 2024).

Companies' environmental reports confirm a significant increase in electricity energy and natural resources consumption, partially due to the AI boom. Admittedly, a challenge for evaluating the relationship between AI, energy and biodiversity is the lack of transparency about emissions data, as prominent model developers such as OpenAI, Google, Anthropic or Mistral do not report emissions in training, i.e. in the process of adjusting the model's parameters to minimize errors, a particularly high energy-consuming phase because it involves numerous iterations (Stanford Institute for Human-Centered AI, 2024, and ITU, 2024). And this is even more the case for the use of water. But among those who do report on it, notably technology and telecommunication companies, the evidence is compelling (Apple, 2024; Dell, 2024; Intel, 2024; Google, 2024; Microsoft, 2024; Nvidia, 2024; Salesforce, 2024; Amazon, 2023; Meta, 2023; IBM, 2023). As summarized in ITU and WBA (2024) operational GHG emissions for Alphabet, Amazon and Microsoft are up 62 percent from 2020, reaching 47 million metric tons alone in 2023, half the total emissions of Peru. Electricity use has grown even faster, up 78 percent over the same period and standing at just over 100 TWh in 2023, around what Colombia and Dominican Republic consume together in a year. Also, Google's data center water usage (both withdrawal and consumption) in 2022 increased by 20 percent compared to 2021, and Microsoft's total water usage even saw a 34-percent increase for the same period (Li et al., 2023).

These developments represent a clear risk for both the companies and global climate goals, particularly achieving the 2030 targets for carbon neutrality – it is estimated data centers' emissions must halve to achieve them – and explain expected extraordinary energy operations. Some of these operations surpass US$ 100 billion, building global funds to finance data centers and energy projects, or directly investing in huge individual data centers with supercomputers. Renewable energies – ranging from wind and solar to geothermal – are also a focus of some of these projects, mostly in Europe and the US. Notably in recent months, some leading AI companies have announced the adoption of nuclear energy in US plants (pending regulatory approval and other technological issues) as a clean, sustainable power source for their data centers (Adams, 2024; Anandira, 2024; Calma and Hom, 2024; Gooding, 2024; Majithia, 2024; Mandler, 2024; Meaker, 2024; Reuters, 2024; Ørsted, 2023).

Empirical academic research is still relatively thin due to the recent onset of the phenomenon and the aforementioned lack of open data, but overall it confirms a tension between AI developments, resource use (e.g. water and energy) and environmental sustainability. AI models themselves have a substantial water footprint for electricity generation and for cooling the servers. Li et al., (2023) provide a methodology to estimate the water footprint of AI models and highlight the necessity of holistically addressing the water footprint along with the carbon footprint to enable truly sustainable AI. As a case study, GPT-3 consumes a 500ml bottle of water for 10–50 responses, depending on when and where it is deployed (and it consumed 700,000 liters in its training). The global AI demand may be accountable for 4.2–6.6 billion cubic meters of water withdrawal in 2027, half of the total annual water withdrawal of the United Kingdom. Semiconductor manufacturing also requires large volumes of water. At least 40 percent of all existing semiconductor facilities will be in basins experiencing high- or extremely high-water stress risks under climate scenarios for 2030 and 2040 – particularly Taiwan and the US southwest desert (Lepawsky, 2024).

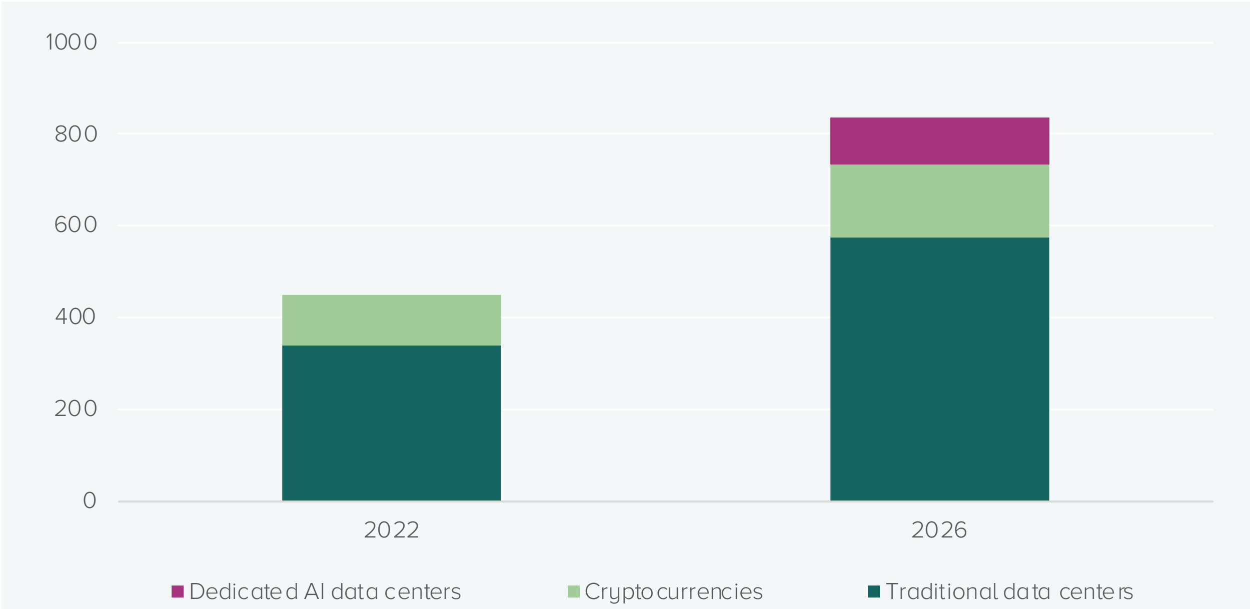
Progress has been made with using recycled, sea- and non-potable water; and certain hyperscale cloud providers indeed are showing great progress on efficiency (on top of the fact that moving to the cloud is more efficient than running physical infrastructures), but more transparency is needed. In particular, companies tend to attribute their water consumption to data centers only, and their figures reflect direct water usage, ignoring water used in electricity generation (Mytton, 2021).

