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A Place-Based Infrastructure Approach for Bioeconomies in the Amazon Region

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Luciano Charlita de Freitas | Felipe de Albuquerque Sgarbi

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Abbreviations

ANA	Autoridad Nacional del Agua (Peru)
ANAC	Agência Nacional de Aviação Civil (Brazil)
ANATEL	Agência Nacional de Telecomunicações (Brazil)
ANEEL	Agência Nacional de Energia Elétrica (Brazil)
ANI	Agencia Nacional de Infraestructura (Colombia)
ANLA	Autoridad Nacional de Licencias Ambientales (Colombia)
ANTAQ	Agência Nacional de Transportes Aquaviários (Brazil's national agency for waterway transportation)
AOI	area of interest
ASPACS	Association of Agro-Extractive Producers of Colônia do Sardinha (Brazil)
cm	centimeter
CPR LATAM	Center for Public Research on Latin America (Latin America)
DANE	National Administrative Department of Statistics (Colombia)
EGI	electrical grid instability
EPE	Empresa de Pesquisa Energética (Brazil)
FACTS	flexible alternating current transmission systems
FWA	fixed wireless access
GDP	gross domestic product
GHSL	global human settlement layer
GHz	gigahertz
GIS	geographic information system
HV	high voltage
IBAMA	Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (Brazil)
IBGE	Instituto Brasileiro de Geografia e Estatística (Brazil)
ICMBio	Instituto Chico Mendes de Conservação da Biodiversidade (Brazil)
IDB	Inter-American Development Bank
IDEP	Infraestructura de Datos Espaciales del Perú (Peru)
IPI	Infrastructure Provision Index
IPSE	Instituto de Planificación y Promoción de Soluciones Energéticas (Colombia)
IRI	International Roughness Index
ITU	International Telecommunication Union
kbps	kilobits per second
km	kilometer
km^2	square kilometer
kWh	kilowatt-hour

L	liter
LEO	low earth orbit
m	meter
m^2	square meter
MBM	Microsoft Bing Maps
MHz	megahertz
MME	Ministério de Minas e Energia (Brazil)
MTC	Ministerio de Transportes y Comunicaciones (Peru)
MV	medium voltage
MW	megawatts
NASA	National Aeronautics and Space Administration (United States)
NDCs	Nationally Determined Contributions (under the Paris Agreement)
NLP	National Logistics Plan
NOAA	National Oceanic and Atmospheric Administration
nW/cm²/sr	nanowatts per square centimeter per steradian
OCHA	Office for the Coordination of Humanitarian Affairs (United Nations)
OMF	open mapping at Facebook
ONS	Operador Nacional do Sistema Elétrico (Brazil)
OSINERGMIN	Organismo Supervisor de la Inversión en Energía y Minería (Peru)
OSM	OpenStreetMap
PAC	Programa de Aceleração do Crescimento (Brazil)
PATIS	Plan Amazónico De Transporte Intermodal Sostenible (Peru)
PATS	Programa de Apoyo al Transporte Subnacional (Peru)
PMTI	Intermodal Transport Master Plan (Colombia)
PNL	National Logistics Plan (Brazil)
PPP	public-private partnership
PV	photovoltaic
SAR	synthetic aperture radar
SEIN	Sistema Eléctrico Interconectado Nacional (Peru)
SGB	Serviço Geológico do Brasil (Brazil)
SHAP	SHapley Additive exPlanations
SSPD	Superintendencia de Servicios Públicos Domiciliarios (Colombia)
ton-km	ton-kilometer
TVWS	TV white space
VIIRS	Visible Infrared Imaging Radiometer Suite
VSAT	very small aperture terminal
W	watts
WBG	World Bank Group

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Executive summary







Executive summary

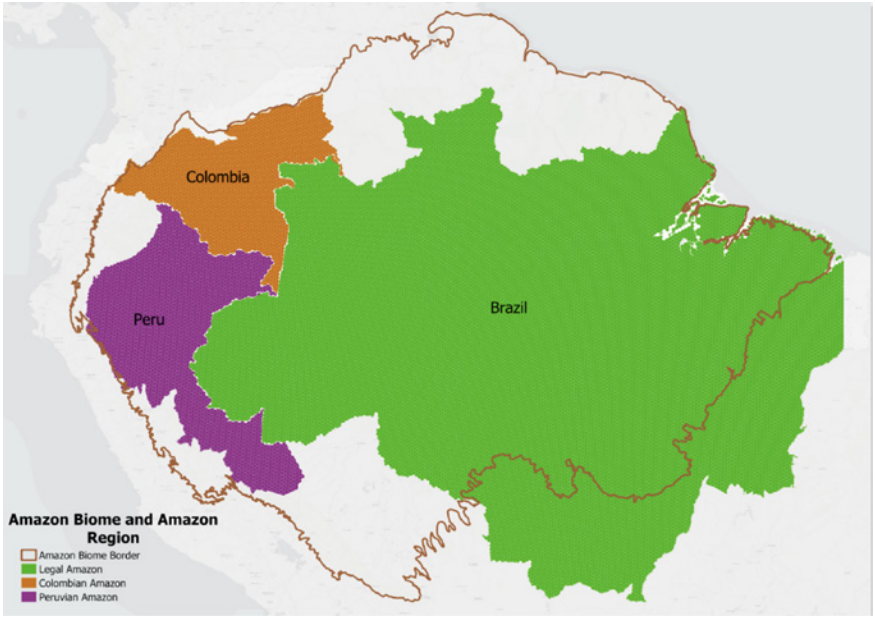
Pathways to jobs, well-being, and sustainable growth in the Amazon region[1] begin with infrastructure—not as an end in itself, but as a means to connect people with what they need to thrive. In a region where communities are spread across vast distances and diverse landscapes, strategic infrastructure investments provide a lifeline by expanding access to jobs, basic services, and further opportunities for economic inclusion. Reliable electricity supply can, for example, expand opportunities for small agricultural businesses and the local processing of forest products; expand access to potable water; and sustain cold storage for products, vaccines, and other emergency medical equipment. Reliable transport systems can help local producers access broader markets and build stronger value chains—especially in emerging bioeconomy sectors—and reduce the travel times and costs involved in getting children to school. Better digital connectivity can offer new means to reach markets (including for bioeconomy products) and access digital financial services, online education, and telemedicine. This study is motivated by a central question—how can infrastructure be harnessed to unlock pathways to well-being and inclusive development in the Amazon, without compromising its ecological integrity?

The Amazon biome, the world's largest tropical rainforest, harbors an exceptional wealth of biodiversity and natural resources. In addition to over half of the Earth's remaining rainforest, it includes various ecosystems, such as lowland and mountainous forests, savannas, and wetlands. It is home to more than 50 million people, many in remote, rural, and riverine communities. The Amazon biome spans nine countries, with most of the forest in Brazil (60 percent), followed by Peru (13 percent) and Colombia (10 percent). The remaining territory is spread across Bolivia, Ecuador, French Guiana, Guyana, Suriname, and Venezuela.

The Amazon region, as defined for the purposes of this report, spans three countries—Brazil, Colombia, and Peru—and is approximately 6.1 million square kilometers (map ES.1), making it larger than entire countries such as India or Argentina.

1 This report's area of interest is the Amazon region, comprising roughly 6.48 million square kilometers and large parts of Brazil, Colombia, and Peru. Based on these countries' territorial boundaries, the region is further divided into the Legal Amazon (in Brazil), the Colombian Amazon, and the Peruvian Amazon. The boundaries of these subregions were obtained using the following sources: Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE) – Municipal Mesh (Malha Municipal), for Brazil; United Nations Office for the Coordination of Humanitarian Affairs (OCHA) – Subnational Administrative Boundaries, for Colombia (sourced from National Administrative Department of Statistics [Departamento Administrativo Nacional de Estadística, DANE]; and Spatial Data Infrastructure of Peru (Infraestructura de Datos Espaciales del Perú, IDEP), for Peru.

Map ES.1 The Amazon biome and, within it, the Amazon region analyzed in this report



Note: For the purposes of this report, the "Amazon region" is the part of the Amazon biome that falls within the jurisdictions of Brazil, Colombia, and Peru. Based on national boundaries, it is further divided into sections, called the Legal Amazon (of Brazil), Colombian Amazon, and Peruvian Amazon, respectively.

Home to more than 32 million people, the region faces profound challenges in achieving inclusive and sustainable development. Central to this challenge are significant gaps in energy, transport, and digital infrastructure that hinder access to essential services, limit economic opportunities, and affect the overall well-being of the population. Infrastructure is not only a backbone for territorial integration and service delivery but also a catalyst for local economies and new productive models, such as the emerging bioeconomy. Infrastructure gaps constrain job creation, the circulation of goods and services, and the viability of sustainable economic alternatives that could both improve livelihoods and protect the Amazon's ecosystems.

At the same time, the Amazon is one of the world's most vital ecosystems, containing over 10 percent of the planet's known biodiversity and playing a critical role in regulating the global climate. The region's ecological fragility has been increasingly threatened by agriculture, illegal mining, and unplanned infrastructure development. These activities have historically propelled deforestation, habitat fragmentation, and the replacement of forests by other land uses. Roads have opened previously inaccessible areas, and illegal logging, mining, and agricultural expansion have led to environmental degradation and social conflicts. As the pressures to improve infrastructure intensify, it is imperative to adopt development models that respect the region's ecological limits while responding to the pressing needs of its people.

While the region is rich in biodiversity and traditional knowledge, it faces deep economic and infrastructure inequalities. Concerted action is needed to support the countries hosting the Amazon rainforest in their efforts to promote sustainable development while safeguarding forests and traditional ways of life.

The bioeconomy holds potential to drive sustainable development in the Amazon—creating jobs, boosting gross domestic product, and improving the well-being of local communities, all while preserving the standing forest. As demonstrated by the New Economy for the Brazilian Amazon (Nobre et al. 2023), harnessing the region's rich biodiversity and the value of native products like açaí fruit, cocoa, Brazil nuts, babaçu oil, honey, rubber, and copaíba can deliver tangible results. This approach supports job creation, income generation, and the development of new products and services based on the forest's biological resources. By relying on renewable assets native to the Amazon, local communities can maintain their ecosystems' natural balance while benefiting economically. The bioeconomy offers a viable, sustainable alternative to harmful practices such as monoculture and illegal resource extraction. Communities in the Amazon play a central role in protecting the forest, and expanding job opportunities through the bioeconomy is essential both to sustain their livelihoods and to ensure the forest remains standing, while strengthening the traditions and rights of Indigenous and other local communities.

The sustainable growth of the bioeconomy depends on addressing significant infrastructure deficits that impact the feasibility, scalability, and equity of value chains for native products. Major gaps in transport, energy, digital connectivity, and water access hinder value chain development, especially for small-scale and Indigenous producers.

This study is motivated by the need to better understand infrastructure gaps in the Amazon and their impact on bioeconomy value chains and community well-being. Its aim is to identify targeted, integrated, and climate-sensitive solutions that close these gaps while preserving ecological integrity. By identifying where and what types of transport, energy, and digital investments are most urgently needed, this report seeks to inform decision-makers of pathways for balanced, inclusive, and sustainable development.

The report focuses on the traditional bioeconomy, rather than industrial or large-scale cultivated production, as traditional models better align with long-term forest conservation and community-driven development. There are distinct risks of natural resource overexploitation associated with extractive and large-scale cultivation activities. As Homma (2017) describes, many extractive economies follow a trajectory that begins with unmanaged extraction, evolves through management and domestication, and ultimately leads to the commoditization of resources. This progression can undermine ecological stability. In contrast, the traditional bioeconomy—rooted in local knowledge systems and small-scale, sustainable practices—plays a critical role in stabilizing forest frontiers, conserving biodiversity, and supporting community-led, place-based development models. The report advocates for approaches that simultaneously promote human well-being, job creation, economic diversification, and forest conservation, recognizing that the future of the Amazon and its people depends on achieving this delicate, urgently needed balance.

The traditional bioeconomy plays a vital role in supporting remote communities, and its capacity to create more and better jobs is expected to grow. Projections included in this report indicate annual growth within the traditional bioeconomy sector, suggesting the possibility of doubling employment by 2050. According to current productivity estimates, approximately 42,000 new jobs may be generated over this timeframe.

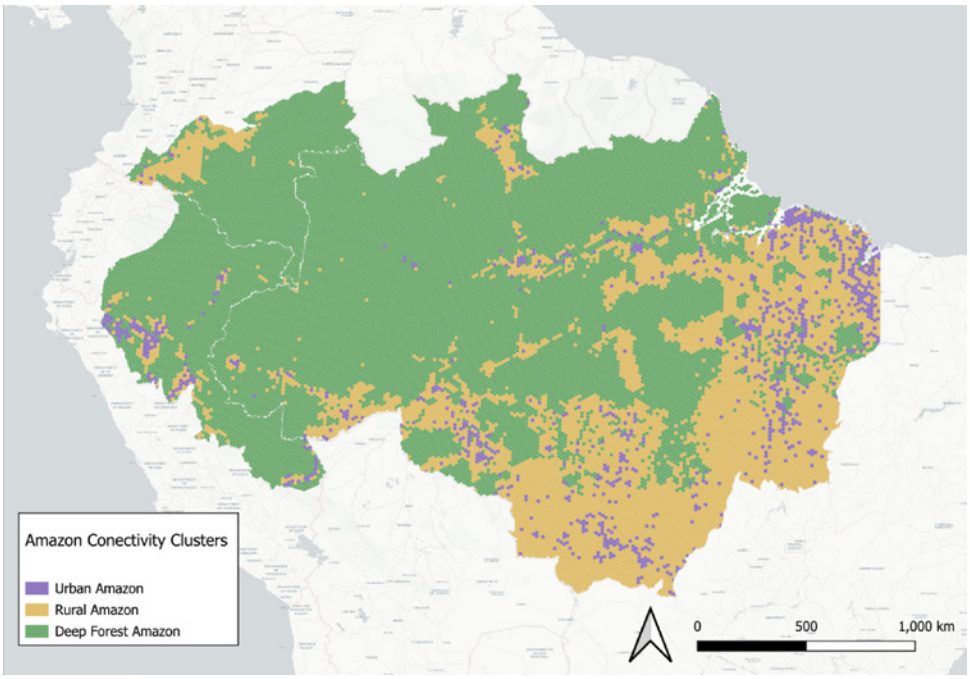
Connectivity clusters of the Amazon region

The Amazon region is characterized by unique spatial and infrastructural patterns that present profound challenges to inclusive, sustainable development. Metropolitan areas, particularly in the Legal Amazon (Brazil), are home to millions of people. The region's remaining low-density, highly dispersed population is concentrated in small and medium-sized towns along rivers, facing major barriers to inclusive development due to vast distances, difficult terrain, and weak infrastructure. These challenges limit access to essential services, especially for remote and Indigenous communities. A uniform infrastructure model cannot deliver equitable development, cost efficiency, or environmental integrity across these settings.

Given the vast diversity in connectivity and environmental conditions, the Amazon region is best understood by considering three distinct connectivity clusters: the Urban Amazon, Rural Amazon, and Deep Forest Amazon (map ES.2). These clusters are defined based on levels of transport, energy, and digital connectivity; access to services; and environmental characteristics. This clustering recognizes the region's heterogeneity and helps identify and respond to the region's differentiated development and conservation needs.

- **Urban Amazon:** Densely populated, anthropized, accessible territories around capitals and peripheries and denser infrastructure networks.
- **Rural Amazon:** Areas along major rivers and highways, balancing ecological sensitivity and connectivity needs.
- **Deep Forest Amazon:** Sparsely populated, isolated zones along secondary rivers. These rivers are often difficult to navigate, resulting in significant travel times between population clusters and limited access to services. The Deep Forest Amazon is similarly distant from electricity grids and digital infrastructure.

Map ES.2 Considering the Amazon region as three distinct connectivity clusters, defined by degree of connectivity and development



Note: The Urban Amazon (purple), Rural Amazon (gold), and Deep Forest Amazon (green) are defined here based on levels of transport, energy, and digital connectivity; access to services; and environmental characteristics. km = kilometer.

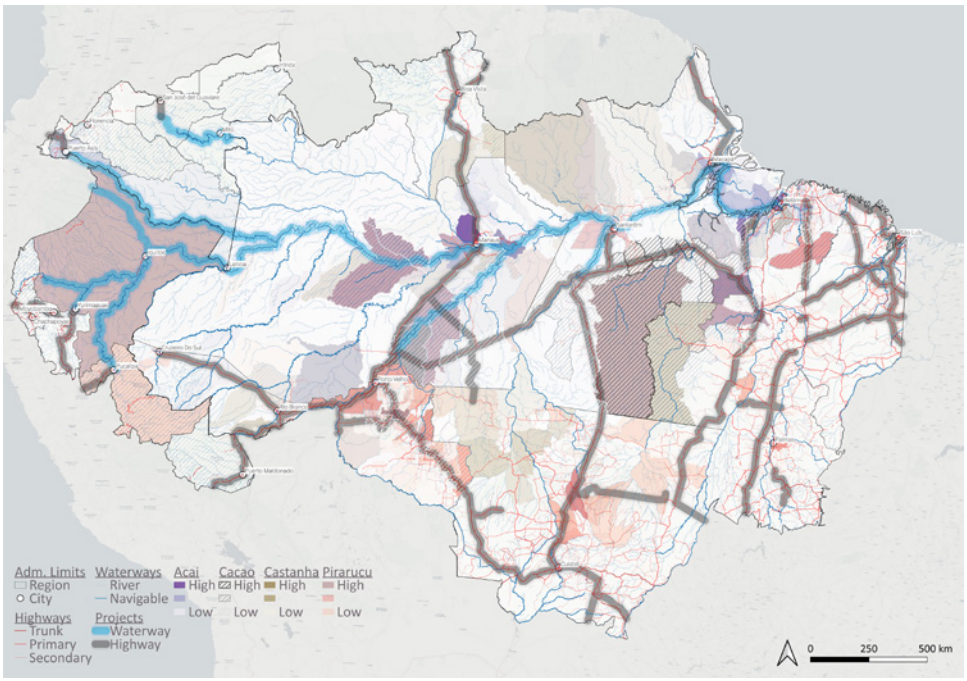
Bioeconomy constrained: How infrastructure gaps limit opportunities in the Amazon

Amazon bioeconomy products—like açaí, Brazil nuts, pirarucu, and cocoa—depend on multimodal logistics that are today shaped by geography and infrastructural gaps that limit market access and economic returns (map ES.3). The harvesting locations of bioeconomy products are across the Deep Forest and Rural Amazon, meaning there is limited connectivity from the beginning of the supply chain. Açaí, predominantly produced in Pará (Brazil), is transported via small river boats, with 90 percent of production consumed locally within the Amazon region. Primary flows move toward hubs like Belém and Manaus, with secondary routes extending to São Luís and Porto Velho. In Acre (Brazil), açaí travels eastward to Rio Branco, while in Peru's Loreto region, limited production is distributed by river to Iquitos and Pucallpa.

Brazil nuts follow similar logistics, starting with river transport from remote areas in the southern municipalities of Amazonas, and other states of Brazil's Legal Amazon, then shifting to roads for distribution to Manaus, Belém, and Rio Branco, for national and export markets. Pirarucu, a highly perishable fish, is mostly consumed locally (75 percent) and transported

in small boats from sustainable reserves. In Brazil, production is centered in Amazonas, with flows to Manaus, Belém, and Cuiabá. In Peru, Indigenous fish farms in Loreto's Pacaya Samiria and Putumayo-Marañón reserves supply regional markets in Loreto, San Martín, and Ucayali. In Colombia, logistical constraints limit pirarucu distribution to local Indigenous markets along the Putumayo and Caquetá Rivers. Cocoa relies more heavily on road transport. In Brazil, Pará and Rondônia are key producers, and Medicilândia serves as a central hub for collection. In Colombia, production from departments such as Caquetá, Putumayo, and Guaviare is routed through regional highways to processing and export centers.

Map ES.3 Source areas of four bioeconomy products



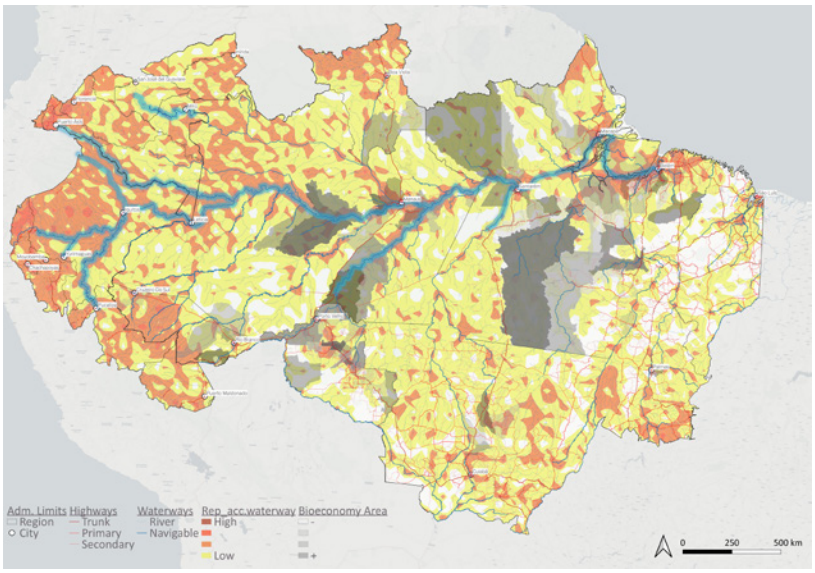
Source: Based on data from IBGE for Brazil, UPRA for Colombia, and Banco Central de Reserva for Peru.

Note: Castanha is the Portuguese term for Brazil nuts; pirarucu is a freshwater fish native to the Amazon. km = kilometer

The first stage of transport for most bioeconomy products typically involves small boats or canoes moving goods from harvesting sites to nearby markets and initial processing points. Rivers serve as the primary mode of transport in the region, essential for reaching remote regions (map ES.4). For communities across the Amazon, rivers are a key element of transport connectivity (map ES.5). However, river mobility is increasingly compromised by operational constraints, infrastructure gaps, and climate impacts. Operational constraints include high fuel costs, aging vessels, and long distances, which increase transport delays and spoilage, especially without cold storage. Poor maintenance, lack of signaling, and limited navigational aids reduce safety and reliability. Seasonal droughts and declining river levels, intensified by climate change, increasingly disrupt navigation. These challenges in the first transport leg often prevent products from reaching regional markets, limiting them to local consumption.

Port and dock infrastructure across the Amazon is unevenly distributed and poorly equipped to support the bioeconomy. While major ports in Manaus, Santarém, and Belém are expanding to accommodate large-scale agricultural exports, smaller ports and docks—vital for bioeconomy products on their route to major urban centers and also riverine and Indigenous communities—often lack necessary cargo facilities and floating structures to handle fluctuating river levels. During dry seasons, makeshift ramps and dirt paths are often the only loading options, causing delays, safety risks, and bottlenecks. These limitations directly impact bioeconomy value chains, where refrigeration, reliable schedules, and efficient loading are essential to maintain product quality and value.

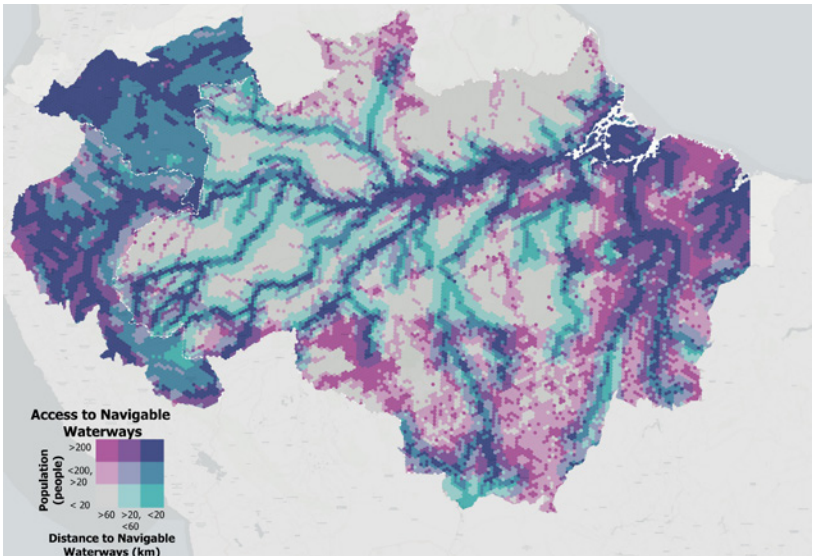
Map ES.4 Areas of bioeconomy and river access



Source: Based on World Bank Group database (2025).

Note: km = kilometer.

Map ES.5 Population density and connectivity to navigable rivers

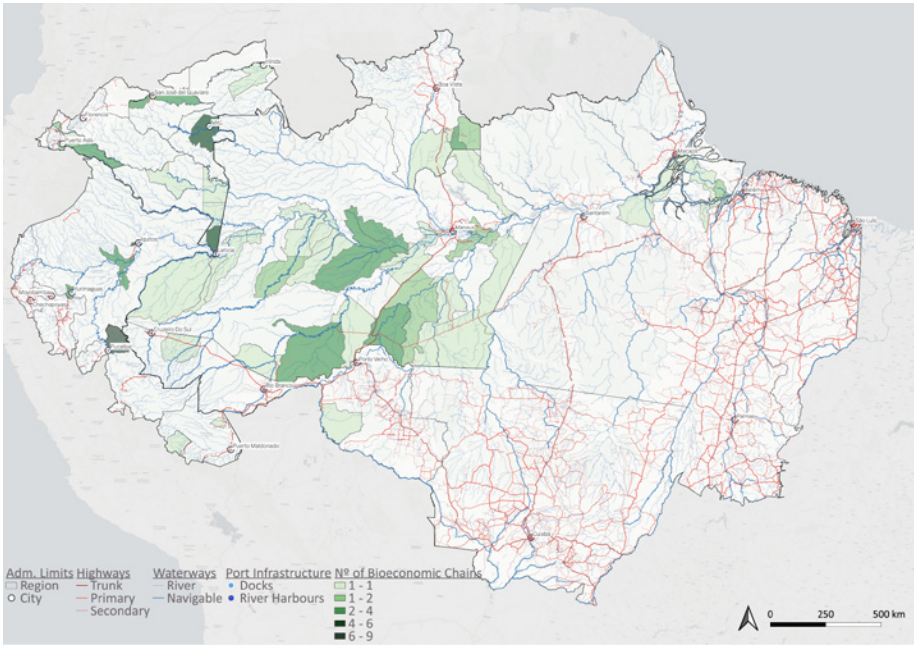


Note: The map correlates access to navigable rivers (darker turquoise) with population (darker purple). Areas where populations have a good level of access to rivers are shown in dark blue. km = kilometer.

Remote, small communities across the Amazon region are bioeconomies' initial processing hubs, where workers typically handle basic tasks such as cleaning, sorting, or beating (in the case of açaí) and therefore serve mostly as consolidation points. Unreliable electricity severely limits their ability to add value through drying, freezing, or storage. Power outages are frequent, at up to 40 days per year in Roraima (Brazil), 114 in Madre de Dios (Peru), and 310 in Caquetá (Colombia). Without reliable electricity, perishable products are vulnerable to pest damage and spoilage. Spoilage rates can reach up to 50 percent for pirarucu in riverside villages and 40 percent for açaí in areas far from urban processing centers. These losses severely undermine the productivity, income potential, and food security of local populations, weakening the resilience and economic viability of Amazon bioeconomy systems.

Energy access and quality remain a major barrier to value-adding activities across the Rural and Deep Forest Amazon. For the bioeconomy, unreliable energy supply limits cold chain logistics and agro-processing. Existing electrification programs focus mainly on small household systems, which are inadequate for powering productive infrastructure like refrigeration and processing facilities. Map ES.6 highlights municipalities with producers of one or more bioeconomy products but with inadequate electricity infrastructure. Satellite-derived proxies for electricity access reveal significant territorial disparities in access to electricity. The assumption is that lower levels of visible light at night correspond to lower levels of energy access. Map ES.7 plots this light intensity. Upon visual inspection, it becomes easy to see that more remote corners of the Amazon experience a lower level of access relative to the urban centers. Cities like Manaus are easily identifiable relative to the surrounding rural hinterlands. Most of those areas rely on isolated, diesel-powered generators that are expensive, polluting, and typically provide electricity for a limited number of hours per day.

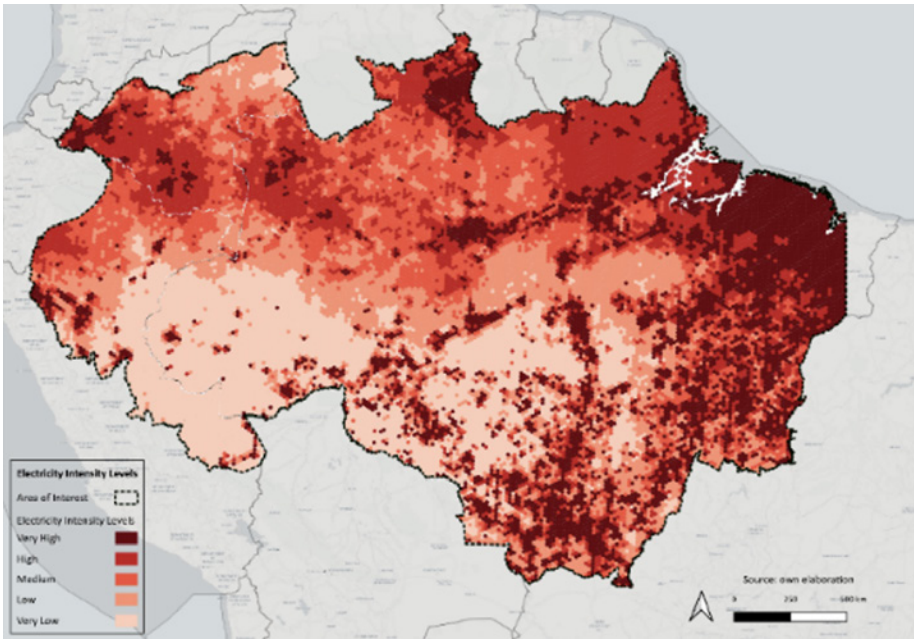
Map ES.6 Municipalities with bioeconomy production and electricity access issues



Source: Original compilation.

Note: The green areas highlight municipalities that serve as hubs of bioeconomy production, with the darker shades indicating a greater diversity of bioeconomy products. km = kilometer.

Map ES.7 Energy intensity levels, using nighttime lights as a proxy



Note: The map plots the intensity of nighttime lights across the area of interest. Areas highlighted in light red represent communities where light intensity is low. Assuming that light intensity correlates with energy access (as discussed in chapter 1), the lighter red areas correspond to regions with lower levels of access to energy. km = kilometer.

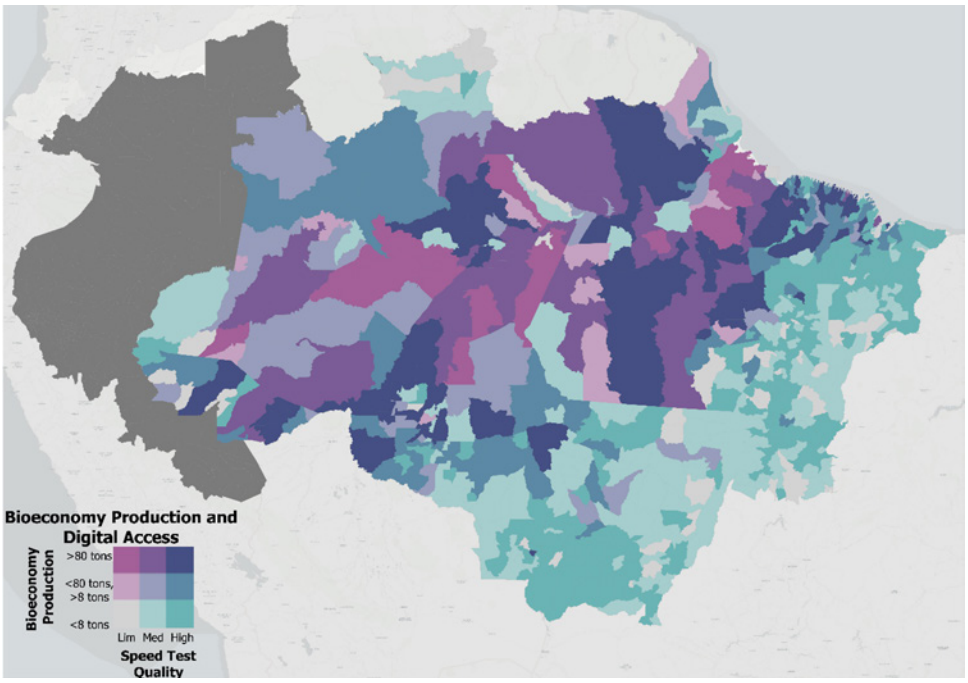
As a result, most bioeconomy processing occurs in major urban centers in the Urban Amazon, where energy supply is more reliable. A spatial divide between production areas and these urban centers separates value-adding activities from rural and Indigenous producers. Without local, high-quality energy access, communities rely on traditional methods such as drying or salting to preserve goods, which reduces quality and market value. Expanding small-scale processing near production zones would increase local income and create jobs—but requires reliable energy solutions. Despite solar and biomass potential, decentralized renewable energy systems remain underutilized due to regulatory, technical, and financial hurdles.

The absence of refrigeration at small ports, docks, and consolidation points across the Rural Amazon significantly constrains the profitability of Amazon bioeconomy value chains. For highly perishable products like pirarucu—mostly consumed locally due to preservation challenges—expanded refrigeration would improve market access and food security by extending shelf life. However, 60–80 percent of the territory of the Amazon region lacks reliable electricity, making cold storage infeasible in many remote areas. Thus, strengthening energy infrastructure is essential to enable processing and increasing income retention at the local level.

Despite the central role of rivers, port and dock infrastructure is insufficient and precarious, lacking storage, sanitation, and logistics areas. In Colombia's Putumayo River basin and Brazil's Juruá and Purus river basins, inefficiencies contribute to postharvest losses, especially for highly perishable bioeconomy goods like açaí and pirarucu. This further restricts the bioeconomy and prevents development in disconnected, underresourced communities. Variations in river levels make it essential for ports to have infrastructure that can adapt to changing conditions. This increases the need for floating docks on tributaries across the Deep Amazon and for upgrading ports in the Rural Amazon.

Bioeconomy producers and cooperatives increasingly depend on internet access for logistics, traceability, and financial services, but digital connectivity remains limited in the Rural and Deep Forest Amazon. Digital tools such as mobile payment systems, digital marketplaces, and financial inclusion platforms help expand market reach, improve transparency, and streamline operations. About 60 percent of ports and docks located in areas with active bioeconomy production have access only to limited quality digital connectivity. In key production zones, digital connectivity is insufficient (map ES.8).

Map ES.8 Bioeconomy production and digital access quality



Source: Original compilation.

Note: Areas with high bioeconomy production often coincide with limited digital connectivity, indicated by pink and light violet shades. Evidence of digital connectivity is based on Ookla speed test data (explained in chapter 1). In brief, we use Ookla's data and assume that digital access is possible if a speed test is recorded within a certain radius of various regions reported by Ookla.

Beyond commerce, digital infrastructure is also vital for environmental management and territorial security. Associations such as ASPACS (Association of Agro-Extractive Producers of Colônia do Sardinha) and ACESA (Associação Comunitária de Educação em Saúde e Agricultura) stress the importance of real-time data on transport routes, market prices, and environmental conditions to optimize operations and reduce reliance on intermediaries. In areas like those patrolled by the Coletivo do Pirarucu, where travel to a medium-sized town can take over 40 hours, improved digital connectivity could reduce emergency response times to illegal fishing by up to 40 percent, helping protect lakes, fisheries, and community livelihoods.

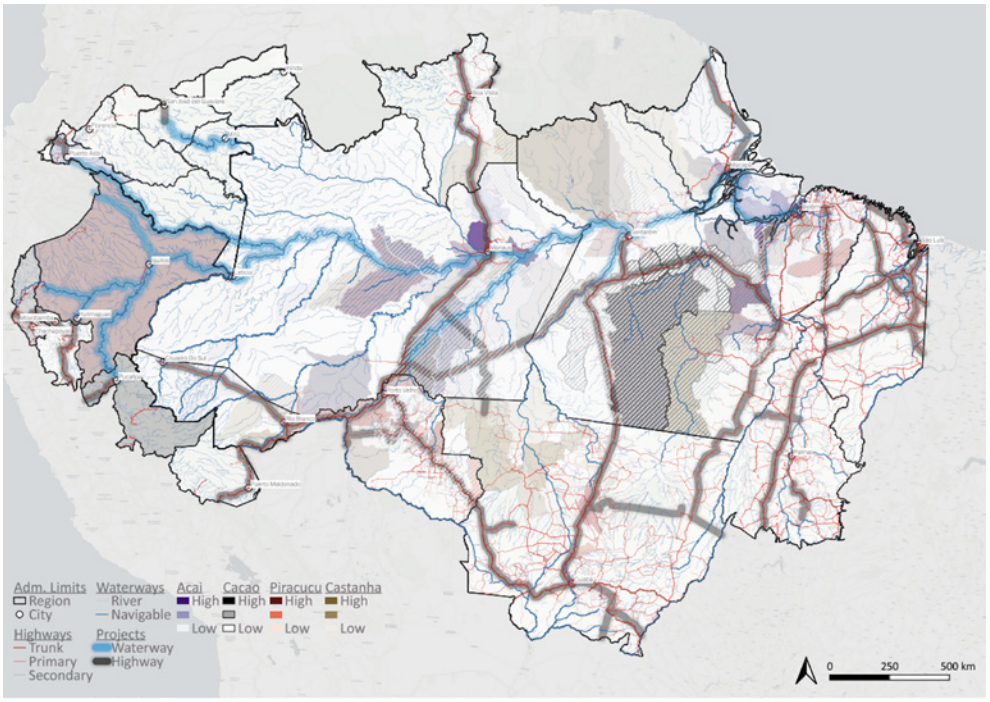
As products move beyond initial collection points, they face additional logistical hurdles. During the second transport leg—involving larger boats or trucks—cargo loads, passing across the Rural Amazon, are often delayed by poor river navigability and degraded roads. In Brazil's Amazonas state, river transport remains dominant, with bioeconomy activity—especially for export-bound goods like Brazil nuts—concentrated along the river upstream of Manaus. Meanwhile, domestic distribution (e.g., of products like cocoa) relies heavily on roads, which connect rural areas to urban processing hubs.

Seasonal fluctuations in the levels of even the major rivers—sometimes reaching 20 meters—combined with increasingly frequent droughts, are creating serious challenges for river transport across the Amazon. Major rivers like the Solimões, Madeira, and Tapajós require constant dredging to remain navigable, while secondary rivers are poorly marked and increasingly difficult to access as droughts intensify. In 2023–24, 90 percent of vessels in Brazil's Amazonas state faced navigation restrictions due to prolonged droughts. These disruptions sharply increased transport costs and delayed the movement of goods. Even when the Amazon River remains navigable, shifting shorelines during dry seasons hinders access to communities and cargo operations, issues also seen along the Madeira River corridor in Rondônia.

Major highways, primarily built to move agricultural commodities to southern Brazilian markets, also serve as key corridors for bioeconomy products. During long-distance transport, perishable goods like açaí and pirarucu require cold storage—which is more accessible along land routes than rivers—reinforcing the importance of road infrastructure in domestic supply chains.

An extensive road network exists in the region, yet road infrastructure is fragmented, poorly maintained, and environmentally disruptive. Most major roadways in the Legal Amazon (80 percent) are estimated to be all-season, and much of the major road network in the Peruvian Amazon (50 percent) and Colombia Amazon (46 percent) is as well. Local roads—critical for linking rural areas to rivers and areas of bioeconomy production—are almost entirely degraded, especially in most remote areas. Poor road quality increases transport costs, isolating communities and limiting access to economic opportunities and essential services. Despite this, a majority of non-bioeconomy agricultural freight in the region, mostly harvested in already deforested areas of the Rural Amazon, is transported by road. While improving connectivity is essential, road expansion poses a significant environmental risk, as deforestation tends to increase within a 5 kilometer radius of new road infrastructure, highlighting the need for careful planning, risk mitigation, and land use monitoring. Given the extensive existing network and its role in connecting remote communities while facilitating agricultural trade, prioritizing maintenance of these existing roadways is key for the region.

Map ES.9 Road and river corridors used to transport bioeconomy products



Source: Original compilation.

Note: Road corridors are shown in brown and rivers in blue. km = kilometer.

Establishing integrated development hubs at ports—combining energy, cold storage, digital services, and logistics support—offers a promising solution to strengthen bioeconomy supply chains. Locating processing facilities closer to extraction zones—such as pulp plants and food processing units—while linking them to efficient river and road connections to inland ports could reduce costs and improve supply chain performance. Intermodal hubs and boats with on-board processing capabilities can enable value-added production in remote areas while reducing waste. Together, these measures will modernize logistics systems, support sustainable economic development, and expand opportunities for Amazon communities.

A place-based approach to infrastructure development

This report outlines a balanced, data-informed strategy to unlock the Amazon's sustainable bioeconomy potential through targeted infrastructure investments that promote economic inclusion and environmental preservation.

Infrastructure development in the Amazon can be advanced in a way that enhances economic opportunities for local communities while preserving critical ecosystems. This requires a targeted, place-based approach informed by the region's environment, geography, and connectivity. For example, investments in improving the accessibility and functioning of the region's river network, which provides low-carbon transport solutions for isolated and urban communities alike, should be prioritized. The region already hosts an extensive road network; it is important to maintain the quality of these assets and improve all-season connectivity between major urban centers and the river network serving isolated communities.

A key guiding principle of the place-based approach is to tailor infrastructure interventions to territorial typologies. Tailoring for each of the three distinct connectivity clusters (refer back to map ES.2) in the region helps safeguard the Amazon's forests and biodiversity while supporting inclusive development and infrastructure development.

- **Urban Amazon.** Improve the efficiency and connectivity of logistics centers along the periphery of the Amazon, enabling them to continue to serve as the engine of regional development, critical for local value chains. Prioritize large-scale investments in river and road infrastructure, urban logistics hubs, renewable energy grids, and fiber-optic networks to enhance connectivity, improve public services, and expand market access for bioeconomy products.