AI algorithms are energy-intensive, leading to increased CO2 emissions. A seminal study covering some of the most popular LLMs back in 2022 (i.e. even before the generative AI boom) showed that the training of one particular model emitted 25 times that of flying one passenger round trip from New York to San Francisco, or enough energy to power the average American home for 41 years (Luccioni et al., 2022, Stanford Institute for Human-Centered AI, 2023; see Luccioni et al., 2024 for estimated CO2 emissions of different AI models performing different tasks).

This fast expansion of data centers worldwide due to surging demand from AI, cloud computing and other digital technologies requires large-scale computing power and energy. Investment in data centers globally is projected to reach US$ 200 billion by 2028, with a notable focus on edge data centers, designed to process data closer to its source, enhancing speed and reducing lag for AI and IoT (Internet of things) functions. As of early 2024, the United States leads with 5,381 data centers, far ahead of other nations; Germany and the United Kingdom follow, with 521 and 514 centers, respectively, with no LAC country in the top 10 (Statista, 2024 and IDC, 2024).

Looking forward, requirements of energy and resources will increase. According to the International Energy Agency (IEA, 2024a), electricity consumption from data centers, AI and cryptocurrency could double in 2026 vs 2022. These technologies together reached an estimated 460 terawatt-hours (TWh) in 2022, with projections pointing out that data centers' total electricity consumption could reach more than 1,000 TWh in 2026 (Figure 2). This demand is equivalent to the electricity consumption of today's Brazil, Chile, Mexico and Uruguay (using U.S. *Energy Information Administration* electricity consumption data).

Figure 2. Estimated electricity demand from traditional data centers, dedicated AI data centers and cryptocurrencies (TWh of electricity)



Source: IEA (2024a)

More focused estimates, again by IEA (2024b), show that AI data center electricity consumption was estimated in 2022 to be in the range of 240 to 340 TWh, less than 1.3 percent of total electricity consumption (i.e. excluding data networks and crypto mining). And, despite projections anticipating a significant increase by the end of this decade, AI data centers account for less than 10 percent of total electricity demand growth at the global level, which is roughly on a par with demand growth for desalination, and less than a third of the demand growth for both electric vehicles and space cooling in the buildings sector. And this is independent from foreseeable technological advances in IT equipment and hardware deployment, as well as policy decisions. Additionally, data center operators are now among the most active clean electricity purchasers as clean electricity supply becomes central to their sustainability strategies.

However, it is crucial to incorporate a nuanced approach to renewable energies, especially regarding sources like hydropower whose sustainability is increasingly questioned. While renewable energy solutions are essential, their environmental and social implications can vary significantly. Hydropower, often categorized as sustainable, has been scrutinized for its impacts on biodiversity, water usage and local communities. This variation in renewable sources suggests that a more refined *taxonomy* of AI-sustainable energy sources would be beneficial. Such a classification could guide companies in prioritizing truly sustainable options, enhancing transparency and fostering a responsible AI ecosystem.

Also, risks exist but actually arise from the high spatial concentration of data centers and constraints on generation and grid capacity, as well as from water demand. Data center clusters are driven by the benefits of proximity to infrastructure such as fiber optic cables and power resources, to data customers and to local ecosystems and human capital talent. Location decisions are also driven by incentives and regulation and by climatic considerations: cooler places have lower cooling needs.

This spatial concentration is already creating tensions, with several regions issuing moratoria on further data center development or taking steps to restrict it (IEA, 2024b). Another key spatial dimension to consider about the environmental footprint of data centers beyond their overall energy use stems from the fact that, because emissions are powered by local electric grids depending on the grids' reliance on fossil fuels, their carbon intensity can vary dramatically by region.

Unfortunately, data and analysis on present and projected use of water to cool down data centers is not available to comparable levels of rigor to our knowledge. But the hyperactivity of business operations in this dimension suggests it is one of the key sustainability challenges.

An opportunity for Latin America?

Around 60 percent of global terrestrial life and diverse freshwater and marine species can be found within LAC. The region is also rich in some of the key resources AI needs (lithium, copper, nickel and rare earth elements) for semiconductors, energy and water. Latin America and the Caribbean produces 40 percent of the world's copper – led by Chile, Mexico and Peru, though declining ore quality poses long-term challenges. The region also supplies 35 percent of global lithium, with Argentina and Chile as major players. Latin America and the Caribbean holds more than half of global lithium reserves, with Bolivia having untapped potential. Further investment in other critical minerals like graphite, nickel and rare earth elements could open new opportunities, particularly in Brazil (UNEP, 2024a, and Bernal et al., 2023).

The availability of these natural resources and renewable energies along with good connectivity and climate conditions (low temperatures) make Latin America arise as one of the key regions for the expansion of sustainable AI data center development. As Cohen (2024) described, "data centers are the factories of AI, turning energy and data into intelligence." Given it is probable that the US cannot break through all domestic energy bottlenecks, a global AI infrastructure buildout presents an opportunity for other economies. Beyond the usual candidates – the Arab Gulf, Canada, European Nordics, Japan and South Korea – Latin America can be an option. So far, only Brazil and Mexico (with 168 and 179 data centers, respectively) enter the top countries in the world (Statista, 2024), with numerous projects being announced in these two countries and expanding to Argentina, Chile, Peru and Uruguay.

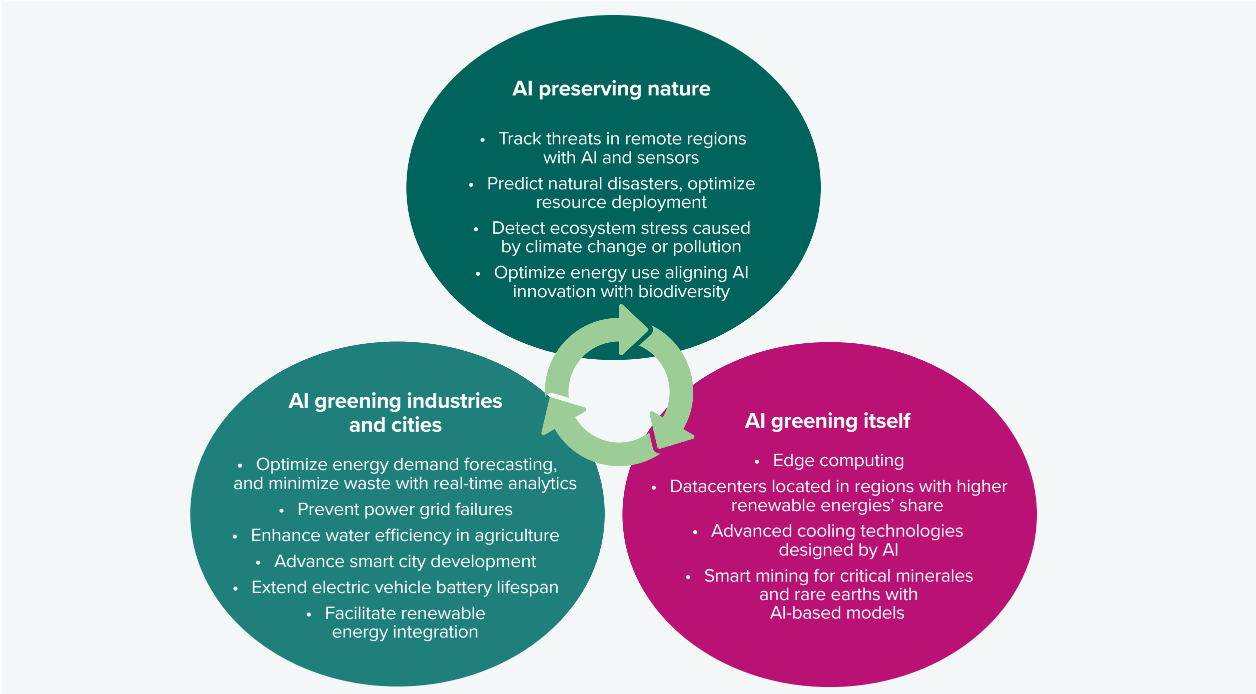
All in all, the evidence so far shows that AI is not yet on the optimal path due to the environmental and social impacts of this intensive pressure on natural ecosystems through deforestation, unsustainable mining and increasing demand for minerals and water, particularly in resource-rich regions, as many are in LAC. In particular, issues have arisen mostly from the quantity of water to cool data centers in regions prone to droughts and potable water shortages in Chile, Mexico or Uruguay, coupled with a lack of transparency in many of these projects about their resource intensity (AFP, 2024; bne IntelliNews, 2024; El Observador, 2023; Graham, 2024; Livingstone, 2024; McGovern and Branford (2023, 2024). The recently released Chilean Datacenters Plan Nacional 2024–2030 can provide a good practice for the region in terms of combining incentives, training and environmental accountability, with the goal of mobilizing US$ 4 billion and tripling this industry's size by 2030. However, bio-innovation activities in the region are also still dominated by bio-utilization methods (such as the extraction of chemical compounds for the cosmetics, pharmaceutical and agroindustries), which provides further limits to scalability without ecological damage. Therefore, while AI presents a tool for economic advancement, its integration must be balanced with ethical considerations to ensure that technological progress does not come at the expense of ecological degradation and social justice. The next two sections will describe industry and policy good practices on sustainable AI and some pathways for the future.

III. AI for good. Private and policy-led energy innovations in real-time

Another path is possible, namely that of AI, energy and natural resources interacting as an ecosystem (Figure 1.b). There is growing evidence of remarkable AI-driven innovations on energy issues that set a good basis for the path transition (see Mujica and Muñoz, 2024; ITU, 2024; academic reviews in Chen et al., 2023 and Nti et al., 2022; and ECLAC, 2022 for a policy approach in LAC).

We have labeled these innovations into three groups: AI greening industries and lives; AI preserving nature (i.e. keeping green what should be green); and AI greening itself (Figure 3). These interconnected groups illustrate ways by which AI can minimize its environmental footprint, support sustainable economic practices and preserve essential natural ecosystems.

Figure 3. AI and the green agenda



Source: Authors' elaboration

AI greening industries and lives

AI technologies are revolutionizing industries by promoting sustainable practices. In agriculture, AIdriven precision farming reduces energy consumption while enhancing productivity, by employing sensors and advanced analytics to monitor soil, water and climate. Similarly, in manufacturing, AI enhances resource efficiency through real-time monitoring enabled by IoT and 5G networks (Rojek et al., 2023 and Tace et al., 2023).

AI in the energy sector itself holds a transformative role. AI can significantly improve energy efficiency through predictive analysis, optimizing real-time energy consumption and adjusting demand based on environmental and operational data, as seen in applications like smart grids and energy management systems. These innovations help reduce fossil fuel consumption and greenhouse gas emissions. Additionally, AI facilitates the integration of renewable energy sources by forecasting the variability of solar or wind generation, thus balancing energy supply more effectively across the grid. Various AI approaches, including structured data management, data mining capabilities and machine learning techniques, support an AI ecosystem that enables smart energy grids. These tools allow for a system of systems that enhances grid performance and reliability. AI further enhances flexibility by forecasting supply and demand, and optimizing production patterns based on historical data, environmental conditions and power plant capacities, thus minimizing energy waste. Moreover, AI and machine learning can prevent grid failures, increasing reliability and security. As AI enables the digitalization of the grid, the technology offers powerful tools for managing future grids, although addressing associated risks remains essential (Rozite et al., 2023, Serebryantseva, 2023, and Şerban and Lytras, 2020).