- **Rural Amazon.** Focus on decentralized, integrated solutions that improve service delivery locally while enhancing the connectivity of the Deep Forest and Urban Amazon. Investments in strategic development port hubs with refrigerated storage, quality digital access, hybrid renewable energy systems (solar + batteries + biomass), and community-managed internet networks have the potential to enable small-scale producers to participate in regional and national markets. Electromobility for school and health transport routes can improve access to services. All these interventions need to be tailored to the size of the community and its level of integration with regional road, river, energy, and digital networks.

- **Deep Forest Amazon.** Promote small-footprint, mobile, and technology-based solutions adapted to the fragile environment and dispersed populations. Priorities include small floating docks, solar-powered boats, cargo drones, hybrid energy systems (solar + batteries + biomass + diesel backup), and satellite-based digital access points to support basic services, emergency care, and the commercialization of bioeconomy products.

A significant opportunity lies in improving connectivity across the Amazon by transforming selected ports in the Rural and Deep Forest Amazon into strategic development hubs that integrate transport, energy, and digital connectivity. The overarching access goal is to connect decentralized bioeconomy production zones with processing centers and urban markets, while enhancing access to essential public services. This place-based approach positions river ports as platforms for economic opportunity, service delivery, and inclusion across diverse geographies.

The approach differentiates two complementary infrastructure enhancements:

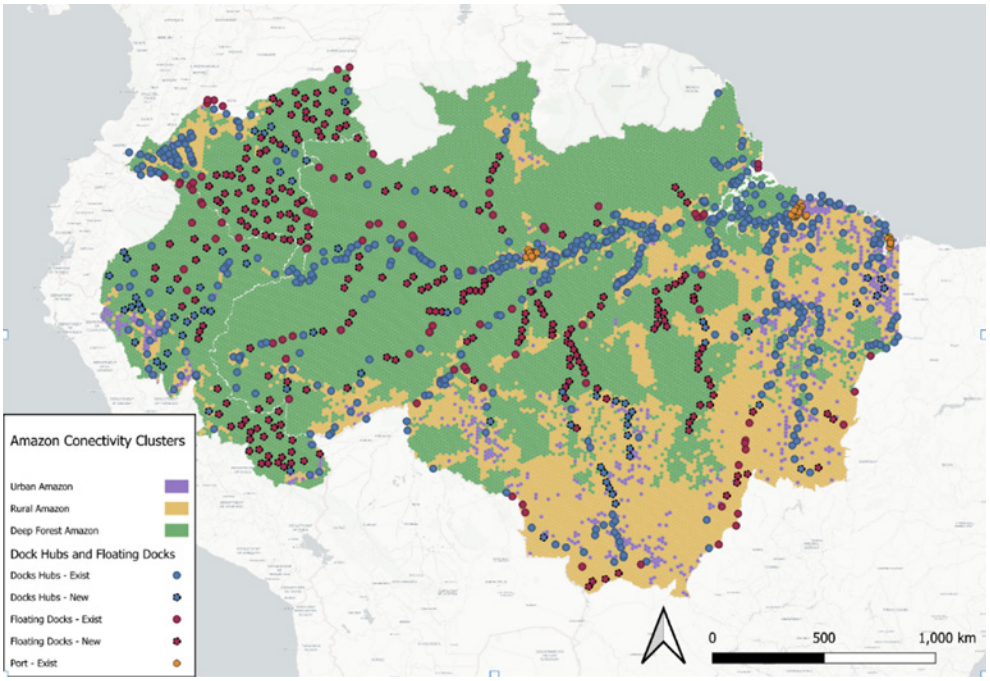
(a) Strategic development hubs are permanent river facilities enhanced with modern logistics (loading/unloading, warehousing, cold chain), passenger terminals, and dependable power and broadband links to anchor local economic activity and service delivery.

(b) Floating docks provide adaptable access points in Deep Forest settings, where permanence is constrained by hydrology, seasonality, and dispersed settlement patterns.

By combining investments in port passenger and cargo facilities with fit-for-purpose energy systems (from solar and hybrid solutions to grid connections) and digital connectivity (from baseline satellite internet to community broadband and integration with fiber/4G/5G), the hubs are designed to unlock market access, reduce travel times and logistics costs, and strengthen the resilience of supply chains and services across the Amazon.

Establishing a combined network of approximately 970 strategic development hubs and floating docks is projected to enable access for nearly 13.9 million people, with an estimated total capital investment of about US$3.24 billion—equating to roughly US$233 per person served. Typical site costs reflect the depth of integration: strategic development hubs range from about US$3.1–4.0 million per site, while floating docks average around US$0.5 million per unit. The portfolio is predominantly capital expenditure, with higher energy-related outlays in remote areas due to off-grid and hybrid requirements and relatively greater digital and grid-integration spending in more urbanized settings. The results indicate that an additional 309 river facilities (see map ES.10)—consisting of new strategic development hubs, and floating docks—are needed to provide adequate coverage for currently underserved bioeconomy in the Deep Forest, Rural, and Urban Amazon.

Map ES.10 Strategic development hubs, and floating docks to support the bioeconomy



Source: Original compilation.
Note: km = kilometer.

Prioritizing integrated multisectoral solutions that bundle transport, energy, and digital connectivity investments can yield stronger local impacts and improve cost efficiency. Aligning interventions across sectors enhances service delivery and economic development while reducing environmental footprints through coordinated and compact infrastructure planning. This could include, for example, pairing river navigability improvements with the installation of underwater fiber-optic connectivity and subaquatic high-voltage transmission; coordinating energy improvements with electric mobility solutions; and developing e-commerce platforms for the bioeconomy in parallel with digital coverage improvements.

New technologies offer scalable and flexible solutions well-suited to the Amazon's challenging geography and dispersed populations. Deploying decentralized and renewable systems—particularly in energy, connectivity, and water access—can help overcome the limitations of conventional infrastructure and bring essential services to remote communities. Solutions such as satellite cell mobile connectivity, drone use for cargo delivery, and solar-powered boats are some of the new technologies already piloted across the region.

The investment roadmap follows the place-based approach centering on the enhancement of strategic development hubs, which link communities to rural hubs with minimum-viable infrastructure and onward to urban centers that provide logistics, processing, and export capacity. Considering the the sizable investments needed and the challenges of bringing bundled infrastructure across a vast territory and in a challenging environment, the roadmap proposes a phased approach. The phasing seeks to maximize economic opportunity and service delivery without compromising ecological integrity.

The investment plan unfolds in three steps: Short-term investments (years 1–5) prioritize strengthening the existing foundations across the Urban and Rural Amazon to further enhance their accessibility and quality of service. Efforts during the medium term (years 5–10) will improve access in areas that can be reached and focus on rural networks consolidation and piloting of solutions in the Deep Forest Amazon. Long-term interventions (years 10–15) will benefit from pilots across the Amazon region and help scale low-footprint technologies for full inclusion. Through its phased structure, the roadmap proposes the sequencing of preparatory tasks—feasibility analyses, engineering designs, and permitting—in the early years, to build readiness for later investment stages, particularly those targeting more remote areas, ensuring continuity and implementation readiness over time.

Table ES.1 Phased investment roadmap for the Amazon bioeconomies (5-10-15 years)

Time horizon	2025–2030	2030–2035	2035–2040
Focus / Sector	**Strengthening the foundations at hubs in the Urban Amazon and the accessible Rural Amazon**	**Consolidation and scaling of enhancements in the Rural Amazon and piloting of solutions in the Deep Forest Amazon**	**Scaling the inclusion of the Deep Forest Amazon**
Transport	• Develop rural strategic development hubs (e.g., Codajás, San Vicente del Caguán, Caballococha): sheltered loading, temperature-controlled storage, digital kiosks. • Upgrade urban ports (Manaus, Belém, Iquitos, Florencia): cargo handling, cold chain, safety signaling; phased fuel transition; last-mile urban logistics and public transport improvements.	• Roll out standardized spokes from hubs: floating/community docks with a basic cold chain; scheduled feeder services aligned to hub departures; electromobility routes for schools/clinics that also serve producers. • Maintenance of existing roads to decrease seasonal isolation.	• Basin-wide floating docks; solar-electric boats/ ferries on fixed schedules; solar cargo floating market platforms with an integrated cold chain. • Cargo drones for urgent healthcare deliveries.
Energy	• Reinforce High-voltage interconnections; add utility-scale storage where economic. • Medium-voltage hybrid systems (solar/ biomass/batteries) at rural hubs sized to productive loads (ice, freezers, pulping, drying). • Advance the Humaitá–Caladinho II project, and the Macapá reinforcement; complete Tucuruí–Roraima link; and implement Iquitos–SEIN interconnection to reduce diesel dependence.	• Scale Medium-voltage hybrids across rural basins; deploy right-sized microgrids with grid-forming inverters in spoke communities for a stable 24/7 basic service. • Incentivize industrial bioenergy hubs to oversize hybrid generation and export surplus via local/isolated microgrids under simplified feed-in rules.	• Universal multi-source microgrids (solar + biomass + batteries; efficient diesel only for backup); add micro-hydropower where feasible. • Expand community energy hubs (power + cold rooms + training) and industrial bioenergy hubs.

Time horizon	2025–2030	2030–2035	2035–2040
Focus / Sector	**Strengthening the foundations at hubs in the Urban Amazon and the accessible Rural Amazon**	**Consolidation and scaling of enhancements in the Rural Amazon and piloting of solutions in the Deep Forest Amazon**	**Scaling the inclusion of the Deep Forest Amazon**
Digital	• Establish municipal broadband centers (urban ports) and cooperative connectivity points (rural hubs) with traceability, e-commerce, and logistics apps; synchronize with power/transport when they become operational.	• Extend last-mile access: hybrid mix—fiber where feasible, fixed wireless access/TV white space at the forest fringe, and satellite backhaul deeper in. • Default apps for traceability, e-commerce, payments, and logistics; digital literacy and operation and maintenance training; align activation with transport timetables and reliable power.	• Satellite-based communication hubs and community internet access points supporting tele-education/telemedicine; culturally adapted platforms (Indigenous languages). • In each spoke, a connectivity point (school/clinic/cooperative) with tools for traceability, payments, logistics scheduling, and tele-services; promote digital literacy and productive use.

Policy approaches supporting integrated infrastructure for Amazon bioeconomy

Achieving the sustainable growth of the Amazon bioeconomy requires a new generation of policy approaches that integrate infrastructure development with environmental stewardship and social inclusion.

Strategic investment in strategic development hubs is essential. These hubs should combine energy, transport, and digital infrastructure to unlock entire value chains, expand market access, and stabilize local economies. Ports and medium-sized towns across the Amazon already serve as natural nuclei of service provision and economic activity. These strengths should be leveraged and reinforced through targeted infrastructure investments and by improving the connectivity of more remote locations to these hubs. In addition to serving as centers of economic activity, these hubs can function as centers for development via education, vocational training, and telehealth in remote areas. Investments should focus on water access solutions, such as rainwater harvesting, and expand microfinance and community funds to empower cooperatives managing schools, health posts, and energy systems. Vocational programs in renewable energy, agro-processing, and ecotourism—alongside affordable digital services and literacy initiatives—are essential for enabling communities to harness infrastructure for both economic and social inclusion.

A key priority is the modernization of river transport systems. This includes resilience investments in rivers, the introduction of electric boats, the renewal of aging fleets, and the enhancement of river safety through improved signaling and reliable passenger services. Equally important is the transition from fragmented energy access programs to integrated systems that support the productive use of electricity. These systems should be capable of powering small-scale processing refrigeration facilities using renewable energy sources such as solar, biomass, and battery storage.

Improving access to infrastructure and services using the place-based approach requires reliable, granular data on transport, energy, and digital coverage, particularly in underserved territories. Governments should expand the use of open data, satellite imagery, and mobile data records for planning and monitoring, while strengthening technical capacity at subnational levels. Additionally, policies must address the differentiated needs of Indigenous, Afro-descendant, and riverine populations to scale successful pilots into effective structural investments. Financing mechanisms should combine public and private resources through blended finance, green bonds, and tailored public-private partnership models. Finally, stronger regulatory frameworks for bioeconomy products—including certification, traceability, and fair-trade branding—will further improve market opportunities and consumer trust, ensuring that infrastructure and policy investments drive inclusive, sustainable development in the Amazon.

The report is structured as follows: Chapter 1 provides an overview of the key connectivity characteristics in the Amazon region and explains how these, in combination with environmental conditions, define three distinct connectivity and forest clusters. It details infrastructure provision across transport, energy and digital sectors in the Amazon. Chapter 2 analyzes how infrastructure gaps constrain the development of the Amazon's bioeconomy. Chapter 3 concludes with a proposed roadmap of actions to support bioeconomy development, outlining sector-specific approaches for transport, energy, and digital infrastructure.

Chapter 1. Understanding connectivity and infrastructure provision in the Amazon region

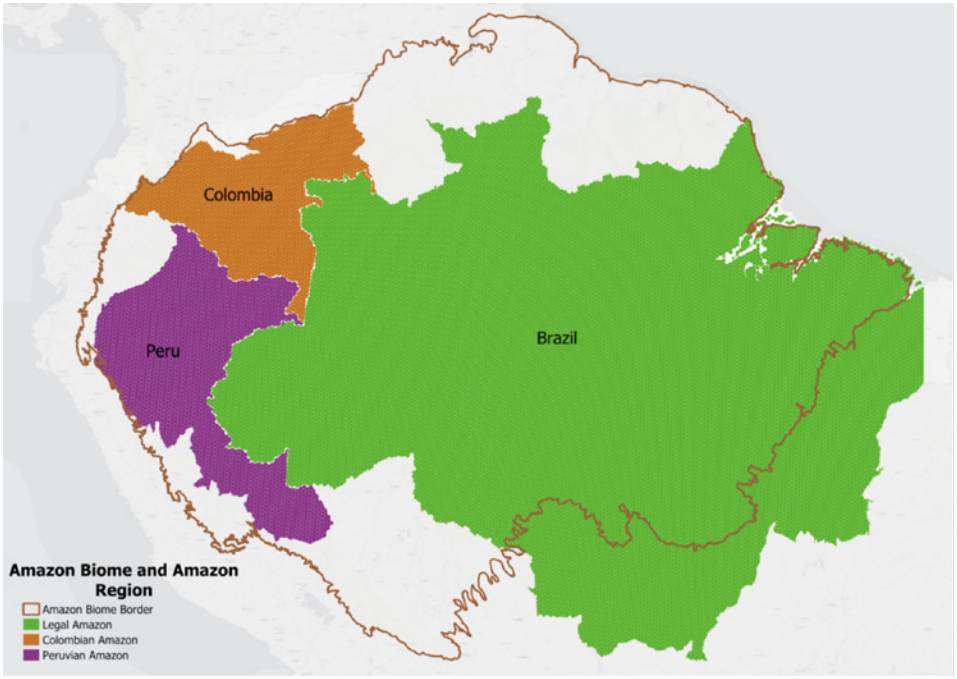


Chapter 1 key points

- The Amazon's river network spans over 380,000 km. More than half the population (16.4 million people) live within 10 km of navigable rivers. Only about 20 percent of non-urban populations (1.8 million) live within 10 km of a port/dock. Only approximately 12 percent of more than 380,000 km of rivers are navigable, and during the 2023–24 drought, cargo loads on key routes fell approximately 60 percent and freight rates rose up to 150 percent. Supporting infrastructure remains scarce, with just 730 identified ports and docks or about one per 43,000 people.
- A road network spanning 1.7 million kilometers traverses the Amazon, yet the region has low road density, at about 0.01 km/square kilometer (km^2), (vs roughly 0.2 km/km^2 in high-income countries). A significant share of all roads have extremely rough surfaces with International Roughness Index (IRI) >10 m/km. About 77 percent of rural populations live within 2 km of an all-season road, but about 85 percent of residents in heavily forested regions do not. Road expansion is linked to deforestation concentrated within approximately 5 km of corridors—underscoring the need for low-impact, climate-resilient designs.
- Energy access in the Amazon region lags national averages and is unreliable particularly in remote areas: reported outage days reach 310/year in Caquetá (Colombia), 114/year in Madre de Dios (Peru), and 40/year in Roraima (Brazil); 70–90 percent of off-grid communities rely on isolated (often diesel) systems.
- About one in five people across the region either lack internet access or cannot afford it, but a wide digital divide persists between urban/rural areas and the Deep Forest Amazon: 79.9 percent of Brazil's north has 4G connectivity (vs 92.4 percent nationally); the smallest municipalities average roughly 50 percent mobile coverage while large ones reach roughly 96 percent; in Peru's Amazon, penetration ranges from 7.3 percent (Amazonas) to roughly 49 percent (Ucayali). While the quality of fixed digital network connection has improved over the years, it is high only for 20 percent of the population, predominantly in the urban areas.

The Amazon biome, the world's largest and most biodiverse tropical forest, harbors an exceptional wealth of natural resources. It constitutes over half of the Earth's remaining tropical rainforest; includes diverse ecosystems, such as lowland and mountainous forests, savannas, and wetlands; is home to over 50 million people, many in remote, rural, and riverine communities; and spans nine territories, with the majority of the forest in Brazil (60 percent), followed by Peru (13 percent) and Colombia (10 percent) (map 1.1). The rest of the biome (17 percent) is spread across Bolivia, Ecuador, French Guiana, Guyana, Suriname, and Venezuela.

Map 1.1 The Amazon biome and, within it, the Amazon region analyzed in this report



Note: For the purposes of this report, the "Amazon region" is the part of the Amazon biome that falls within the jurisdictions of Brazil, Colombia, and Peru. Based on national boundaries, it is further divided into sections, called the Legal Amazon (of Brazil), Colombian Amazon, and Peruvian Amazon, respectively.

The Amazon region, as defined for the purposes of this report, is the portion of the Amazon biome that falls within the borders of three countries: Brazil, Colombia, and Peru. So defined, the Amazon region spans approximately 6.1 million square kilometers (km^2), making it larger, geographically, than entire countries such as India or Argentina.

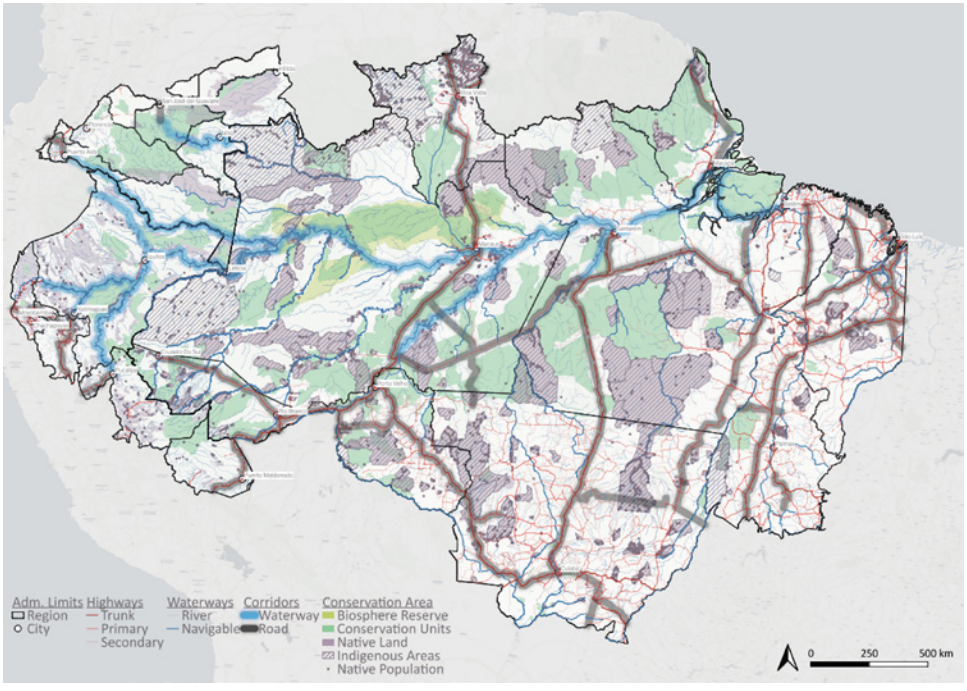
The Amazon region hosts a diverse population of 32 million,[2] almost half of whom reside in cities, reflecting a significant trend toward urbanization. This urban demographic plays a crucial role in driving the region's economic productivity, engaging in sectors such as trade, services, and industry. Urban centers in the Amazon serve as vital nodes for economic activities, supporting infrastructure development and service provision that leverage the region's abundant natural resources.

2 The population of the area of interest was calculated using World Pop 2020 unconstrained UN-adjusted rasters with a 100-meter resolution (https://hub.worldpop.org/geodata/listing?id=69).

In parallel to this significant urbanization trend, the activities of rural communities are of critical importance, across multiple dimensions. These communities are deeply connected to the land, employing sustainable methods of agriculture and forestry, as well as artisanal practices, to sustain their livelihoods while preserving ecological balance. Indigenous groups, including communities in voluntary isolation, play a vital role in maintaining cultural heritage and advocating for environmental conservation (Hanusch 2023). The geographical distribution of communities varies considerably across the three countries under study (maps 1.2 and 1.3). Certain territories have a notable Indigenous presence (e.g., the Amazonas and Guainía departments in Colombia, the Loreto and Ucayali departments in Peru, and Amazonas state in Brazil), while other areas have a more limited presence. Many Indigenous groups live in extremely difficult conditions.

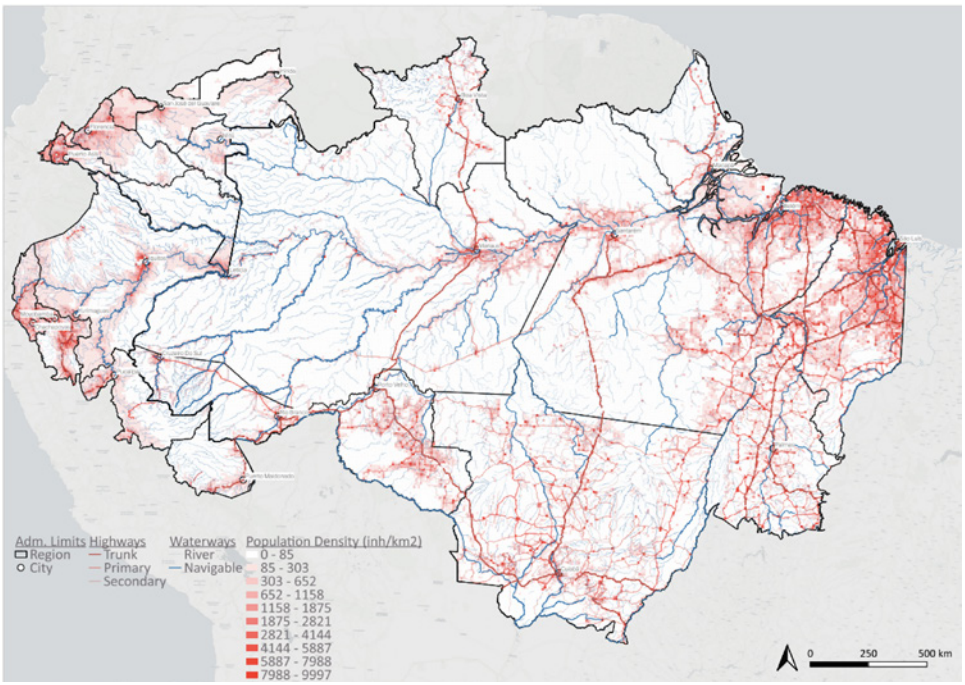
Several socioeconomic and environmental trends have compelled local communities to adapt their lifestyles and in some cases leave their homes, leading to a decline in their population. These trends include challenges around land rights; access to education, health care, and safe drinking water; as well as inadequate infrastructure, which has rendered electricity services unreliable, transport inadequate, and digital connectivity poor. While urban settlements in the Amazon face these same challenges, they are pronounced in remote and isolated communities, including Indigenous communities. The lack of access to services such as energy, transport, water and sanitation, digital connectivity, education, and health hinders well-being, the development of businesses, and job generation.

Maps 1.2 and 1.3 Indigenous communities primarily live in conservation areas, far from the more populous urban centers



Source: Original compilation.

Note: Figure shows conservation units (green), native land (gray), Indigeous areas (stripped), biosphere reserves (yellow), and native population (dots). km = kilometer.



Source: Original compilation.

Note: Darker red signifies higher population density. km = kilometer.

Many communities largely depend on the gathering of non-timber forest products, fishing, and hunting, all activities that are highly vulnerable to further deforestation and biodiversity degradation. Meanwhile, local economies are already characterized by high poverty and job informality. In the Colombian Amazon, poverty is most severe in departments where Indigenous populations have a significant presence, productive businesses are few, and informal work is prevalent. Similarly, in Peru, informal work rates exceed 75 percent across departments, reflecting a precarious labor market and a lack of social protection. Poverty rates are disproportionately high in the Legal Amazon, which is home to 15.7 percent of Brazil's population living in poverty and extreme poverty, despite representing only 12.5 percent of the country's total population (IBGE 2022).

These challenges are particularly acute in Indigenous communities, which face geographical, social, and cultural barriers. Data for the Colombian Amazon reveal a correlation between high poverty levels and a significant Indigenous presence (DANE 2024). The communities living here face high barriers to full participation in local economies, even as extractive activities threaten to deplete essential natural resources. They also experience acute disparities in health care. Indicators for these communities severely lag national averages; infant and maternal mortality rates are high, as is the incidence of infectious diseases such as malaria, tuberculosis, hepatitis, and leishmaniasis.

Infrastructure in the Amazon

The Amazon region is characterized by a unique spatial and infrastructural pattern that presents profound challenges to inclusive, sustainable development. Metropolitan areas, particularly in the Legal Amazon, are large and densely populated. The remaining low-density, highly dispersed populations mainly reside in small and medium-sized towns along rivers, where inclusive development is a major challenge due to vast distances, difficult terrain, and weak infrastructure. These barriers limit access to essential services, especially for remote and Indigenous communities.

Infrastructure is of foundational importance to connectivity, which, in this report, encompasses three dimensions: transport connectivity, energy access, and digital connectivity. *Transport connectivity* refers to people's ability to access essential services and opportunities—such as education, health care, and jobs—through available infrastructure and services, including roads, navigable rivers, ports, and docks. *Energy connectivity* considers a minimum level of electricity service, as measured by the availability of lighting. *Digital connectivity* pertains to people's ability to communicate and access information using internet services. This aspect plays an increasingly vital role by enabling the digital marketing of bioeconomy products, online education, and telemedicine. Together, these facets of connectivity shape the overall accessibility of essential services and opportunities, influencing social inclusion, economic development, and the overall quality of life.

This report leverages multiple datasets to build a holistic picture of connectivity and infrastructure provision in the Amazon. First, the team preparing the report integrated official government datasets capturing road networks, navigable rivers, and key public facilities (schools and hospitals) for each country in the study region. We then enriched these data with open-source data, such as OpenStreetMap (OSM), as well as proprietary data procured from the World Bank Development Data Partnership to account for unofficial or missing features. Google's buildings footprint data served as a proxy for building density and potential economic activity, while Meta usage–based population metrics provided insight into settlement patterns and community demographics. To measure digital connectivity, we utilized internet speed data (e.g., from Ookla), which revealed variations in service quality and broadband penetration. A set of basic infrastructure indicators (e.g., electricity grid coverage) helped capture broader development conditions. To clarify environmental constraints and guide sustainable infrastructure planning, we gathered geospatial data on official natural parks and protected forested areas in Brazil, Colombia, and Peru. Finally, we conducted first-person interviews and surveys to validate insights gained from observational data.

The above efforts revealed an existing network of infrastructure that, while present, is also fraught with gaps that impact people's daily lives and limit opportunities for development. River and road networks crisscross the region but fail to provide meaningful interregional connections, specifically for small communities, while the low quality of transport services further limits market access. Energy access in the region is severely inadequate, with many communities spending more days with disruptions to service than without. Digital access, while available in many parts of the Amazon, is of limited value as its low quality often fails to facilitate access to educational, health, and economic services. The environmental vulnerabilities of each sector are widespread and increasingly the source of disruptions as natural disasters become more common due to climate change.

The data compiled for this report cover the vast river system that traverses the Amazon, which serves to organize life in the region, and provide natural connections, but also remains underutilized and poorly funded. Of the more than 380,000 kilometers (km) of rivers in the region—a potentially vast, low-emission transport network—only 12 percent is classified as navigable.[3] These rivers determine where people live and work; roughly 52 percent of the population (16.4 million people) resides within 10 km of a navigable river. Communities are thus clustered near accessible rivers, which are crucial for wider economic and service networks. However, infrastructure supporting river mobility is scarce. A comprehensive survey of available port and dock infrastructure identified 730 ports and docks. A 2017 study by Brazil's national agency for river transport (Agência Nacional de Transportes Aquaviários, ANTAQ), in partnership with the Federal University of Pará, identified 196 river terminals across the states of Amazonas, Pará, Amapá, Roraima, Rondônia, and Acre, of which 129 were in Pará alone, underscoring its central role in the region's river transport network.

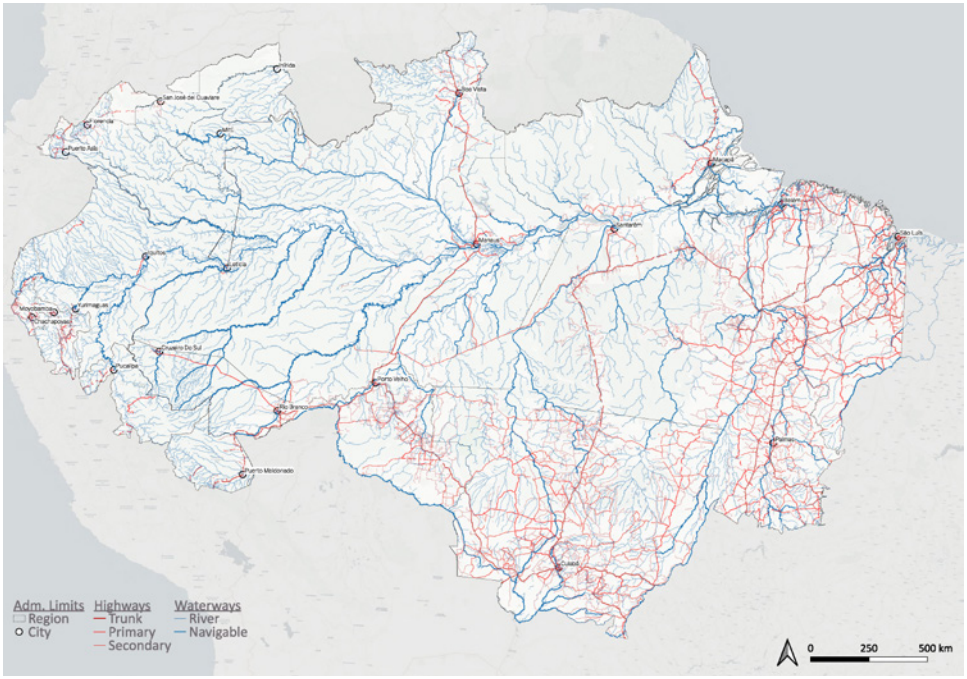
Turning to road infrastructure, the Amazon region's trunk, primary, secondary, and tertiary roadways[4] cover about 150,000 km. Taking out the tertiary category leaves what we define as the major road network, which covers about 70,000 km (map 1.4). Traditionally, local roads are those classified as tertiary. However, the mapping exercise conducted for this report reveals that an additional set of residential and otherwise unclassified roadways spans the Amazon. Incorporating these roadways expands the region's road network to an impressive 1.8 million kilometers. The local road network—encompassing the tertiary, residential, and unclassified categories—covers about 1.7 million kilometers. Unless otherwise noted, the analysis below focuses on the major road network.

3 Navigability data are sourced from ANTAQ, the Brazilian Agency for River Transport (2024).

4 Road categories are drawn from each country's classification system.

The Amazon's entire road network (classified and unclassified) is concentrated in Brazil, which hosts 95 percent of all roadways. The rest is divided about equally between Colombia (30,000 km) and Peru (45,000 km). Major roadways are located along the region's periphery, in agriculturally important production areas. Areas not currently covered by the rainforest, such as Maranhão, Mato Grosso, Pará, Rondônia, and Tocantins, have a high density of roads, including of major roads. This is because, in Brazil, major highways were developed and planned to support the development of agriculture, primarily soy and corn crops. Such initiatives were restricted, initially, to regions not traditionally covered by the rainforest. While their extent is limited, Brazil hosts over 60,000 km of major roadways. The Colombian Amazon has almost 5,000 km of major roads and the Peruvian Amazon, about 5,400 km.

Maps 1.4 Major road network in the Amazon region



Source: Original compilation.

Note: Trunk, primary, and secondary roadways are shown, but not tertiary and other local roads. km = kilometer.

The region's road density is among the lowest in the world. Taking the three countries together, the population-weighted average (normalized) road density of trunk and primary roads is about 1 km of roadway for every 100 km^2 of land. Again, for the region overall, the total road density (including local roads not shown in map 1.4) is about 0.42 km/km^2. These ratios are far lower than those in high-income countries, where, for every 100 km^2 of land, there are about 80 km of roads overall, and at least 20 km of primary roads, and where the density for trunk or primary roads is about 0.2 km/km^2 and about 0.8 km/km^2 for roads overall (Gonzalez-Navarro et al. 2024). Put simply, roads exist where people are located, but they are, understandably, not arranged to provide access across the entire Amazon region.

This low density is a feature of the region and not an issue to be resolved or overcome in the process of development planning. The low density is explained by the defining characteristic of this region: its dense tropical rainforest. However, the sparse road network shapes the structure of economic activity in the region. Duranton et al. (2014) demonstrate that the quantity of road infrastructure within cities influences the sectoral composition of their local economies. At least in high-income countries, cities with higher road densities specialize in manufacturing-oriented sectors. A low supply of local road infrastructure is not only limiting in terms of accessibility but it also shapes local economic opportunities. Accommodating the region's natural justification for lower road density—the need to preserve the rainforest—local economies can still be developed by investing in river-based transport and targeted interventions to promote the bioeconomy.

Turning next to energy infrastructure, remote areas of the Amazon rely heavily on isolated power systems because they are located far from national grids (map 1.5). These isolated systems,[5] used by an estimated 70–90 percent of off-grid communities in the region, are not connected to national grids and often rely entirely on diesel generators, which are costly and vulnerable to climate events, logistical disruptions, and fluctuating fuel prices.[6] Interior regions like Roraima and Acre in Brazil, Loreto in Peru, and Vaupés in Colombia depend on decentralized, stand-alone systems, on which even entire cities, such as Boa Vista[7] (Roraima), Iquitos (Loreto), and Leticia (Amazonas), rely completely. In many rural areas around these regions, coverage is limited and service interruptions are frequent, further constraining development and public service delivery.

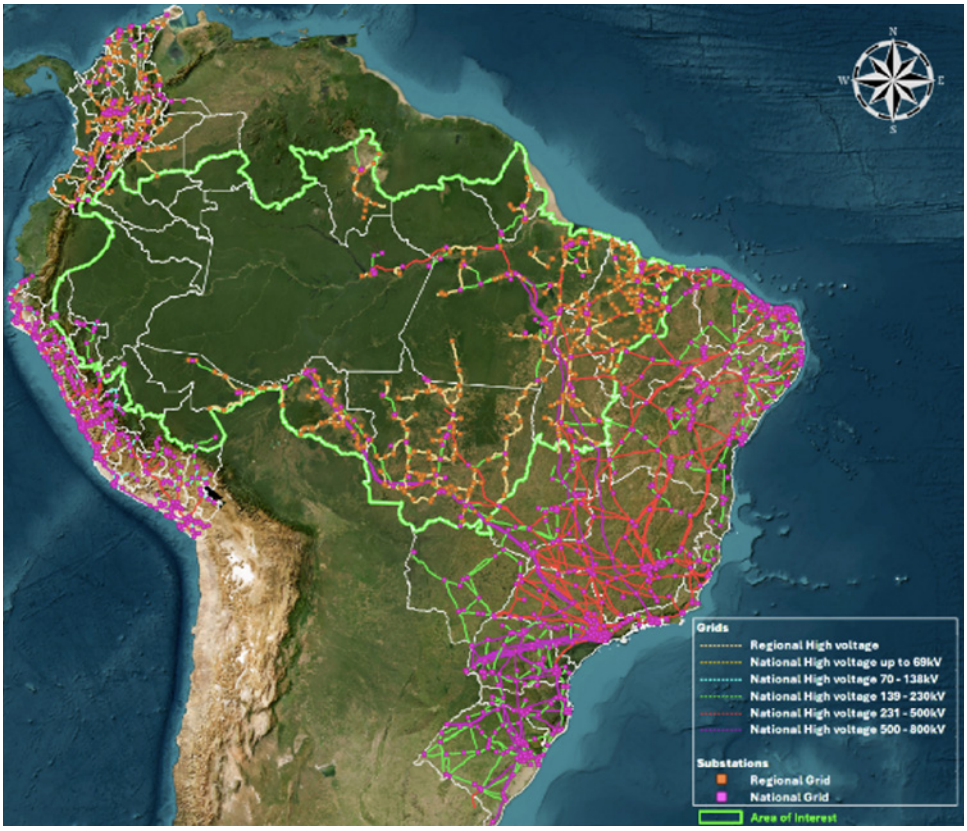
Although isolated systems have historically been the most suitable technology for providing electricity in parts of the Amazon, they have significant disadvantages. First, operating them is quite costly, due to the need to transport diesel fuel over long distances, often by river. Second, transport disruptions—including when river routes, the only means of access to many areas, are blocked during dry seasons—cause fuel shortages, leading to outages. Third, these systems are often poorly maintained, compounding the risks of blackout. Map 1.6 illustrates the current state of grid connectivity; municipalities shown in dark red rely entirely on isolated systems. These same areas demonstrate some of the lowest per capita electricity consumption in the region, confirming structural inequalities in energy access and economic opportunity.

5 Isolated systems are defined as closed grid systems, not connected to national grids.

6 Isolated systems running on diesel are exposed to supply disruptions during the dry season, when diesel deliveries by river may be interrupted in regions without road connectivity.

7 Boa Vista in Roraima is expected to be connected by the end of 2025.

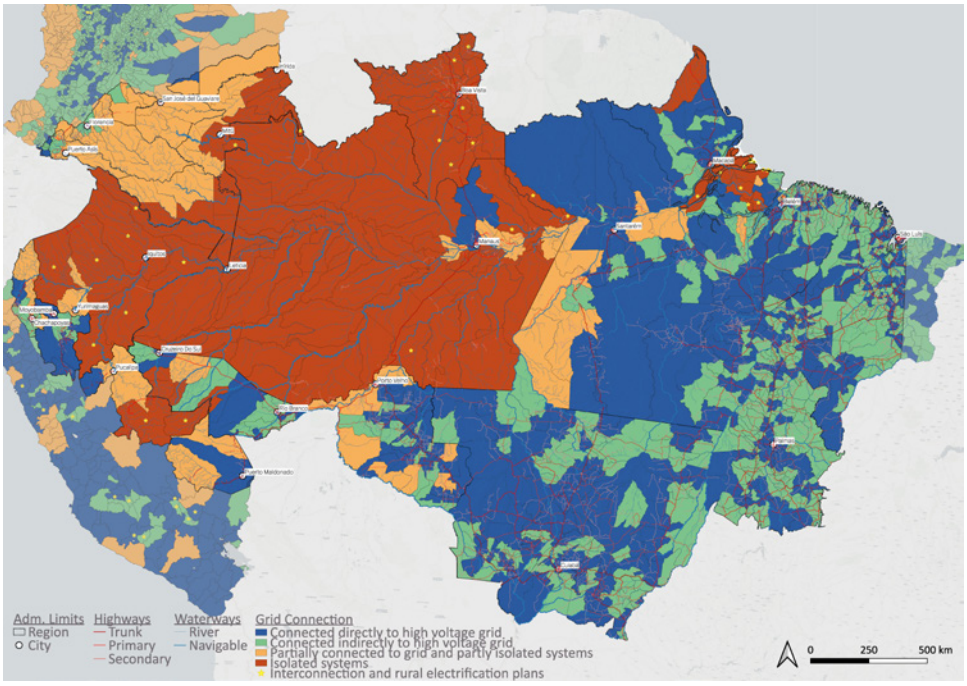
Maps 1.5 Remote areas rely on isolated systems, or are connected to only regional grids



Source: Original compilation based on EPE (2024), OSINERGMIN (2024), and UPME (2024).

Note: kV = kilovolt.

Maps 1.6 More remote areas have no grid connections and rely on isolated systems



Source: Original compilation based on ANEEL (2024), OSINERGMIN (2024), UPME (2024), IPSE (2024), and MME (2023).

Note: HV = high voltage; km = kilometer; MV = medium voltage.

Isolated systems are a major reason the Amazon region's electricity mix remains heavily dominated by diesel, resulting in costly, highly polluting, and deeply unreliable energy supply. There is a stark contrast between national electricity mixes, where hydropower and renewables dominate, and the isolated systems used in the region, which rely overwhelmingly on fossil fuels. For example, Brazil's national energy mix is one of the cleanest in the world, with renewables-based generation constituting over two-thirds. The situation is similar in Peru and Colombia, where renewables have a large share in national energy generation. However, a close look at the Amazon region reveals an entirely different situation. Brazil has over 35 gigawatts of installed hydropower capacity in the Amazon, yet most of this energy is transmitted to distant markets, such as São Paulo and Rio de Janeiro. In 2021,[8] the Legal Amazon accounted for 27 percent of nationwide generation but consumed only 11 percent. Meanwhile, the region's vast hydroelectric potential—and its significant benefits—remain largely untapped.

Across Colombia, Peru, and Brazil, digital connectivity infrastructure in the Amazon is shaped by both physical and technological constraints.[9] While Brazil leads with the most extensive fiber-optic backbone—including through innovative subfluvial cables along major rivers—significant gaps remain, particularly in the Legal Amazon and in cross-border links, given the absence of a direct fiber connection between the three countries. Map 1.7 shows the status of subfluvial cables in the region.[10] Colombia and Peru have national fiber networks, but their reach into Amazonian departments like Loreto and Amazonas is limited; rural and Indigenous communities often rely on costly satellite internet or lower-capacity mobile networks. Recent initiatives—such as Brazil's Infovia 02 project, which includes a fiber-optic cable connecting to Leticia (Colombia), and Peru's Amazon Fiber project—aim to bridge these gaps and improve regional integration.