AI's role in urban management is equally transformative. Smart cities utilize AI-powered IoT systems to optimize mobility, energy use and waste recycling. For example, parking sensors reduce congestion and emissions, while AI solutions in electric vehicles enhance battery performance and lifespan. In aviation, route optimization powered by AI minimizes environmental footprints, demonstrating the technology's wide-ranging impact (Melguizo and Muñoz, 2022; Bourechak et al., 2023).

AI preserving nature

AI is emerging as a crucial tool for environmental preservation, particularly in biodiversity-rich regions like LAC. Machine learning models analyse satellite and sensor data to detect deforestation, pollution and poaching, enabling real-time interventions in ecosystems like the Amazon. This supports global climate goals by preserving biodiversity hotspots critical for carbon storage (Smith, 2024; Young and Nunes, 2023; Huawei, 2023 and 2024).

Moreover, AI aids in disaster management by predicting hurricanes, floods and other natural events, providing early warnings that save lives and minimize damage. Advanced analytics detect ecosystem stress caused by climate change, enabling preemptive conservation actions in high-impact areas such as forests and wetlands (AWS Public Sector Blog Team, 2022; Gomes, 2023; Matias and Nearing, 2024; Silvestro et al, 2022). AI also offers a reciprocal benefit, drawing inspiration from nature to develop innovative solutions for energy and resource efficiency, illustrating the symbiotic relationship between technology and biodiversity.

AI greening itself

Efforts to minimize AI's environmental footprint are accelerating. Technologies like edge computing reduce energy demands by processing data closer to its source, while AI models increasingly rely on low-carbon energy grids and renewable resources. Leading companies like Salesforce have showcased significant emission reductions by utilizing energy-efficient data centers and advanced cooling technologies.

Advanced cooling technologies designed by AI, including liquid cooling systems and dynamic workload management, water conservation and recycling, seawater use and rain harvesting are being designed to limit the environmental impact of large-scale AI operations (Gamazaychikov, 2024; Walsh, 2024; Alland, 2023; Amazon Team, 2023; Intel, 2023; Jyothi, 2023; The Economist, 2023; Thomas, 2022; Evans and Gao, 2016; Nicolai, 2013).

Also, AI leaders are seeking to improve their energy matrix by investing in renewables. As highlighted before, data center operators are among the biggest purchasers of clean electricity. The top 10 corporate buyers of clean energy power purchase agreements in 2023 included Amazon, Meta, Alphabet and Microsoft (IEA, 2024b).

Additionally, AI supports the transition to greener energy sources by optimizing mining processes for critical materials and improving the efficiency of renewable energy infrastructure (The Economist, 2023, and Corrigan and Ikonnikova, 2024).

All together, these AI-driven pathways allow envisioning an ecosystem where AI, energy and natural resources are integrated, contributing to sustainable development goals. This comprehensive approach would not only optimize AI's energy use but also build resilient economies and protect essential natural resources. By aligning technological innovation with environmental preservation, AI can play a transformative role in creating a sustainable and greener future. Indeed, evidence for China suggests a U-shaped relationship between AI and energy transition with AI initially negatively impacting energy transition (Lee and Yan, 2024). Therefore, it will need to maintain, scale up and expand these initiatives, within a development strategy, in order to overcome the net negative impact of the present situation.

Policies matter

These private-sector-led innovations respond to actual or prospective policies (both incentives and penalties and regulation) and confirm that policies matter. Normative international and national instruments to address environmental impacts of AI have been issued recently, such as the US *Federal Artificial Intelligence Environmental Impacts Act*[1] and the *European Union AI Act*,[2] which includes standards for reducing energy and resource consumption during AI training and deployment. However, to date, there remains no standardized way of measuring, reporting or mitigating the environmental impact of AI.

Also, on the incentives side, the US 2022 *Inflation Reduction Act*[3] allocated US$ 369 billion for energy security and climate change incentives to individuals and companies to expand solar, wind and battery storage production, similar goals to the 2019 *EU Green Deal*[4] and the 2021 *Fit for 55 Package*.[5] China included reducing carbon intensity, enhancing energy efficiency and scaling up renewable energy development in the 2021–2025 Five-Year Plan. Also, the Belt and Road Initiative, while not focused on green energy, includes significant renewable energy projects and has pushed for green investment worldwide and in LAC (Myers et al., 2024). The decarbonization of power grids and the focus on energy-storage technologies and handling of intermittent renewable energy are common goals in all these initiatives.

1 www.congress.gov/bill/118th-congress/senate-bill/3732/text

2 www.europarl.europa.eu/doceo/document/TA-9-2024-0138_EN.html

3 home.treasury.gov/policy-issues/inflation-reduction-act

4 commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

5 commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-europeangreen-deal/fit-55-delivering-proposals_en

Finally, focusing on transparency, China, EU and US established mandatory disclosures by companies on emissions, energy use and climate risks, particularly for big companies, and firms in energy and energy-intensive industries, in line with international recommendations. However, global standards are needed. UNESCO under its *AI & Ethics Recommendation* (UNESCO, 2021) is developing a pioneer roadmap for measuring the environmental footprint of AI, presented at the last AI Action Summir held in France in February 2025. More generally, the *UNDP Artificial Intelligence Landscape Assessment* also covers the environmental dimension in the security pillar, identifying the role of AI to contribute to biodiversity and nature preservation. The 2024 revision of the OECD AI Principles explicitly added 'environmental sustainability' as a key consideration (OECD, 2024a). And UNEP (2024a) and ITU (2024) released a summary of relevant standards that are available and under development.

In Latin America and the Caribbean, the Renewable Energy for Latin America and the Caribbean (RELAC) initiative,[6] with the Inter-American Development Bank as technical secretariat, would be a natural ally. It was created with the goal to increase the share of renewable energy in the electricity mix of LAC countries to at least 70 percent by 2030, promoting regional cooperation in renewable energy adoption and grid integration.

Again, a key but less explored area, which needs to be policy-led given market failures, is how to untap and benefit from innovations from startups, particularly those at biodiversity centers exploring nature-inspired solutions for energy. This, in turn, could help AI transit from the AI finite *resource model to a symbiotic dynamic* if the biodiversity-bank of ideas translates into specific energy solutions for industries. The next section will review some of the latest developments.

Overall, achieving a sustainable energy transition in the age of AI requires policy frameworks that are both flexible and grounded in environmental priorities. AI-driven approaches can support governments in crafting responsive, data-centered energy policies that address real-time metrics on energy consumption, emissions and resource use. Integrating advanced data science and machine learning, these frameworks enable more efficient resource management, prioritize carbon reduction targets and consider socioeconomic impacts, paving a balanced path toward net-zero goals. Such approaches can foster accountability and transparency in AI's environmental impact, encouraging both private and public sectors to adopt greener AI practices (Danish and Senjyu, 2023; WEF, 2024).

6 hubenergia.org/en/relac

IV. The potential of biomimicry. When natural and artificial intelligences meet for energy solutions

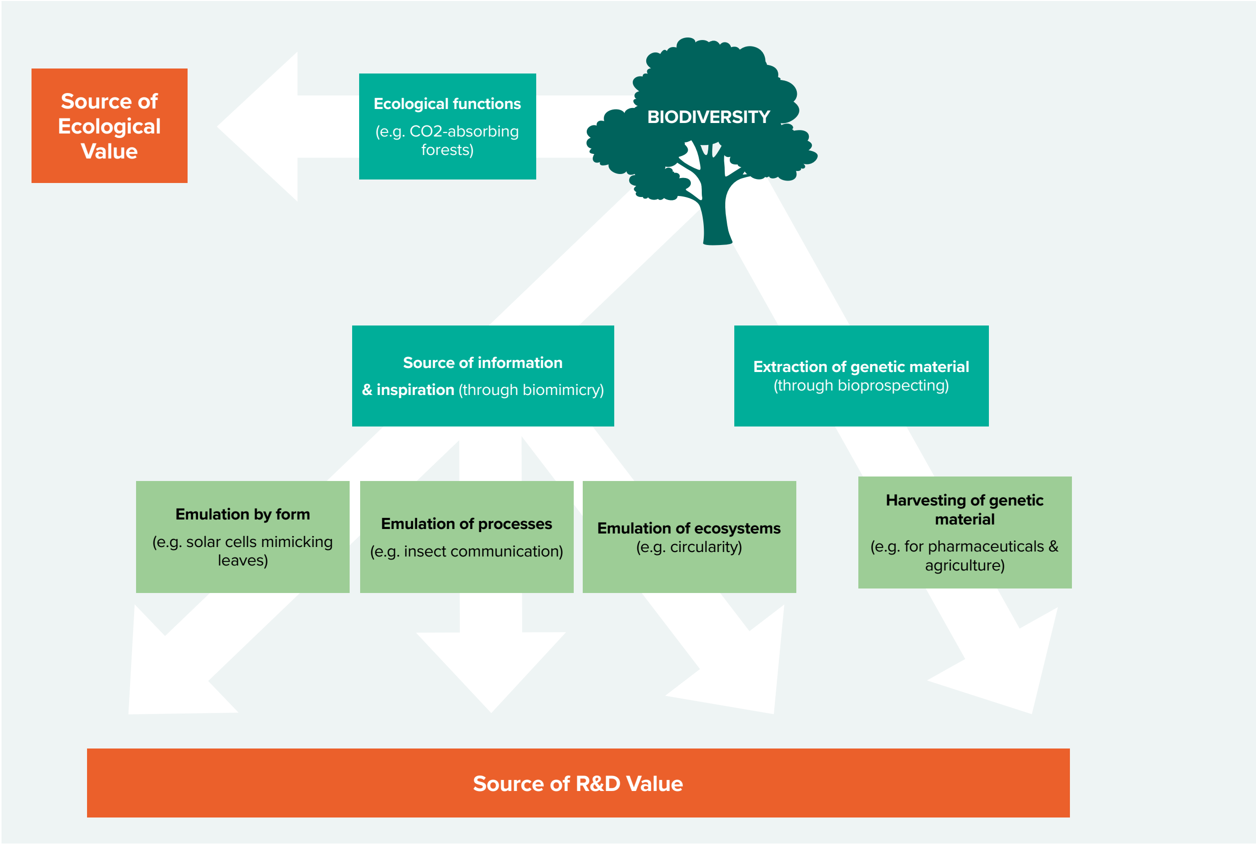
In many ways, biodiversity has its place at the core of this potential virtuous *nature-conscious AI ecosystem*. As shown in the previous section, AI offers powerful tools for conserving biodiversity. AI can monitor endangered species, optimize agricultural practices to reduce deforestation, and predict climate change impacts in order to mitigate biodiversity loss. A far less explored strategy lies in the use of knowledge from nature to develop AI systems that not only measure and mitigate environmental impact but unlock new areas of knowledge to leap to the sustainable innovation frontier. Indeed, why not design AI models that seek inspiration and learn from strategies found in nature to solve human design challenges to create a healthier, greener and more sustainable future?