The expansion of 3G and 4G mobile networks has been the main driver of increased connectivity in recent years, yet coverage is uneven, and many remote areas still depend on 2G or 3G.[11] Map 1.8 highlights the extent of mobile tower coverage in the region. Cell towers in the Amazon adequately cover populated areas, but municipalities with a more spread-out population clearly experience cell coverage issues. Towers with lower-frequency bands (i.e., sub 1 gigahertz [GHz]) are appropriate for dense forested areas, for wider reach with fewer towers (spaced some 10 km apart). However, the towers typically deployed, employing legacy 2G/3G technologies, provide low capacity, and connection is not very

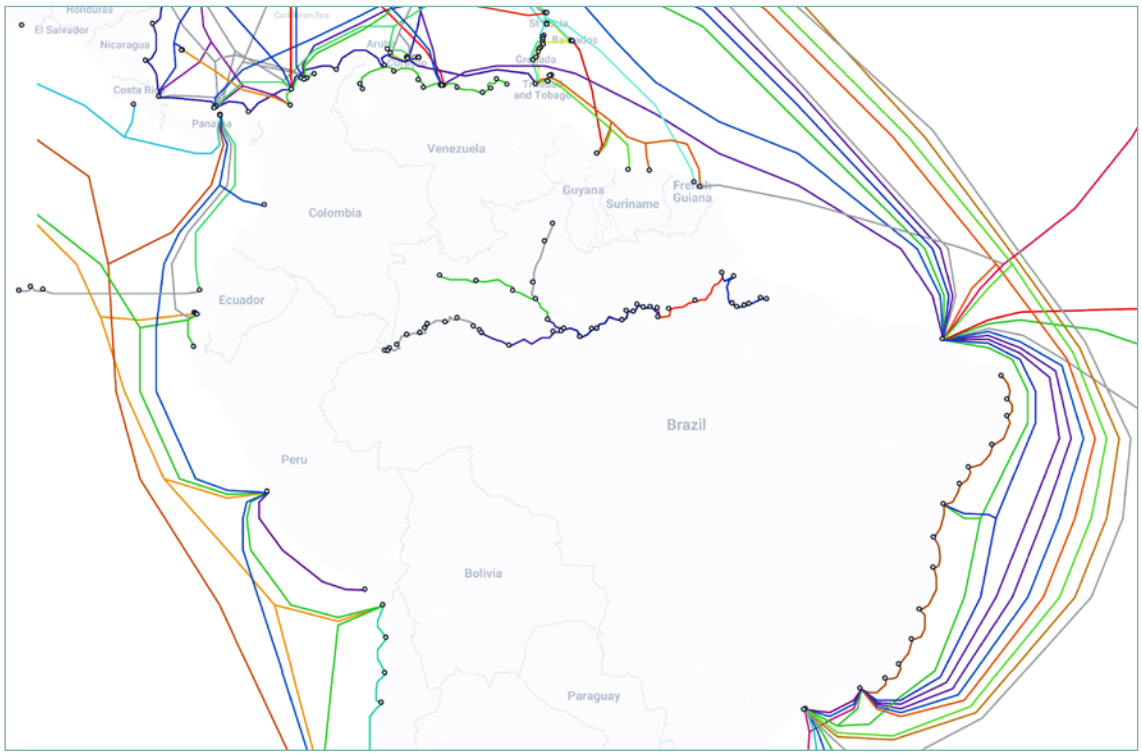
8 Based on calculations using EPE (2024).

9 Digital connectivity in the Amazon region relies on three distinct infrastructure systems: (1) fixed links, which are broadband cables that provide high-speed connections from the coast to the interior, forming the so-called backbone network, complemented by the backhaul network composed mainly of other fixed cables with a lower capacity than the backbone network; (2) cell towers, which distribute the signal to user devices (such as cell phones) received from high-bandwidth fixed links or serve as wireless backhaul sites (i.e., beacons) transmitting signals wirelessly; and (3) satellite access, which utilizes various satellites orbiting the Earth, allowing specific ground reception dishes to connect to the internet, and requiring ground network connections.

10 Project Amazon connection: https://www.amazoniaconectada.eb.mil.br/fases.

11 See Alliance for Affordable Internet.

Maps 1.7 Subfluvial cables in the Amazon region

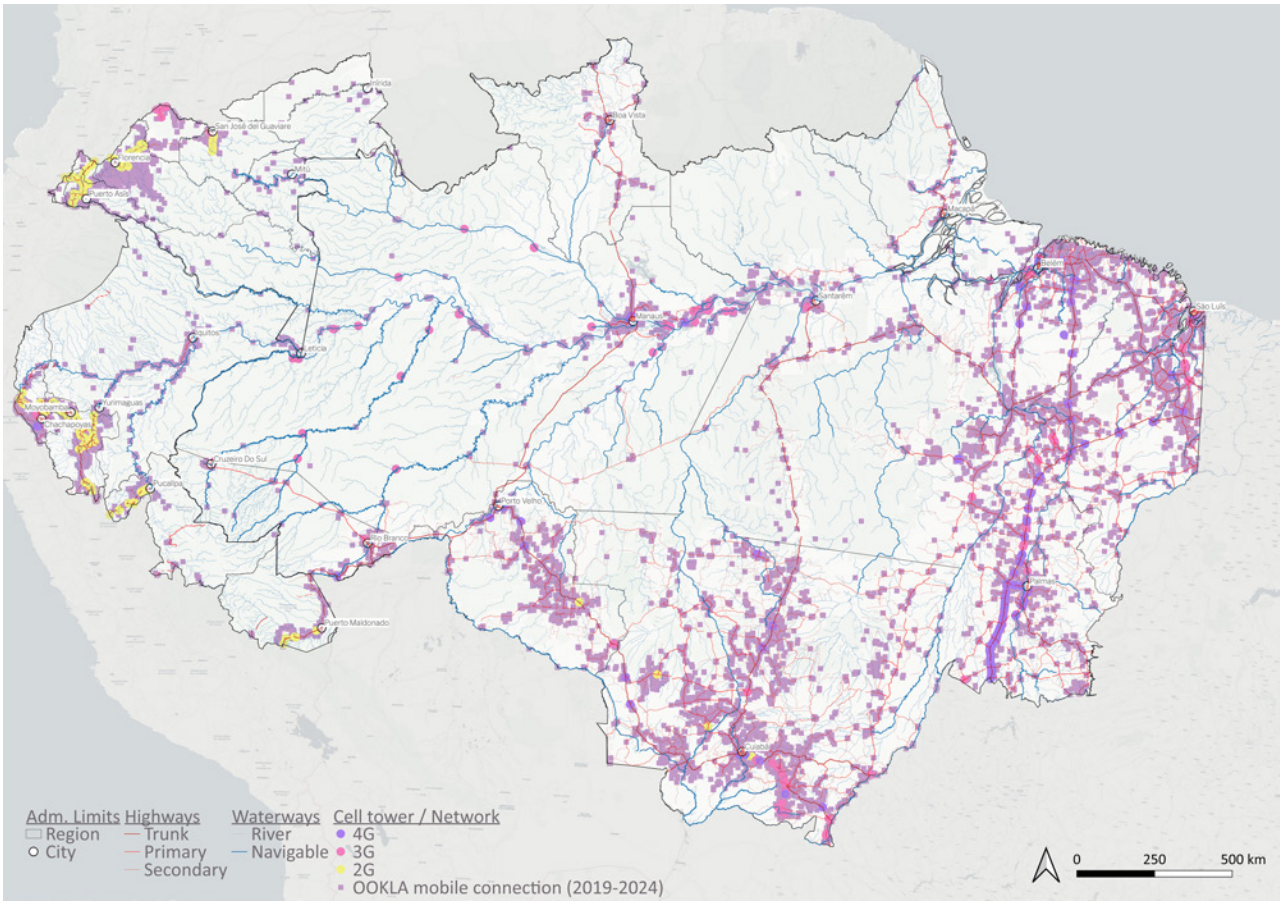


Source: https://www.submarinecablemap.com/.

fast. In more urban contexts, towers with higher-frequency bands (GHz bands) employing state-of-the-art technology (i.e., 4G/5G) are preferable since connection is better (faster and higher bandwidth), but their reach is narrower, requiring towers to be spaced 500 m to 1 km apart. Thus, one would expect that for each tower in rural zones, there would be about 20 in urban areas.

Coverage in rural areas might be sufficient in terms of reach but connection quality does not support advanced internet use. The Peruvian Amazon predominantly has towers with 2G and 3G technologies, requiring many inhabitants to travel to specific locations outside their communities just to make calls or access information online (map 1.8). In Brazil, only 79.94 percent of the population in the northern region has 4G access, compared with 92.44 percent nationally (CPR LATAM 2024).

Maps 1.8 Mobile coverage by connection quality



Source: Based on World Bank Group data (2024).
Note: km = kilometer; WBG = World Bank Group.

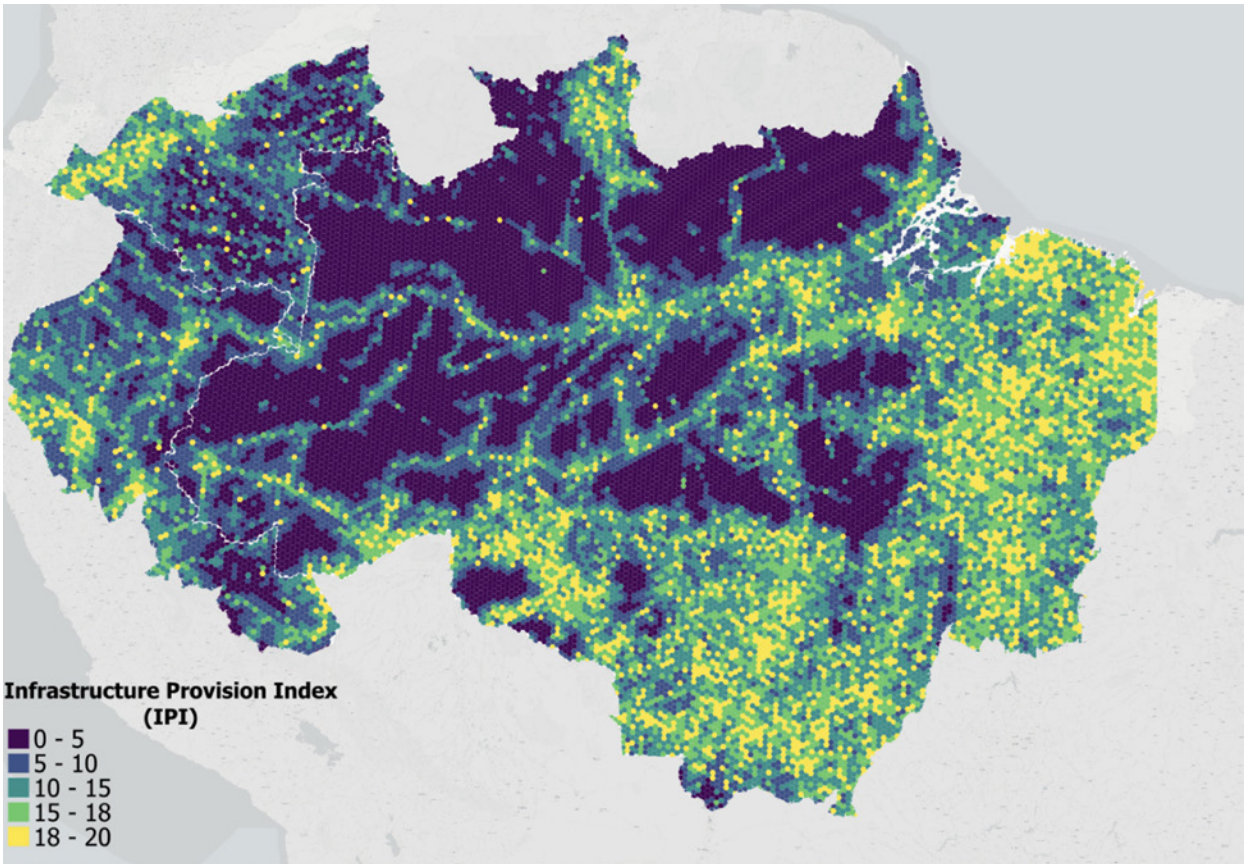
Infrastructure Provision Index

The inventory presented thus far in this chapter reveals the scope of existing infrastructure in the Amazon, which facilitates access for remote communities yet suffers from gaps and limitations that impede development. In summary, communities continue to face significant barriers to accessing essential services—including energy, transport, water and sanitation, digital connectivity, education, and health—across the Amazon region. Vast distances, difficult geography, and the insufficient provision of infrastructure restrict access to opportunities and basic services, perpetuating cycles of poverty and exclusion.

We next examine the key infrastructure gaps that impede job creation, worsen health outcomes, limit human capital growth, and perpetuate poverty in the region. Gaps are obvious through the data analyzed in this report, complemented by spatial analyses. While the patterns vary, many areas in the Amazon region consistently lag national averages, hindering communities' development prospects and quality of life.

To study these gaps systematically, we developed a two-part approach: first, we constructed a summary index capable of describing the state of infrastructure and connectivity locally, in small regions across the Amazon. Second, we used this index to partition the region into clusters experiencing similar gaps, for which similar solutions may apply. The Infrastructure Provision Index (IPI) metric assesses the availability and accessibility of physical infrastructure in small areas and reveals a heterogeneous landscape of infrastructure development throughout the region (map 1.9). The IPI is described in more detail in box 1.1; put simply, a higher value of the index indicates the availability of infrastructure. A high IPI score may indicate that access to roads or rivers is adequate, that an airport is present, that digital connectivity is possible, or that energy access is guaranteed, or some combination of these.

Maps 1.9 Spatial infrastructure provision across the Amazon



Source: Original compilation.

Note: The higher the IPI, the greater the degree of infrastructure development and connectivity. According to the analysis conducted for this report, an estimates 9 million people in the Amazon region experience a low degree of infrastructure provision (areas in blue).

Infrastructure provision across the Amazon region is spatially uneven, with distinct core–periphery patterns. In map 1.9, the areas highlighted in yellow are where infrastructure provision is highest. Primarily located in the eastern Amazon and along key corridors, these likely correspond to urban centers and their peripheries, where multiple types of infrastructure converge to deliver comprehensive service coverage. In contrast, areas with intermediate levels of provision, shown in green, form a transition zone, tracing the contours of major transport corridors. These zones represent moderately developed areas, possibly emerging urban centers or rural regions with relatively better connectivity and service access.

Both availability and accessibility of physical infrastructure significantly lag national averages in the Amazon regions of Brazil, Colombia, and Peru. The IPI is constructed for the Amazon area of each country and for the country overall, and table 1.1 shows a comparison of the results. In Brazil, the availability and accessibility of physical infrastructure are high in just over half of the (geographic) area of the country, and the IPI values are among the lowest possible in only 12 percent of the area. The situation is quite different in Brazil's Legal Amazon, of which only 21 percent has high availability and accessibility of physical infrastructure, and close to half (48 percent) of the geographic area has low access, indicated by low IPI scores.[12]

Table 1.1 Physical infrastructure is significantly less available and accessible across the Amazon region in each of the three countries analyzed

Country	IPI value	Amazon area	Non-Amazon areas
Brazil	High	21%	52%
	Moderate	32%	36%
	Low	48%	12%
Peru	High	24%	43%
	Moderate	31%	36%
	Low	44%	21%
Colombia	High	20%	43%
	Moderate	28%	37%
	Low	52%	20%

Source: Original compilation.

12 In Peru, nationally, 43 percent of areas enjoy robust access to infrastructure—yet only 24 percent of the Peruvian Amazon reaches that level. Meanwhile, 44 percent of the Legal Amazon in Brazil falls into the lowest tier of access. A fifth of the Colombian Amazon has robust infrastructure access, far lower than the 43 percent average in the part of Colombia outside the Amazon.

The most isolated zones of the Amazon without access to adequate infrastructure, as indicated by the IPI, are primarily heavily forested regions. A 200,000 live in areas with the lowest IPI scores (0–5) (shown in dark purple on map 1.9), which are essentially infrastructure deserts, with no access to basic transport, energy, and digital services. These areas often coincide with remote or environmentally sensitive zones, where infrastructure access is constrained—by geographical isolation or environmental regulations. Thus, the improvement of conditions in these areas presents a particularly difficult challenge.
These stark gaps highlight the importance of improving connectivity in the region, but increased connectivity heightens the risk of environmental degradation. The correlation between infrastructure availability and deforestation is unfortunately striking. In work prepared for this report, Hsu et al. (2025) examined the extent of deforestation's impact in areas close to roads. This analysis measures how far deforested areas are from roadways (1–10 km). Indicators of deforestation remain stable beyond a 5 km buffer range, suggesting that the spatial impact of road infrastructure extends up to approximately 5 km. In other words, the results of this work affirm the conventional wisdom that road infrastructure exacerbates deforestation but clarify that this impact is limited to a range of within 5 km of a roadway.

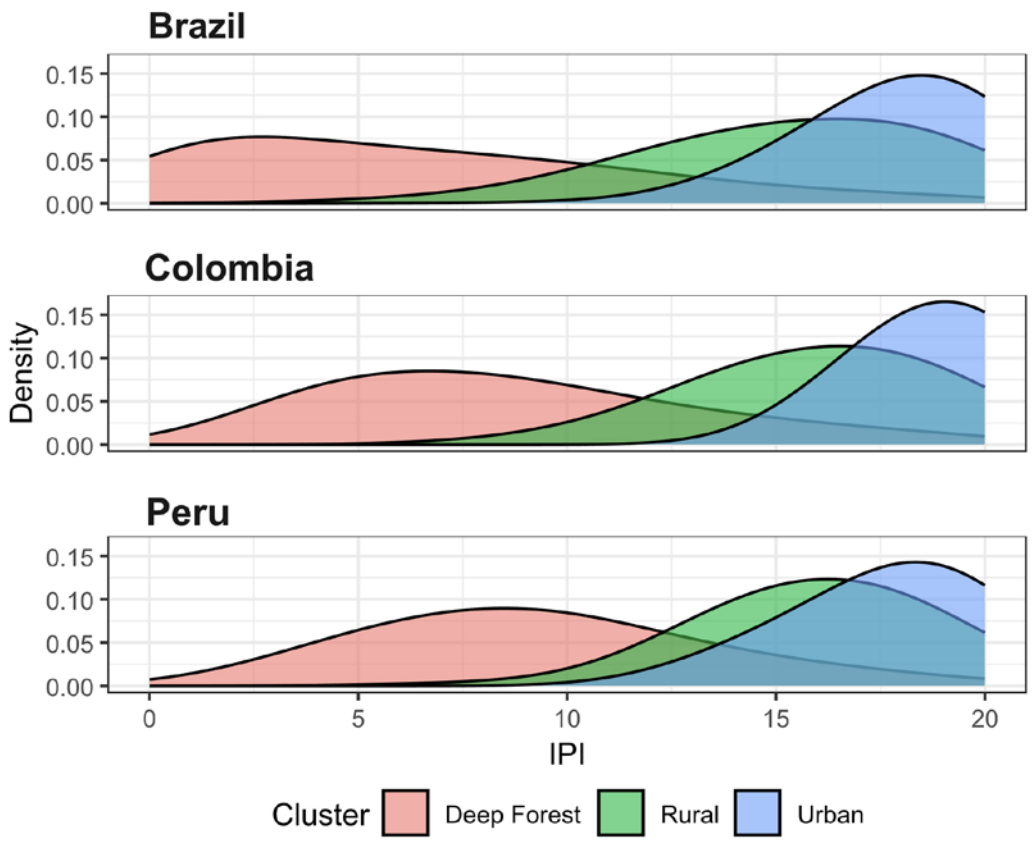
Electricity expansion and digitalization may affect deforestation dynamics, including indirect effects through enhanced market connectivity, shifts in land-use decisions, and the siting of infrastructure. Renewable energy deployment can pose land degradation and biodiversity risks, particularly for utility-scale solar PV, such as habitat fragmentation, species disturbance, and cumulative impacts from site preparation, access roads, and interconnection corridors. In deep forest, remote settings, decentralized solutions (e.g., minigrids and standalone systems) may offer lower environmental footprints while improving energy access. It is essential that these potential environmental and social impacts are systematically considered in the decision-making process to ensure that project development supports sustainable outcomes.

These findings call for spatially targeted planning to address infrastructure inequality in the Amazon region and to promote inclusive development while maintaining the environmental systems critical to the region's economy. Prioritizing areas otherwise overlooked in regional development strategies is essential. By focusing investments in these critical zones—especially those with geographic advantages but low service coverage—governments can close infrastructure gaps, improve livelihoods, and create more equitable growth across the Amazon. Targeted interventions also allow for considerations relevant to sensitive local environmental and social conditions, ensuring that progress does not come at the cost of the region's ecological integrity. Throughout the remainder of the report, we provide more details on the key infrastructure segments and gaps highlighted in this connectivity analysis.

Box 1.1 Using the Infrastructure Provision Index to identify three connectivity clusters

The Infrastructure Provision Index (IPI) is a composite metric used to assess the level of access to essential infrastructure across the Amazon, including transport, electricity, education, health services, and digital connectivity. The index is built through a multi-step machine learning process, using K-means clustering, based on building density and normalized infrastructure features—including transportation accessibility (distance to roads and navigable rivers), population density, building density, digital connectivity (internet speed), electricity coverage (night-time lights), and access to essential services, such as distance to schools and hospitals. Each feature is weighted based on its average SHAP (SHapley Additive exPlanations) values, and these weighted values are aggregated to generate the final IPI score for each region. The resulting index provides a spatially detailed, data-driven tool for identifying underserved areas and guiding targeted infrastructure investment.

Figure B1.1.1 Distribution of the IPI across the Amazon clusters



The IPI is the foundation of the clusters that organize our analysis, but the clusters do not induce a strict partition of the IPI. Figure B1.1.1 plots the distribution of the IPI by each cluster for each country. Some areas classified as rural have high IPI scores while others have quite low scores. This is because the presence of infrastructure does not always ensure connectivity. Some areas may have an airport but otherwise lack access to roads or riverways. Thus, the areas around them likely lack infrastructure, while the area as a whole lacks broader connectivity. We highlight this to underscore the variation present, within the region as a whole and within each cluster, and to emphasize the importance of targeted approaches to improving infrastructure provision in the region.

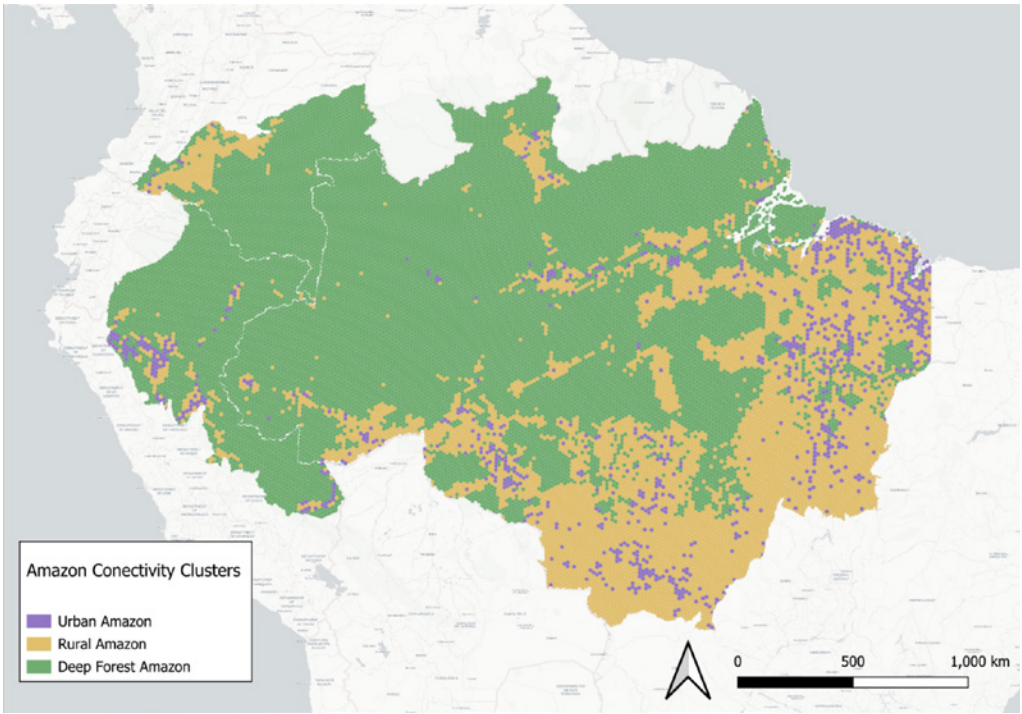
This general spatial arrangement of the IPI reflects a core–periphery structure. The farther from urban centers and transport corridors, the lower the level of infrastructure provision. This pattern highlights the longstanding tendency of infrastructure investment to follow narrow axes of expansion, leaving vast portions of the Amazon underdeveloped.

The most critical development challenge lies within the moderate range of the IPI (values between 5 and 17), which encompasses an estimated 9.4 million people. Figure B1.1.1 highlights that these regions exist within each cluster. These communities continue facing an acute infrastructure gap despite their relative accessibility, signaling an urgent need for intervention. These zones often house communities that, while not located in the most remote parts of the forest, still suffer from inadequate infrastructure. This mismatch between human presence and service availability points to development blind spots, where residents may endure limited economic opportunities and difficult living conditions despite being situated in relatively more accessible regions.

Connectivity clusters of the Amazon

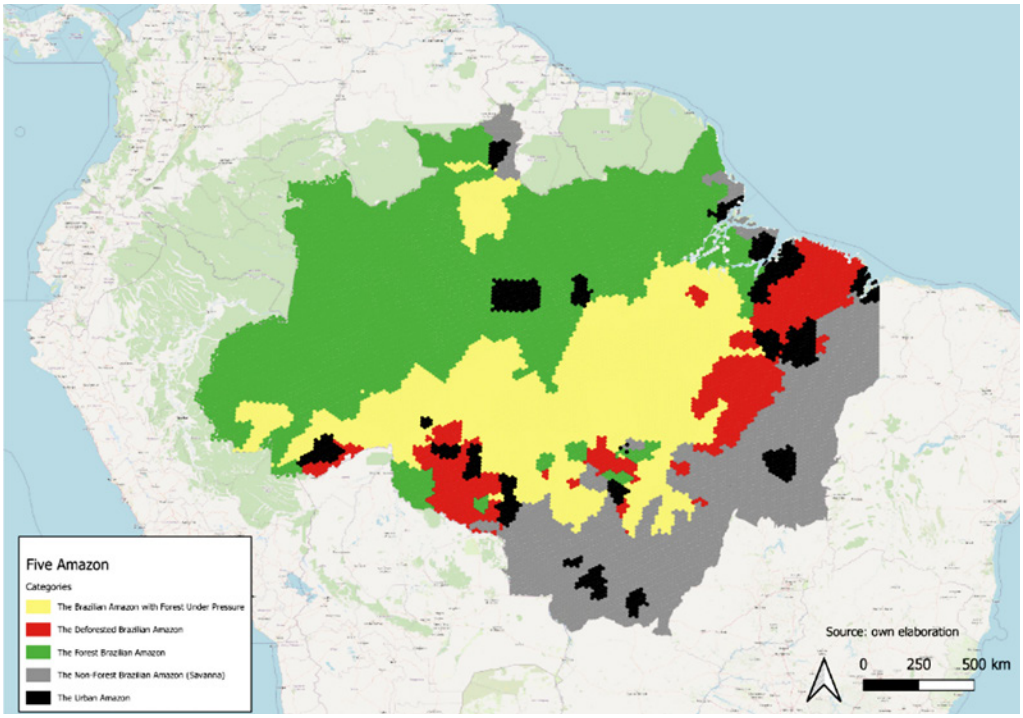
To address the gaps outlined above while acknowledging the complexity and diversity of the Amazon region, we developed a three-tier model for categorizing areas of the region based on transport, digital connectivity, energy, proximity to services, and environmental variables (map 1.10). The three resulting connectivity clusters—which we refer to as the **Deep Amazon, Rural Amazon, and Urban Amazon**—are based on the IPI, but defined more broadly to account for both connectivity levels and environmental characteristics, acknowledging the heterogeneity of the region. This approach builds upon the methodology developed in the Amazônia 2030 Project (Imazon 2023) for the "Five Amazons" in Brazil's Legal Amazon, while introducing key enhancements. The "Five Amazons" methodology—originally developed by Amazônia 2030 in 2007 and further refined in 2002 by the Amazon Project—is based on vegetation cover and deforestation (map 1.11). Our clustering expands the set of variables used—particularly by incorporating measures of transport, digital, and energy connectivity, as well as proximity to services—and extends the geographic scope to include the Colombian and Peruvian Amazon. Like the framework of the Amazônia 2030 Project, this clustering also accounts for the presence of forested and protected areas, but does so in a broader and more integrated regional context.

Map 1.10 The Amazon region's three distinct connectivity clusters reflecting varying degrees of connectivity and development



Note: The Urban Amazon (purple), Rural Amazon (gold), and Deep Forest Amazon (green) are defined here based on levels of transport, energy, and digital connectivity; access to services; and environmental characteristics. km = kilometer.

Map 1.11 The five zones of the Legal Amazon, using hexagon methodology



Source: Based on Imazon (2023).
Note: km = kilometer.

The Amazon is not a homogenous region: its clusters differ dramatically in both geographic scale and population density (see table 1.2). This diversity complicates efforts to identify infrastructure gaps at the regional level, as each cluster—Urban Amazon, Rural Amazon, and Deep Forest Amazon—faces unique constraints and priorities. Effective analysis therefore requires a place-based diagnostic approach, tailored to the specific needs and realities of each cluster. Moreover, the environmental significance and spatial configuration of each cluster impose additional limitations on infrastructure development, often necessitating bespoke, context-sensitive solutions.

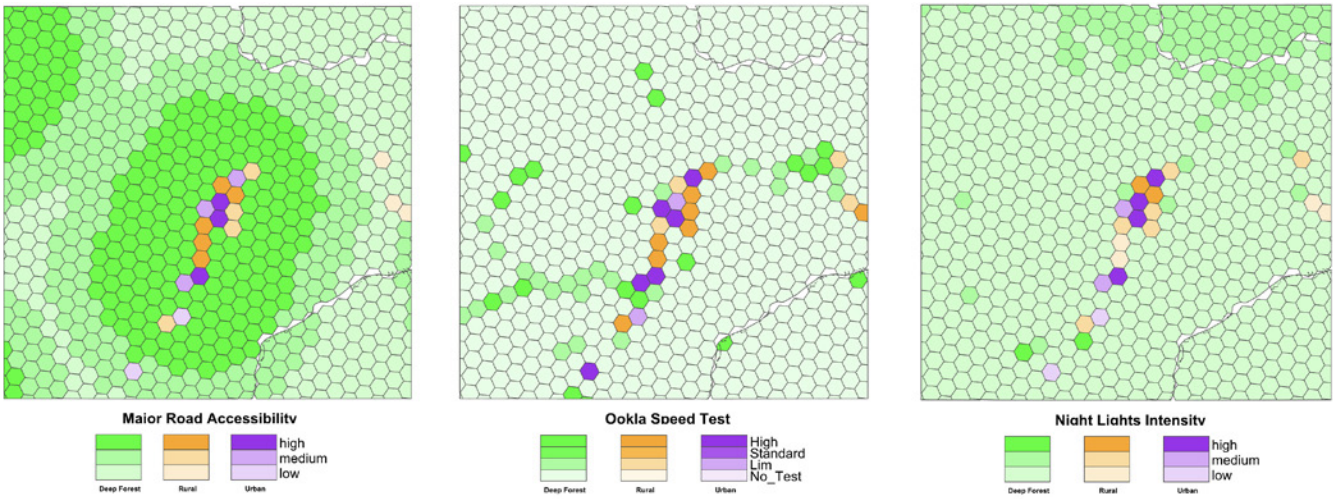
Table 1.2 Population and surface area of the three Amazon clusters

	Population (inhabitants)				Geographic area (km²)			
Country	Urban	Rural	Deep Forest	Total	Urban	Rural	Deep Forest	Total
Brazil	20,122,479	5,153,034	1,717,407	26,992,920	245,622	1,728,137	3,006,509	4,980,269
	(74.5%)	(19.1%)	(6.4%)	<85.1%>	(4.9%)	(34.7%)	(60.4%)	<81.5%>
	[90.9%]	[82.0%]	[52.1%]		[87.3%]	[93.5%]	[75.6%]	
Colombia	282,536	669,401	616,060	1,567,997	2,048	71,342	405,327	478,717
	(18.0%)	(42.7%)	(39.3%)	<4.9%>	(0.4%)	(14.9%)	(84.7%)	<7.8%>
	[1.3%]	[10.7%]	[18.7%]		[0.7%]	[3.9%]	[10.2%]	
Peru	1,743,261	461,350	962,249	3,166,859	33,758	49,549	564,752	648,058
	(55.0%)	(14.6%)	(30.4%)	<10.0%>	(5.2%)	(7.6%)	(87.1%)	<10.6%>
	[7.9%]	[7.3%]	[29.2%]		[12.0%]	[2.7%]	[14.2%]	
Total	22,148,276	6,283,785	3,295,715	31,727,776	281,428	1,849,028	3,976,587	6,107,044
	<69.8%>	<19.8%>	<10.4%>		<4.6%>	<30.3%>	<65.1%>	

Note: The values in parentheses indicate share of national total; square brackets indicate share of cluster total; and angled brackets indicate share of regional total.

Looking at the region's connectivity clusters helps characterize its infrastructure gaps. Consider map 1.12, which plots differing degrees of access to infrastructure around Iquitos in the Loreto department of Peru. Iquitos is one of the region's largest cities, and it is part of the Urban Amazon cluster. The three panels of the map highlight that Iquitos has access to major roadways, high-quality energy services, and that most of its residents are likely to also have digital connectivity. Yet, in the areas surrounding Iquitos, its hinterlands, the situation is quite different. A few rural areas benefit from some degree of access, but most areas are sparsely populated and poorly connected Deep Forest. Communities here have limited transport options and experience low infrastructure provision. Iquitos acts as the major hub of the area, connecting it to distant markets and making services accessible to those in the hinterlands. The gaps experienced in Iquitos are distinct from those experienced in the surrounding Rural and Deep Forest Amazon. The solutions proposed for each region must also be distinct, therefore. Where possible, the Rural Amazon, which already benefits from a certain level of infrastructure access, can serve as a service center for disconnected Deep Forest regions, helping to preserve the region's ecological integrity. The clustering process, and the extensive data collection efforts undertaken for this report, make such targeted, place-based solutions possible.

Map 1.12 Road, digital, and energy connectivity in and around Iquitos, Peru



In the following subsections, we systematically identify and describe the most critical infrastructure gaps for each cluster, considering the opportunities for targeted interventions as well as the possible challenges.

Rural Amazon

- The Rural Amazon is defined by its potential as a link between urban and even more remote areas, as well as by the infrastructure gaps that it experiences. The zone has a sizeable population (6.3 million), but its vast geographic expanse means that the population is thinly spread out. The Rural Amazon has experienced some degree of deforestation, and extractive industries dominate its economy.

- The Rural Amazon already has an impressive infrastructure network. Access to all-season roadways within 2 km is high, at 77 percent. Over 90 percent of communities are digitally connected.

- Yet, service quality in the Rural Amazon remains poor. Energy access is informal and unreliable in more than half of the cluster. While digital connectivity is widespread, connection in sparsely populated areas is likely slow, unable to support services like telehealth. While access to roads is high, these are predominantly local and do not facilitate interregional connection.

- Targeted efforts to improve infrastructure, for example, along an already expansive river network, will not only increase the opportunities available for the Rural Amazon but also for the communities in the Deep Forest, which rely on rural areas for services.

The Rural Amazon covers a diverse geographic area of nearly 2 million square kilometers and hosts a population that faces persistent challenges due to the limited provision of transport, energy, and digital infrastructure. The cluster's economy is dominated by extractive industries, such as traditional agriculture and cattle ranching. Many rural areas have already experienced varying degrees of deforestation, but the forests still retain significant ecological value and natural regeneration potential. As such, infrastructure investments must be carefully designed to improve human development outcomes while protecting and restoring environmental assets. Promoting nature-sensitive, inclusive, and climate-resilient solutions in rural areas is vital to expand market access, enhance livelihoods, and support both social and ecological resilience across the Amazon.

Access to quality education, health care, and basic infrastructure must be urgently improved if the economic potential of the rural communities is to be realized. As shown in table 1.2, the Rural Amazon is home to 6.3 million people, 20 percent of the entire population of the Amazon region. The cluster has low population density, on average about 3.4 people per square kilometer, and hosts nearly 27,000 schools, but more than 15 percent of the population lives farther than 10 km from them. There are more than 600 health care facilities in the cluster, but 80 percent of the population lives more than 10 km from them.

As discussed above, extensive river and road networks cross the Amazon region as a whole and the Rural Amazon in particular. River and road networks shape life in the Amazon by organizing where people live and where economic activity takes place (see map ES.5 in the executive summary). Specifically in the Rural Amazon, access to all-season roadways is high. Table 1.3 presents this clearly: access to all-season roadways within 2 km in the Rural Amazon is 77 percent (about 7 million people). This is quite close to the proportion of the Urban Amazon with a similar degree of access (87 percent). The situation is different in the Deep Forest Amazon, however, where access to all-season roadways within 2 km is about 85 percent, and the majority of the population is without access. (Box 1.2 discusses our procedure for estimating which road segments are all-season.)

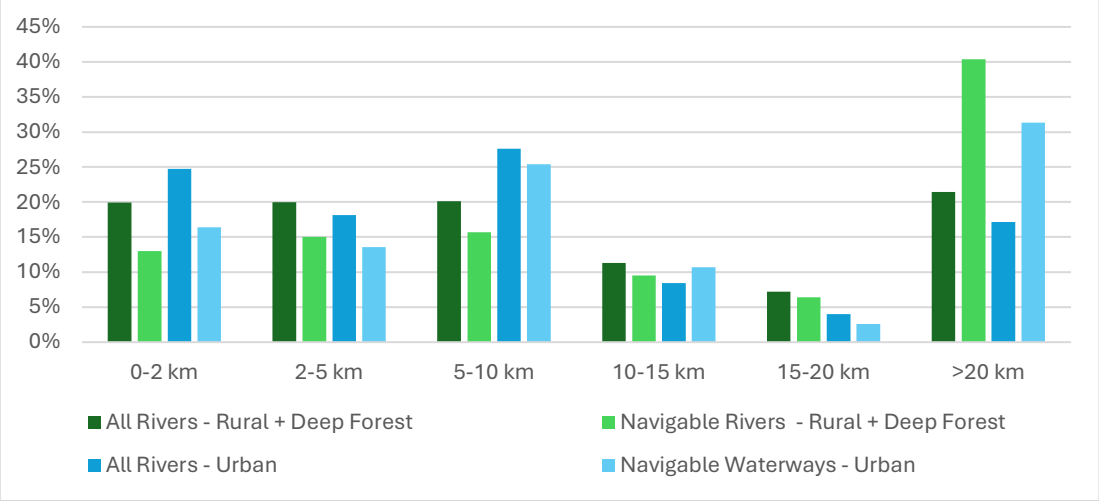
Table 1.3 Access to roadways across the three Amazons

Region	Access to all-season roadways within 2 km (Rural Access Index)	Access to paved roadways within 2 km	Access to paved major roadways within 2 km
	(Share of population)		
Urban Amazon	87.3%	60.6%	48.6%
Rural Amazon	77.0%	20.9%	8.5%
Deep Forest Amazon	15.7%	5.2%	0.9%

The access provided by the network of all-season roadways is currently inequitable, and much of the region remains inaccessible by road. While road infrastructure is prevalent, major roadways that facilitate interregional connection are concentrated along the periphery of the region, leaving other communities to rely on local roads for access to markets and health and education facilities. For example, in Colombia, in Vaupés, Guaviare, and Guainía, almost the entire classified road network is composed of local roads, whereas in Caquetá, Rondônia, and Pará, the share of local roads is closer to 60 percent. This issue persists even in the Urban Amazon. Iquitos, Peru, a major city, is not accessible by road.

Rather than expanding this extensive network, integrated solutions that promote resilient access are necessary to bridge this gap. All-season local roads that connect communities to rivers—and onward to larger cities—can enable them to better capitalize on their natural advantages. Figure 1.1 highlights the value of this approach given the existing river network. About 55 percent of the population lives within 10 km of a river. This proportion is slightly higher in the Urban Amazon, but more than 20 percent of the Rural and Deep Forest Amazons share access within the same distance band. This indicates that promoting access to rivers is an important avenue for improving access to markets access and access to services in the region.

Figure 1.1 More than half of the region's population (52%) living less than 10 km from a river



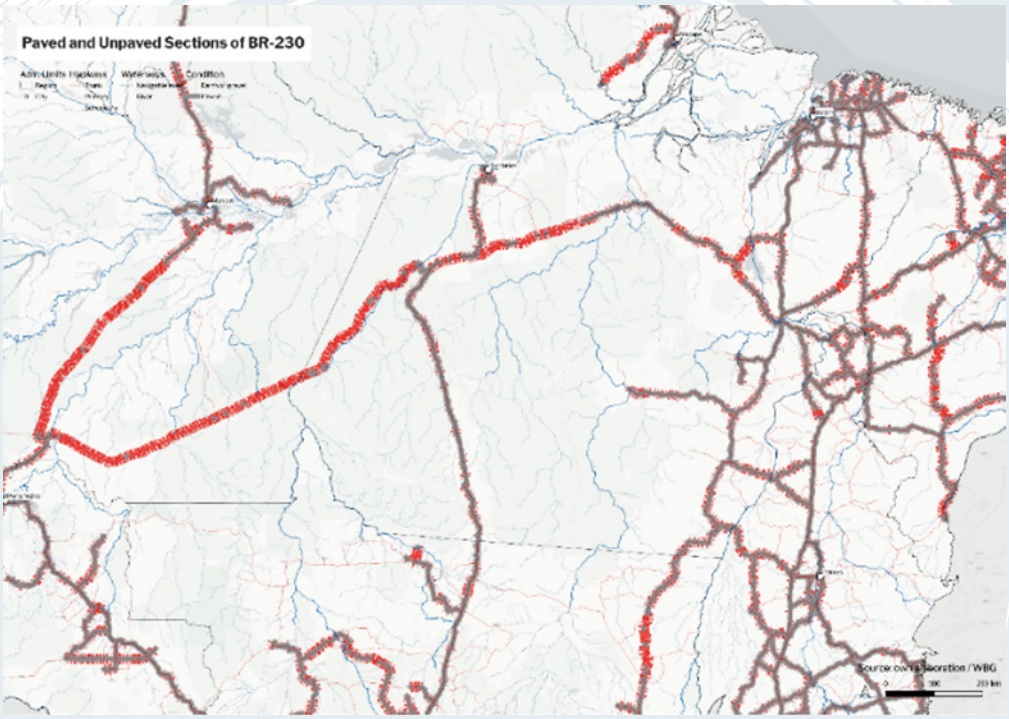
Note: The estimated number of people living within 10 km of a river is 16.4 million. km = kilometer.

Box 1.2 How road segments were estimated as being all-season

Road quality was estimated utilizing open-source databases and following a two-step process. First, an extensive mapping effort utilizing official and open-source databases of road inventories was compiled and reconciled. Second, the European Space Agency's Sentinel satellites' imagery was utilized to impute pavement status (paved or unpaved) and estimate the International Roughness Index (IRI). We used the methodology discussed in Alteia 2025 (more details are provided in the technical appendix A1). Put simply, smooth and rough road surfaces reflect light differently, and satellites can detect such differences. Estimates are satisfactory, with 80 percent accuracy.

Map B1.2.1 presents one example of the associated database. For any major roadway included in our database, we are able to determine its pavement status. The associated map helps do this for sections of BR-230, Brazil's trans-Amazonian highway.

Map B1.2.1 Analysis of BR-230

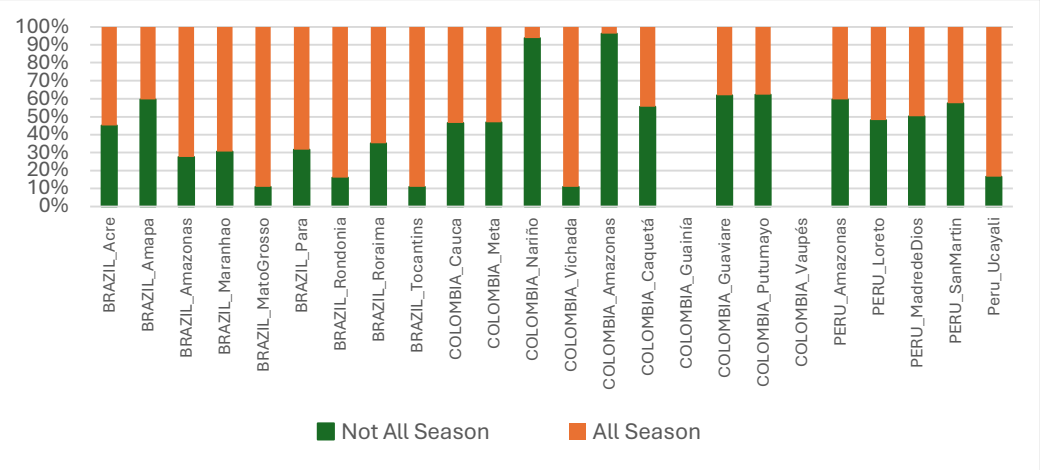


Note: km = kilometer; WBG = World Bank Group.

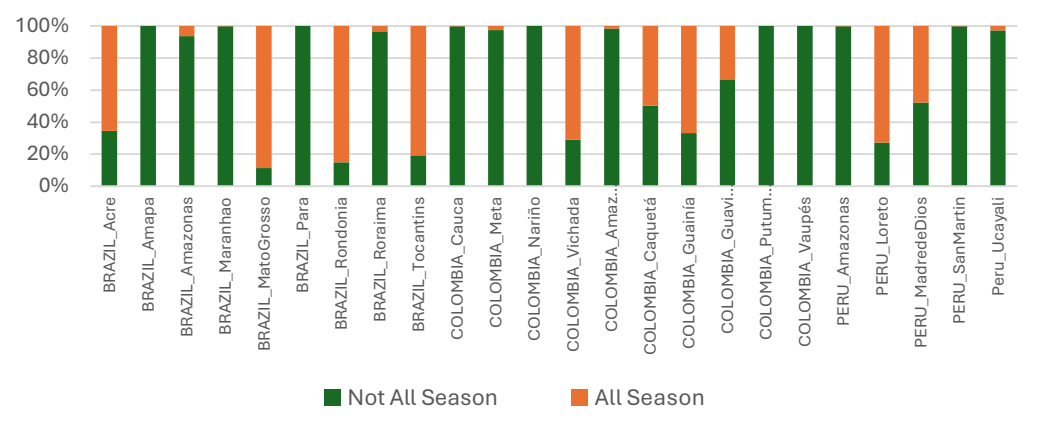
We follow the guidance in World Bank (2016) to construct a Rural Access Index using International Roughness Index (IRI) measures derived from remote sensing data. All-season roads are defined as having an IRI below 6 m/km for paved roads and an IRI below 13 m/km for unpaved roads. The results for major and local road networks are presented in figure B1.2.1.

Figure B1.2.1 Estimated proportion of all-season roads in states/departments in the Amazon region

(a) Major road network

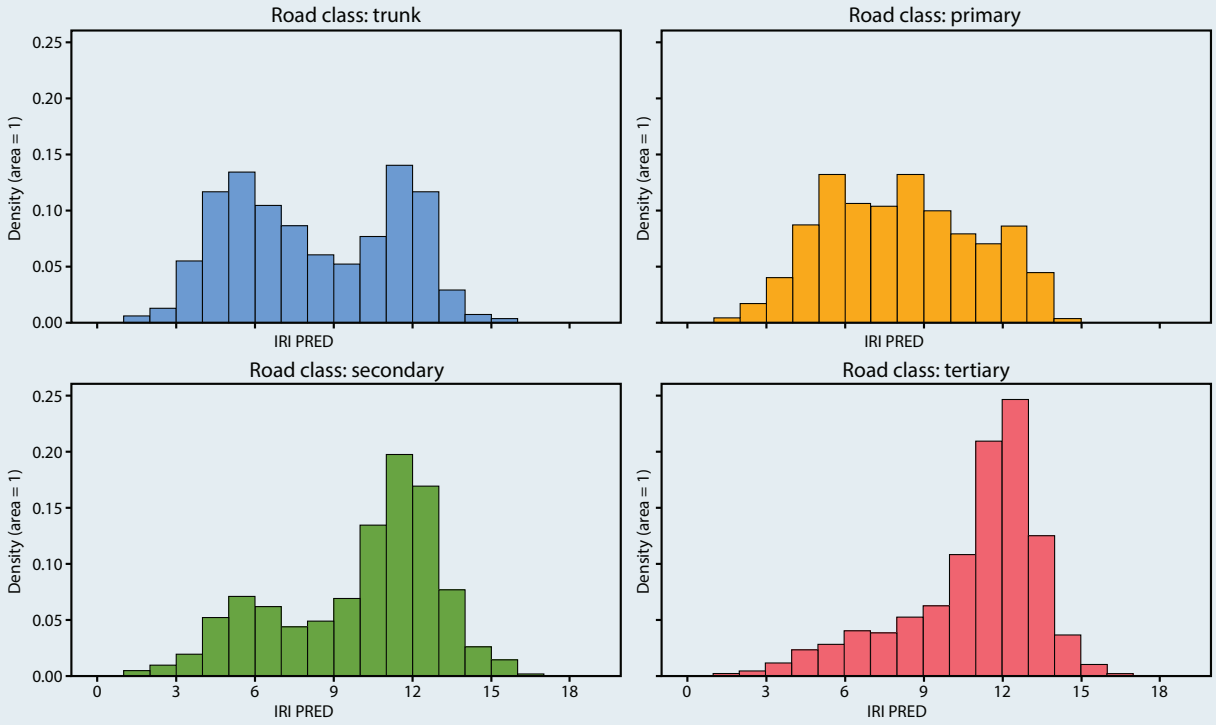


(b) Local road network



One important observation is that road quality in the region, overall, is quite poor. The label "all-season"—even when applied to major roads—often conceals the poor state of infrastructure. Figure B1.2.2 plots the length-weighted distribution of the IRI for road segments within the region. A significant share of roads, including those designated as trunk or primary routes, register IRI values above 10 m/km—a level that indicates extremely rough surfaces that put severe strain on vehicles. Higher IRIs dominate larger parts of each road network.

Figure B1.2.2 Quality of major roadways is highly variable

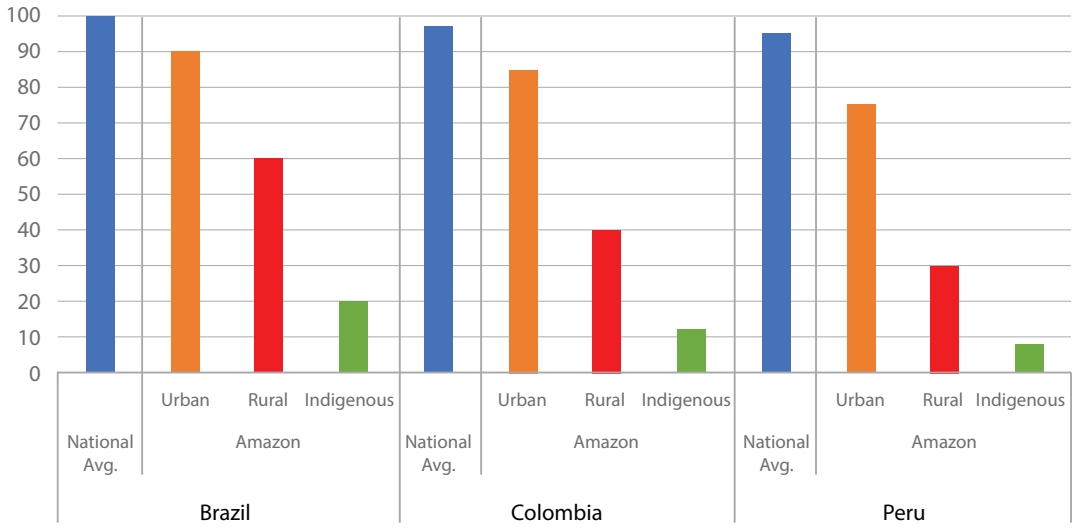


Source: Original compilation.

Note: A length-weighted distribution of the IRI is plotted for road segments by type. IRI = International Roughness Index measured in units of meters/kilometer.

Energy access is another limitation faced in the Rural Amazon. Electricity access in major urban centers remains more than 30 percentage points higher than in the Rural and Deep Forest Amazons (figure 1.2). Meanwhile, electricity access in the Urban Amazon remains about 10–20 percentage points below national averages. In fact, for each of the three countries analyzed here, energy access rates are the lowest in the states and departments within the Amazon region. Even as electrification rates are near universal at the national level, areas in the Amazon continue to experience severe access gaps. In the Peruvian Amazon's Loreto, only 61 percent of households have electricity access—14 percentage points lower than the national average of 75 percent. Alternative sources such as candles and petrol lamps are widespread. Energy access in the Colombian Amazon remains significantly below national levels, especially in the most remote departments. In Amazonas, Guainía, and Vaupés, electricity coverage ranges between 83 and 89 percent, far below the national average of 99 percent. Guainía is the most affected, with a 16 percentage point gap.

Figure 1.2 Access to energy in the Amazon region lags national averages, particularly in rural and Indigenous areas (access to energy by region, in %, 2023)



Source: Original compilation based on EPE (2024), Ministerio de Energía y Minas MINEM (Peru) (2023), XM (2024), and IPSE (2023, 2024).

Note: The labels urban, rural, and Indigenous do not correspond perfectly to the Urban Amazon, Rural Amazon, and Deep Forest Amazon, respectively. It is not possible to replicate the figure for the clusters used in this study based on available data, yet it remains informative given the overlap between urban/rural/Indigenous regions and the three clusters.

For access to electricity, we used satellite-derived proxies to reveal significant territorial disparities. The assumption is that lower levels of visible light at night correspond to lower levels of access to energy.

Nearly 1 million residents of the Rural Amazon are identified as experiencing among the lowest levels of access to electricity (table 1.4). While approximately 78 percent of the Amazon's population resides in areas with high-intensity nighttime light, indicating likely access to reliable, grid-based electricity, this coverage is heavily concentrated in the Urban Amazon. In contrast, less than 45 percent of the Rural Amazon is estimated as having access to a similar degree of high-quality, reliable electricity. In the Deep Forest Amazon, 46 percent of the population experiences the lowest quality of energy service. More than 4 million people live in areas characterized by a moderate level of nighttime light intensity, which may indicate some degree of low-level or unreliable energy access.

Table 1.4 Population by cluster and energy intensity levels

Region	High	Moderate	Low
Deep Forest Amazon	16.5%	37.3%	46.2%
Rural Amazon	44.8%	40.7%	14.5%
Urban Amazon	97.1%	2.7%	0.2%
Population	24,858,425	4,380,641	2,488,709

Note: Low intensity corresponds to nighttime luminosity of 0–0.32 nW/cm²/sr. Such a range corresponds to little or no electrical light detected. Moderate corresponds to 0.32–0.43 nanowatts per square centimeter per steradian (nW/cm²/sr), which indicates informal or low-level energy access. High corresponds to a recorded luminosity of above 0.43 nW/cm²/sr. This is aligned with the levels recorded in the largest cities across the three countries studied and corresponds to access to reliable, grid-based electricity.

These findings highlight that while extreme isolation contributes to energy scarcity, most underserved areas are not fully disconnected but are still poorly integrated into larger infrastructure networks. Tailoring investments to these spatial realities—for example, expanding transportation and energy infrastructure in rural areas with low connectivity—can drive more equitable development. At the same time, interventions must be sensitive to ecological thresholds, especially in pristine forest areas, to ensure that development does not come at the cost of biodiversity.

Given the limited availability of data on digital connectivity, and the absence of harmonized data at the country level, this study leverages crowd-sourced datasets. Speed test records from Ookla,[13] a major crowdsourcing supplier in South America, are used as a proxy for internet access. The datasets have two primary sources: (1) user-initiated speed tests and (2) automated background tests performed by certain applications. While Ookla's core objective is to assess connection quality, its granular, geolocated data also serve as a useful proxy to infer digital coverage. By comparing the annual internet speed tests with population data, we identified the extent of coverage within the population. Over time, the number of speed tests tends to decrease—not because coverage is worsening, but because users typically test their internet speed when they first establish a connection and then subsequently stop. In this analysis, areas without any recorded speed tests over the past five years were classified as likely lacking internet coverage.[14]

13 Ookla's Speedtest data: https://registry.opendata.aws/speedtest-global-performance/.

14 This approach has limitations, including potential coverage underestimation in areas where internet access exists but users either do not run speed tests or use applications that do not collect automated measurements. Additionally, the proxy's reliability is influenced by market dynamics. In regions where internet service providers actively encourage or integrate speed testing using Ookla-based tools into their customer support protocols, data coverage tends to be higher and more representative. Conversely, in areas where providers rely on alternative speed test platforms or do not promote regular testing, the absence of recorded Ookla tests may not accurately reflect actual network availability. To assess the reliability of this proxy, we compared the coverage results to official mobile coverage figures from Brazil's telecommunications regulator (ANATEL). The comparison showed a strong alignment, with discrepancies generally within ±2 percent at the state level. In Peru, where official data are more limited, the Ookla-based proxy identified a significantly larger connected population than reported by government sources, further supporting the utility of this proxy as a coverage estimation tool in data-scarce environments.

This assumption is based on the premise that in locations with active, usable connections, at least occasional speed tests or automated measurements would be expected. About 20 percent of the population consistently shows no test data across all years, indicating that they are without internet coverage or are unable to afford internet access.

Based on this methodology, the results indicate that one in five persons in the Amazon region either lack internet access or cannot afford it.[15] In both Colombia and Peru, a significant portion of the Amazon region's population lacks internet connectivity. Areas such as Amazonas in Colombia, and Loreto and Amazonas in Peru, are particularly affected. Official statistics from Peru further highlight this disparity. According to 2024 data from the National Institute of Statistics and Informatics, internet penetration rate is lowest in the Amazonas Department in Peru, at just 7.34 percent. Levels are much higher in Ucayali (48.7 percent) and San Martín (41.6 percent). Connectivity is relatively low also in Madre de Dios and Loreto, where 32.06 percent and 24.3 percent, respectively, of the population is connected. Internet penetration in the region as a whole considerably lags national averages.[16]

While digital connectivity is available in some form in large proportions of the Rural and Urban Amazons, there is a clear divide between urban centers and rural and Indigenous communities. Table 1.5 highlights the proportion of each cluster that benefits from digital connectivity. The high share of connected urban and rural populations relates to the availability of underlying infrastructure: fixed broadband tends to be better in urban areas. This high degree of connectivity is striking when compared with the Deep Forest, less than half of whose population appears to have some form of connectivity.

Table 1.5 Fraction of population in the three Amazon subregions with evidence of internet connectivity

	Urban	Rural	Deep Forest
Brazil (%)	100.0	93.6	60.6
Colombia (%)	100.0	91.0	35.0
Peru (%)	99.8	89.6	27.5

15 As a sensitivity check, official figures for Brazil's northern region suggest that approximately 15 percent of the population lacks broadband access, supporting an assumption of a 5 percentage point margin of error as reasonable. Further progress—through the integration of multiple datasets, including crowdsourced inferences—may yield a more accurate picture of broadband coverage in the Amazon region. While this figure may vary depending on the estimation method used, it underscores the significant challenges the region faces in expanding broadband connectivity.

16 At the national level, internet usage rates in the three countries are comparable to the Latin American and Caribbean average of 75 percent. In 2023, internet penetration reached 84 percent in Brazil, 73 percent in Colombia, and 75 percent in Peru—though still below the Organisation for Economic Co-operation and Development (OECD) average of 90 percent (World Bank 2006).

Many rural and Indigenous communities rely heavily on mobile networks or satellite connections for internet access. Mobile internet networks have become steadily faster across the Amazon region, providing top-tier speeds to a larger share of the population. An analysis of the evolution of mobile internet speeds reveals a clear trend of improvement in the study area. In 2019, 39 percent of the population was in the highest-speed quintile; by 2024, this figure had risen to over 50 percent. Yet, geographical conditions and economic factors, including the affordability of connectivity, are key barriers limiting the expansion of this infrastructure further, especially in remote areas. Box 1.3 presents an overview of these factors and explores the challenges associated with promoting increased cellular coverage to expand digital access in the Rural Amazon.

Satellite-based broadband has higher latency and lower throughput than cellular networks, but it remains a viable solution for many applications and can be swiftly deployed. Satellite-based broadband connectivity has been increasing in the Legal Amazon, creating an additional connectivity option. The technology's ability to overcome natural barriers and provide coverage in remote, rural, and underserved urban areas makes it a strategic asset for national digital inclusion. In just three years, 2022–25 (BBC News Brasil 2023), over 90 percent of cities in the Legal Amazon gained one or multiple reception dish antennas for access to satellite internet connection, specifically, a low Earth orbit (LEO) satellite broadband connection. For instance, in Brazil, the number of active satellite broadband connections has grown significantly, from 161,000 in 2018 to over 552,000 in 2024 (ANATEL 2025). While 5G offers twice the throughput and lower latency, LEO satellites can still support key services, even though they might not be very suitable for real-time applications requiring high-speed data transfer.[17]

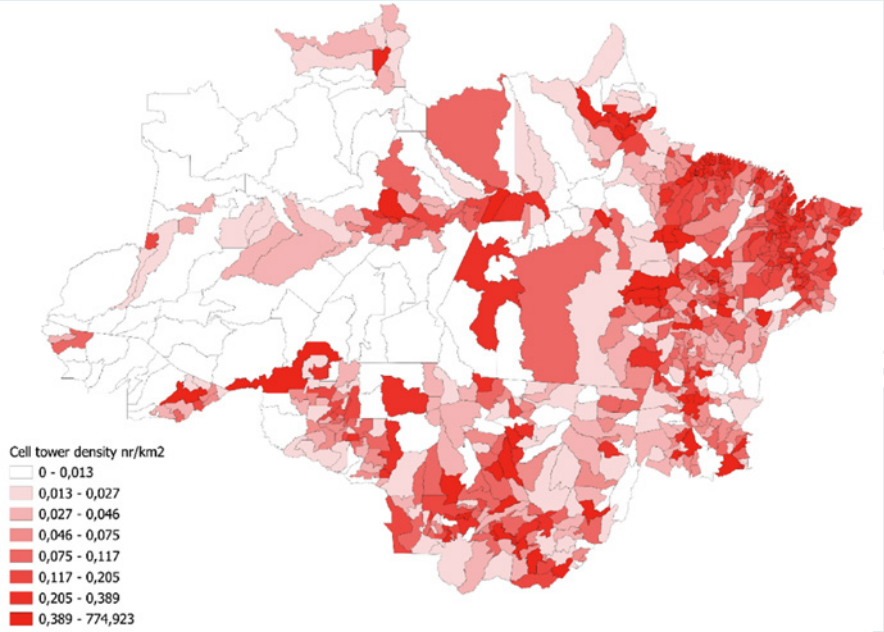
Box 1.3 Estimating internet access levels across the Amazon region

Cell towers in the Amazon appear to adequately cover the Urban Amazon, but not the Rural and Deep Forest Amazons, which feature a more dispersed population. Towers with lower-frequency bands (i.e., sub 1 gigahertz [GHz]) are appropriate for dense forested areas, for wider reach with fewer towers (spaced some 10 km apart). However, the towers typically deployed, employing legacy 2G/3G technologies, provide low capacity, and connection is not very fast. Indeed, coverage in rural areas might be sufficient in terms of reach, but connection quality does not support advanced internet use. This is the case in the Peruvian Amazon, which predominantly has towers with 2G and 3G technologies, requiring many inhabitants to travel to specific locations outside their communities just to make calls or access information online. In Brazil, only 79.94 percent of the population in the northern region has 4G access, compared with 92.44 percent nationally (CPR LATAM 2024).

17 For online education, LEO satellite broadband works well in supporting access to prerecorded lessons and educational materials, although live streaming may be difficult. For telemedicine, basic consultations, medical record sharing, and batch diagnostic imaging are feasible, but real-time procedures like remote surgery may be limited. Digital banking services such as balance checks, fund transfers, and payments function effectively. Rural farmers, meanwhile, can access weather updates, market prices, and advisory services online using satellite internet. For weather and environmental monitoring, satellite internet enables remote sensor data transmission to track weather patterns, forest fires, and other ecological factors.

Consider the case of Brazil, where, in the Legal Amazon, some 5.2 million of the least-populated communities are outside the range of mobile telephone coverage. While network coverage in Brazil has grown steadily over the past four years, and 80 percent[18] of this region's population is already connected, coverage is disparate between big and small communities (map B1.3.1). Coverage is far more limited in 87 percent of small municipalities (of fewer than 50,000 residents), where it is 30 percent less than in larger municipalities. In fact, the 34 largest municipalities (with over 100,000 inhabitants) have a 96 percent coverage rate, whereas 15 percent of the smallest municipalities have just 50 percent coverage on average.

Map B1.3.1 Cell tower density by municipality



Note: nr/km^2 = number per square kilometer.

A reliable and cost-effective electricity source is needed before adding a cell tower. Typically, these towers connect to the electricity grid. But this is not possible in remote areas, where they could instead rely on diesel generators and solar panels. Many electricity generation centers in the western Amazon are isolated and rely on diesel-powered systems. However, achieving full digital connectivity with widespread, fully operational cell tower coverage would demand enormous quantities of diesel. A single cell tower consumes 120 kilowatt-hours (Zodhya 2023; GSMA and IFC 2014) on average daily. If all 53,427 towers needed to cover the sparsely populated Amazon regions (<10 inhabitants per square kilometer) relied on diesel-based electricity, then a staggering 44.1 million liters (Van Loon Maritime Services n.d.), or 337,500 tons of diesel, would be needed daily. Transporting this quantity would require at least 10 large tanker vessels—the maximum permissible size due to draft restrictions in the upper sections of the river (Van Loon Maritime Services n.d.). The high cost of diesel in remote areas makes digital connectivity even more expensive. For example, the Association of Residents of the Rio Iriri Extractive Reserve (Associação dos Moradores da Reserva Extrativista Rio Iriri, AMORERI) reports that most families in this area rely on diesel generators, and fuel prices go up to US$3 per liter in isolated regions, restricting internet.

18 Calculations made using ANATEL data, available at: https://informacoes.anatel.gov.br/paineis/meu-municipio

Urban Amazon

- The Urban Amazon is the largest cluster by population (22.1 million people), yet the smallest by area (0.3 million square kilometers). It hosts the most densely populated urban centers, and connectivity is high.
- It is not access but quality that defines infrastructure in this cluster. Close to 90 percent of the cluster lives within 2 km of an all-season road, and roads overall are of the highest quality in this cluster. Energy access is not only widespread, but has become more reliable due to interconnections to national grids. Nearly 100 percent of the cluster is digitally connected via physical cable, at the highest speeds and greatest capacity in the region.
- The Urban Amazon is the region's economic engine, facilitating access to markets, both foreign and domestic. The density of major roadways and ports is highest in this cluster. Opportunities for the overall region will grow if investments are made to improve these connections and to provide improve connectivity between the Urban Amazon and the Rural and Deep Forest Amazons.

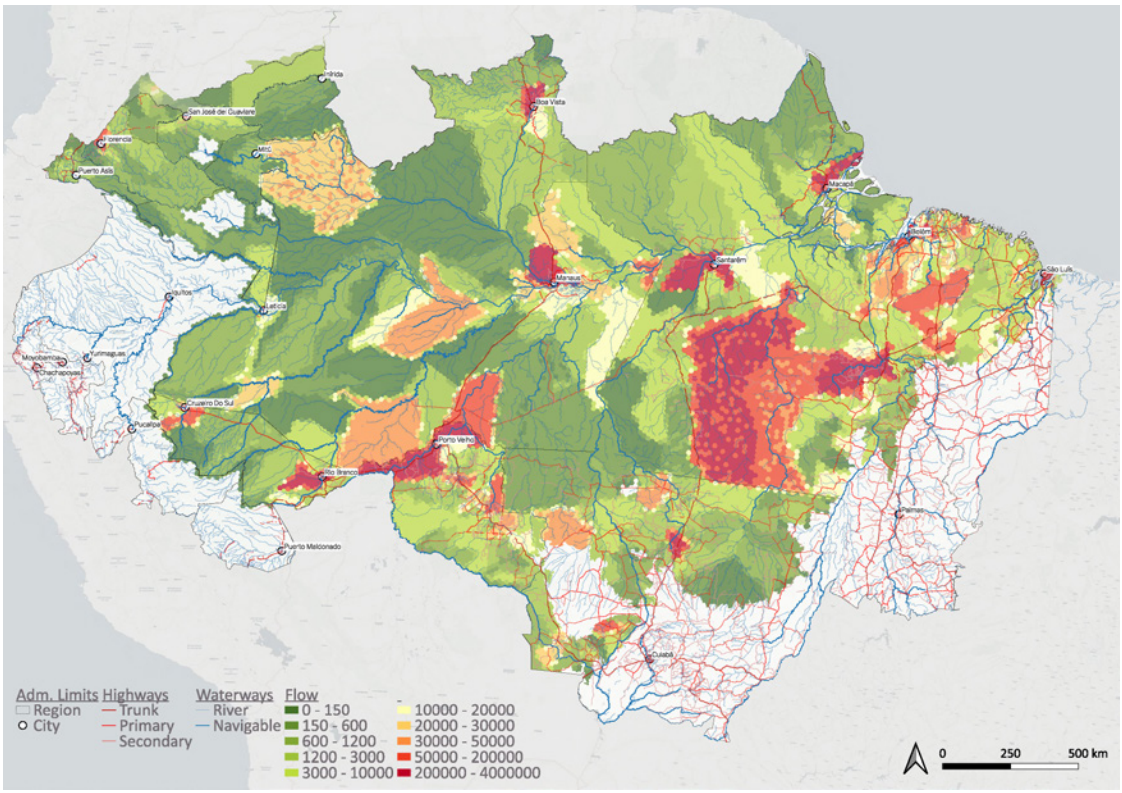
The Urban Amazon encompasses the most highly populated and dense urban areas of the Amazon region, where infrastructure provision and connectivity are both high. As shown in table 1.1, the cluster hosts 22.1 million people or nearly 70 percent of the region's population, despite covering only 5 percent of the territory. The cluster hosts 97 percent of the urban population, defined as those living within an area where population density exceeds 100 inhabitants per square kilometer. Indeed, all of the Amazon's largest cities, such as Manaus and Iquitos, are in the Urban Amazon. The Urban Amazon hosts close to 40,000 schools and 2,000 health care facilities, which is about 800 more than the Rural and Deep Forest Amazons, combined.

Urban centers are central hubs of economic activity, services, and infrastructure. For example, access to major roadways is high in the Urban Amazon, which hosts about 0.1 km of major roadways per square kilometer—orders of magnitude more than the other clusters. On the other hand, significant deforestation and ecosystem degradation in these territories have left limited natural vegetation. They are surrounded by disconnected rural and peri-urban communities, which host bioeconomy activity, opening a possibility of establishing connectivity with them. Strategic investments in these urban cores can boost the bioeconomy and improve access to education and quality services. Improving the linkages between these hubs and surrounding territories can turn these centers into engines of regional development.

A detailed analysis of travel patterns in the Colombian and Legal Amazons shows distinct patterns of trip generation and confirms the centrality of the Urban Amazon in the region. Mobile phone data were used to obtain unprecedented insight into the region's transport patterns. The region was partitioned into zones. Mobility was estimated using origin-destination matrices built across 505 zones in Brazil and 101 in Colombia. Box 1.4 describes the major patterns of traffic and trade in the region, utilizing publicly available sources of data.

Most trips start out in the Urban Amazon. These are the areas shown in red in map 1.13, with large areas of influence reaching as far as 300 or 400 km. In Brazil, this is the case in Belém and São Luis; Manaus and Porto Velho; and, to a lesser extent, Boa Vista, Rio Branco, and Macapá. Other key starting points in Brazil are in still more remote positions around rivers, such as in the Coari municipality (Amazonas), the Tabatinga–Benjamin Constant–Leticia cross-border area, the headwaters of the Rio Negro in Brazil, and the cocoa-growing area of Medicilândia (Pará).

Map 1.13 Monthly mobility patterns in the Amazon, indicating the directionality of traffic flows

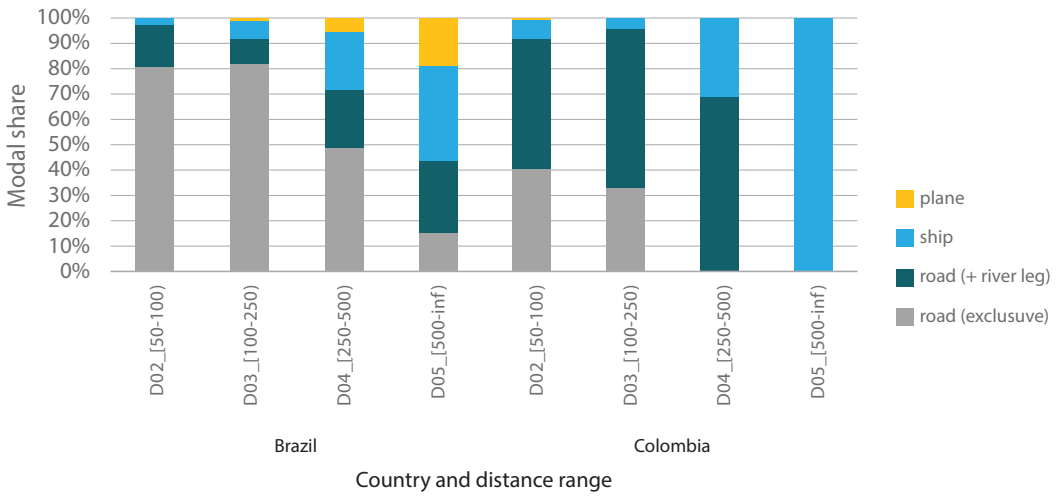


Source: Original work produced during preparation of this report.

Note: km = kilometer.

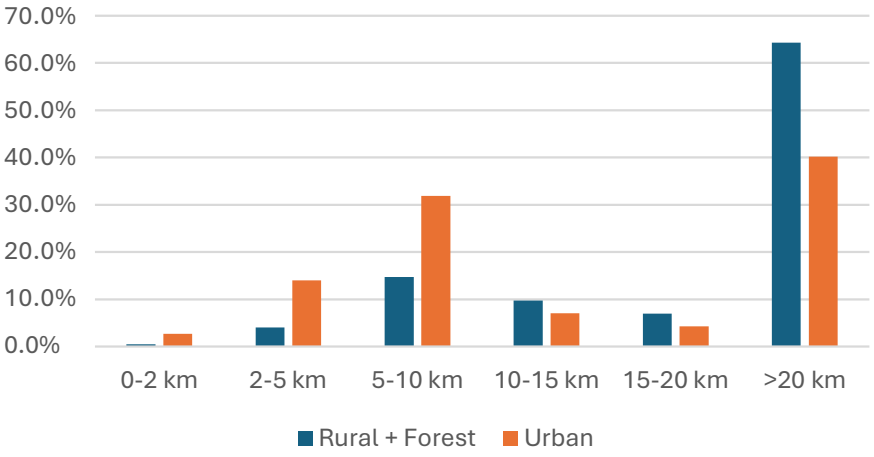
Figure 1.3 shows the modal share for various distance bands within the Colombian and Legal Amazons. Road transport dominates short- and medium-distance travel across the Amazon, but in Colombia, its use drops from 40 percent (50–100 km) to 33 percent (100–250 km), vanishing for trips exceeding 250 km, while combined road and river transport grows from 52 percent to nearly 70 percent for trips between 50 and 500 km. In Brazil, over 80 percent of trips up to 250 km rely on roads, but this falls to 49 percent for 250–500 km and just 15 percent past 500 km, as river transport rises to 23 percent (250–500 km), 37 percent (500–1,000 km), and 100 percent for the longest journeys.

Figure 1.3 Modal share by distance band



Source: Based on World Bank and Nommon (2024).

Figure 1.4 Accessibility to ports and docks, by type of cluster



Source: Original compilation.

Note: km = kilometer.

River transport plays a critical role for (1) short connections between riverside or coastal zones, and (2) longer journeys along major navigable rivers (especially for distances over 250 km). In Brazil, long trips are mainly across the Amazon River (primarily the corridors through Manaus and Belém), the Tocantins River (primarily across Belém and Palmas), the Madeira River (primarily between Manaus and Porto Velho), and Guaporé (an important agricultural corridor across the border between Brazil and Bolivia). For instance, a trip between Manaus and Porto Velho would take five days and cost US$118–596 on average.[19] In Colombia, exclusive road travel is rare outside urban areas; many regional connections require segments of ship trips.

19 https://brazilbooking.com/product/boat-ticket-manaus-porto-velho/

The presence of port and dock infrastructure in the Urban Amazon increases access to markets, both foreign and domestic, from this cluster relative to the clusters in the Rural and Deep Forest Amazons. Consider the cluster's ports: every major maritime port is located in the Urban Amazon, and the region hosts about 300 ports or docks. Figure 1.4 describes access to both ports and docks in the Urban Amazon: Just under half of the cluster's population, or 10.7 million people, have access to ports or docks within 10 km. These facilities help move cargo and people. In contrast, the Rural and Deep Forest Amazons, while still having access to these facilities, do not experience such benefits: about 20 percent of the Rural and Deep Forest populations (1.8 million people) live within 10 km of a port or dock, of which many lack basic services like passenger waiting areas, storage, and sanitary amenities. Diagnostic work in Colombia highlighted these deficiencies in the Putumayo River Basin, with similar challenges identified in Brazil's Juruá and Purus river basins. These deficiencies particularly impact the ability of remote regions to ship perishable goods.

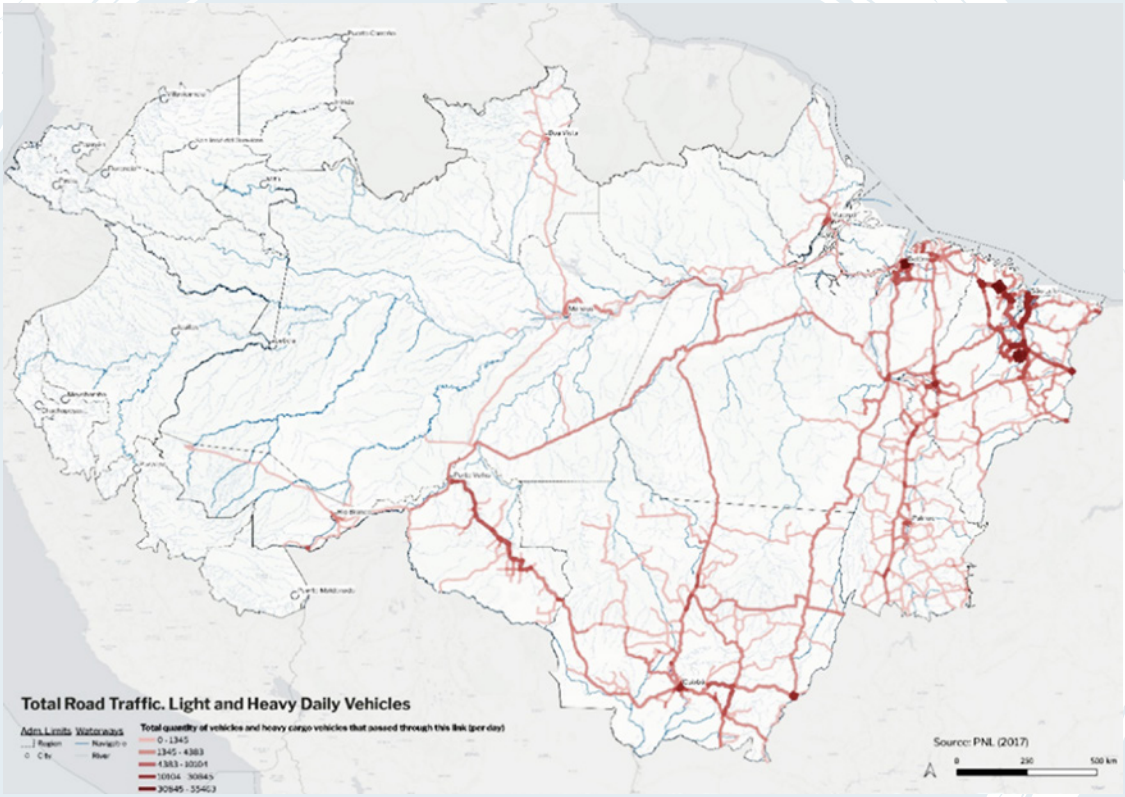
River transport plays an important role across the region's international borders and would benefit from harmonized investments in transport infrastructure and binational service provision. One prominent example is the twin cities of Tabatinga (Brazil) and Leticia (Colombia), which form a key cross-border hub. Although these cities are in different countries, their residents frequently engage in shared services and commerce, with no physical or legal travel restrictions. The analysis confirms high-frequency, short-distance, cross-border movements between them, vital to the socioeconomic fabric of the region. This analysis additionally allows for the study of longer-distance travel via aviation. Using the mobile phone data discussed above, this study was able to identify trips that were likely taken by air. Using these, a ranking of critical aviation routes was developed, and connectivity gaps as well as high-potential corridors for added or reconfigured air service were identified. Importantly, the analysis also highlighted a clear distinction between aviation accessibility between the Urban Amazon and surrounding areas.

In the Urban Amazon, hubs like Manaus and Belém anchor national and international connectivity, and the longest trip flows are concentrated here. Several second-tier cities (Boa Vista, Santarém, Macapá) show a high share of plane trips, indicating room to strengthen intra-Amazon links. Airports in these regions enable long-distance travel over short timeframes. In contrast, long connections originating in the Rural and Deep Forest Amazons are made almost exclusively by road or river, even when distances would justify flying. This is because upstream communities lack power, storage, and service platforms to support air operations, and because many origin-destination pairs still have no direct flights (e.g., Itaituba generates many long trips but has just one route, to Manaus). **Indeed, airports in the Amazon function almost exclusively as urban assets because the enabling conditions that make scheduled air service viable and useful (reliable grid power, cold chains, maintenance services, and market-facing logistics) are concentrated only in cities**.

Box 1.4 Major traffic and trade patterns in the Urban Amazon

Trade and traffic in the Amazon are defined by the Urban Amazon and, more specifically, the cluster's interconnections with road, river, and port infrastructure. Major roadways, such as the Trans-Amazonian Highway (BR-230), BR-319, and BR-174, are critical for connecting urban centers and facilitating the movement of agricultural commodities. Road traffic is most pronounced along the periphery of the Amazon, particularly between Belém, Maranhão, and Piauí, and along key agricultural corridors like Cuiabá–Porto Velho and Cuiabá–Sinop–Mirituba. Infact, a majority of the region's agricultural output is transported by road according to Brazil's 2025 NLP. These highways not only support the agricultural sector but also serve as vital links between cities, helping to move goods and people across the region. Map B1.4.1, which details road traffic flows, shows the importance of these corridors and their role in connecting urban hubs. Despite the dominance of road transport—accounting for about 72 percent of total ton-kilometers in the Amazon, higher than the national average—many areas remain underserved, and river crossings often depend on ferries, leading to significant delays.

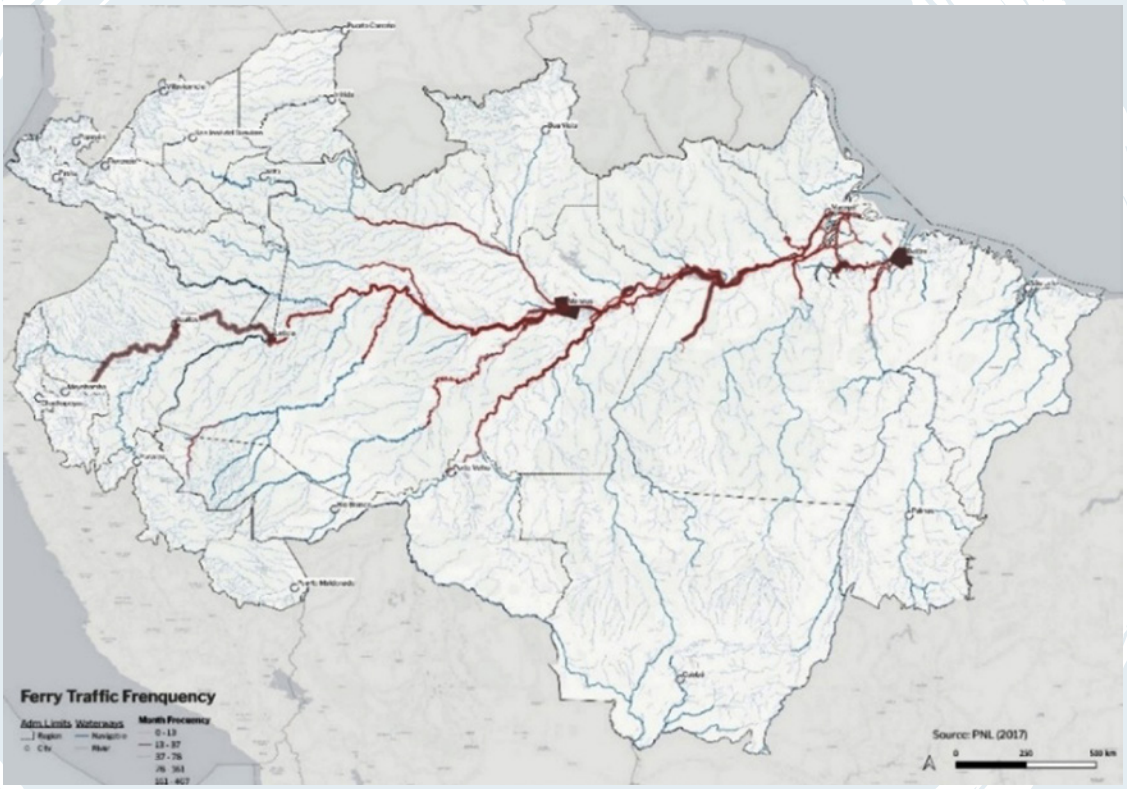
Map B1.4.1 Road traffic flows in the Amazon



Note: km = kilometer.