A particularly promising area is that of the so-called biomimicry, which relies on a perspective of biodiversity as a bank of ideas (Lebdioui, 2022a and 2024). Biomimicry (also referred to as biomimetics, bio design, bio-inspiration or nature-inspired innovation) involves learning from and emulating biological forms, processes and ecosystems tested by the environment and refined through evolution (Benyus, 1997). It is different from harvesting organisms to accomplish a function: rather than using an organism to 'do what it does', *biomimicry* aims to leverage the design principles embodied by the organism (Figure 4).

Biomimicry could add around US$ 1.6 trillion to total global output by 2030, with electronics manufacturing, utilities (water and energy) and more generally engineering-sector revenues positively impacted between 5 and 15 percent (Fermanian Business & Economic Institute, 2013). Nature can offer models for sustainable energy, ranging from sector-specific tasks (generation, transmission, storage) to global efficiencies across industries. Innovations inspired by natural processes can lead to breakthroughs in energy efficiency and renewable technologies. Acting as natural R&D, evolution has historically selected the most efficient and optimal designs and discarded the non-functional ones. Evidence suggests that energy efficient designs could transform up to 10 percent of the transportation equipment industry (including cars, trucks, planes and boats), for instance. Biomimicry solutions found and developed in LAC therefore hold potential to push the innovation frontier around energy generation, CO2 capture and removal, and resource efficiency, as well as open investment opportunities in those areas.[7]

7 This energy focus is justified by the fact that this sector offers the most synergies between existing industry challenges, solutions from nature and regulatory incentives, and on the challenges digital sectors are facing, described in Section II.

Figure 4. From biodiversity to R&D value: forms, processes and ecosystems



Source: Lebdioui (2022a)

Nature-inspired energy solutions in practice

The energy transition is one of the greatest challenges of our time, and nature offers a variety of models that can be adapted to reduce their environmental impact. Admittedly, this is a very exploratory exercise since this industry is at its infancy and the boom of AI-related energy is very recent. Therefore, in this section, we explore and analyse nature-inspired solutions for energy consumption in general, with the view that some of these solutions may bear considerable relevance for AI systems.

Many solutions in nature offer superior solutions for energy production, efficiency and storage, and could be the basis of useful ideas for sustainable innovation around energy use for AI (Table 1). Those solutions can be classified based on their characteristics, whether leveraging and emulating principles found in nature's *forms*, *processes* or *ecosystems*.

Table 1. Examples of use of biomimicry for sustainable energy solutions

Forms	
Sustainable materials	Biomaterials, inspired by structures like spider silk or insect exoskeletons, can be both lightweight and strong. By applying these materials to AI hardware design, it is possible to reduce the energy needed for material production and device operation.
Optimization of resource distribution	Deep learning of microbial patterns and fungal networks, such as mycelium, which distribute resources with minimal energy, can inspire distributed AI architectures minimizing data transfer and processing energy (e.g. edge computing where processing happens close to the source of data).
Energy efficiency through new forms	Applying the design of whale fins (with their protrusions called tubercles) to the blades of wind turbines improves aerodynamics, allowing for kinetic energy to be converted into electricity more efficiently (WhalePower project). Use of natural ventilation principles observed in termite mounds significantly reduces air conditioning use and energy consumption (e.g. Eastgate Center, Zimbabwe). This system is used to cool buildings for improved energy efficiency.
Superior data storage structures	Synthetic DNA could be used to store digital data, optimizing energy use.
Processes	
Energy generation (including photosynthesis)	Artificial photosynthesis can be used to improve the efficiency of solar cells (such as Daniel Nocera's artificial leaf). AI can be trained on the mechanics of photosynthesis to optimize solar-powered energy sources or even develop artificial photosynthesis. This could help produce on-site energy that powers AI systems sustainably. The structure of seaweed can inspire processes to generate electricity from the flow of water (BioPower Systems' BioWave). These generators are set up in coastal areas, providing clean, renewable energy. Piezoelectric batteries, which are self-charging power cells that convert mechanical energy (the energy related to an object's motion and position) into chemical energy can be a solution for electric vehicle battery charging, improving long-distance smart mobility. Electricity generation inspired by the organic structure of the pectoral fin of electric fish (such as rays), composed of electro plaques – flattened cells stacked in vertical columns like piles of coins.
Energy-efficient sensor networks	Biological sensor models offer important lessons to improve AI systems, given the superiority of the various highly sensitive and efficient sensory systems found in nature (such as the olfactory senses of dogs or navigation systems of bees, birds and bats). By studying these systems, AI developers can create sensors that are more efficient and require less energy for functions like environmental monitoring.
Thermal management and cooling	Some species (e.g. volcanic long-horned beetles) have evolved with natural ways to dissipate heat and chemical reactions to reduce their body temperature. Hardware inspired by these natural thermal regulation methods could improve the efficiency of cooling systems in data centers and AI hardware.
Ecosystems	
Circular energy and material flow models	Principles of circularity and re-use of waste into inputs for other productive systems inform natural ecosystems that operate on principles of waste recycling where the byproduct of one species becomes the resource for another. By designing AI systems inspired by these circular principles, excess heat and byproducts (like data center heat) can be redirected and used to fuel other processes, lowering the net energy consumption.
Real-time adaptation for energy consumption	Just as ecosystems dynamically adjust to environmental changes, AI systems can be designed to scale their operations based on real-time energy availability and environmental conditions.

Source: Authors' elaboration based on AskNature.org, BioMiG and a review of the scientific literature

In terms of the emulation of *forms*, biomimetic designs can optimize energy capture and distribution. For instance, microbial patterns and fungal networks, which enable resource distribution with minimal energy, could inspire distributed AI architectures that minimize data transfer and processing energy, such as in edge computing where processing happens close to the source of data. WhalePower's wind turbines incorporate whale fin structures to improve aerodynamics, enhancing wind capture for electricity generation. Similarly, Zimbabwe's Eastgate Centre shopping mall is an example showcasing research on how to reduce energy consumption by mimicking termite mound ventilation, while biomaterials like spider silk inspire lightweight, durable materials in AI hardware, reducing production energy.