The Amazon's extensive river network is indispensable, especially in areas where road infrastructure is sparse or unavailable. River transport is not only the backbone of cargo movement in remote and rural areas but also plays a central role in passenger mobility. Passenger river transport is concentrated along corridors such as Santarém–Manaus in Brazil and Iquitos–Yurimaguas in Peru, with significant flows at the mouth of the Amazon River and between Manaus and Leticia (Colombia). Ferry services are frequent in these corridors, with some routes handling hundreds of thousands of passengers annually. Map B1.4.2, which shows ferry traffic frequency, highlights the sections of rivers with the highest passenger and ferry activity, emphasizing the critical role of rivers in connecting isolated communities and supporting daily life in the region.

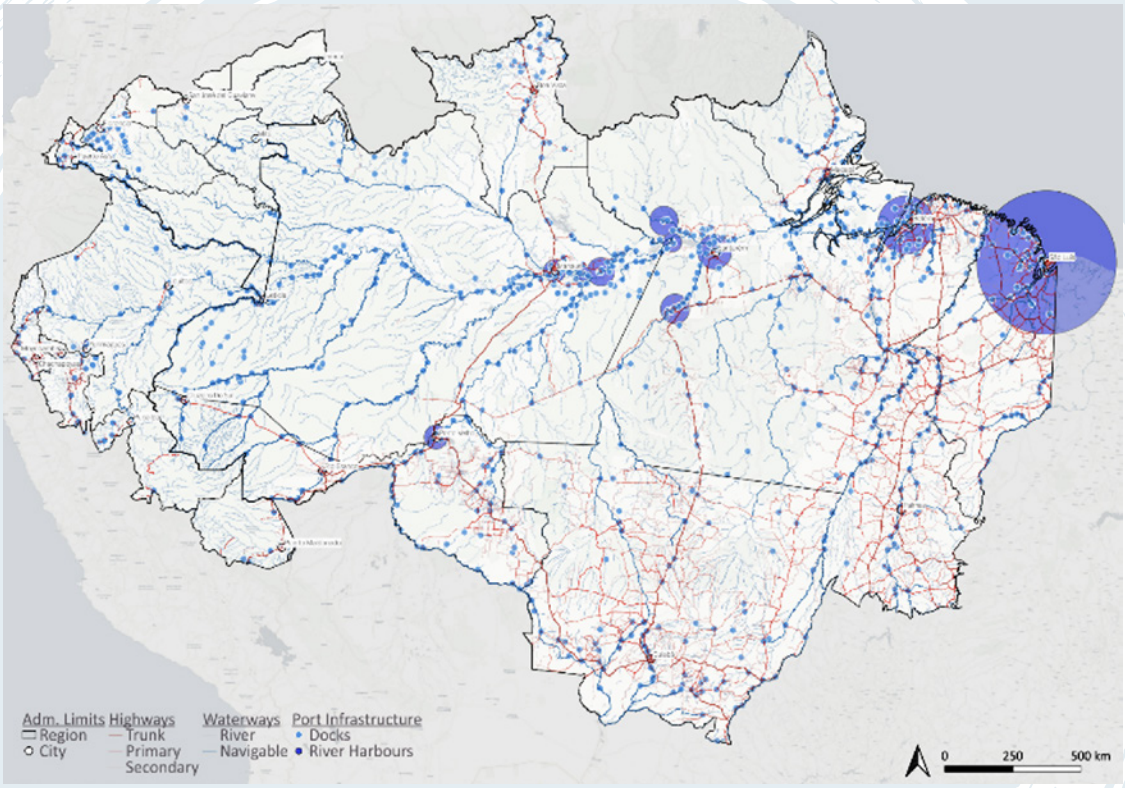
Map B1.4.2 Frequency of ferry traffic



Note: km = kilometer.

The Urban Amazon is pivotal in facilitating and concentrating trade and traffic flows. Cities like Belém, Manaus, and Santarém act as key nodes, hosting major port infrastructure and serving as gateways to both domestic and international markets. The port of Belém, for example, is strategically located at the intersection of major river systems, enabling efficient export of products sourced from the Amazon and attracting significant investment. In 2024, river ports on the Brazilian Amazon handled 140 million tons of cargo, with Porto Velho and Miritituba alone processing about 25 million tons of agricultural commodities. The Arco Norte initiative, which focuses on expanding port infrastructure along the Amazonian river system, has made the region a major export route for grains, surpassing traditional southern ports. Map B1.4.3 depicts the distribution and cargo volume for ports and docks and further illustrates how urban centers anchor the Amazon's trade and transport system, ensuring connectivity despite the region's challenging geography.

Map B1.4.3 Port and dock distribution and cargo volume

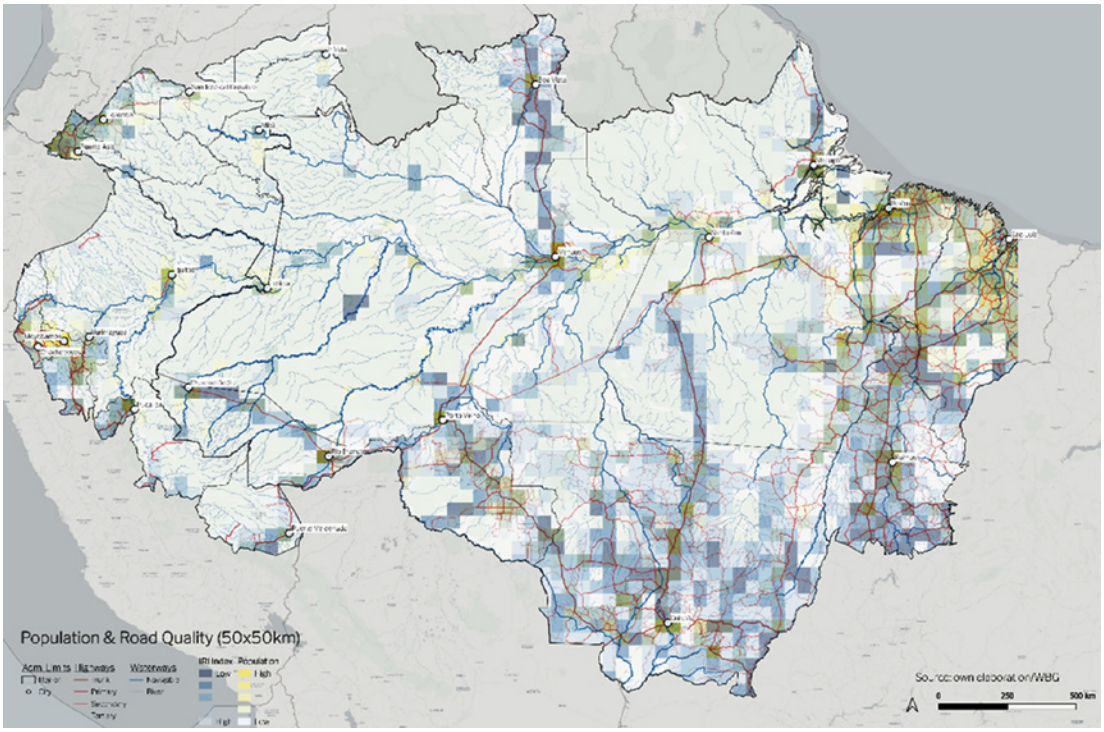


Note: km = kilometer.

The Urban Amazon is a hub and key facilitator of economic activity partly because this cluster has higher-quality infrastructure. As described in Box 1.4, existing infrastructure in the Urban Amazon helps organize economic activity. The non-bioeconomy agricultural sector, whose products are mostly grown and harvested in the Rural Amazon in the south and east of the region, utilize the Urban Amazon's ports as well as the major roadways connecting the major urban centers. Consider map 1.14, which correlates population with quality of local roads. Larger populations tend to benefit from high-quality infrastructure (darker greener sections of the map). This suggests that better-quality infrastructure that promotes regional and inter-regional access can create economic opportunities. Policies and investments targeted at promoting the maintenance of existing infrastructure should be prioritized to ensure it continues providing such opportunities.

The situation is the opposite for Deep Forest and remote areas (lighter blue sections). A dual challenge thus affects these nonurban clusters: limited road quantity and inadequate road quality. For regions experiencing relatively poor access to roads, the quality of road infrastructure that does exist adds to the challenge. Heterogeneity in infrastructure quality and the prevalence of poor-quality road infrastructure raise the cost of doing business. Box 1.5 discusses how infrastructure quality relates to affordability issues across the transport, energy, and digital sectors. Ensuring that existing infrastructure is of sufficient quality to promote sensible access, such as providing access to river networks for remote communities, will ensure that this infrastructure can help, instead of limit, economic opportunities in the Rural and Deep Forest Amazons.

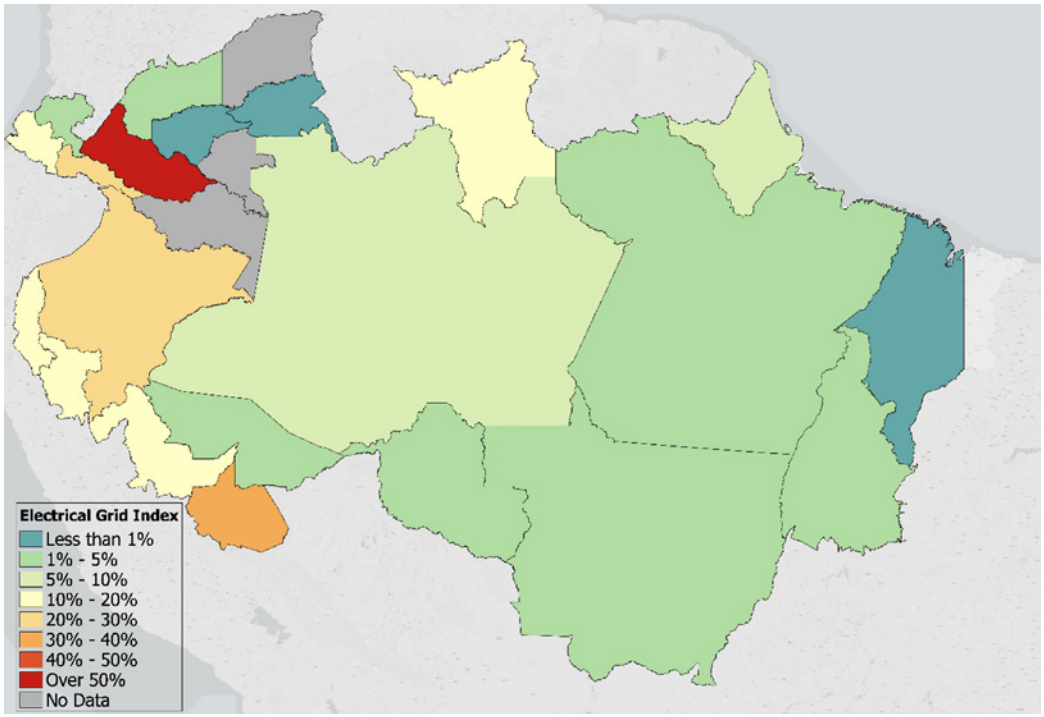
Map 1.14 Population is correlated with infrastructure quality, resulting in lower-quality infrastructure in remote areas



Source: Original compilation.

Note: For the major road network in the Amazon region, a length-weighted distribution of the IRI is plotted for road segments by their type. IRI = International Roughness Index measured in units of meters/kilometer; km = kiometer.

Map 1.15 Variations in energy supply quality across the region causes frequent electricity supply disruptions



Source: Based on ANEEL (2024), OSINERGMIN (2024), and SSPD (2023).

Note: The EGI s expressed as the fraction of a year lived with power outages at each location. It was calculated by multiplying the yearly average power outage duration (DIU/SAIDI/DEC) by the yearly average power outage frequency (FIU/SAIFI/FEC), as reported by energy distributors. The green hues reflect rare outages and thus higher service quality levels; orange and red reflect a higher EGI score, i.e., more frequent and longer outages and thus lower service quality.

Relative to the Urban Amazon, the Rural and Deep Forest Amazons also experience gaps in energy provision and the related infrastructure. To assess energy fluctuations experienced by a consumer, the Electrical Grid Instability (EGI) index was utilized.[20] The EGI was based on data on the average annual duration and frequency of power outages in Brazil, Colombia, and Peru.

Electricity supply is unreliable across the Amazon region, characterized by a level of instability far above national averages. As expected, more developed areas, such as São Paulo (Brazil), Callao (Lima, Peru), and Bogotá D.C. (Colombia), have EGI scores below 0.5 percent (map 1.15), meaning electricity is disrupted fewer than two days per year. In contrast, significant gaps are observed in the Amazon region. In Roraima (Brazil), the average resident experiences 40 blackout days per year. In Madre de Dios (Peru), outages total 114 days annually—about one every three days. The worst case is Caquetá (Colombia), where electricity is interrupted 310 days a year. According to IPSE (2024), 66 percent of the population of Caquetá experiences outages daily, and 18 percent have electricity fewer than five hours a day.[21] These figures show that even when electricity is technically "available," its quality is so low that it severely constrains everyday life. Frequent power cuts and voltage drops limit digital access, disrupt health care services, undermine food refrigeration, and reduce the viability of bioeconomic production—reinforcing cycles of exclusion and underdevelopment in the region.

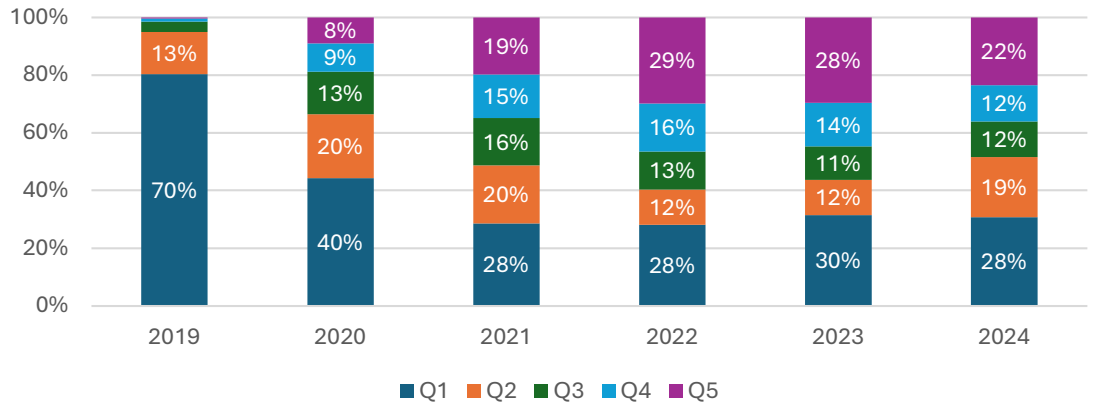
20 The EGI is calculated by multiplying two variables—duration and frequency of supply interruptions—to estimate the total blackout hours per year and then expressing that figure as a share of the 8,760 hours in a year (of 365 days). A higher EGI score reflects more frequent and longer outages and thus lower service quality.

21 Official data from IPSE (2024) for zones disconnected from the national grid (Zonas No Interconectadas, or ZNI).

Turning next to digital infrastructure, fixed and mobile network speeds—key indicators of the quality of digital connectivity—have recently improved in the Urban Amazon. Understanding the current state of both fixed and mobile network speeds helps identify existing gaps and prioritize investments necessary for meaningful digital connectivity.

Yet fast and stable fixed-network connectivity remains a challenge, despite significant improvements over the years. In 2019, over 80 percent of the population fell into the lowest-speed quintiles (Q1 and Q2), according to Ookla data. By 2024, this figure had improved substantially, to around 50 percent. But despite this positive trend, the proportion of the population experiencing higher speeds (Q4 and Q5) remains relatively low; only about 20 percent of the Urban Amazon's population was in the highest-speed quintile in 2024, indicating potential for further improvements in network speed across the area. Over time, the percentage of individuals in the second-lowest quintile (Q2) has also declined, suggesting a reduction in low-speed connections overall (figure 1.5).

Figure 1.6 Evolution of fixed-network speed, by quintile, in the study area

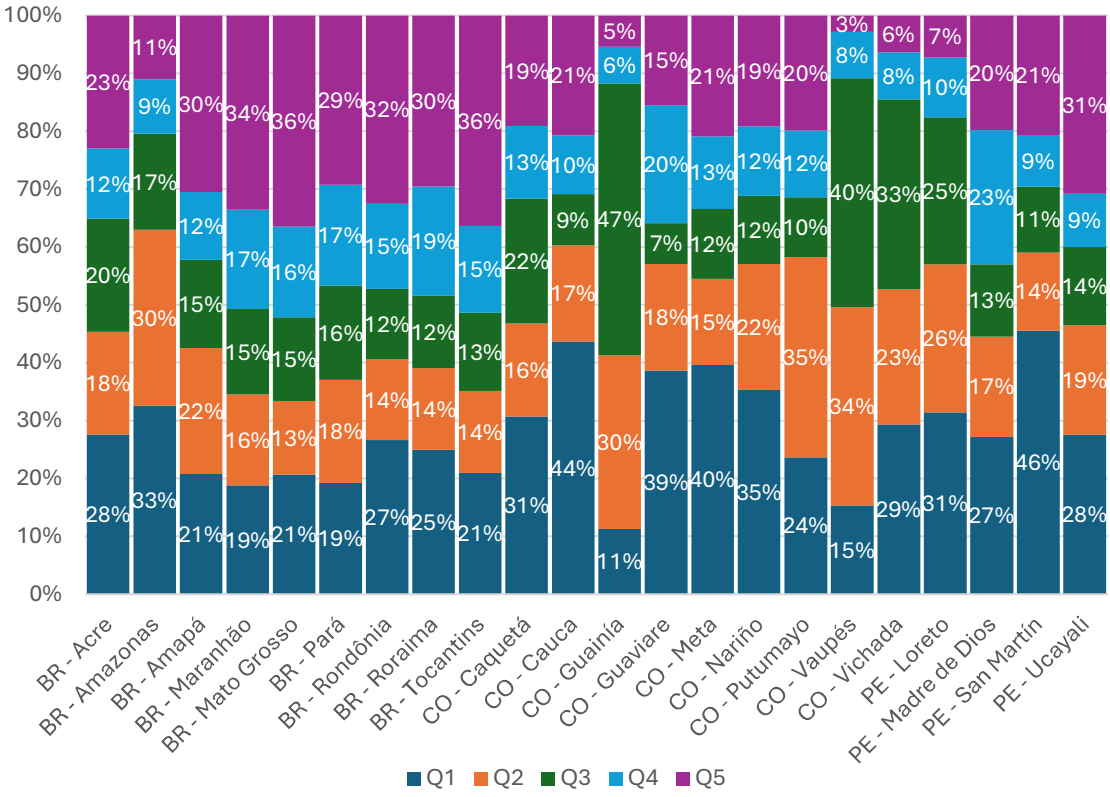


Source: Based on Ookla data.
Note: Q = quarter (of a fiscal year).

Challenges persist in the Rural and Deep Forest Amazons. Consider figure 1.6, which presents the distribution of network speeds by state and department. The figure highlights that the limitations of digital infrastructure continue to impact a large segment of the population. However, there is clear evidence of progress in fixed-network speed, with notable improvements between 2019 and 2024. Yet, the most significant advancements have occurred in higher-speed quintiles, highlighting that benefits are likely accrue to regions already benefitting from improved connectivity.

The severe limitations in the access to and quality of digital connectivity were highlighted during interviews in the Colombian Amazon. A representative of AMUR in Puntamayo told us, "There are days when the [internet] signal goes down and you are completely disconnected [...] That's talking about the population centers. In the villages: nothing [in the way of connectivity]. The communities have their cell phones, but they only connect to the internet when they go to town and that's where they receive information. [In] the border area with Ecuador, there are more antennas and at least the signal is strong enough to receive WhatsApp. But you can't say, I'm going to call you directly.' That's impossible."

Figure 1.5 Evolution of fixed-network speed, by quintile, in the study area



Source: Based on Ookla data.
Note: BR = Brazil; CO = Colombia; PE = Peru.

Box 1.5 The affordability of transport, energy, and digital services in the region

Substandard infrastructure across numerous sectors can cascade into an affordability crisis that further limits access to economic opportunities within the three Amazons. Consider first the case of road quality and transport costs. Transport costs have been shown to be dramatically higher in developing than high-income countries (Atkin and Donaldson 2015; Herrerra Dappe et al. 2025), and poor road quality is an important driver of these costs (Cosar

and Demir 2016). Interviews compiled for this report show that freight rates in the region can be excessively high. In Pará, cargo transport rates ranged between US$0.09 and US$0.17/ton-km. These costs are consistent with the figures for many low- and middle-income countries but far exceed those in high-income countries, where cargo transport rates are about US$0.01/ton-km (Herrera Dappe et al. 2025). Comparable data are not easily available for Peru or Colombia, but high commuting costs in Peru, equal to about US$20–50/week, were reported in qualitative interviews.

High costs of energy are among the main barriers to electricity use in the Amazon. Sixty-five percent of residents[22] in Brazil's northern states—including Amazonas, Acre, Roraima, Rondônia, Pará, Amapá, and Tocantins—rank electricity as their biggest household expense, even above food (Instituto Pólis 2024). Among low-income families, 53 percent spend over half of their income on electricity, and 60 percent have not fully paid their bills. Across all income groups, 22 percent are in debt to their energy provider. While consumer, producer, and investor subsidies exist, these financial burdens remain a major source of exclusion from reliable energy access and contribute to a cycle of default and disconnection.

Energy in the Amazon is costly due to reliance on diesel generation. Fuel prices in the Amazon are significantly higher than in other parts of the three counties. For example, in Brazil, gasoline cost (Amazonas 365, 2025) R$6.11/liter (l) (US$1.06) in São Paulo, R$7.29/l (US$1.26) in Manaus, and over R$8.49/l (US$1.46) in interior cities like Parintins (Amazonas 365, 2025) in February 2025. In Leticia, in the Colombian Amazon, gasoline cost approximately US$1.11/l on average as of February 2025 (El Tiempo, 2025; Cambio, 2024). Similarly, in Peru, gasoline cost US$1.27/l in Loreto in February 2025 (OSINERGMIN, Peru 2025).

High transport costs worsen the already substantial energy costs. The cost and reliability of diesel imports are primary drivers of energy costs in the region, which relies on diesel-based generation. Fossil fuels must be shipped over long distances, often on rivers, and transport is often unreliable. For example, transporting diesel over 1,500 km from Manaus to Tabatinga can take 20 days when river conditions are good and over a month during the dry season. In Colombia, diesel is delivered to Leticia over 3,000 km over 40 days via pipes, roads, and rivers. These supply chains are vulnerable to increasingly frequent climate shocks, such as prolonged droughts, which disrupt transport and can cut off fuel delivery entirely.

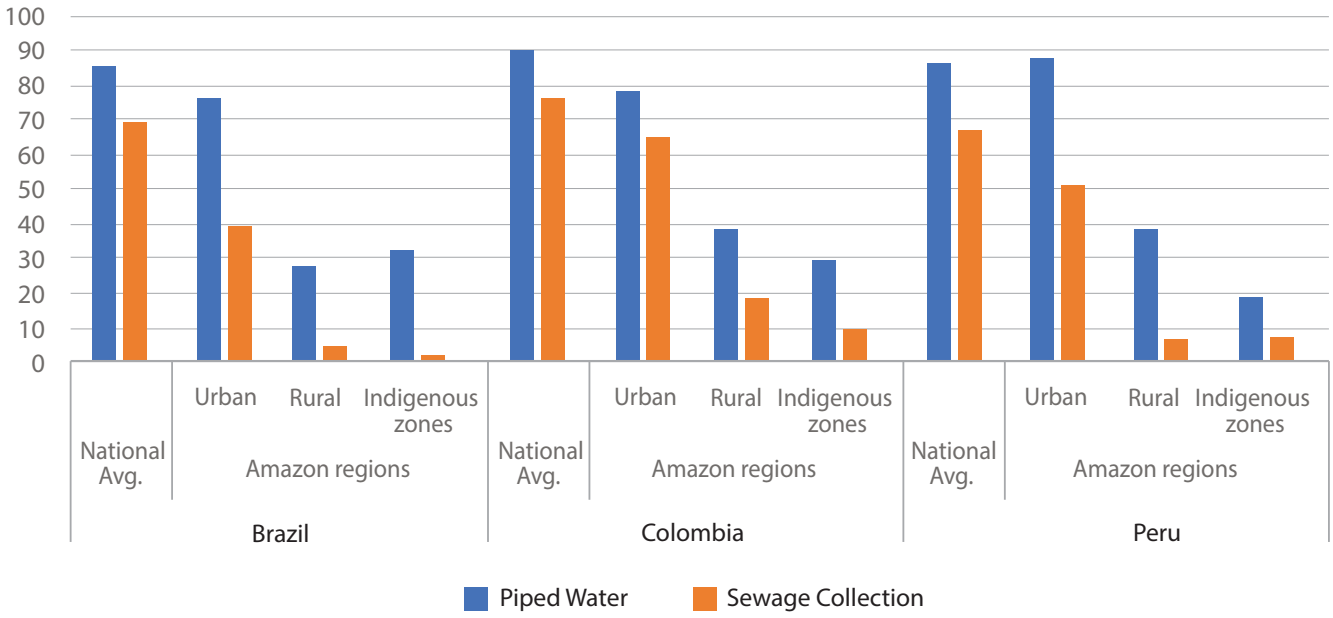
nfrastructure gaps in energy and transport make connectivity costlier for remote communities, for which cellular towers, heavily dependent on fossil fuels, are the key option for connectivity. Connectivity costs between US$10 and US$60 monthly, representing 3–16 percent of the average monthly per capita household income in Brazil (based on figures from the Government of Brazil [2024]).[23] In Colombia, data compiled for this report reveal that households in populated centers and dispersed rural areas bear internet costs that are twice the national average.

22 These low-income families benefit from lower electricity tariffs.

23 These findings align with those of a recent World Bank (2023) report: internet services may account for more than 15 percent of the monthly income of the lowest-income households.

Gaps between the Urban Amazon and the Rural and Deep Forest Amazons extend to water and sanitation services as well. Water and sanitation remain critical determinants of health and quality of life. The continued lack of access to safe drinking water and adequate sanitation facilities in many Amazonian communities leads to preventable diseases and high child mortality rates. Reliable water and sanitation systems require energy for pumping and treatment, and distribution, underscoring the need for coordinated planning and investment across both infrastructure sectors.

Figure 1.7 Piped water and sewage services in the Amazon region lag national averages, in particular in rural and Indigenous areas, 2023 (%)



Source: Based on PNAD (2023), DANE (2023), and INEI-ENAHO (2023).

The scarcity of clean drinking water and adequate sanitation services exacerbate the risk of contamination and the spread of waterborne diseases. Figure 1.7 highlights disparities between the region and national averages together with interregional disparities. Given that health conditions are deeply tied to access to work opportunities and income, this situation limits opportunities for the Rural and Deep Forest Amazons to "catch up" with the Urban Amazon. Almost 40 percent of the population in the Legal Amazon lacks access to drinking water, according to Rodrigues and Silva (2023), and a similar figure can be observed in several departments in Colombia (SSPD 2019). But this concern is most severe in Peru; less than 10 percent of the population in most Peruvian Amazon departments have access to safe water (INEI 2024).

Sanitation services are equally deficient. Access to the public sanitation network inside the home is more prevalent among the Urban Amazon. In the Peruvian Amazon, access is lowest in Ucayali—only 37 percent of households report access—whereas it is at 49 percent in San Martin. A septic tank or cesspool remains prevalent in households without indoor access to a public sanitation network; on average 25–32 percent of all households in all regions use a septic tank, except in Ucayali, where latrines dominate (at one-third of households). A significant share of households lack sewage collection and are using an open field: 12 percent of households in Loreto and 5 percent in Madre de Dios and Ucayali. In Colombia, all departments in the Amazon region also have significantly lower access to sanitation solutions: the access rate is at 24 percent in Vaupes, the lowest compared with the 75 percent non-Amazon average. Some regions in the Legal Amazon face similar challenges, even those hosting part of the Urban Amazon cluster—for example, just over 20 percent of households have a connection in Pará.

Deep Forest Amazon

- This is the largest cluster by geographic area (3.9 million square kilometers), but the smallest by population (3.2 million). The region is defined by its dispersed, poorly connected population and its pristine forest.

- The cluster has the smallest major road network among all the clusters, has the lowest degree of digital connectivity, and the smallest share of population with energy access.

- In the Deep Forest, multiple infrastructure gaps overlap and leave isolated communities with limited economic opportunities and scarce access to critical services. Over 80 percent of the population lives more than 10 km from a health care facility and a third lives a similar distance away from the nearest school. Unreliable electricity and poor internet connectivity hinder communities' ability to overcome these challenges.

- To preserve the ecological integrity of the region, targeted, technologically innovative, solutions must be utilized. Expanding digital access for online education and telehealth, alongside using drones and other low-impact transport solutions for better connectivity, will be critical for improving the development opportunities in the region.

Of the three connectivity clusters, the Deep Forest Amazon has the largest area and is the ecologically best preserved. The cluster covers about 4 million square kilometers, or 65 percent of the entire region. These remote areas remain largely untouched and are home to 3.2 million people and also ecosystems and biodiversity vital to the Amazon's global environmental function. However, the small and often Indigenous populations residing here are severely isolated due to lack of transport, energy, and digital infrastructure. Indeed, the region has the lowest degree of digital connectivity, the largest population without access to energy, and the smallest road network among the three Amazon clusters.

Without reliable access, communities face persistent food insecurity, limited access to education and health care, and economic vulnerability. The cluster hosts more health care facilities than the Rural Amazon (681 relative to 626), but the low population density and poor connectivity raise the cost of receiving critical services. Given the cluster's dispersed population and high ecological value, any intervention must prioritize environmental preservation and be guided by community-led, affordable, and modular solutions. Investments improving basic services and resilience through low-impact approaches can protect natural ecosystems while addressing the fundamental needs of local populations.

In the Deep Amazon, the intersection of limited access to infrastructure and poor-quality transport, digital, and energy services constrain local communities. In this section, we highlight the key gaps resulting from these compounding infrastructure gaps.

Access to and quality of education: Creating opportunities for the next generation

Improved transport, energy, and digital infrastructure are indispensable for ensuring that children and youth in the Amazon can access quality education. Many schools in the Amazon remain difficult to reach, lack reliable electricity, and have no digital connectivity. These gaps reinforce cycles of inequality and limit the human capital potential of the Amazon's next generation.

Long travel distances can severely impact students' attendance and the continuity of learning. Figure 1.8 presents the fraction of each cluster's population that lives within a given distance from the nearest school. In the Deep Forest Amazon, only 10 percent of the population lives within 2 km of a school (aerial distance), over 34 percent must travel more than 10 km, and 4 percent lives over 50 km away from a school. While access has improved in the Rural and Urban Amazons (with 22 percent and 100 percent of the population within 10 km, respectively), weak energy supply and low digital connectivity levels contribute to the access gap in the Deep Forest Amazon.

A lack of reliable electricity access further strains educational outcomes as schools struggle to provide full teaching hours, integrate digital learning, or retain students. Data for Brazil, Colombia, and Peru show a correlation between electricity access and education outcomes: in areas with low electrification, enrollment in early childhood and secondary levels is on average one-third lower than national rates (figure 1.9). In Deep Forest communities, students often study by candlelight or kerosene lamps. Completion rates are similarly affected; Amazonian students lag by up to 20 percentage points in primary education, and secondary school completion levels reach only half the national average. Without targeted investment in electrification for learning environments, the region's educational gap will persist, limiting opportunity for the next generation.

Figure 1.8 Most people in the Rural and Deep Forest Amazon live farther than 5 km from a school

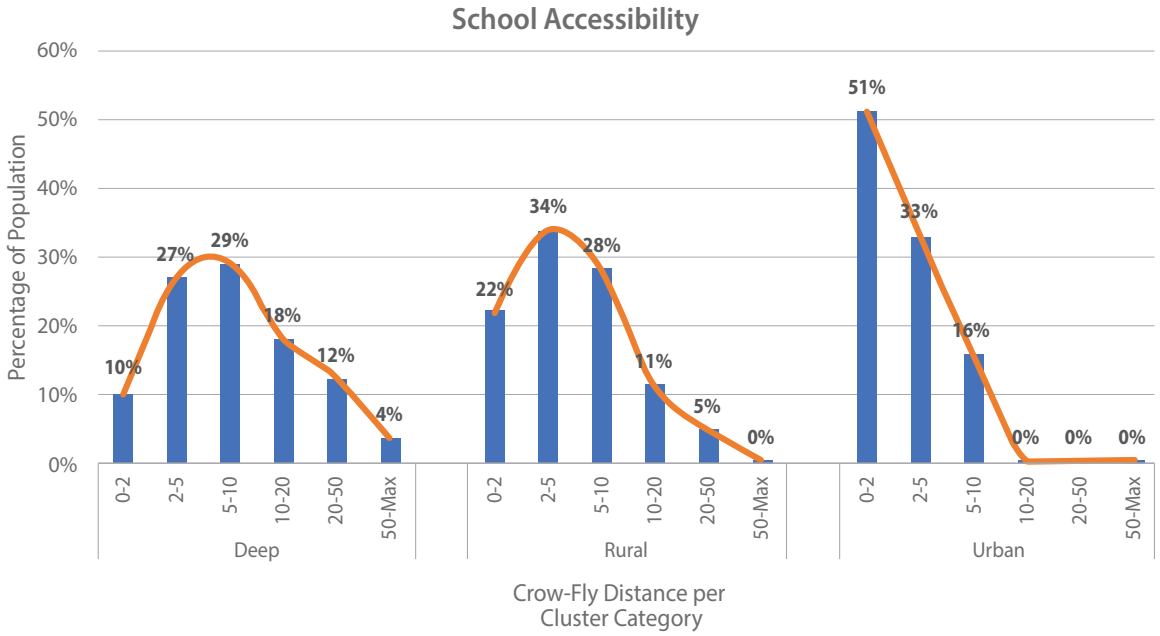
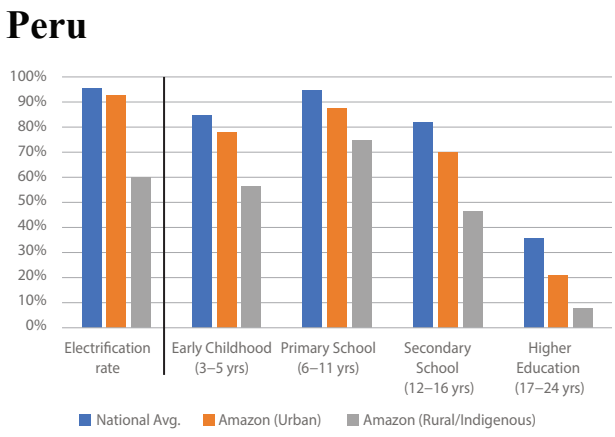
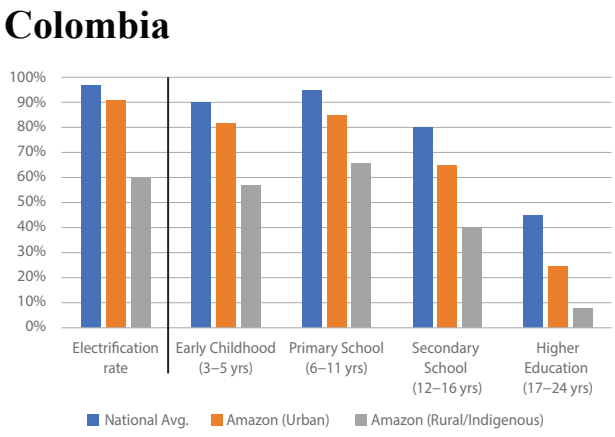
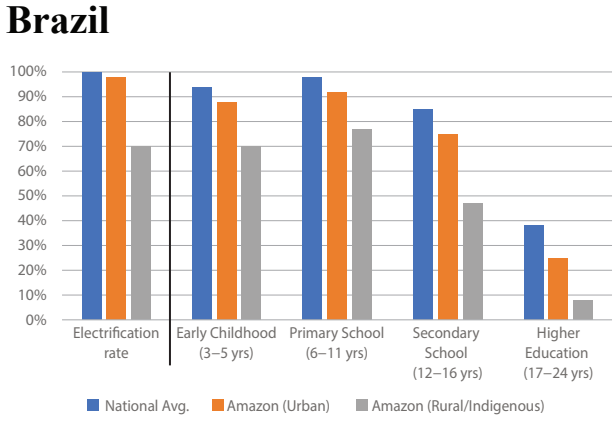


Figure 1.9 Electrification and enrollment rates by school level, 2023 estimate (%)







Digital connectivity in schools across the Amazon region remains limited, uneven, and in many cases poorly documented. We used Ookla Speedtest data, considering a school connected if there was at least one internet test within a 300-meter radius of an Ookla grid.[24] In total, we considered 85,059 schools.[25] Map 1.16 plots the results of this analysis. Digital coverage of schools is highest in the Legal Amazon in Brazil, at 75 percent, followed by the Peruvian Amazon (53 percent) and the Colombian Amazon (30 percent).

The quality of digital connections in schools in the Amazon region remains highly unequal: connectivity is consistently better in schools in the Urban Amazon than the Rural and Deep Forest Amazon.[26] In Brazil's Urban Amazon, 85.9 percent of schools have high-performance internet connections. Peru's Urban Amazon follows, with 58 percent of schools reporting high-performance connectivity, while 9.5 percent have standard and 8.7 percent limited connectivity. In contrast, disparities are greater among Colombian schools in the Urban Amazon: 31 percent have high-performance internet, 16.3 percent standard, and 25 percent limited connectivity.

The Rural and Deep Forest Amazons face significant digital infrastructure gaps. However, coverage is relatively better in the Legal Amazon than its neighbors. In the Rural Amazon of Brazil, 59.1 percent of schools appear to have internet connectivity, and, notably, 42.1 percent benefit from high-performance connections. This stands in stark contrast to Colombia and Peru's Rural Amazon regions, where only 10.9 percent and 21.9 percent of schools, respectively, reach high-performance levels. In the Deep Forest Amazon, digital connectivity drops dramatically: just 27.7 percent of schools in Brazil have high-performance connections, compared with 15.8 percent in Peru and a mere 11.8 percent in Colombia. Brazil's relatively higher performance in rural and remote areas presents a valuable case study for possible replication across neighboring countries. Additionally, data indicate that schools at the initial and primary education levels are particularly underconnected across the region. In all three countries—Brazil, Colombia, and Peru—many initial and primary schools either lack digital speed reporting or are entirely without internet connectivity, suggesting persistent service gaps at the most foundational stages of education.

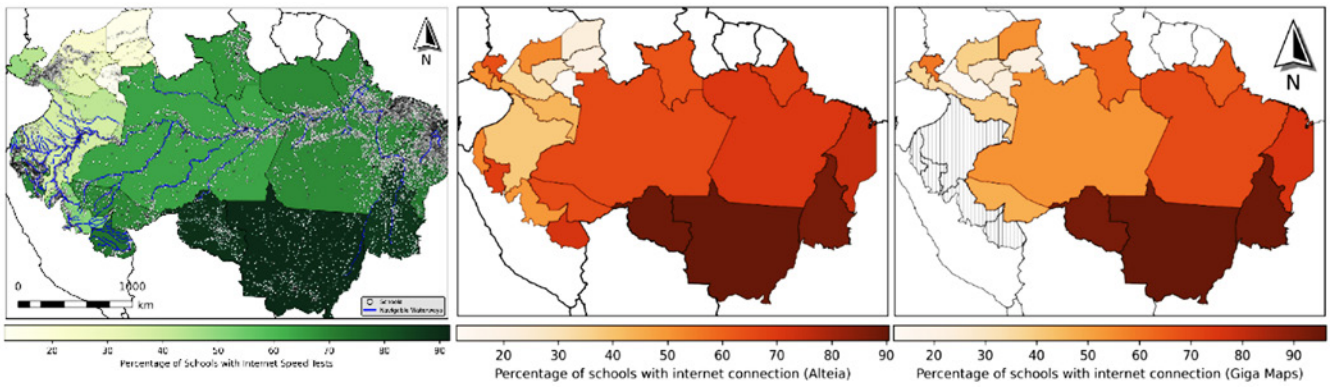
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24 This database measured the internet considering grids of 600 meters x 600 meters.

25 The GIGA initiative of the United Nations Children's Fund (UNICEF), which offers a real-time register of internet access globally, offers an additional way to measure school connectivity (https://maps.giga.global/map). This database includes information on 55,793 schools. According to these data, large portions of the Colombian and Legal Amazon have schools either without internet access or with limited available data on their status. In the Peruvian Amazon, the situation is less clear, with schools recorded as having unknown connectivity. Where more detailed data exist, as in Brazil, significant gaps are evident: in the state of Amazonas, for example, up to 36 percent of public primary and secondary schools lack internet access, and in Acre, this is 32 percent. In Colombia, digital connectivity is significantly more limited; in Caqueta, 88 percent of schools are not connected.

26 To assess whether available digital connectivity can support the use of advanced digital education tools, the study assessed the quality of internet access in schools across the region. Based on global recommendations, we defined three levels of digital connectivity quality—**high-performance connectivity**: more than 50.000 kilobits per second (kbps) (50 Mbps); **standard connectivity**: 25.000 kbps (25 mbps) to 50.000 kbps (50 Mbps); and **limited connectivity**: lower than 25.000 kbps (25 Mbps). For a comparison of broadband in schools and colleges in the United Kingdom, see Giga (2023); , and for Brazil, GICE (2022).

Map 1.16 Share of schools with possible digital connectivity and with a known internet connection



Source: Based on data from Ookla, Alteia, and GIGA.
Note: Maps present the share of schools with digital connectivity according to the database indicated below the legend. Scales are provided in image. km = kilometer.

Health access and quality: Reducing vulnerabilities and saving lives

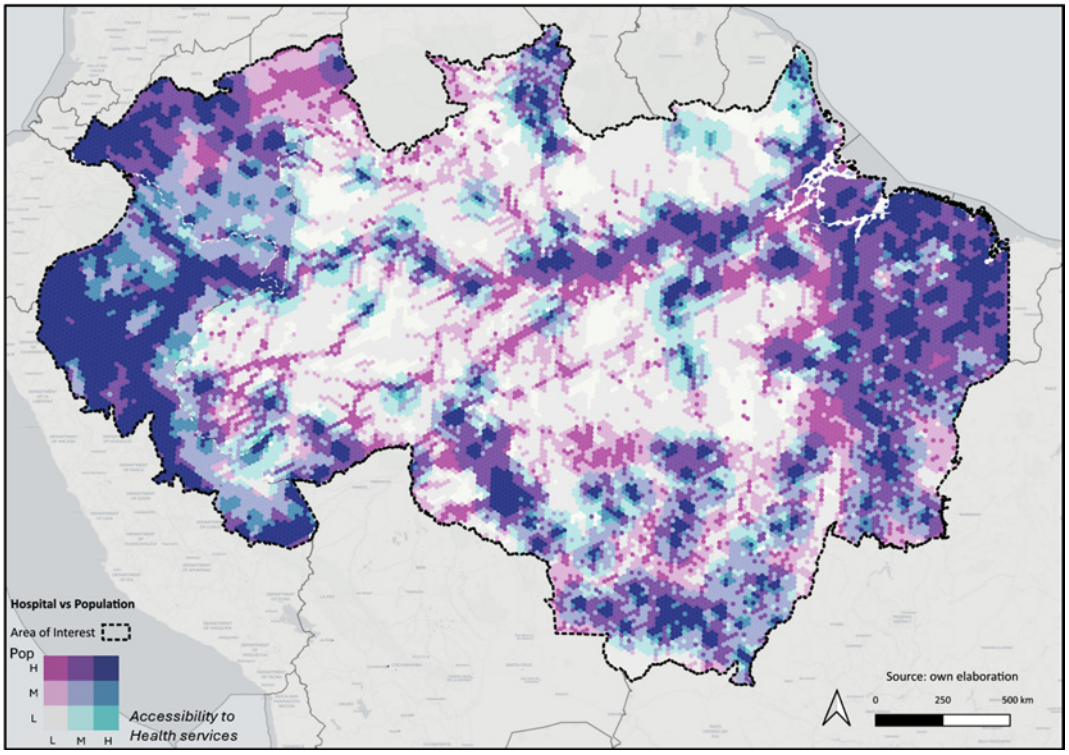
Inadequate health care facilities and services also have a negative impact on the living conditions of the region's communities. High infant and maternal mortality rates, along with the high prevalence of tropical diseases, are challenges common to Colombia and Brazil. Of particular concern is the growth of maternal mortality rates in the states of Roraima and Pará, Brazil; these grew at an annual rate of 7.81 percent in 2010 and 2.27 percent in 2021 (Lima et al. 2025). In Peru, chronic child malnutrition is especially high, reaching 21.7 percent in the department of Loreto (INEI 2023). Isolated communities face even greater health risks due to their very limited access to health care services, including immunization.

Health service delivery in the Amazon faces profound obstacles in reaching vast territories. The availability of transport, energy, and digital services has an influence here. Emergency response is also limited by transport delays, energy shortages, and lack of cold chains for vaccine storage.

A third of the region's population faces significant challenges in accessing hospitals. Many are at risk due to the lack of nearby medical facilities. For residents of the Deep Forest, reaching a hospital could mean traveling for hours—or even days—over rivers or poorly maintained roads. Only 6 percent of the population of the Deep Forest Amazon lives within 5 km of a hospital, while more than 61 percent must travel over 20 km—some even beyond 50 km—to reach care. Conditions are similarly challenging in the Rural Amazon, just 7 percent of whose population lives within 5 km, and nearly 64 percent must travel more than 20 km. Even in the Urban Amazon, where infrastructure is relatively stronger, access gaps persist: approximately 5.37 million people—representing 24 percent of the urban population—live more than 10 km from the nearest hospital.

Access to health care is constrained by the quality of medical facilities and the difficulties faced in trying to reach them. In map 1.17, turquoise indicates locations with high population density but low accessibility to hospitals—clear indicators of infrastructure lagging demographic growth. This mismatch is especially evident in certain inland areas and along the region's edges, underscoring the need for spatially targeted investment in health care infrastructure to meet the needs of these underserved communities. Communities receiving urgent medical attention late face higher mortality rates due to preventable illnesses.

Map 1.17 Hospital Population Index showing population density and access to hospitals



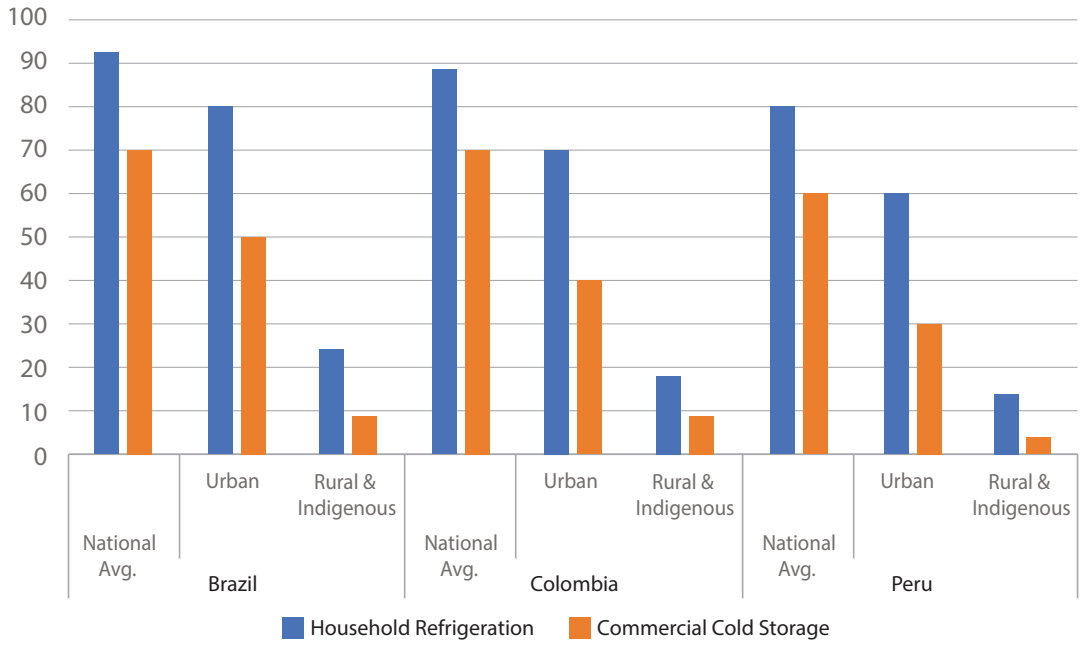
Source: Based on World Bank Group database (2025).
Note: Areas highlighted in turquoise and pink represent communities where residents, despite forming significant population centers, have limited access to critical facilities. km = kilometer.

Lack of reliable electricity in the Amazon undermines access to quality health care, particularly for rural and Indigenous communities. Health care access in the Amazon region is among the worst in Latin America due to its remote geography, underfunded infrastructure, and systemic inequities.[27]

27 Indigenous peoples in the Amazon face serious health inequalities. This is reflected in indicators worse than national averages, such as high infant and maternal mortality rates and the prevalence of infectious diseases such as malaria, tuberculosis, hepatitis, and leishmaniasis. These diseases, especially in childhood, carry a high mortality risk, which is exacerbated by poor diagnostic information and limited accessibility to adequate health services (ORA 2024).

The storage of temperature-sensitive medicines—such as vaccines, insulin, and antibiotics—remains a major challenge in the region as power supply is either unstable when available or entirely absent. A majority, 60–80 percent, of the territory of the Legal, Colombian, and Peruvian Amazons lacks reliable electricity for operating refrigerators (figure 1.10). Intermittent supply, or lack of backup power, often prevents health posts in remote areas such as the Deep Forest from using essential medical equipment, including oxygen machines, ultrasound scanners, or sterilization tools. This issue is acute in areas where over 80 percent of communities can be accessed only by boat or small plane. Such communities receive delayed emergency care and are rendered even more vulnerable. Even in communities with health centers nearby, unreliable electricity disrupts services and increases reliance on traditional or informal care. These conditions compound preventable health risks, particularly for newborns and young children, who need electricity-dependent care, such as neonatal warming units or vaccines as per schedule.

Figure 1.10 Access to commercial cold storage and household refrigeration, by area type, 2023 (%)

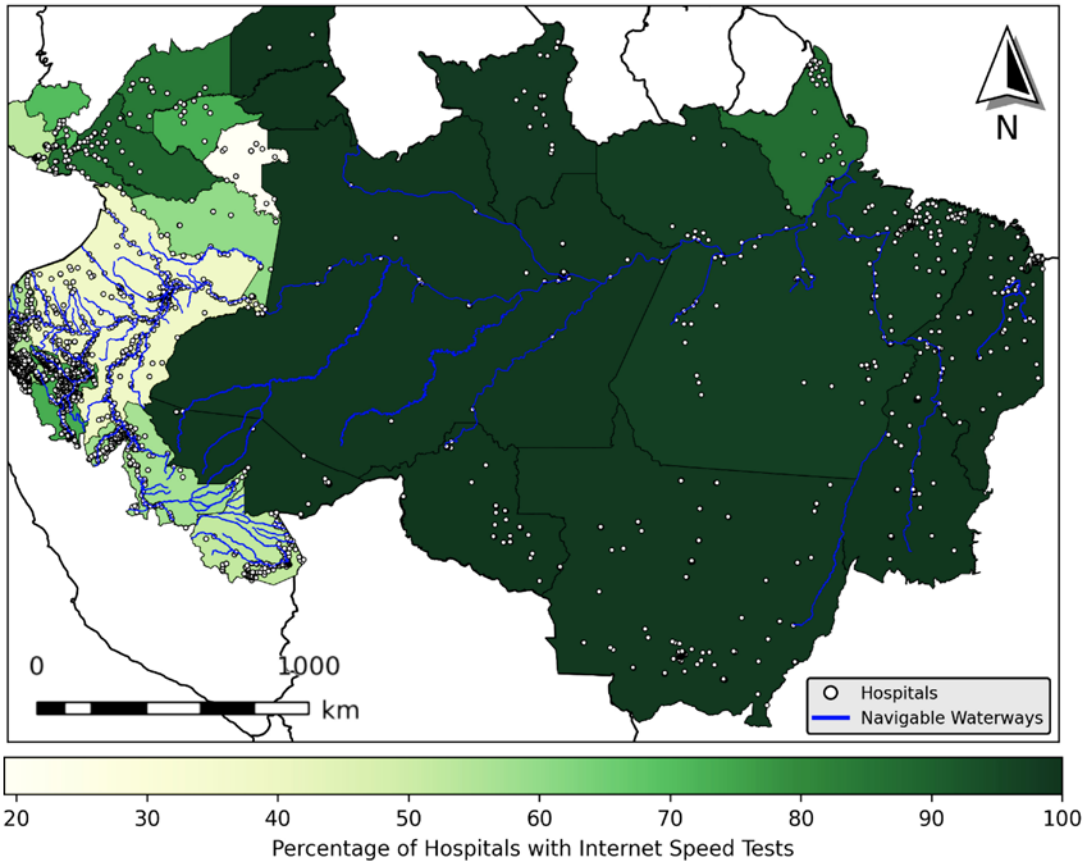


Source: Based on IBGE, ANEEL, and Ministry of Mines and Energy for Brazil; DANE, UPME, and Ministry of Mines and Energy for Columbia; and INEI, OSINERGMIN, and Ministry of Energy and Mines for Peru.

Given these gaps in access and service provision, expanding digital infrastructure is not just a technological upgrade but a public health necessity. Telemedicine offers a practical solution, making it possible to provide remote consultations; perform diagnostics; and provide follow-up care through video calls, messaging, and the sharing of medical images. However, these services require reliable, high-speed internet. The importance of this is especially evident in areas lacking basic sanitation and clean water, where residents are frequently exposed to skin conditions, gastrointestinal infections, and other preventable illnesses. Without timely intervention, made possible through telemedicine, these minor health issues could escalate into serious conditions.

Health centers and hospitals across the Amazon need high-quality digital connectivity to deliver better health services, especially in remote and isolated areas via telemedicine. Nearly 73 percent of health centers in the Amazon region seem to have internet connectivity, with 2,473 facilities digitally connected (map 1.18). The highest concentrations of connected centers are found in and around the urban areas of Chachapoyas, Moyobamba, and Pucallpa in Peru. Information on digital connectivity speeds is missing for 891 health centers—roughly one-quarter of all facilities in the region—highlighting the need for more complete and reliable data to better assess and address connectivity gaps.

Map 1.18 Digital connectivity of the region's hospitals



Note: Colors indicate the share of hospitals with digital connectivity as measured by Ookla speed tests. km = kilometer.

Hospitals in the Deep Forest and Rural Amazons generally have lower-quality digital connectivity. For instance, 26.9 percent of Brazilian hospitals in the Deep Forest Amazon do not present internet speed data. This percentage reduces to 4.7 percent in the Rural Amazon and 0.3 percent in the Urban Amazon. Only 29 hospitals in Brazil lack internet speed data, indicating the modest size of the digital connectivity gap in the Legal Amazon's health care infrastructure. The Colombian Amazon exhibits a similar pattern: more than 80 percent of hospitals in the Rural and Urban Amazons have internet speed data. Finally, the Peruvian case is more critical: 74.2 percent and 50.8 percent of hospitals in the Deep Forest and Rural Amazons lack internet speed data. Thus, the Peruvian Amazon should be prioritized for investment, particularly in its Deep and Rural regions, besides the Deep Forest Amazon of Colombia and Brazil.

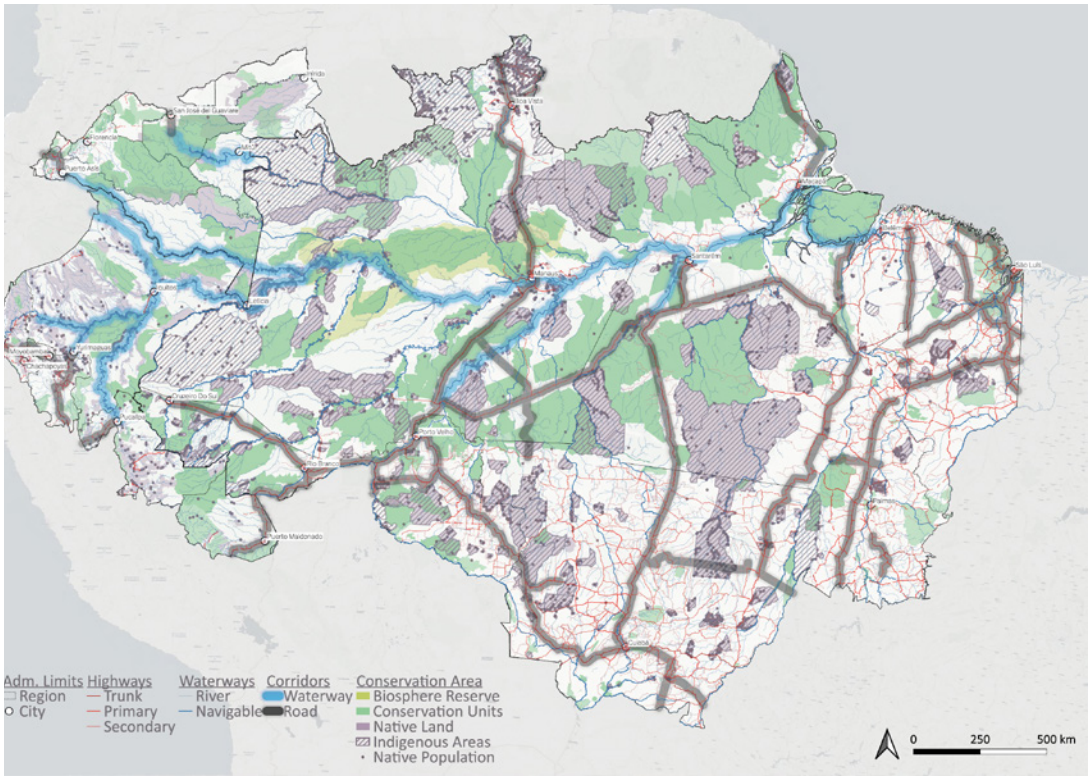
An integrated, cross-sectoral approach combining energy, connectivity, sanitation, and human resource development is needed to address key health care challenges in the Amazon. Organizations consulted during the analysis highlight the possibility of establishing health posts equipped for medium-complexity procedures, supported by hybrid energy systems (solar/diesel) to ensure continuous operation and proper refrigeration of medical supplies. Expanding digital connectivity is also seen as critical to enable telemedicine services. According to ASPACS (Association of Agro-Extractive Producers of Colônia do Sardinha), locating health posts closer to productive areas can even boost local productivity by reducing work absences related to untreated or delayed illnesses.

Environmental concerns and vulnerabilities in the Deep Forest

The ecological importance of the Deep Forest, and its growing environmental vulnerabilities, increases the complexity of developing solutions to infrastructure gaps in the region. As highlighted above, the region is sparsely populated, and this lack of density limits the availability of feasible solutions to help overcome infrastructure gaps that create education and health-related shortcomings. Improving access is not as simple as constructing a road or extending power lines to these remote communities. Preserving the environmental integrity of the region is paramount to protect the way of life of local communities while preserving the economic opportunities afforded by the developing bioeconomy sector. Identifying low-impact, targeted, and place-based solutions has never been more important, as environmental risks, and vulnerabilities of existing infrastructure begin to become more prevalent.

Road infrastructure is a critical piece of infrastructure that can be used to improve connectivity, yet the expansion of road networks can expand deforestation. Map 1.19 makes these risks clear by overlaying conservation areas and Indigenous reserves against major road and river corridors. The correlation between infrastructure availability and deforestation is unfortunately striking. As discussed above, Hsu et al. (2025) examined the extent of deforestation's impact in areas close to roads and revealed that an area of deforestation occurs 1–10 km from roadways. As noted, the present analysis clarifies that the range extends to 5 km.

Map 1.19 Conservation areas, native lands, and road and river corridors



Source: Original compilation.
Note: km = kilometer.

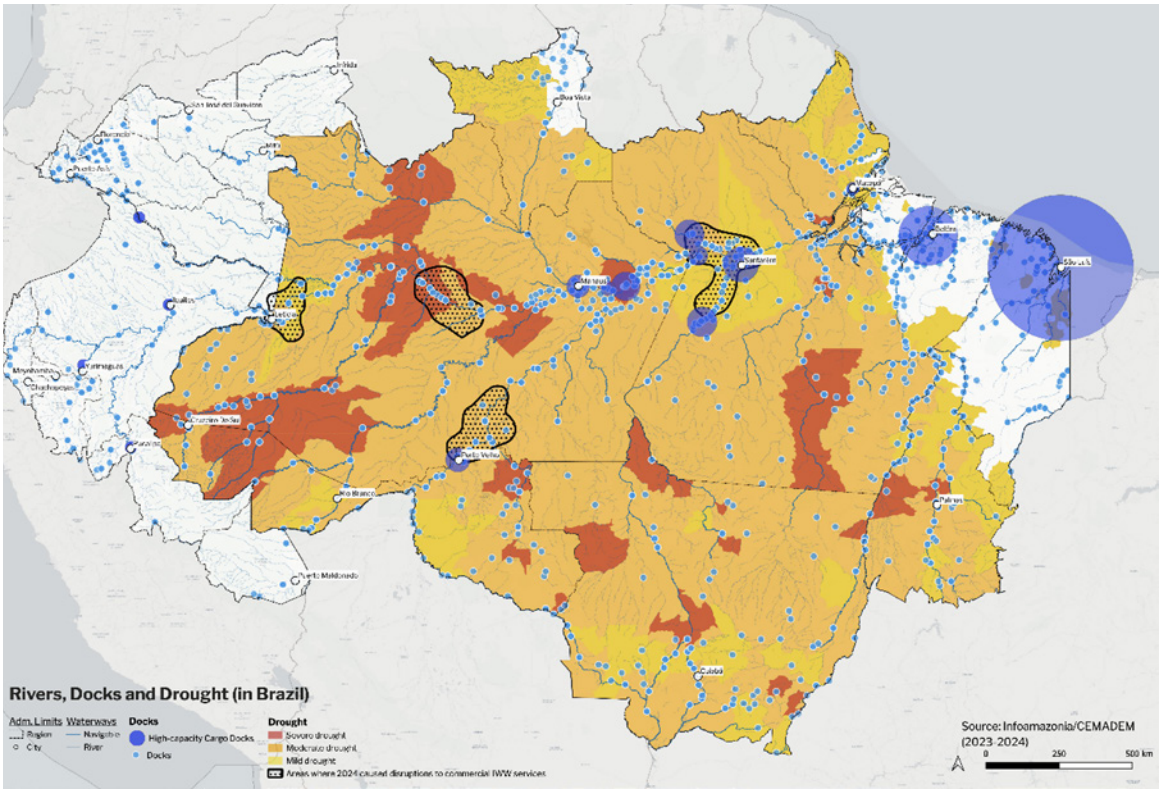
Appropriately targeting green infrastructure could help mitigate the risk of deforestation. Research has shown that rural roads are particularly harmful to forests, as trunk roads lead to networks of smaller, sometimes informal, roads, often making way for illegal logging (Soares-Filho et al. 2004). However, upgrading local road networks in remote communities could improve mobility for short-distance travel and make the transport of bioeconomy products to ports and docks more reliable. Sustainable approaches, such as Colombia's standards for green roads,[28] offer alternatives that can improve residents' quality of life while minimizing environmental impacts.

Leveraging the region's second major transport network, its river system, is one green solution, but it is increasingly vulnerable to frequent droughts. Seasonal variations of 12 to 15 meters (m) in river levels are common across the region's main rivers (e.g., the Amazonas, Solimões, Madeira, and Tapajós) between the rainy and dry seasons. However, recent extreme droughts like those in 2005, 2015–16, and 2023–24 indicate a shortening of the drought recurrence interval, previously estimated at 20 years. Droughts now occur with less predictability and greater severity, significantly disrupting navigation. The 2023 and 2024 droughts reduced the river level at the Manaus river port to the lowest seen since 1902. Data

28 Environmental guide for wildlife crossings on linear infrastructure (Guía ambiental de pasos de fauna silvestre en infraestructura lineal) and Environmental management guide for tertiary roads (Guía de manejo ambiental para vías terciarias) developed jointly by the Ministry of Environment and Sustainable Development and the Ministry of Transport in Colombia.

from the Geological Survey of Brazil (Serviço Geológico do Brasil, SGB) show that levels vary across most monitored rivers and in some cases include episodes of complete drying. Map 1.20 highlights areas sensitive to drought, including key ports and docks, zones prone to low water levels, and locations where commercial navigation was disrupted during the historic 2024 drought.

Map 1.20 Map of drought-sensitive areas, including those affected by the 2024 drought



Source: Based on World Bank, InfoAmazonia, CEMADEM, and SGB 2025.
Note: km = kilometer.

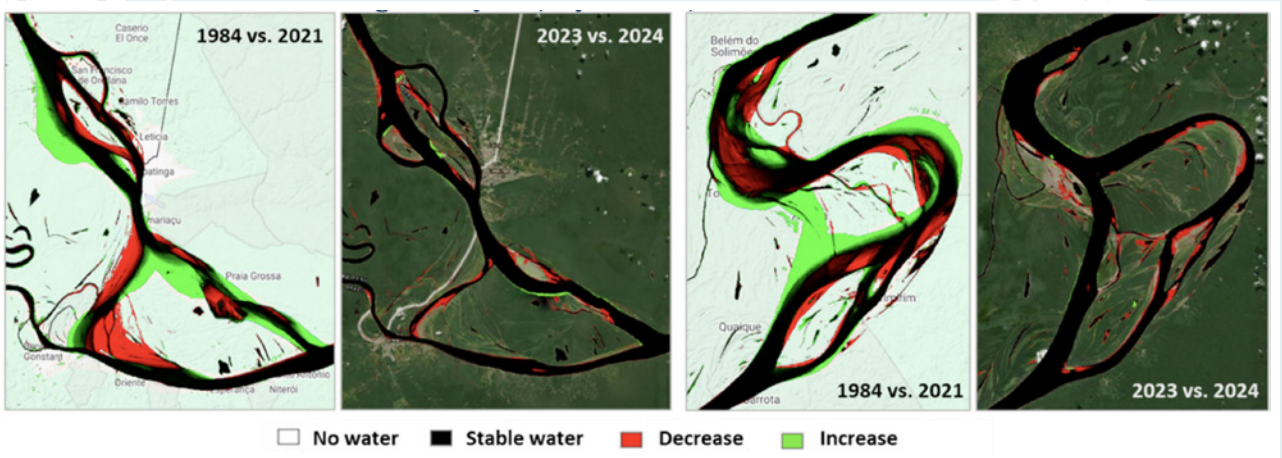
The vulnerability of river transport jeopardizes both logistics and community access to essential goods and services. Box 1.6 discusses this report's methodology for assessing the extent of river-related vulnerabilities in the region. Communities along small tributaries are disproportionately affected, often facing seasonal isolation. Commercial river transport is also disrupted. Travel times increase, cargo capacity is diminished, and freight rates surge. For example, during the 2024 drought, the journey between Porto Velho and Itacoatiara increased from 8 days to 20 days, cargo loads were reduced by 60 percent, and freight rates rose by as much as 150 percent. This is within a context of already high transport costs: the reference transport fee along the Madeira River, between Porto Velho and ports on the Amazon River, such as Santarém and Itacoatiara (Amazonas), is set at R$35 per tonne (Cargill tariff 2024).

Box 1.6 Assessing the vulnerability of river transport

Knowledge of river course changes and long-term weather trends is invaluable in informing river management and emergency preparedness. The World Bank collaborated with the European Space Agency to assess the dynamics and vulnerabilities of water bodies in the Amazon, covering an area of approximately 60,000 km², including a large section of the Amazon River around the city of Leticia, a Colombian city along the Amazon River at the border of Peru, Colombia, and Brazil. The methodology used is presented in the technical annex and can be replicated to inform decision-making on river management throughout the Amazon River basin.

Use of open satellite data (Sentinel-2) allows for easily scalable comparison of water extent between dry and wet seasons across different years. The biannual analysis is available over the long term (map B1.6.1: 1984/2021) and conducted for the most recent years (map B1.6.1: 2023/24). It focuses on quantifying the change of water extent within the dry seasons over the area of interest used for the hydrological inventory. Map B1.6.1 depicts the inventory for a sample area, illustrating that significant increases and decreases in water levels have naturally and simultaneously occurred along the selected river segment over the long term.

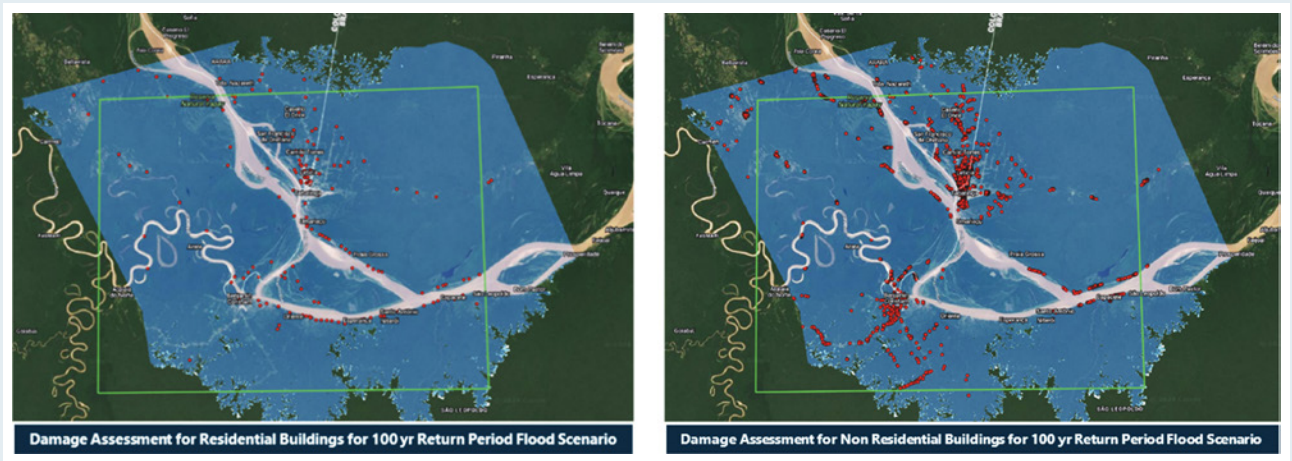
Map B1.6.1 Riverbed change in Leticia between 1984 and 2021 (GSWL); and between 2023 and 2024 based on satellite image analysis (dry season)



Source: Global Surface Water Layer (GSWL) on basemap; change analysis on Sentinel-2 Satellite imagery.

River flood modeling revealed Leticia's extreme vulnerability to flood risk: flooding events projected at 50-year intervals are expected to exceed 18 m. They become even more extreme for longer return periods of 100 years (map B1.6.2), and 500 years. Considering residential buildings, nonresidential buildings, and roads, the assessment classified damage levels from none to very high, based on flood depth and duration. The results underscored the urgent need for targeted mitigation strategies, such as improving drainage infrastructure, restoring floodplains, and promoting sustainable land use practices.

Map B1.6.2 Assessing flood damage of 100-year-return events to residential and nonresidential buildings



Source: Based on ESA satellite data.

The findings of the assessment inform several strategic recommendations to boost flood resilience in the Amazon. Foremost, more effective floodwater management requires upgrading and expanding drainage infrastructure. Further, promoting sustainable land use practices can help reduce deforestation and increase the basin's natural capacity to absorb floodwaters. Also essential is to preserve and restore floodplains, which act as natural buffers against flooding. Finally, community preparedness must be prioritized by developing early warning systems and emergency response plans to protect lives and property during flood events.

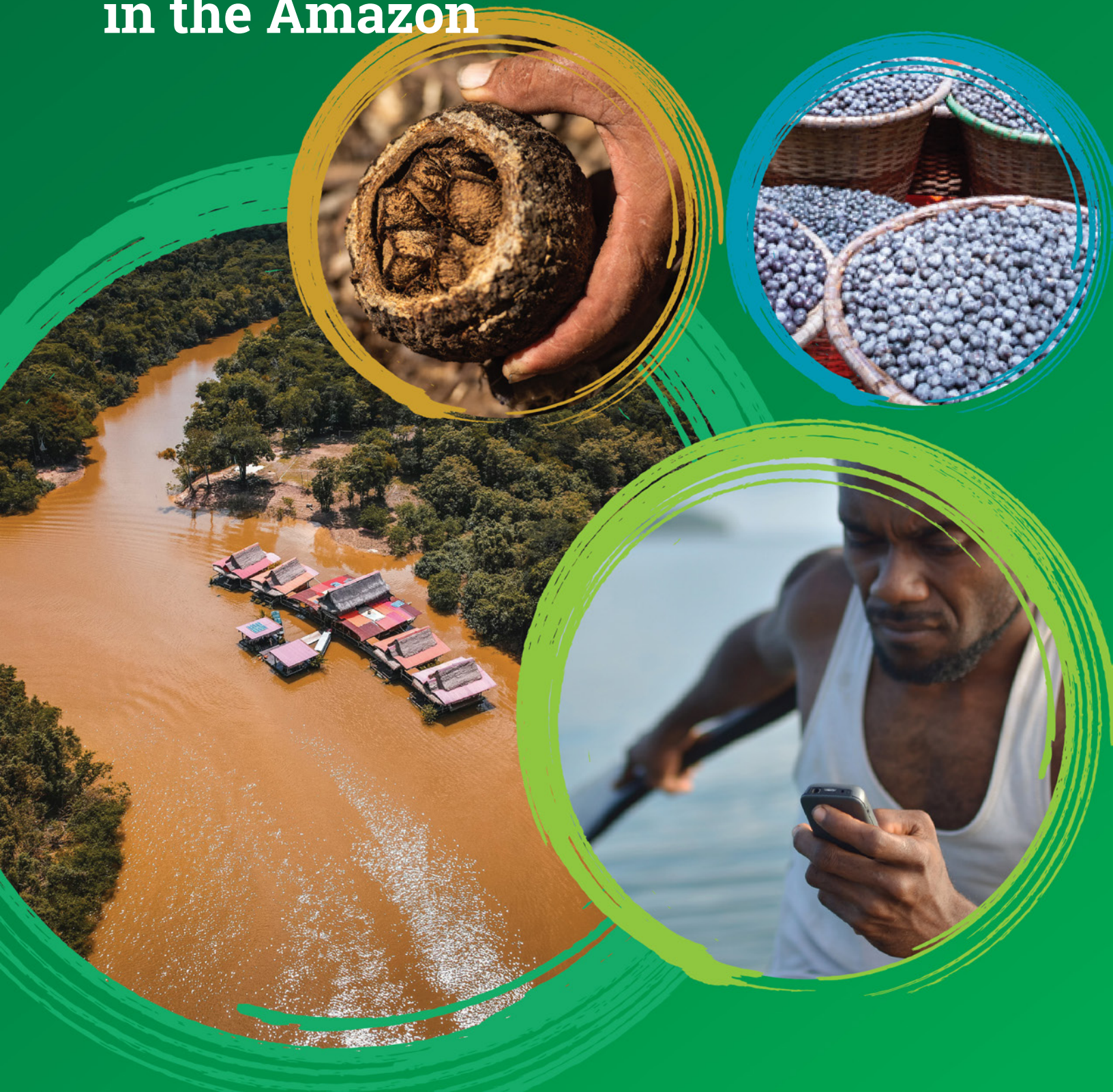
Climate-related disruptions, including droughts and the associated constraints imposed on transport networks, strain the region's energy infrastructure. The 2023–24 South American drought exemplified this vulnerability (RealTime1 2023). Water levels hit record lows, and there were acute shortages of potable water, widespread wildfires, and severe disruptions in the river transport of fuel and other supplies. In Amazonas, Brazil, the energy supply of 23 cities was critically affected when the drought disrupted fuel transport by river. Brazil's Santo Antônio hydroelectric plant was forced to shut down for the first time since 2012, while the Balbina Dam operated at just 30 percent capacity. Colombia's reservoirs shrunk significantly, raising concerns of blackouts and rationing. Peru, which generates over 50 percent of its electricity from hydropower, is also exposed to these risks. In the Deep Forest, heavy reliance on fossil fuels as an energy source implies further disruptions due to the inaccessibility of key transport networks.

The Amazon region's digital infrastructure is also highly vulnerable to extreme weather events. Flooding submerges fiber-optic cables and damages telecommunication towers—as seen in 2023, when 120 km of fiber-optic networks failed, severing communication for 400,000 people (MMA 2024). During the dry season, fixed internet cables laid beneath rivers are exposed and left vulnerable to damage from passing boats. Heat waves accelerate equipment wear and drive up cooling costs for data centers, with a 5 percent increase in cooling expenses for every 1°C temperature rise (Marengo et al. 2018). The 2024 heat wave in Manaus even led to thermal shutdowns, causing widespread internet disruptions.

Geographical isolation complicates maintenance and recovery efforts. Many remote sites are difficult to access, especially during extreme weather. The 2023 drought, for example, stranded vessels transporting equipment. Telecommunication repairs were delayed. Additionally, storms disrupt satellite connectivity—40 percent of satellite dish antennas required major recalibration after misalignments caused by the 2023 tropical storm season (Schaeffer et al. 2023).

Any increase in the instability of the region's infrastructure would have cascading effects on development and climate resilience. In a region already underserved by reliable energy and transport systems, further disruptions threaten to hinder progress in critical sectors like health, education, and bioeconomy development. Indeed, such disruptions can disrupt digital infrastructure as well. Without targeted adaptation measures, the Amazon's energy and digital infrastructure will remain a key vulnerability that undermines both economic and climate goals.

Chapter 2. Bioeconomy constrained: How infrastructure gaps limit opportunities in the Amazon



Chapter 2 key points

- Traditional bioeconomy value chains follow a hub-and-spoke network that originates in the Deep Forest and Rural Amazons. Following harvest, these chains typically use river transport to move goods to production centers in mid-sized Rural communities. Larger markets and activities with greater value addition are primarily situated in the Urban Amazon.
- Transport is the primary bottleneck for bioeconomy products: slow, unreliable river logistics and inadequate storage/scheduling drive large perishability losses (up to about 50 percent for pirarucu and roughly 40 percent for açaí) and limit market access; upgrading river transport, scheduling, and storage is foundational for value capture.
- Port/dock infrastructure that fails to adapt to seasonal river level changes severs communities from markets during low-water periods; resilient, floating/adjustable docks and basic refrigeration at strategic hub location are critical to maintain year-round bioeconomy flows.
- Reliable energy access is indispensable for cold chains and local processing, yet large areas of bioeconomy-producing regions lack it; deploying decentralized solutions (e.g., solar microgrids) can unlock refrigeration and value addition, reducing forced raw bioeconomy sales at low prices.
- Digital connectivity gaps in bioeconomy areas weaken coordination, traceability, and market access; improving last-mile digital connectivity enables just-in-time logistics, buyer–producer matching, and real-time quality control, raising efficiency and prices.
- Integrated, targeted infrastructure packages for refrigeration at river hubs, modular processing centers, and reliable power and digital connectivity have transformative potential; scenario modeling indicates that such investments could boost açaí by more than 60 percent and pirarucu by more than 100 percent by 2050.
- Projections included in this report indicate annual growth within the traditional bioeconomy sector, suggesting the possibility of doubling employment by 2050. According to current productivity estimates, approximately 42,000 new jobs may be generated over this timeframe.

This report focuses on the traditional bioeconomy over industrial or large-scale cultivated production, since the traditional bioeconomy is more compatible with long-term forest conservation and community-driven development. This chapter examines the infrastructure gaps that hinder the economic opportunities presented by the traditional bioeconomy sector.

In the Amazon region, the bioeconomy offers a promising path to reconcile environmental conservation with economic development, addressing both social and ecological challenges. By leveraging nontimber bioeconomy forest products and ecosystem services, communities can shift away from destructive, extractive practices toward sustainable livelihoods under the concept of "conservation through commercialization" (Arnold and Pérez 2001). At the center of this is the active participation of local communities, especially Indigenous peoples, who are directly dependent on these ecosystems, making them key stakeholders in local conservation efforts to safeguard biodiversity and mitigate external threats (Pokorny 2013).

Box 2.1 Definition of the bioeconomy

> **"The bioeconomy can be defined as the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors, and enable a transformation to a sustainable economy."**

International Advisory Council on Global Bioeconomy 2020
https://openknowledge.fao.org/server/api/core/bitstreams/69461f09-2a88-4f43-92cc-099e733f167d/content.

Traditional versus cultivated bioeconomy

The traditional bioeconomy and cultivated bioeconomy differ significantly in their impacts on the environment and society. The traditional bioeconomy utilizes existing natural resources and ecosystems with minimal disruption, thereby preserving natural habitats and maintaining biodiversity. It promotes the use of a wide range of native species and traditional varieties, which enhances genetic diversity and ecosystem resilience. This approach incorporates sustainable practices developed over generations, such as rotational grazing, agroforestry, and integrated pest management. Additionally, the traditional bioeconomy supports the provision of ecosystem services like pollination, water purification, and soil health, all of which hold significant economic value.

In contrast, the cultivated bioeconomy typically involves large-scale farming, which can damage habitats and reduce genetic diversity. It focuses on high-yield crops, which may increase vulnerability to diseases and pests, necessitating significant investments and higher operational costs. Such extractive activities could lead to the overexploitation of natural resources. Homma (2017) describes a trajectory that begins with extractive activities and culminates in management and domestication, eventually resulting in the commoditization of products. In an example of this trend, Freitas et al. (2015, 2021) show that the increasing exploitation of açaí in the Amazon region has contributed to the decline of local biodiversity.

Key bioeconomy activities in the Amazon region

This report highlights several key bioeconomy products that have the potential for sustainable use while bolstering local incomes. A recent report from the World Resources Institute, "New Economy for the Brazilian Amazon" (Nobre et al. 2023), identified 13 products as important to the region. Meanwhile, fishing in the Amazon is vital for the economy and environment as it provides local food and nutritional security.

The detailed analysis focuses on four products: açaí, cocoa, Brazil nuts, and pirarucu. These products have been selected based on their (1) economic potential[29] and (projected) global demand, (2) ecological importance in promoting forest conservation and sustainable agricultural practices, and (3) potential contribution to food security.

AÇAÍ



Açaí production is concentrated in the Brazilian state of Pará, with a smaller presence in other areas of the Legal Amazon and the Colombian Amazon. The nutrient-rich floodplain areas of Pará are conducive to high-yield cultivation, particularly for growing and harvesting açaí berries (*Euterpe oleracea*). Both small-scale and industrial producers coexist in Pará, promoting socioeconomic diversity (Escate Lay et al. 2021, 129).

In 2019, Brazil produced 1.4 million tons of açaí (from both cultivated and traditional bioeconomy), generating around US$740 million in revenue. The state of Pará, the leading açaí producer, accounts for 94 percent of Brazil's production (Poli, Cenamo, and Koury 2021, 10). This sector supports 150,000 direct and indirect jobs within the açaí value chain and exports to 35 countries. Key açaí production centers in Pará include Limoeiro de Ajuru, Cametá, and Ponta de Pedras, where traditional producers are concentrated, as well as Óbidos, home to the largest irrigated açaí plantation covering 1,400 hectares (Lopes et al. 2021, 5). Belém serves as a major consumption and distribution hub, with port infrastructure that facilitates access to national and international markets (Oliveira 2023, 29). Other states, such as Amazonas, Maranhão, and Roraima, are expanding their production to diversify supply in response to rising domestic and international demand. Amazonas focuses on subsistence and local markets, with traditional management practices ensuring sustainability and cultural preservation. Açaí acts as both a dietary staple and a source of income through direct sales in markets such as Beruri and Codajás (Escate Lay et al. 2021, 133). Processing is often artisanal, maintaining nutritional quality and catering to local demand. In the Marajó

29 In Brazil, açaí, cocoa, and Brazil nuts together represent about 70% of the gross production value of the entire food extractives segment, according to data from PEVS - Production of Plant Extraction and Forestry – IBGE (2022a). While pirarucu production represents approximately 2.5 percent of the total value of Brazilian fishery activity (Municipal Livestock Survey – PPM, IBGE, 2022b), it has high local importance, especially since aquaculture predominates in the country.