The emulation of *processes* would consist of seeking inspiration from biological mechanisms, such as photosynthesis (for instance, the artificial leaf aims to replicate photosynthesis to improve energy efficiency for industrial applications), while technologies such as BioWave generate electricity by simulating the motion of seaweed in ocean currents. For the specific context of AI hardware, energy consumption could decrease with thermal management and cooling innovations inspired by how distinct species (such as volcanic beetles) have evolved to dissipate heat with natural regulation methods, which could hold lessons for improving the efficiency of cooling systems in data. These solutions illustrate how mimicking biological processes can enhance energy production and sustainability.

The AI industry may also benefit from *ecosystemic* innovations that draw inspiration from the interactions between various living organisms. For instance, the principle of circularity found in nature and whereby waste is turned into resources for other organisms can be applied to data centers and other AI systems to reduce net energy use. Inspired by ecosystem adaptability, AI systems can also be designed to dynamically adjust energy consumption based on availability, optimizing energy efficiency. By emulating the self-regulating and waste-reducing models found in nature, these innovations offer promising pathways to sustainable energy management.

If this is the case, what is missing for us to leverage the informational value of nature for better, ecosystemic AI in order to replace resource-intensive AI? Admittedly, the path towards bio-inspired innovation for AI energy improvement is paved with considerable challenges and coordination failures. One major obstacle lies in the fragmented state of biological data and taxonomic systems. Currently, nature's vast repository of information – spanning millions of species and ecosystems – is organized inconsistently across various databases, many of which are outdated or limited in scope. This is also the case for research centers between different LAC nations, which poses a great challenge for data sharing and merging. A significant overhaul and harmonization of these taxonomic systems are required to enable researchers to access a unified, comprehensive database. By standardizing how we categorize and describe biological data, scientists could more easily search for specific traits, behaviours or efficiencies in nature that could translate into AI applications, such as optimized energy usage.

Such a harmonization of taxonomic systems is an essential prerequisite for the use of AI for biodiversity. With access to better and more reliant biodiversity data, along with advances in computational power, AI itself can play a vital role in identifying and analysing patterns within ecosystems and species that excel at particular processes, like energy efficiency, resource distribution or thermal regulation. AI can help pinpoint organisms or ecosystems that are exceptionally efficient in certain areas, offering models that engineers and developers can adapt to reduce energy demands in AI systems by analysing large data sets on biodiversity. This bio-inspired approach not only opens up new avenues of research but also encourages cross-disciplinary exploration, bringing together ecologists, computer scientists and engineers.

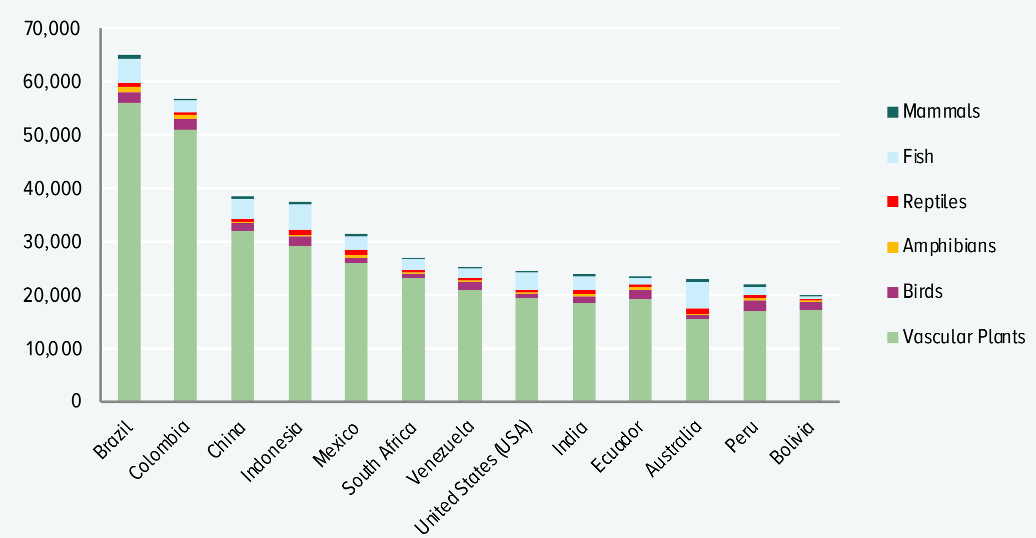
However, realizing this vision also brings regulatory and resource-related challenges. Establishing frameworks that support responsible and legal access to biodiversity data, as well as providing resources for researchers to build and use advanced analytical tools, is critical. Without supportive policies and adequate funding, researchers may struggle to develop the tools necessary to extract actionable insights from nature's patterns. Addressing these barriers would not only accelerate bioinspired innovation but would also position biodiversity as a cornerstone for sustainable technological advancements in AI and energy.

Latin America and Caribbean potential, and the role of proactive policy action

LAC is a global biodiversity hotspot, making it a critical player for our planet's health and in the sustainability agenda. The region provides critical ecosystem services for the world and has seen pioneering initiatives for recognizing nature's rights (Figures 5 and 6). Nevertheless, in light of the need for economic development and job creation, its biodiversity faces threats from economic models prioritizing extraction and short-term economic gains. The historic dependence of many LAC economies on extractivist models of development with acute reliance on commodity exports has come at the expense of the environment but also long-term economic resilience, including a heightened exposure to climate and transition risks. The economic and ecological risks of the integration of LAC economies as a raw-materials provider in global value chains (including tech and AI) are reinforced in the context of the transition to a low carbon economy, given the region's endowment in the critical minerals that are necessary as inputs for low carbon technologies.