Archipelago, açaí serves as the primary income source for agro-extractive and quilombola communities, supported by cooperatives that help overcome market access challenges (Potiguar and Sá de Oliveira 2016, 12).

In Colombia, açaí production is dispersed, with primary activities focused in the Pacific basin and secondary activities in the Amazon basin. Harvesting and processing mainly occur along the Caquetá, Putumayo, and Amazon rivers (Sinchi 2015). Harvesting in the Amazon basin involves climbing native palms to collect fruits using sustainable practices in key locations such as Puerto Guzmán, Curillo, Solita, and Puerto Santander in Caquetá; Puerto Asís and Puerto Leguízamo in Putumayo; and La Pedrera in Amazonas (Guerrero, Caicedo, and Benavides 2020). Initial processing is small scale, occurring in communities such as Leticia, Puerto Leguízamo, and San José del Guaviare, where fruits are cleaned and partially processed into frozen pulp or freeze-dried powder (Sinchi 2015). However, geographical isolation due to the parallel flow of the Caquetá and Putumayo rivers, which only connect to the Amazon River after entering Brazil, along with limited road infrastructure and a reliance on air travel, poses significant logistical challenges (Guerrero, Caicedo, and Benavides 2020). Colombia exports 60 percent of its açaí production to Brazil, where it is consumed or reexported to other countries.

Both Brazil and Colombia rely on traditional harvesting practices and small-scale producers in the açaí value chain, but they differ notably in their approaches to processing and commercialization. In Brazil, artisanal processing is deeply tied to cultural traditions, particularly in riverside and urban communities, where açaí is prepared for immediate local consumption, preserving its sociocultural significance. Meanwhile, industrial processing in Brazil focuses primarily on pulp production, serving domestic and export markets, with agro-industries adhering to advanced food safety standards. In contrast, Colombia emphasizes centralized processing, with community centers and industrial facilities focused on freeze-dried powder and frozen pulp for high-value international markets, such as cosmetics and nutraceuticals. While Brazil's processing practices highlight a blend of local and industrial approaches, Colombia's strategy is oriented toward niche export markets.

BRAZIL NUTS (*castanha-do-Pará*)



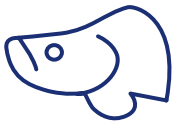
Brazil is the world's leading producer of *castanha-do-Pará*. The states of Acre, Amazonas, Rondônia, and Pará not only produce Brazil nuts in large volumes, they also employ extractive practices that integrate local socioeconomic activities, conservation efforts, and traditional lifestyles, with communities playing a crucial role. Extensive extractive reserves thus coexist with community-based sustainable practices, as preserving intact forest ecosystems is crucial for producing high-quality products.

Annual castanha-do-Pará production in Brazil, nearly evenly split between domestic consumption and exports, totals 33,100 tons, with an estimated US$300–400 million in domestic annual market value. Approximately 45 percent of the production is exported, while the remainder serves the domestic market (Lopes et al. 2023; WRI 2024). The Brazil nut is processed into high-value products such as oils, flours, and cosmetic ingredients, primarily for international markets in Europe and North America (Charity et al. 2016).

In Peru and Colombia, Brazil nuts are produced on a much smaller scale. In Peru, production is concentrated in the Madre de Dios region, with a focus on fair trade and export, which offers an alternative model for value addition. Local communities carry out harvesting activities supported by fair trade initiatives that facilitate access to international markets. In Colombia, production is largely informal and unregulated, hindering the tracking and monitoring of market dynamics and economic transactions by public authorities. It is centered on riverine areas, where Indigenous and small-scale producers face logistical and infrastructural challenges.

The Brazil nut value chain is highly decentralized, but collectors retain a tiny fraction of the final product value. The actors involved in production, processing, and commercialization include (1) Indigenous and local communities responsible for the sustainable management of Brazil nut trees and harvesting; (2) cooperatives and rural producer associations that oversee organization, initial processing, and value chain coordination; (3) the industrial processing sector, which adds value through packaging and commercialization; and (4) government and nongovernment organizations that provide technical assistance, financial resources, and capacity building.

PIRARUCU



Riverine and Indigenous communities in Brazil and Peru rely on the pirarucu value chain for their livelihoods, while focusing on sustainable fishing practices. In Brazil, key pirarucu activities are carried out within protected areas and sustainable development reserves, where community-based management systems regulate fishing practices to ensure species conservation. In Peru, pirarucu aquaculture has become increasingly important, especially in regions like Ucayali, where production is tied to local efforts to conserve biodiversity and generate income. In Colombia, however, pirarucu fishing is still an emerging economic activity, with a limited focus on sustainable management systems.

In Brazil, production revolves around sustainable fishing in protected areas, backed by emerging aquaculture practices that support conservation and community development. Production is concentrated in the states of Amazonas (primarily), Rondônia, Acre, and Pará. In the state of Amazonas, the Mamirauá Sustainable Development Reserve is a key site for the community-based management of pirarucu activity that centers on traditional fishing practices with sustainability efforts (Instituto Mamirauá 2021). Brazil has advanced quota-based systems in these protected areas. Several sustainable aquaculture projects have emerged especially in Rondônia and Acre to enhance production efficiency (Silva et al. 2020; WWF-Brasil 2019). In Pará, despite supporting several local economies, the value chain faces logistical barriers and plays a lesser role nationally (IBAMA 2018).

In Peru, production has accelerated in the Loreto and Ucayali regions, where aquaculture operates alongside biodiversity conservation initiatives. These areas account for nearly 80 percent of the national aquaculture rights granted for pirarucu farming. Local communities benefit from sustainable fish farming systems that generate income and promote ecosystem preservation, supported by a legal framework under the General Law of Aquaculture that fosters a regulated environment to meet market demands.

Brazil and Peru share similar pirarucu processing structures but have different goals. Initial cleaning, gutting, and chilling are typically performed by small-scale producers or cooperatives in both countries. However, Brazil focuses on artisanal processing, adhering to stringent food safety standards, while Peru prioritizes industrial-scale filleting and freezing for export.

While Peru has more established export channels, Brazil boasts a more developed coordination network. Brazil distributes pirarucu products through both local and international markets, with intermediaries linking fishers to distributors and consumers. Peru features robust export channels; however, Brazil's coordination and support mechanisms are more developed with local cooperatives and the government actively promoting technical training and market access. In Peru, nongovernment organizations and the government have helped develop sustainable fishing practices, but in Colombia, support remains limited and less organized.

COCOA



Cocoa production in the Amazon is concentrated in Brazil, especially within agroforestry systems in the state of Pará, and, to a lesser extent, Rondônia and Amazonas. Agroforestry systems integrate cocoa with native species and other crops, ensuring sustainability while conserving biodiversity. Pará leads the country's cocoa production, primarily through family farmers utilizing integrated farming methods. Rondônia is emerging as a cocoa production hub, but moderate volumes and logistical challenges hinder its integration into larger value chains. Amazonas has limited production, though similar systems are being implemented to help local communities diversify their incomes.

Cocoa production in Brazil, which reached approximately 200,000 tons in 2019, has provided significant economic and environmental benefits. On the economic side, the state of Pará, the main producer of cocoa, generates about US$3.5 billion annually and provides income for about 150,000 families (Guerra, de Jesus, and Martins 2021, 5; Poli, Cenamo, and Koury 2021, 10). Environmentally, agroforestry techniques have improved soil quality and contributed to ecosystem restoration in degraded areas.

Both Pará and Rondônia are well-established regional hubs within the cocoa value chain but struggle to create added value. In Pará, Medicilândia is a key production hub, while Belém serves as a logistical center for distributing cocoa to domestic and international markets. In Rondônia, Porto Velho functions as a regional center for consumption and redistribution. However, much of the production is exported as raw material, bypassing value-adding processes such as fermentation and drying, which limits the economic potential for local producers in both states.

Small-scale farmers form the backbone of a value chain that includes a diverse range of actors, such as farmers, cooperatives, community associations, agro-industrial companies, and intermediaries. Each play distinct roles in production, processing, and commercialization. Cooperatives and local associations provide technical support, improve market access, and ensure a fairer distribution of economic benefits. Processing industries, concentrated in urban centers, handle value addition to meet quality standards for domestic and international markets. Even though most of the production is exported as raw material, investments in postharvest practices could unlock opportunities in high-value segments and new export markets.

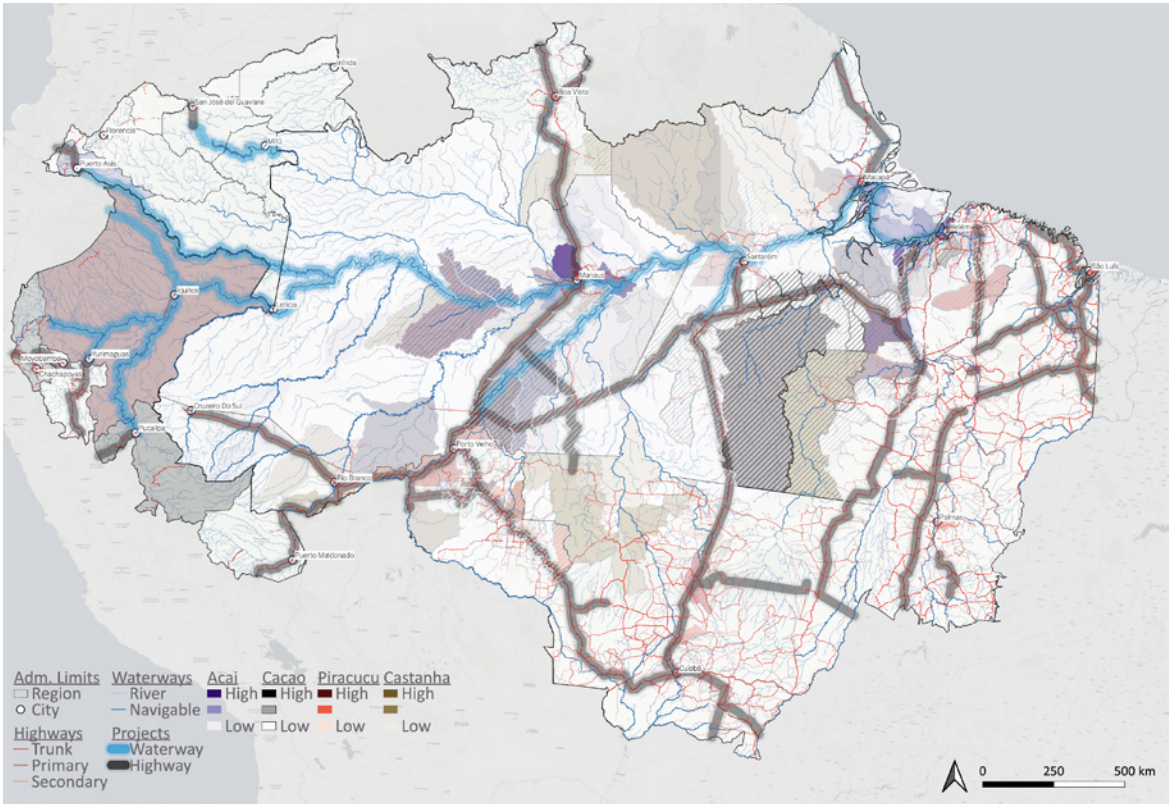
Harvesting and collection: Access barriers in the forest interior

The Amazon's bioeconomy supply chain begins in the Deep Forest and Rural Amazon, where rural and Indigenous communities harvest most products. Value-adding activities near harvesting locations are minimal, typically limited to basic cleaning and sorting. Most products must be transported to smaller towns that serve as consolidating centers, where initial processing occurs and some goods are absorbed into local markets.

Transport infrastructure is the first and most immediate constraint for bioeconomy products, affecting their reach to distant markets, timeliness, and cost.

To analyze how transport corridors in the Amazon region facilitate the movement of bioeconomy products, a gravity model was used to estimate disaggregated flows between key origin and destination centers. The model utilized data on production and infrastructure and research on the value chains of bioeconomy products. Map 2.1 plots transport infrastructure alongside the distribution of production areas for açaí, Brazil nuts, cocoa, and pirarucu.

Map 2.1 Road and river corridors used to transport bioeconomy products



Source: Original compilation.
Note: Road corridors are shown in brown and rivers in blue. Castanha are Brazil nuts, and pirarucu are large freshwater fish. km = kilometer.

The model, together with qualitative interviews with sector stakeholders, reveals transport patterns for bioeconomy products where flows not destined for local consumption are funneled into regional hubs. These vary by product:

- **Açaí**, primarily produced in Pará in Brazil, is moved by river to hubs such as Belém and Cametá. Export opportunities are significantly constrained due to a lack of cold storage facilities, as the product is highly perishable and must be processed within 48 hours of harvest.

- **Brazil nuts**, on the other hand, are primarily destined for export. Production is concentrated in southern Amazonas, with most of the region's harvest transported by road and river to major cities such as Manaus, Belém, and Rio Branco, which are connected to maritime shipping networks.

- Most **pirarucu** in Brazil are also sourced from Amazonas, while in Peru, they are predominantly produced in Loreto. Fish farms operated by Indigenous communities within Loreto's Pacaya Samiria and Putumayo-Marañón natural reserves feature sustainable resource management. Regional flows lead to Manaus and Porto Velho, which house the logistical services necessary to preserve the fish.

- Finally, Pará and Rondônia (Brazil) are the main producers of **cocoa**. Colombia, too, produces significant amounts, especially in the Caquetá, Putumayo, and Guaviare departments. Medicilândia (Pará, Brazil) serves as a regional hub, aggregating local harvests, before facilitating the transport of preprocessed cocoa via highways to larger production centers.

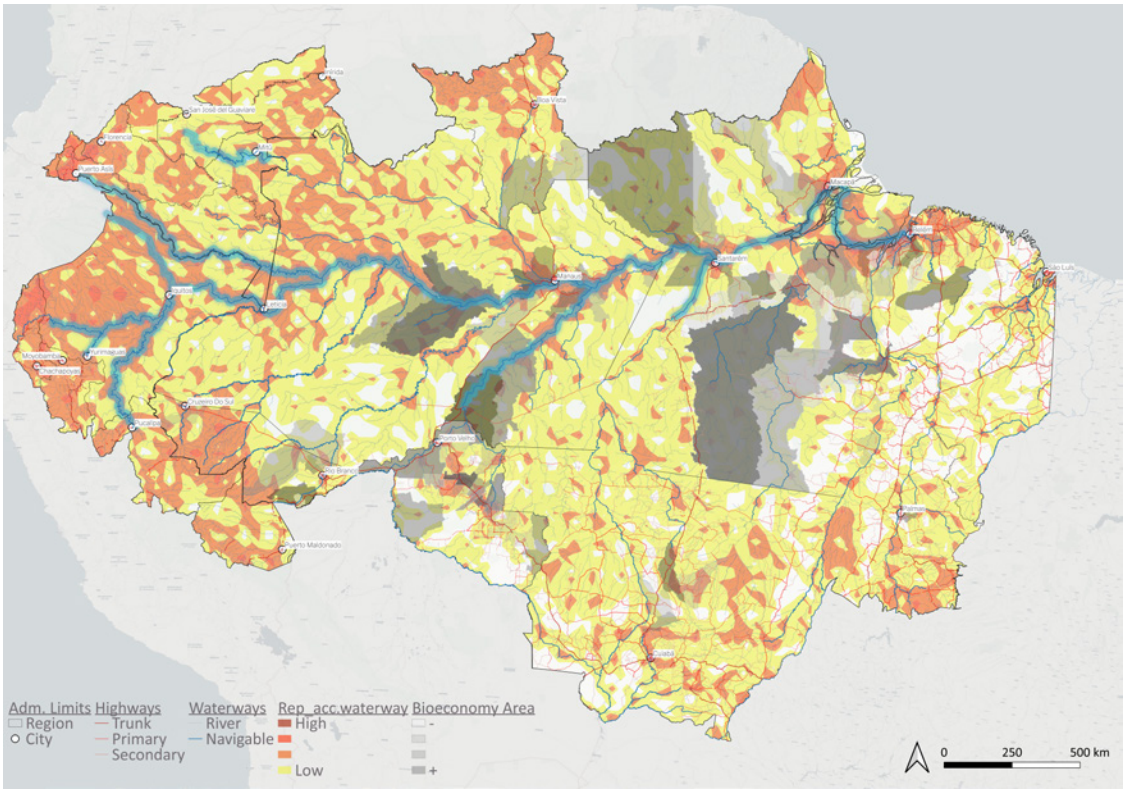
Efficient and functional transport infrastructure is vital for moving these products, yet significant gaps exist. Road transport, the dominant mode for agriculture, lacks year-round connectivity, particularly in remote regions where bioeconomy products are cultivated. Consequently, water transport remains the backbone of regional mobility in the Amazon, though it has seasonal restrictions and poor infrastructure. Improvements to both modes is critical for the development of this industry and the sustainable economic opportunities it creates.

The initial transport leg for most bioeconomy products typically involves small boats or canoes moving goods from the harvesting site to a basic processing location. This stage faces challenges such as high fuel costs, poor vessel quality, and long distances. Slow travel times combined with inadequate storage conditions often lead to significant product spoilage. The first processing points—often small area hubs—handle tasks such as cleaning or beating and serve only as cargo consolidation points for onward transport. Travel times during this first leg determine if a product can be commercialized beyond the nearest communities.

The second transport leg is typically carried out by larger boats that provide mixed passenger and cargo services. These vessels, however, lack fixed schedules, predictable travel times, and appropriate cargo protection, which adds further uncertainty and risk to the value chain.

Understanding bioeconomy logistics helps assess the challenges and opportunities for market access in the Amazon. Açaí is transported in small river boats and primarily consumed locally—90 percent produced in the Legal Amazon remains within the region before reaching hubs like Belém (Pará) and Manaus (Amazonas). Secondary logistical flows extend toward São Luís (Maranhão) and Porto Velho (Rondônia), reflecting a structured regional supply chain. In Acre, production typically moves eastward toward Rio Branco. In Peru, where production is more limited, açaí is distributed via river transport to Iquitos and Pucallpa. Brazil nuts are transported via rivers in remote areas, before switching to trucks for national distribution in Brazil. Pirarucu is mainly consumed locally (75 percent), due to its perishability, and transported in small boats. In Brazil's Amazonas, supply is centered in Manaus, with distribution from Pará going to Belém and Mato Grosso linking northern production zones to Cuiabá. Pirarucu transport relies heavily on local small river boats for remote communities. In Colombia, logistical constraints limit pirarucu distribution to Indigenous communities along the Putumayo and Caquetá rivers. In Peru, fishing communities distribute it to regional markets in Loreto, San Martín, and Ucayali.

Map 2.2 Areas of bioeconomy and river accessibility



Source: Based on World Bank Group database 2025.

Note: km = kilometer.

The resilience and navigability of river-based transport is a critical determinant of the viability and scalability of bioeconomy activities in the Amazon. As bioeconomy products are sourced in the Deep Forest and Rural Amazon, where road access is limited, rivers are the primary logistical lifeline. Map 2.2 overlays bioeconomy production areas with access to riverways in the region. Across all sectors, freight flows are the most significant on the Madeira and Tapajós rivers, and the Amazon river up to Manaus. For wider national and international trade, maritime ports facilitate exports, especially of processed and value-added products. However, increasing climate volatility has exposed structural weaknesses in navigability. The 2023–24 drought brought navigation on the Madeira and Tapajós to a halt, delaying the movement of goods, while the Amazon river's shifting shorelines during the dry season has disrupted access to producing communities. In Rondônia, production relies on the Madeira river export corridor, expected to be concessioned soon, to improve the significant navigation constraints posed by low water levels. In Peru, bioeconomy production benefits from a relatively well-developed river network that is connected to the national road system. In contrast, river navigation in the Colombian Amazon is largely restricted to small vessels, hindering the efficiency of transport and the development of bioeconomy activities. Navigation restrictions translate to rising transport costs, longer transit times, and forced modal shifts.

To ensure the functionality and resilience of the small ports and docks serving the bioeconomy, it is essential to account for the seasonality of Amazonian river levels—these can fluctuate by up to 20 meters between wet and dry seasons, making fixed infrastructure unreliable and inaccessible. Many docks lack adaptable designs, such as floating platforms, leaving communities cut off from transport and markets during low-water periods. Access to ports is also hindered by poorly maintained footpaths, which become impassable due to heavy rains or drought-induced soil degradation. These factors limit the ability of ports and docks to serve as reliable hubs for transport, trade, and service provision, undermining their potential to support bioeconomy value chains and the mobility needs of riverside communities. As highlighted in chapter 3, providing floating docks in the Deep Amazon with basic infrastructure such as solar-powered energy would significantly improve the transport of bioeconomy products.

First transformation and local value addition: Processing at the source

Most processing—whether açaí pulping, cocoa fermentation, or pirarucu filleting—requires reliable power, clean water, and cold storage. These are unavailable in the Deep Forest Amazon, and as shown in the analysis below, largely limited in the Rural Amazon. Key bioeconomy production hubs continue to face power supply challenges despite their central role in value chains. As shown in table 2.1, municipalities that are important producers of bioeconomy products still have inadequate electricity infrastructure, and rely on isolated diesel plants or medium-voltage grid connections to other cities. Given their strategic importance, these hubs should be prioritized for electricity network upgrades (such as high-voltage interconnections to the national grid when possible, or a transition from fossil fuels to renewables if not) to generate positive spillover effects across entire value chains. Table 2.1 highlights municipalities that appear in 4 or more of the 11 chains analyzed, while map 2.3 depicts the bioeconomy hubs across the region.

Energy needs for small-scale bioeconomy processing can be substantial. A recent study by Pereira (2023)[30] analyzed the energy requirements of a small (1,000 tons/year) açaí processing cooperative. The plant's equipment requires an estimated installed capacity of 375 kilowatts (kW) (for classification, washing, squeezing, freezing, and storage), with electricity consumption ranging from 80,400 kilowatt-hours (kWh) in the offseason to 214,800 kWh during the harvest season. To meet this demand, an optimal energy mix would combine a 293 kW photovoltaic (PV) installation with an 800 kW biomass generator fueled by açaí residues.

The availability of refrigeration is dependent on electricity, which remains unreliable and unaffordable in many areas. Most remote communities rely on isolated energy systems that cannot support refrigeration, with 60–80 percent of the Amazon region lacking reliable electricity for operating refrigerators (see figure 1.10). Most processing facilities are concentrated in urban centers, where energy supply is relatively better. This increases transport costs, reduces the share of added value retained by local communities, and limits job creation in rural and Indigenous areas. Preservation alternatives such as drying or salting lead to product loss and diminish market value. Because of the region's high temperatures and humidity, spoilage rates are as high as 50 percent for pirarucu in riverside communities and up to 40 percent for açaí in areas distant from processing centers—significantly undermining productivity and income potential for local populations. The absence of localized cold storage forces producers to sell raw goods quickly, often at lower prices, to intermediaries.

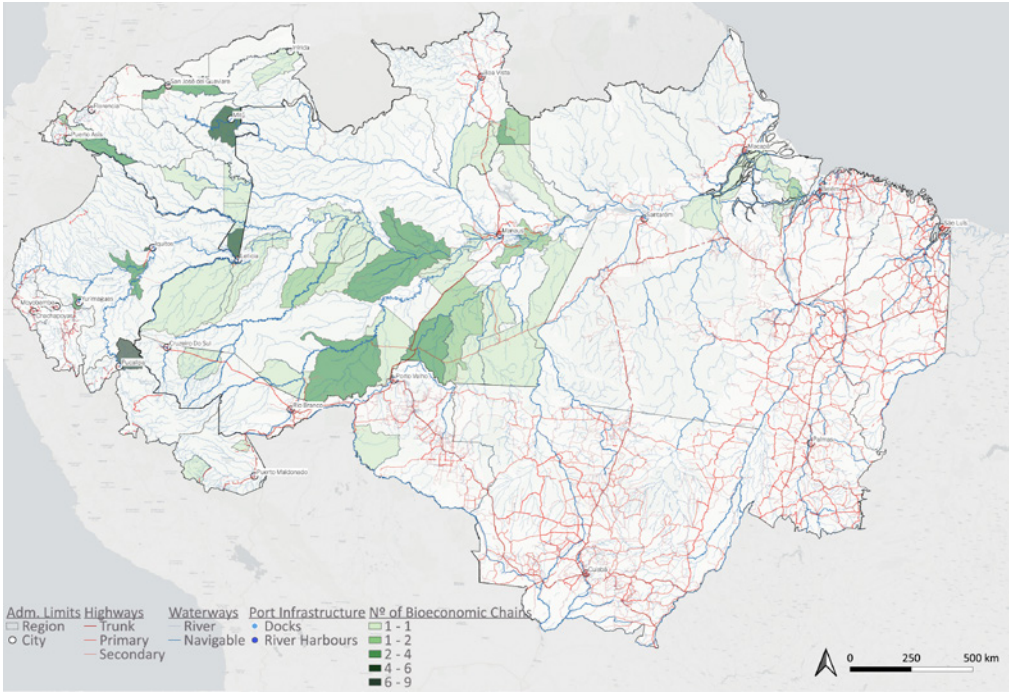
30 Inter-American Development Bank conducted a study in 2023 on optimal energy access configuration in the Brazilian states of Amazonas, Acre, Pará, and Roraima, to provide insights for the Mais Luz para Amazônia project.

Table 2.1 Bioeconomy hubs facing electricity infrastructure gaps

Product	Brazil	Peru	Colombia
Açaí	Anori/AM, Carauari/AM, Coari/AM, Codajás/AM, Humaitá/AM, Itacoatiara/AM, Lábrea/AM, Manicoré/AM, Afuá/PA, Anajás/PA, Limoeiro do Ajuru/PA, Muaná/PA, Oeiras do Pará/PA, São Sebastião da Boa Vista/PA	Iquitos/LOR, Nauta/LOR, Requena/LOR, Yurimaguas/LOR, Pucallpa/UCA	La Pedrera/AMA, Letícia/AMA, Santander/AMA, Currillo/CAQ, Puerto Santander/CAQ, Solita/CAQ, San José del Guaviare/GUV, Puerto Asís/PUT, Puerto Guzmán/PUT, Puerto Leguízamo/PUT
Brazil nuts	Amaturá/AM, Autazes/AM, Beruri/AM, Boca do Acre/AM, Canutama/AM, Coari/AM, Codajás/AM, Humaitá/AM, Lábrea/AM, Manicoré/AM, São Paulo de Olivença/AM, Tefé/AM, Guajará-Mirim/RO, Rorainópolis/RR, São Luiz/RR, São João da Baliza/RR, Caroebe/RR	Iberia/MDD,	
Pirarucu/ Arapaima/ Paiche	Codajás/AM, Coari/AM, Manacapuru/AM	Iquitos/LOR, Nauta/LOR, Requena/LOR, Pucallpa/UCA	Letícia/AMA, Puerto Nariño/AMA, Mitú/VAU
Cocoa		Aguaytía/UCA, Pucallpa/UCA	

Source: Based on ANEEL (2024), OSINERGMIN (2024), UPME (2024), IPSE (2024), and MME (2023).
Note: Brazil: AM - Amazonas; PA – Pará, RO – Rondônia, RR – Roraima; Peru: LOR – Loreto, MDD – Madre de Dios, UCA – Ucayali; Colombia: AMA – Amazonas, CAQ – Caquetá, Guainía, GUV – Guaviare, PUT – Putumayo, and VAU – Vaupés.

Map 2.3 Municipalities with bioeconomy production and electricity gaps



Source: Original compilation.
Note: The green areas highlight municipalities that serve as hubs of bioeconomy production, with the darker shades indicating a greater diversity of bioeconomy products. km = kilometer.

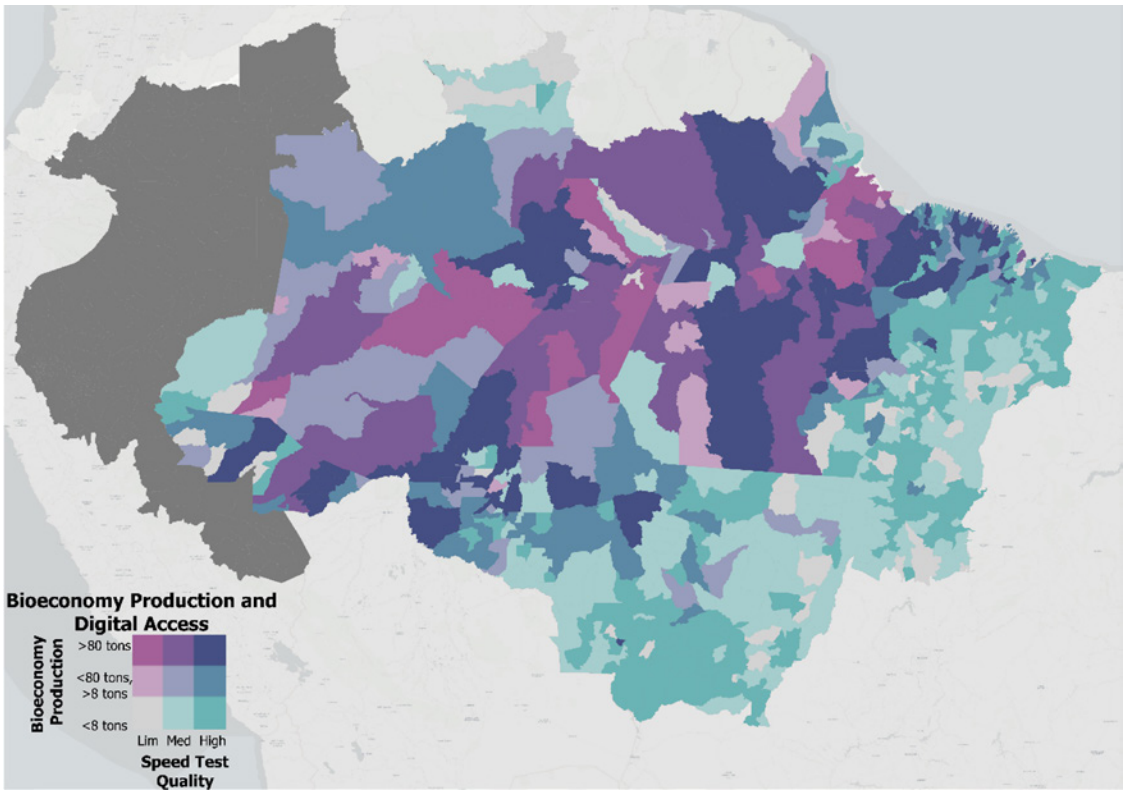
Given the critical role of river transport in moving bioeconomy products, ports and docks—especially those equipped with storage and refrigeration—emerge as potential hubs for product value-added activities. The availability of cold storage at small ports and docks could significantly strengthen local bioeconomies by reducing postharvest losses, improving product quality, and increasing household income. It would also support local food security by preserving part of the harvest for household consumption, especially for perishable products such as pirarucu (a high-value fish consumed locally due to limited preservation capacity). Chapter 3 assesses the possibility of expanding the number of ports and upgrading selected facilities into development hubs across the Deep Forest and Rural Amazon to improve transport for bioeconomy products, accessibility for local communities, and sustainable economic development for remote areas.

Electricity access, therefore, is a critical enabler of bioeconomy production, warranting a closer analysis of their interdependence. To better understand this nexus, we cross-referenced disaggregated data on cities with high bioeconomy potential with data on electricity infrastructure gaps, focusing specifically on access to medium- and high-voltage grids within productive municipalities. However, the scope of the analysis was limited to physical infrastructure availability and did not consider service quality. Poor supply quality may therefore still hinder value generation in key production hubs such as Pará and Maranhão (Brazil), even though they are grid connected and not flagged as having major infrastructure deficits. A summary of the findings is presented in table 2.1.

Expanding and improving electricity supply would therefore have transformative impacts. Energy-enabled refrigeration and small-scale processing units near harvesting sites could cut transport costs, reduce losses, generate jobs, and strengthen local economies, while enabling communities to retain more value locally. Investment in reliable energy access is thus critical to enhancing competitiveness in both local and international markets.

Digital connectivity in the Amazon's key production zones is insufficient, hindering the efficiency of bioeconomy supply chain management. Map 2.4 illustrates the relationship between bioeconomy production and digital connectivity across the Amazon. High production areas often overlap with regions of limited digital connectivity, indicated by pink and light violet shades. Conversely, regions with better connectivity (turquoise tones) typically show with lower bioeconomy volumes, indicating that many high-production areas are digitally isolated. Strengthening digital connectivity in these productive zones could improve bioeconomy outcomes by enabling real-time tracking, access to broader markets, coordination with processing or distribution centers, and enhanced support for local producers.

Map 2.4 Many high-production bioeconomy areas are digitally isolated



Source: Based on Ookla data.

Poor digital connectivity renders bioeconomy activities in the Amazon less efficient and less profitable, particularly for rural communities in the Deep Forest Amazon and Rural Amazon. Organizations such as Natura and 100 percent Amazônia emphasize that unreliable internet access disrupts supply chain coordination, resulting in communication delays between producers and buyers. On the other hand, stable internet, while advantageous, can be expensive. AMORERI highlights that satellite internet costs can reach US$560 per VSAT[31] antenna, with monthly fees ranging from US$40 to US$100. While broadband via radio is more affordable at US$20, it offers less stability, especially in remote and riverside areas. These challenges contribute to high expenses and inconsistent digital service quality in isolated locations.

Improved digital connectivity can unlock significant economic potential for the Amazon's bioeconomy. Natura estimates that expanding broadband access in remote areas could reduce supply chain costs and improve operational results by 15–25 percent through

31 A very small aperture terminal (VSAT) is a compact satellite communication system that enables the transmission and reception of data, voice, and video signals.

better communication with producers and fewer purchase delays. Similarly, 100 percent Amazônia, in partnership with initiatives such as Cupuaçu do Quintal, estimates that faster communication could boost the commercialization of cupuaçu products (such as cupuaçu nibs, oils, and butter) by 20–30 percent, opening new distribution channels, while AMORERI anticipates up to 30 percent more efficient coordination and commercialization of products such as Brazil nuts and babaçu.

High-quality digital connectivity is necessary for the local bioeconomy and for effective environmental management. Organizations such as the Association of Agro-Extractive Producers of Colônia do Sardinha (ASPACS) and Associação Comunitária de Educação em Saúde e Agricultura (ACESA) stress the importance of real-time information on transport routes and market prices to ensure reliable transportation, lower transport costs, and reduce reliance on intermediaries. Digital technologies also improve environmental monitoring and territorial security. Coletivo do Pirarucu highlights that river travel to municipal centers in remote areas can exceed 40 hours, hampering rapid responses to illegal fishing and increasing losses. Stable internet access could boost response times by up to 40 percent, thereby better protecting lakes and fisheries.

Digital connectivity depends on access to stable and reliable electricity, highlighting the interdependence between the two. Frequent power outages, low voltage, or a complete lack of electrification undermine the functionality of digital infrastructure, particularly in remote bioeconomy-producing areas. Even the most advanced digital systems cannot operate effectively without reliable energy, which hinders essential internet-enabled services for production, education, and market integration. Additionally, digital infrastructure is increasingly vulnerable to climate-induced extreme weather events, threatening the reliability and sustainability of regional connectivity.

Distribution and market access: Reaching end markets

In the Urban Amazon, bioeconomy products connect with major cities that serve as gateways to broader domestic and international markets. High-value processing and advanced transformation occur only in these urban centers, making them critical nodes for capturing significant economic value in the bioeconomy.

However, bioeconomy products often fail to access high-value markets due to infrastructure constraints throughout the value chain. For instance, while Brazil nuts and cocoa are destined for international markets, limited access to packaging and certification centers restricts their competitiveness. Similarly, açaí and pirarucu, though valued in gourmet and health-food sectors, are mostly consumed locally due to their perishability and a weak cold chain infrastructure. Large-scale distribution is available only in the Urban Amazon and requires integration with national road corridors (e.g., BR-230, BR-364) and port infrastructure. However, many of these corridors are unreliable, facing issues such as ferry crossings, seasonal closures, and inadequate facilities. Ports that could function as value-adding nodes (particularly with cold storage facilities) are rarely equipped for this role.

The modeling exercise identified numerous corridors critical for the region and for the bioeconomy more specifically. Among the important corridors connecting the region to domestic and international markets are the north-south corridors (BR-319 and BR-174), which span the entire Amazon rainforest and connect Porto Velho (Rondônia), Manaus (Amazonas), and Boa Vista (Roraima) to Bolivia/Peru on the one end and Venezuela/Guyana on the other. The Trans-Amazonian Highway (BR-230) links the northeastern edge of the region—Belém and São Luís to Porto Velho. Table 2.2 lists other important corridors for the bioeconomy.

Table 2.2 Key river and road transport corridors for bioeconomy products

Transport corridor	Key bioeconomy products
Madeira River – BR-319 corridor from Porto Velho to Manaus	Brazil nuts
Tapajós River	Açaí, Brazil nuts
BR-364 in Rondônia	Pirarucú, cocoa
BR-364 in Acre	Brazil nuts, cocoa
BR-163 – BR-230 in Pará	Cocoa

Transport corridor	Key bioeconomy products
BR-174 in Amazonas	Açaí
BR-174 in Roraima	Brazil nuts
BR-230 in Pará	Cocoa, Brazil nuts
BR-230 in Amazonas	Brazil nuts
Connection BR-010 / Belém–Barcarena	Açaí
Putumayo River in Colombia	Açaí, cocoa
Hidrovía Amazónica in Perú (Ucayali, Huallaga, Marañón)	Pirarucú, cocoa
Interoceanic road in Peru (30C – Acre, Puerto Maldonado, Pacific)	Cocoa

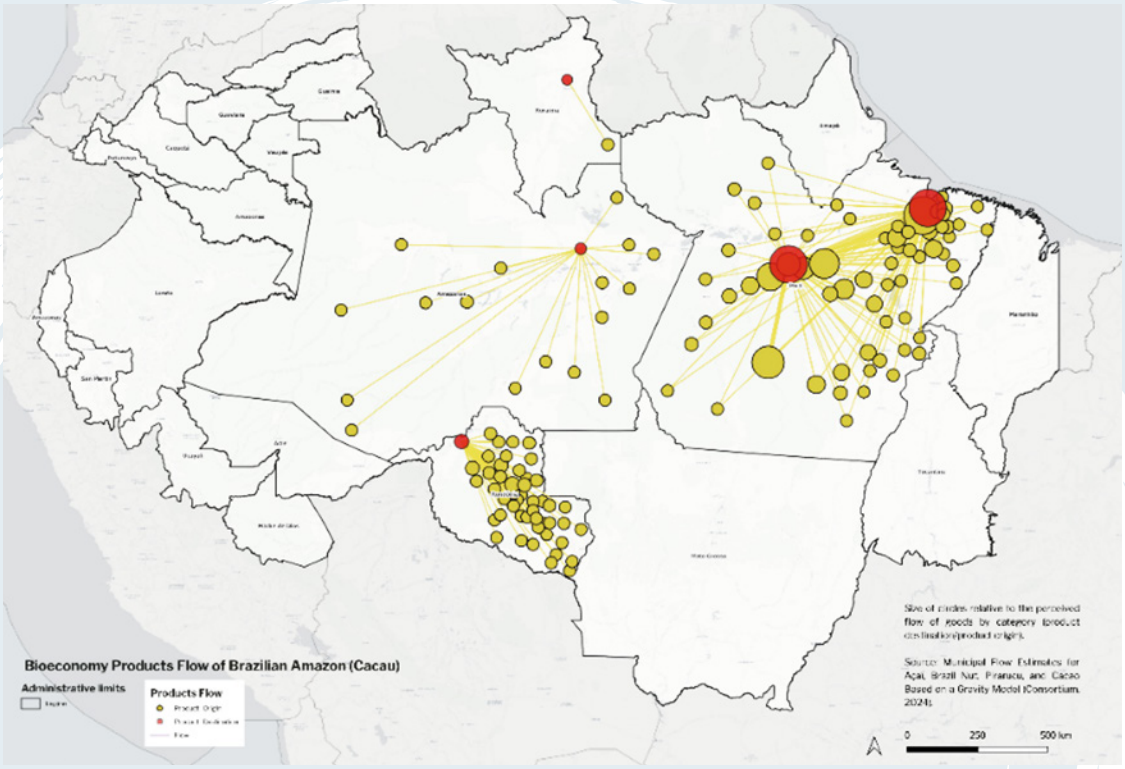
Domestic (nonlocal) distribution of bioeconomy products from production centers to domestic markets is mostly by road. The significance of road transport lies in the interplay between transport networks and bioeconomy value chains. Products destined for international markets (e.g., Brazil nuts) typically use rivers for easier access to maritime networks. But local roads link rural areas to urban centers, which, as in the case of cocoa, is precisely where most processing occurs (box 2.2). Major highways, specifically in Brazil, facilitate the distribution of agricultural products to major population centers in the south, thereby supporting the domestic distribution of bioeconomy products. Additionally, products like acai and pirarucu require cold storage for long-distance transport. Such requirements are typically only met via road transport.

Box 2.2 The importance of roads in transporting cocoa

Cocoa serves as a useful case study, illustrating the benefits that road infrastructure provides to the bioeconomy, particularly in the Amazon region. In Brazil, cocoa production is highly concentrated in the southern part of Pará and includes certain municipalities with the highest production volumes. In Peru, cocoa production is a vital economic activity, particularly in the Amazonian regions of Loreto, Ucayali, and San Martín, where smallholder farmers utilize agroforestry systems to cultivate high-quality cocoa. Most of the harvested cocoa is processed locally and sold in both national and international markets, reflecting a growing demand from artisanal chocolate makers and export-oriented cooperatives. Similarly, in Colombia, cocoa production plays a vital role in the agricultural sector, particularly in departments such as Caquetá, Putumayo, and Guaviare.