However, the most important asset the region disposes of is not a mined metal but its rich biodiversity. Biodiversity has to be fully integrated into the innovation and the AI agendas. Far from being a constraint on development, biodiversity can be harnessed for long-term economic prosperity, innovation and sustainability. Moving forward, LAC countries have a unique opportunity to harness their biodiversity in a way that breaks free of an unhelpful dichotomy between nature and productive development.

Figure 5. Most biodiverse countries in the world are in Latin America (#species)



Source: Authors' compilation based on Mongabay data

Since the 1990s, the region has already witnessed a range of pioneering efforts to leverage the economic value of biodiversity with varying outcomes and degrees of success. The region's experimentations to date with several types of biodiversity-based activities, ranging from payments for ecosystem services and ecotourism to bioprospecting, provides critical lessons for the development agenda, presenting both benefits and limitations, especially in terms of value creation and environmental sustainability (Purkey, 2021 and Lebdioui, 2022b). This is why, moving forward, the governments in the region can seize a new window of opportunity to harness their biodiversity to leapfrog to the innovation frontiers, especially in the blossoming field of AI, which has been dominated by firms in Asia, Europe and North America (OxValue.AI, 2024). But achieving this objective entails a major rethinking of industrial and innovation policies. Policy coordination, comprehensive national AI strategies involving different stakeholders – from academia, to industry, policymakers, and conversation agencies – and resource mobilization will be key.

Figure 6. Distribution of terrestrial biomes in Latin America and the Caribbean

Source: CAF (2023)

V. AI, biodiversity and energy. Reflections on the way forward and policy recommendations

The rapid growth of AI has reshaped numerous sectors globally, introducing unprecedented capabilities but also significant environmental impacts. The trends in energy consumption, along with rising resource demands to support these technologies, conflict with global sustainability goals and biodiversity preservation. This tension between technological advancement and environmental health has been highlighted by an increasing number of international organizations that have sounded the urgent call to balance digitalization with ecological preservation to achieve a sustainable future. While digitalization has brought undeniable social and economic benefits, its environmental impact cannot be overlooked. Left unchecked, digitalization could lead to significant biodiversity loss and climate impacts.

So, what does it take to shift from a resource-intensive AI model to an ecosystemic AI model, where quality data and advances in computational power are matched with energy efficiency and biodiversity-consciousness as core input rather than a sole outcome?

Fortunately, a paradigm shift is arising through policy initiatives and public-private partnerships aimed at aligning AI and energy demands with biodiversity conservation goals. Efforts to improve the environmental footprint of technology are taking shape across regions, exemplified by investments in renewable energy for data centers, carbon-neutral commitments by tech companies, and new regulations targeting sustainable digital practices. These actions underscore the impact that carefully crafted incentives and regulations can have. Governments, industry and tech leaders are beginning to recognize that environmental sustainability in the digital era requires collective responsibility and collaboration.

One of the most promising, though less explored, areas in this journey towards sustainable technology is bio-inspiration (biomimicry), which focuses on *innovation inspired by nature*, designing solutions that mimic biological processes to address technological and environmental challenges. This approach holds potential for transforming AI and energy systems by incorporating ecological principles from design. Nature-inspired AI could, for example, enhance energy efficiency by learning from biological processes that optimize energy use, whether through optimal networks for resource distribution, shapes that allow for thermal control, or new forms of sustainable energy generation. This can be achieved by leveraging and emulating principles found in nature's forms, processes or ecosystems. By positioning biomimicry as a central pillar of the sustainable development agenda, we can view AI, biodiversity and energy as interconnected elements rather than conflicting forces, leading to innovation strategies that support resilience and ecological harmony.

Achieving this vision in LAC will require addressing specific regional challenges. Despite the region's immense biodiversity and natural wealth, it faces hurdles in establishing a virtuous biomimicry-AI ecosystem. These challenges include the lack of a critical mass of specialized human capital due to limited interdisciplinary university training related to bio-innovation; inadequate or limited financial support for biodiversity-based innovation and technological diffusion; weak links between academia and industry to share information and understand potential areas of demand; administrative obstacles to obtaining permits for research on genetic material and biodiverse areas; and limited business awareness regarding the opportunities for the improvement of AI and the potential solutions offered by biomimicry. Therefore, a roadmap for sustainable development in LAC must prioritize capacity-building, by investing in education and training programmes that prepare various stakeholders (academia, industry, policymakers) in bio-innovation and AI with a sustainability focus.

Furthermore, efforts to establish a network/ecosystem of local startups, research institutions and global companies open to innovation in sustainability are crucial. Building a supportive ecosystem that fosters entrepreneurship in biomimicry and sustainable technology - as the Nature Intelligence Venture Studio to be launched by TIDE Centre at the University of Oxford – will enable LAC to better capitalize on its unique biodiversity. By integrating these initiatives into national and regional development strategies, and by ensuring smart regulatory frameworks and proactive productive development policies, the region can lay a solid foundation for sustainable, innovation-driven economic growth. Policy frameworks must also be forward-looking, and governments should promote financing models that encourage long-term investments in sustainability-focused innovation, including tax incentives, grants and public-private partnership initiatives. A regulatory environment that promotes responsible innovation can also attract international partnerships and investments, accelerating the region's development in sustainable technologies.

Latin America and the Caribbean, with its rich natural ecosystems and high potential for renewable energy, is uniquely positioned to pioneer this sustainable path. By fostering a symbiotic relationship between AI, biodiversity and energy, the region has the potential to build a resilient, adaptive economy that can withstand global challenges while protecting natural resources. This vision extends beyond environmental benefits, aiming to transform LAC into a leader in sustainable innovation, creating jobs and enhancing economic stability.

This paper envisions a future where AI, biodiversity and energy are not adversaries but allies, working together to forge resilient societies and economies. By embracing a symbiotic perspective, LAC can lead the way in creating a more balanced, sustainable model for the digital age. A *symbiosis is possible*.

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