Cocoa primarily functions as an intermediate input, collected at domestic hubs via road transport rather than being distributed for local consumption. Map B2.2.1 plots the distribution of local cocoa production in Brazil. The concentration of production in specific regions reflects the historical adaptation of the cocoa sector to areas where sustainable cultivation and management programs have been implemented. Cocoa's value chain is structured and integrated around existing infrastructure, enhancing efficiency in production, processing, and marketing to international markets. The regional consolidation of production makes cocoa the primary bioeconomy product hauled by the road freight sector. Processing centers in Medicilândia, Belem, and Porto Velho gather the raw harvest, preprocess it, and then ship it via highways to major production centers in southeastern Brazil, like São Paulo.

Map B2.2.1 The cocoa value chain is organized primarily around dispersed local production and consolidation at local hubs for downstream processing

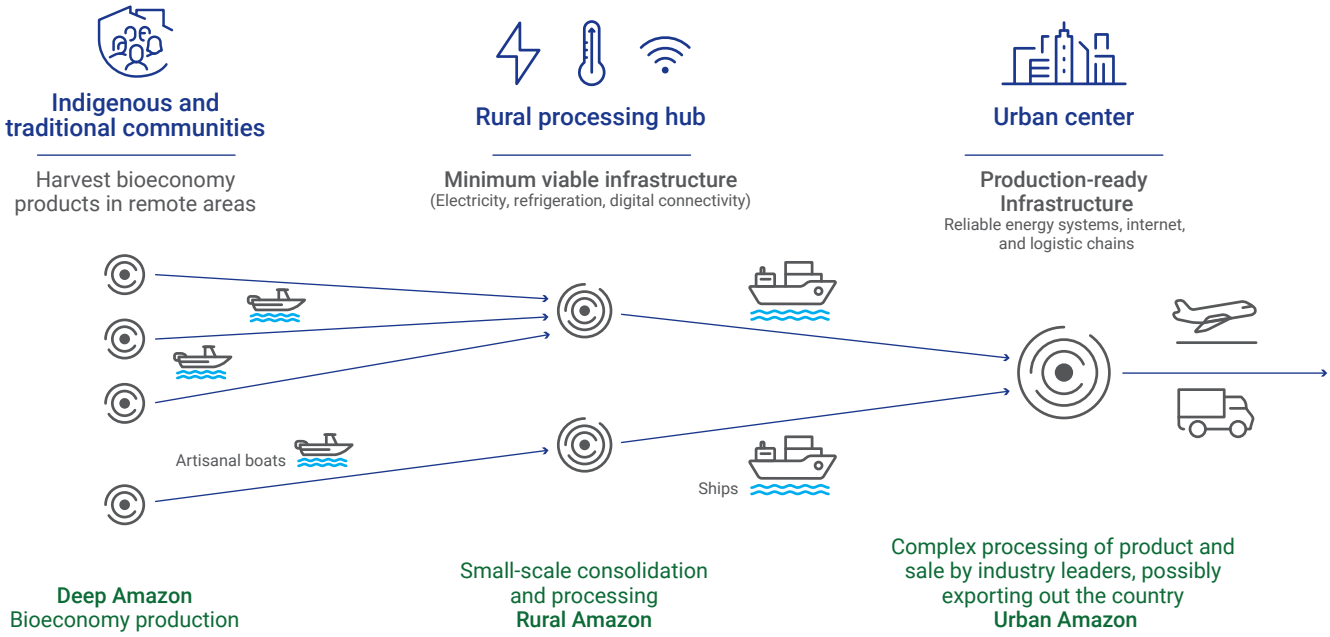


Source: Original compilation.
Note: Focus is given to the larger production centers in Brazil. km = kilometer.

Trunk and primary highways facilitate the growth of the cocoa industry throughout the Amazon. Pará and Rondônia are Brazil's top cocoa-producing states, each intersected by major highways: BR-230, BR-163, and BR-155/158 in Pará and BR-364 in Rondônia. These highways primarily connect the productive farmlands in Mato Grosso and Pará, which grow grains and soy, to ports and international export markets. Additionally, they also provide cocoa producers in these states access to regional production centers and major population hubs. In Peru, cocoa production similarly benefits from access to the Interoceanic Highway (PE-30, which connects to BR-364).

Cross-cutting infrastructure gaps: The compound effect

Infrastructure needs across the bioeconomy value chain are not siloed. A lack of electricity affects transport (cold chain), processing (machinery), and digital connectivity (market updates). Poor digital access hampers logistics coordination and financial inclusion. The interrelated nature of these gaps necessitates that interventions be integrated and strategically sequenced.



Realizing the potential of the bioeconomy is contingent on targeted infrastructure investments that support communities while preserving ecosystems:

- **River docks with cold storage and solar power** for fish and fruit.
- **Modular processing centers** located in rural clusters.
- **All-season rural roads** connecting communities to rivers, not just highways.
- **Solar microgrids** tailored for community cooperatives.
- **Digital connectivity upgrades** to enhance logistics and traceability.

Scenario modeling indicates that under an optimistic infrastructure investment case scenario, açaí production could rise by over 60 percent and pirarucu by over 100 percent by 2050. Achieving these gains depends on addressing the specific infrastructure gaps outlined in this chapter.

Growth potential: Opportunities for expanding sustainable bioeconomy production

While the production of açaí, Brazil nut, pirarucu, and cocoa has developed to different levels in the analyzed countries, all have significant untapped potential. Better infrastructure, policies, and stakeholder coordination can bring about substantial growth. This section includes demand projections for these products through 2050, considering scenarios (baseline, high growth, and low growth[32]) that account for potential market expansions, changes in consumer preferences, and international market trends. Climate change impacts are excluded from the scenarios due to the difficulty of accurately quantifying their effects across various bioeconomy sectors. The methodology is explained in further detail in the technical annex A6.

AÇAÍ



Açaí production has experienced inconsistent growth over the past decade. Production levels have fluctuated significantly, necessitating adaptation by stakeholders in the value chain. For instance, production in 2018 was 8 percent higher than in the previous year but dropped by over 20 percent in 2019 (Guerra, de Jesus, and Martins 2021, 4; Lopes et al. 2021, 7). The global demand for açaí products and the resulting fluctuations compel producers to adapt their processes and develop logistics strategies that minimize costs while maintaining quality. The organization of producers into associations and cooperatives has driven growth in the value chain, providing access to new technologies, better management practices, and greater market opportunities.

Numerous improvements have already been implemented throughout the açaí value chain, but ongoing transformation is essential. The adoption of sustainable management practices and technological innovations—including efficient irrigation, advanced pulping methods, and refrigerated storage—has boosted productivity and reduced postharvest losses. Other measures being explored include ozone sanitization tanks and stainless-steel conveyors for export (Lopes et al. 2019). Certifications such as Fair Trade and organic labels have added value to products, positioning açaí as a premium "superfood" and increasing economic returns for producers (Halla 2022).

32 The key assumptions for the *baseline* scenario included no major interventions or disruptions, gradual improvements in infrastructure and market access, and sufficient organic growth to sustain local and regional markets. For the *high-growth* scenario, the assumptions included investments in infrastructure and policy reforms, demand increases due to product certifications (e.g., organic, Fair Trade), access to premium markets, and equitable distribution of benefits from reforms to local producers. For the *low-growth* scenario, the key assumptions included persistent infrastructure and policy challenges, market bottlenecks and ecological constraints hindering growth, and the benefits of investments being captured by intermediaries, leaving local producers without support to expand production.

Demand projections for açaí indicate an average annual growth rate of 0.95–3.27 percent until 2050. This growth would result in an annual production of over 770,000 tons to nearly 1.6 million tons, compared with the current figure of 600,000 tons. Production will primarily be concentrated in Brazil and, to a lesser extent, Colombia.

The growing demand, however, has raised concerns about socioenvironmental sustainability. Expansion of production, often without adequate safeguards, risks overexploitation of resources and ecosystem degradation. It is critical to expand sustainable initiatives across subregions. For example, in the state of Amazonas, harvesting the fruit of the *Euterpe precatoria*[33] presents a sustainable alternative that supports biodiversity preservation while generating income for local communities. However, Amazonas currently contributes only 1 percent of national production, due to logistical challenges and insufficient policies to strengthen the value chain.

BRAZIL NUT (castanha-do-Pará)



The growing global demand for sustainable and organic products has sparked increased interest in Brazil nuts in recent years, a trend that is likely to continue. There is a rising demand for value-added products such as oils, flours, and bioplastics, along with certifications such as Fair Trade and organic standards that align with consumer preferences. Colombia holds significant potential for expansion, as *castanha-do-Pará* activity is limited, presenting opportunities for investment in logistics and infrastructure.

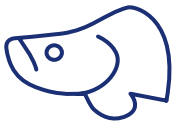
This upward trend is expected to continue moderately, with projected annual growth rates of 1.2–3.4 percent. Although this represents the slowest growth among the bioeconomy activities analyzed in this report, it translates to annual outputs ranging from approximately 15,000 tons to 25,900 tons by 2050, compared with the current 10,500 tons. The output will be primarily concentrated in the Legal Amazon in this case.

The growth potential of the Brazil nut value chain is closely linked to investments in technology and infrastructure. Enhanced drying and storage facilities, along with reliable access to renewable energy sources, could greatly reduce postharvest losses and improve product quality. Further, developing local and regional processing facilities would enable producers to capture a larger portion of the value chain, reducing their reliance on intermediaries and export companies.

33 This species is adapted to upland forests and less flooded floodplains, as it is more tolerant of drier, better-drained soils compared to *Euterpe oleracea*, which is predominant in Pará, the state with the largest açaí production.

Aligning the Brazil nut value chain with bioeconomy principles creates further growth opportunities. Programs that promote sustainable forest management—such as those involving payments for ecosystem services[34]—incentivize harvesters to preserve forest environments, thereby supporting biodiversity conservation. Additionally, developing innovative by-products from nut residues represents an emerging area of growth that balances economic development with environmental sustainability.

PIRARUCU



Pirarucu aquaculture is emerging as a key driver of growth within the pirarucu value chain. More advanced systems in Peru and the Brazilian states of Rondônia and Acre have led to steady production increases, playing a crucial role in expanding this bioeconomy. Local and international organizations can support these initiatives by providing technical training and funding to enhance productivity while minimizing environmental impacts.

There is significant potential for market expansion, particularly in the international trade of high-value processed pirarucu products such as fillets, scales, leather, and bio-jewelry. Key export markets include the United States, the United Kingdom, Italy, and Japan. Broader market access is essential, especially in Brazil and Peru, where domestic consumption is concentrated in major urban centers, with high-end restaurants being the primary consumers.

Pirarucu's potential could materialize in the coming decades, with projected average annual growth rates ranging from 4 to 9.4 percent, depending on the scenario. By 2050, this could result in annual outputs of 11,300–52,700 tons, significantly higher than the current production of 3,200 tons per year. Most pirarucu production would be concentrated in Brazil and Peru.

Improving infrastructure along the value chain in all countries is crucial to meet these demand expansion estimates. Brazil, Peru, and especially Colombia, face accessibility and facility deficiencies at various stages. In Colombia, the pirarucu industry relies on community-based facilities that lack modernization, necessitating significant development.

Variability in precipitation across the Amazon Basin affects the pirarucu's natural distribution and renders certain fishing and farming areas less viable. Droughts, expected to intensify due to climate change in the eastern Amazon Basin, pose a major threat to the pirarucu's habitat. Lower water levels reduce the availability of suitable fishing areas and increase sedimentation, which can obstruct gills and lead to fish mortality. Communities relying on the species may face increased ecological and economic vulnerabilities. During the extreme drought of 2023, authorized fishing quotas in Brazil fell by 30 percent in some regions, severely impacting local livelihoods.

34 Commonly abbreviated as PES, these are monetary incentives provided to stakeholders for delivering ecological services (such as biodiversity conservation and carbon sequestration) in exchange for land management services. They encourage sustainable practices that benefit both the environment as well as local communities.

Institutional support, through technological innovation and technical support, is facilitating the development of the pirarucu industry. In Brazil, advancements such as floating processing units and drainage systems, supported by the Mamirauá Institute for Sustainable Development, are improving processing near capture sites. In Peru, the Institute of Production Technology (Instituto Tecnológico de la Producción) offers cost-benefit analyses and technical criteria for aquaculture infrastructure.

COCOA



Cocoa is poised to experience the highest production growth among the products analyzed, with its average annual growth rate expected to rise from 4.4 percent to 10.1 percent until 2050. This leads to considerable variation in production scenarios for 2050, ranging from 1 million to 7.3 million tons per year, depending on the specific scenario. In all cases, this represents a substantial increase from the current production of approximately 260,000 tons. The output will be primarily distributed among the three countries, with Brazil and Peru leading (in that order).

Technological innovation offers substantial growth opportunities for the cocoa sector. Implementing modern agroforestry techniques, advanced fermentation methods, and efficient drying technologies can greatly improve productivity and final product quality. Additionally, certification programs[35] enable small producers to tap into high-value international markets, boosting their economic resilience and promoting sustainable practices throughout the value chain. As geopolitical challenges faced by major cocoa producers in West Africa shift market focus toward Latin America, small producers stand to gain economically.

Proper transport and storage infrastructure are vital for the expansion of the cocoa bioeconomy. Improved infrastructure would lower costs across the value chain, making the product more efficient and competitive. Coordinated efforts by government agencies, private sector players, and local organizations are necessary to upgrade infrastructure, provide financial support, and bolster capacity-building initiatives.

Improving access to credit and technical assistance is particularly critical for small producers. Local associations and cooperatives play a crucial role in this regard, but their effectiveness is hindered by weak coordination. Improvement in these aspects would facilitate the decentralization of industrial processing centers, reducing their concentration in urban areas and offering more opportunities for rural communities.

35 Such as organic and Fair Trade labels.

Demand Projections and Bioeconomy Growth

Flows of bioeconomy products

Brazil, Peru, and Colombia exhibit significant differences in the organization, scale, and integration of their bioeconomy value chains. In Colombia and Peru, bioeconomy products from the Amazon basin primarily target local markets, while intraregional trade is negligible due to logistical constraints such as distance and perishability. Most production is sold raw, with minimal intermediate processing, in local Amazonian markets. Outdated data matrices for Colombia (2013) and Peru (2007) limit detailed comparative analyses, but existing information suggests that both countries are in the initial stages of bioeconomy chain development. While Brazil has made advances through policies such as the National Policy for Family Farming, small-scale and extractive agriculture is still underrepresented in official statistics. However, the Brazilian matrix (2015), although outdated, remains a reliable representation of product flows due to stable technical coefficients.

Brazil's economic flows were analyzed using an interregional input-output matrix developed by the World Resources Institute, covering 67 sectors, 127 products, and 31 regions (27 within the Legal Amazon). The analysis underscores each state's unique economic contributions: Rondônia (pirarucu and rubber), Acre (rubber extraction), Amazonas (copaíba, Brazil nuts, and pirarucu), Pará (cocoa and açaí), and Maranhão (babassu and honey). Significant intraregional distribution was identified, with forest products supporting local industries (rubber, food, and livestock) and pirarucu primarily directed toward Mato Grosso for processing. Disaggregated product flows for 2021 were simulated using a gravitational model for municipalities in the Legal Amazon and focused on the following four products due to their socioenvironmental and economic significance:

- **Açaí:** 478,600 tons, concentrated in Pará (Cametá, Manacapuru, and Belém), limited by perishability and transport constraints.
- **Brazil nuts:** About 9,500 tons, mainly directed to Belém, Manaus, and Rio Branco for export and local processing.
- **Pirarucu:** 1.5 million kilograms, predominantly handled in Porto Velho and Manaus, which are significant logistical and commercial hubs.
- **Cocoa:** 159,800 tons, notably concentrated in southern Pará (Medicilândia and Belém) and benefiting from transportation infrastructure such as the Trans-Amazonian Highway highway. Medicilândia acts as a key regional processing center for distribution to industries in southeastern Brazil.

Demand projections and scenarios

Demand projections through 2050 were based on a gravitational model and employed three scenarios—baseline, pessimistic, and optimistic—derived from municipal gross domestic product (GDP) data and product-specific growth rates (2013–22 averages):

- **Baseline scenario.** Projects steady growth based on current conditions and gradual infrastructure improvements, primarily strengthening local and regional markets, with limited potential for global competitiveness. No major interventions or disruptions are anticipated.
- **Pessimistic scenario.** Assumes infrastructure limitations, weak policies, and environmental restrictions that could stagnate or minimize growth. It cautions against risks where investments may not benefit local producers, undermining sustainable economic development.
- **Optimistic scenario.** Foresees accelerated and sustainable growth, driven by significant infrastructure investments, policy reforms, and improved access to premium markets through organic and Fair Trade label certifications. Success hinges on ensuring that benefits directly reach local producers.

Collectively, these scenarios outline a spectrum of potential future developments rather than predict a precise future, allowing for flexible and resilient planning in anticipation of future contingencies. The growth rate under the optimistic scenario is assumed to be, on average, 60 percent higher than the trend-based rate, while the pessimistic scenario is projected to be 55 percent lower.

Table 2.3 Growth rates for bioeconomy production

Product	Annual average growth rate, 2013-22 (%)	Baseline annual average growth rate, 2023–50 (%)	Optimistic annual average growth rate, 2023–50 (%)	Pessimistic annual average growth rate, 2023–50 (%)
Açaí	2.2	2.2	3.5	1.0
Brazil nuts	1.7	1.7	2.7	0.8
Pirarucu	10.5[36]	7.7	10.5	4.8
Cocoa	6.4	6.4	10.2	2.9

36 For the period 2016–22.

The optimistic scenario is significantly influenced by logistics infrastructure, inclusive policies, and access to specialized markets (figures 2.1–2.4). However, realizing this potential requires overcoming transport and logistical bottlenecks and ensuring producers have direct access to value-added markets. Without these conditions, growth may remain limited, with minimal long-term impacts on forest conservation and local livelihoods. Notably, the growth of pirarucu is closely tied to the expansion of sustainable aquaculture due to strict regulations on wild fishing enforced by the Brazilian Institute of Environment and Renewable Natural Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, IBAMA). Cocoa has substantial growth potential, driven by rising international demand. If strategic sourcing shifts from Africa to South America, Pará emerges as Brazil's leading cocoa producer by expanding cultivation into previously deforested areas.

Projected gains in forest conservation and living standards critically depend on the engagement of local producers and the equitable distribution of benefits. Without meaningful inclusion of communities, increased production and integration into international markets will not significantly boost incomes, forest conservation, or community well-being. Therefore, the future of the bioeconomy hinges not only on technical solutions but also on political decisions that determine who ultimately benefits from its expansion.

Figure 2.1 Demand growth scenarios for harvested açaí (tons)

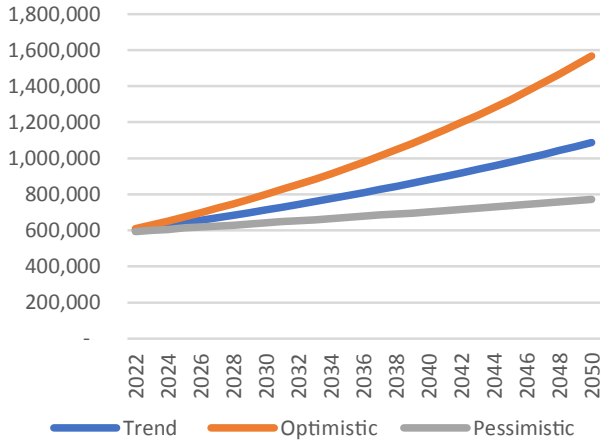
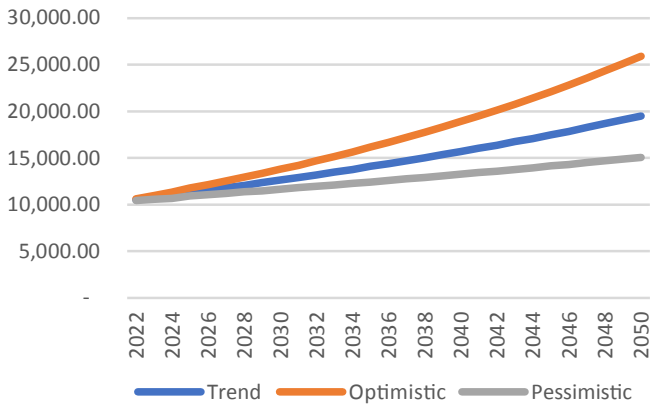


Figure 2.2 Demand growth scenarios for Brazil nuts (tons)



Source: Original compilation.

Figure 2.3 Demand growth scenarios for pirarucu (tons)

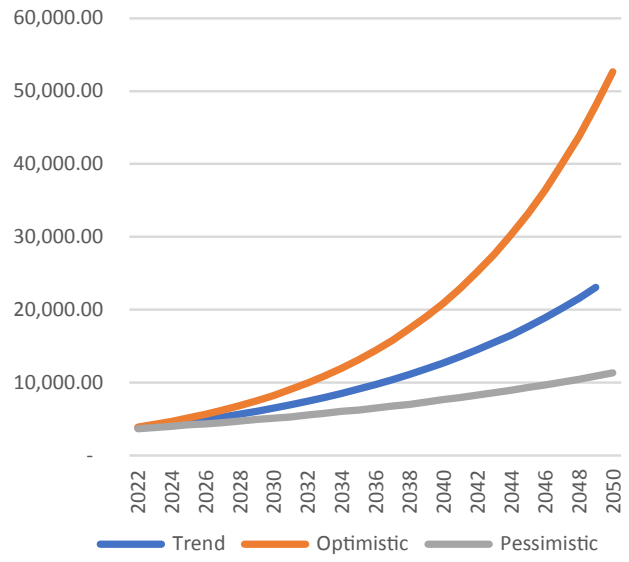
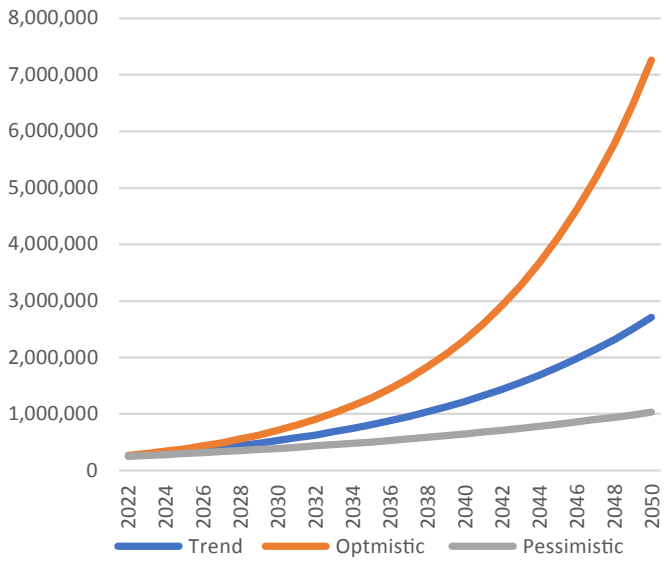


Figure 2.4 Demand growth scenarios for cocoa (tons)



Source: Original compilation.

Job Generation Opportunities for Bioeconomy Sector

To estimate the associated employment effects of the growth projected in the prior section, an input-output (IO) approach leveraging employment multipliers for relevant sectors was used. An employment multiplier is the number of jobs required given the demand for a certain good. These multipliers are obtained using a sector-level IO matrix or a Social Accounting Matrix (SAM) and sector-level employment data. The matrix reveals gross output requirements to produce a single unit of output (in monetary terms) considering all input requirements. Gross output requirements can be translated into employment effects.[37] Due to the concentration of bioeconomy production in Brazil, and due to limited data availability for relevant regions within Colombia and Peru, this analysis is limited to employment effects within the Legal Amazon.

The methodology assumes that job generation is demand driven. An increase in demand for a certain product is expected to impact job generation through three different channels. First, production increases in proportion to the rise in demand, and, as a result, jobs are created (direct jobs). Second, as production grows, more input is required. As in the previous case, a higher demand (of inputs) requires an increase in production, and jobs are created in the input industries (indirect jobs). Finally, holding all else equal, more jobs will increase labor income for some households, and, through that channel, the demand is expected to be higher. Again, production grows, and more input is required and more jobs are created (induced jobs). The estimates obtained in this exercise incorporate these three effects.

37 The methodology used for the current analysis is similar to that in Arakaki (2019) and Arakaki et al. (2021).

The employment multipliers for Brazil nut extraction, açai berry extraction, and fishing in the Legal Amazon were obtained from Ferreira Filho and Fachinello (2015) and Ferreira Filho and Poschen (2019). Both developed a SAM for the Legal Amazon, which includes the three relevant industries. Based on this matrix, they built a closed IO model and computed the employment multipliers. These multipliers for Brazil nut extraction, açai berry extraction, and continental extractive fishing are included in table 2.4. In the case of açai berry extraction, the employment multiplier indicates that 157 jobs are necessary to respond to an increase of US$ 1 million in the final demand of this industry in the Amazon.

According to the optimistic scenario, projected growth in bioeconomy production is

Table 2.4 Employment multipliers by industry for the Legal Amazon

Sector	Employment multipliers
Brazil nuts extraction	249
Açai berry extraction	157
Continental extractive fishing	250

Source: Ferreira Filho and Fachinello (2015) and Ferreira Filho and Poschen (2019).

expected to result in a doubling of employment within the sector by 2050. The result would be the creation of about 40,000 new jobs. Details by product are provided in table 2.5. The enlarged traditional bioeconomy industry would have corresponded to about 0.5 percent of total agricultural employment in the Legal Amazon in 2024. More disaggregated employment data were unavailable, but jobs in the traditional bioeconomy sector are likely to exist in the Rural and Deep Forest Amazons, regions with poor access to economic activities. As infrastructure improvements are likely to create additional employment opportunities in the region, these new bioeconomy-specific jobs may represent only a fraction of the impact of the investments highlighted below.

Table 2.5 Projected bioeconomy growth in the Legal Amazon

Bioeconomy product	Estimated baseline employment in 2022	Projected employment in 2050
Brazil nuts	15,547	40,050
Açai	4,583	11,187
Pirarucu	861	11,705

Source: Ferreira Filho and Fachinello (2015), and Ferreira Filho and Poschen (2019).

Chapter 3. A place-based approach to addressing select infrastructure gaps in the Amazon region



Chapter 3 key points

- Infrastructure solutions should be tailored to fit territorial typologies. In the Urban Amazon, focus on upgrading the quality, resilience, and integration of services; in the Rural Amazon, target secondary networks and service hubs; in the Deep Forest, prioritize technological solutions and improve essential access via rivers, decentralized power, and last-mile digital connectivity.
- Use cities and riverine towns as strategic development hubs to expand access while protecting intact forests. Integrated packages at hubs can unlock bioeconomy opportunities. Refrigerated storage, modular processing, reliable power, and connectivity at central river network hubs, in both the Urban and Rural Amazon, will reduce losses and expand market access for forest and agroforestry products, reinforcing conservation-compatible livelihoods.
- Bundle investments by combining transport, energy, and digital improvements. Reliable electricity is a prerequisite for stable internet; coordinated corridor planning and bundled investments (ports/docks with cold chains, microgrids, and connectivity) deliver larger benefits at lower cost than stand-alone projects.
- Focus first on maintenance and low-impact decentralized investments. In areas with existing roads, improve existing corridors rather than expand ing, to boost reliability, cut costs, and prevent new deforestation. For off-grid regions, use solar and hybrid microgrids, local energy hubs, and efficient refrigeration for cold chains; choose technology based on reliability standards. Bridge the digital divide by combining backbone fiber—via land and water routes—to key towns, with wireless or satellite options for remote settlements, and sync deployment with energy improvements for consistent service.
- Strengthen cross-border and inter-regional links where the demand justifies. Target river and fiber connections at cross-border nodes and binational corridors to improve trade, mobility, and redundancy, while meeting common safety and environmental standards.
- Finance models should match context. Urban and inter-urban upgrades with user revenues can attract private capital; remote services may require public funding, guarantees, or results-based schemes. Standardized power purchase agreements and de-risking can crowd in investment for mini-grids and connectivity.

The analysis and mapping of infrastructure gaps in the Amazon reveal a significant contradiction: improving infrastructure in the Amazon is essential for fostering development opportunities for local communities, yet maintaining certain infrastructure gaps is necessary to preserve local ecosystems. Two key insights are helpful in addressing this contradiction:

1. **Large and intermediate-sized cities function as hubs, enhancing the access of peripheral areas to economic and social services.** Given the region's dispersed population and the need to preserve local ecosystems, it is neither feasible nor advisable to establish hospitals, highways, agricultural processing centers, and power plants in every community. However, it is both feasible and critical to improve access to this infrastructure. Solutions should focus on connecting smaller communities with regional service centers that already provide infrastructure access for surrounding areas. These interventions must be tailored to the size of the community and its integration with regional road, river, energy, and digital networks. Reinforcing service provision and regional connectivity in large and medium cities would further improve outcomes for the entire region.

2. **Well-connected logistics centers on the periphery of the Amazon drive regional development and are critical for local value chains.** These centers exist in large urban settings such as Manaus and Belém, as well as in agricultural regions, including the southeastern states of the Brazilian Amazon—Mato Grosso, Tocantins, southern and eastern Pará, and Maranhão—and the westernmost departments of the Peruvian Amazon. Improved integration into national energy markets and improved physical connections and logistics will facilitate access to domestic and international markets.

There is potential for impactful investment in the Amazon's sustainable economic development while minimizing negative impacts. Recent studies suggest that the aggregate effect of infrastructure investments can be inferred from the travel time savings associated with upgraded transportation links (Allen and Arkolakis 2022). Large corridors featuring trunk and primary roads are likely to yield the greatest benefits. Additionally, permitting limited deforestation in highly productive agricultural areas may help curb global deforestation rates (Farrohki et al. 2025).

Principles of the place-based approach

Infrastructure development in the Amazon can advance economic opportunities for communities, while preserving critical ecosystems. This requires a targeted, place-based approach that considers the region's environment, geography, and connectivity. Four guiding principles shape the place-based approach:

1. **Tailor infrastructure interventions to territorial typologies.** In the Urban Amazon, investments should prioritize integration and connectivity, promoting large-scale infrastructure expansion to ensure capacity, resilience, and efficiency. In the Rural and Deep Forest areas, investments should focus on decentralized, less invasive solutions to promote more inclusive and sustainable development while minimizing environmental disruption.

2. **Identify strategic development hubs to expand reach.** Large and intermediate-sized cities should be strengthened to serve as strategic development hubs. These hubs can improve access to markets and services for surrounding areas with limited connectivity, and concentrate on infrastructure that can effectively serve broader regions.

3. **Prioritize integrated multisectoral solutions.** A multisectoral approach that bundles transport, energy, and digital connectivity investments can yield stronger local impacts and improve cost efficiency. Aligning interventions across sectors enhances service delivery and economic development, while reducing environmental footprints through coordinated and compact infrastructure planning.

4. **Utilize emerging technologies to bridge distances.** New technologies offer scalable and flexible solutions well-suited to the Amazon's challenging geography and dispersed populations. Deploying decentralized and renewable systems—particularly in energy, connectivity, and water access—can help overcome the limitations of conventional infrastructure and bring essential services to remote communities.

Place-based principle #1: Tailor infrastructure interventions to territorial typologies

The place-based approach aims to achieve two main goals: (1) expand productive infrastructure for traditional bioeconomy value chains, and (2) invest in climate-resilient transport, energy, and digital systems. The implementation strategy leverages knowledge of the distinct characteristics of connectivity clusters (i.e., the Urban, Rural, and Deep Forest Amazon), encourages bundled projects, and fosters cross-sector collaboration to maximize developmental impact. Key actions include a combination of targeted infrastructure investments and policy measures at the national, regional, and local levels:

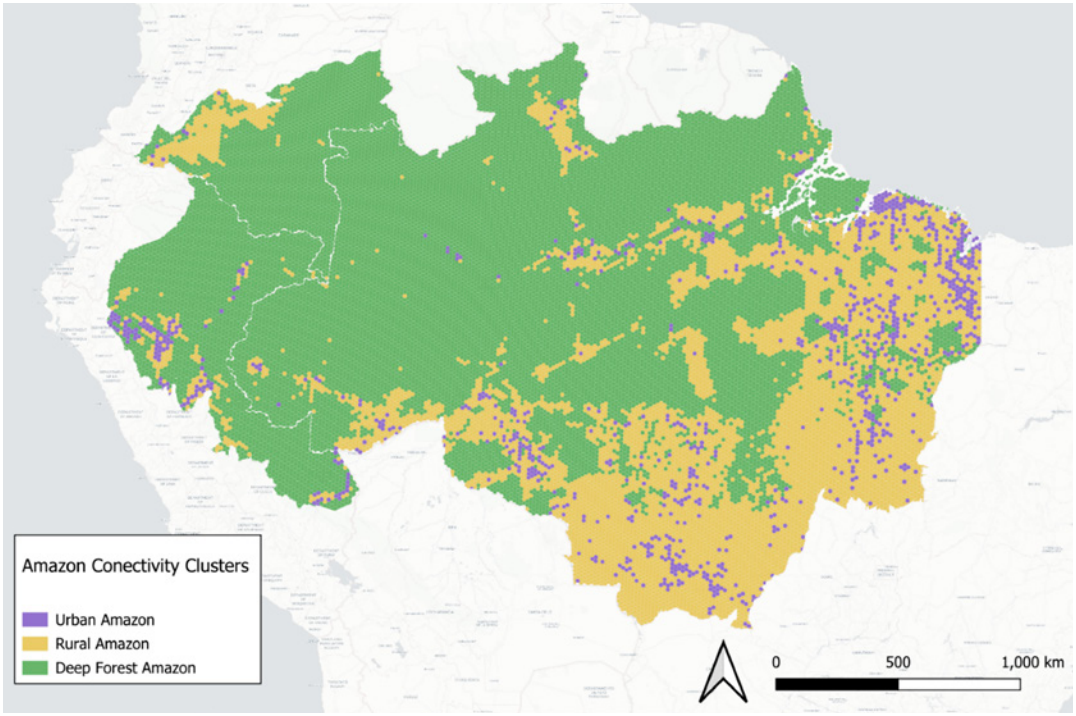
- **Expand transport connectivity by enhancing river navigability and electrifying boat fleets to lower bioeconomy transport costs and ensure sustainable and reliable access between remote communities and regional hubs.** Upgrade dock infrastructure, backed up with logistics solutions adapted to the size of communities served can lower bioeconomy logistics costs. Upgrading and ensuring the sustainable maintenance of existing roadways that remote communities to these river networks and those that connect major cities to improve market access for the region overall.

- **Decentralize energy production through the promotion of solar and hybrid microgrids (solar, biomass, batteries, and diesel backup).** While large hubs benefit from grid connections, smaller or remote communities rely on cooperative energy models using local resources or utility-operated systems, with diesel as a backup. Reliable energy allows for the processing of bioeconomy products closer to communities, enabling them to capture higher profits.

- **Expand digital connectivity** by extending fiber-optic infrastructure through subaquatic networks, and complementing these with cell towers, satellite solutions, and community access points in more remote areas.

Recognizing the distinct attributes of the Urban, Rural, and Deep Forest Amazon, as discussed in chapter 1, we identify specific interventions required for each type of cluster (map 3.1).

Map 3.1 The defining characteristics of the three Amazon connectivity clusters can inform the planning of appropriate interventions



Source: Original compilation.
Note: The Urban Amazon (purple), Rural Amazon (gold), and Deep Forest Amazon (green) are defined here based on levels of transport, energy, digital connectivity, access to services, and environmental characteristics. km = kilometer.

Addressing the region's infrastructure gaps requires deploying interventions that acknowledge the region's complexity and diversity. Strategies must be inclusive and adaptive—designed to support the expansion of the bioeconomy, improve quality of life, and ensure environmental sustainability. The capability of the place-based approach to achieve this delicate balance is illustrated in table 3.1. Before implementing any intervention, an analysis should be conducted to ensure its compatibility with the local regulatory framework and the sector's development objectives.

Table 3.1 Infrastructure interventions that promote infrastructure development while minimizing environmental disruption

Amazon region typology	Transport infrastructure (including urban)	Energy infrastructure	Digital infrastructure
	Place-based approach. *Infrastructure investments in these highly populated areas are essential to enhance regional economic opportunities. Improved integration into national energy markets and better physical connections will facilitate access to domestic and international markets, providing opportunities for economic development without undermining the environmental sustainability of the forest.*		
Urban Amazon. Highly accessible territories, that are anthropized and often located on the periphery of the region or around state or department capitals. Characterized by higher population density, denser infrastructure networks, and a greater concentration of economic activities. These regions serve as processing and economic centers, including for bioeconomy production and trade. Examples of communities and settlements .in this category: *Manaus (Amazonas, Brazil), Belém (Pará, Brazil), Florencia (Caquetá, Colombia), Iquitos (Belén, Peru).*	**Examples of interventions.** Large infrastructure investments aimed to increase capacity and resilience of river transport and road networks; prioritize river transport improvements; river port improvements (including gradual fuel transition); paved roads or gravel roads with stabilized slopes and drainage; urban transport investments for city productivity improvements; housing and urban rehabilitation. **Rationale.** River port investments are crucial for year-round operational reliability. The lack of electrification increases navigation costs and limits refrigeration capacity of port facilities. Paving roads between consumer centers and surrounding communities reduces remoteness and isolation.	**Examples of interventions.** Expanding decentralized and diverse energy systems. High-voltage grid connection with distributed solar generation systems where it has been proven to add stability to the system and reduce network costs. Incentives for community self-generation—solar as an additional low-cost, carbon-free energy source closer to the consumers. **Rationale.** High-voltage interconnections are the most cost-effective solution for the higher energy consumption of large cities and industries. Local distribution utilities can be included in the process of assessing the points on the grid where small-scale distributed energy production can be used as a grid-stabilizing resource, as well as supplying energy close to the point of consumption. In Brazil, investments in distributed solar systems in the Amazon, as in other regions of Brazil, are made by the end users themselves, who make the investment decision based on a cost-benefit analysis that reflects the current net-metering system.	**3.5 Examples of interventions.** Develop fiber-optic, subaquatic cables, along with community broadband networks and cell towers digital centers for e-commenrce, education, public services, as well as integrating public platforms for governance and traceability. **Rationale.** Amazonian cities face frequent connectivity disruptions and insufficient bandwidth, limiting their ability to support digital public services, logistics, and traceability systems. Strengthening infrastructure with redundant fiber-optic links, subaquatic cables, and community broadband networks ensures more reliable, high-quality connectivity. This resilience is essential for maintaining service continuity, especially during outages, and for positioning these cities as regional digital hubs.

Amazon region typology	Transport infrastructure (including urban)	Energy infrastructure	Digital infrastructure
	Place-based approach. *Solutions should include connecting smaller communities with strategic development hubs across the Amazon region that already facilitate access to infrastructure for surrounding areas. These interventions should be tailored to the size of the community and its level of integration with regional road, river, energy, and digital networks. Additionally, reinforcing service provision and regional connections within these strategic development hubs will further improve outcomes for the entire region.*		
Rural Amazon. Partially forested areas that lie along major transportation corridors such as large navigable rivers or the few existing highways, despite being part of a more preserved ecosystem. While ecologically sensitive, these regions are strategically located and therefore facilitate accessibility while playing a key role in regional connectivity. The region hosts some bioeconomy production centers integrated into regional value chains, with access to social services. Examples of communities and settlements in this category: *Codajás (Amazonas, Brazil), San Vicente del Caguán (Caquetá, Colombia), Caballococha (Castilla, Peru).*	**Examples of interventions.** Transform key ports and dock into strategic development hubs to include logistics support (storage, refrigeration) and digital connectivity. Other examples include construction of floating docks, electromobility for school and hospital transport routes, and resilient housing. **Rationale.** Floating docks adapted to fluctuating river levels and shared logistics systems can reduce postharvest losses and improve access to health and education. Electromobility addresses rising diesel costs and ensures service continuity in health/school transport.	**Examples of interventions.** Establish medium-voltage grid connection with hybrid energy systems (solar + batteries + biomass) when technically and economically feasible to ensure resilience for medium- to high-energy demands. Local power plants offset energy quality issues from the grid (e.g., stabilizing voltage and frequency) and serve as backups for the external grid during emergencies. **Rationale.** A medium-voltage alternative can deliver similar benefits to a high-voltage connection at a lower cost, when energy demand is not high enough. Opportunities exist to include power plants that use by-products from local biomass chains (e.g., açaí seeds, cocoa, and Brazil nuts shells) in competitive processes to supply electricity in these locations, assuming the technical and economic viability of the projects is proven. Locating energy sources closer to consumption points reduces grid losses and minimizes maintenance challenges related to climate and logistical issues.	**Examples of interventions.** Implement internet connections via cellular towers. Employ a hybrid approach where communities have access to fiber if near to cables or cell towers; otherwise, install dish units at cooperative centers. **Rationale.** Despite proximity to trunk infrastructure, internet signals can be weak or unstable, with poor coverage and slow speeds, limiting access to education, market platforms, and digital services.

Amazon region typology	Transport infrastructure (including urban)	Energy infrastructure	Digital infrastructure
	Place-based approach. *Limited interventions using small footprint infrastructure and technology-based recommendations to improve connectivity for the most remote and sparsely populated communities, while preserving the environmental integrity of the deep forest.*		
Deep Forest Amazon. Remote and sparsely populated regions, situated far from major urban centers and along secondary rivers that are less navigable, resulting in significantly longer travel times and reduced accessibility. These small communities are distant from electricity grids and digital and other infrastructure, primarily relying on subsistence activities and local barter economies. Examples of communities and settlements in this category: *Anori (Amazonas, Brazil), La Tagua (Putumayo, Colombia), Breu (Yuruá, Peru).*	**Examples of interventions.** Construction of small floating river docks, reinforced resilient local paths, and infrastructure facilitating river-based transport. Implement solar-powered boats for community transport and cargo drones for small goods. **Rationale.** In areas with limited access to transport infrastructure, developing resilient connectivity is impactful. Upgraded paths and bridges can establish minimum local mobility standards, while improving docks improve access to regional hubs. Cargo drones offer viable alternatives for traditional transport when logistics are unfeasible or for urgent deliveries (health, emergency supplies).	**Examples of interventions.** Implement distributed generation systems; hybrid energy systems (solar + batteries + biomass + diesel backup); stand-alone systems or shared community energy plants running mostly on solar power + batteries, supplemented by bioeconomy residues where economically and technically feasible, with diesel as an energy backup. These systems should operate under cooperative energy management models or local utilities, in compliance with applicable regulations. **Rationale.** Extending grid connections to remote communities is often cost-ineffective due to low energy demand. A more viable solution would involve substituting diesel with modern grid-forming energy technologies, while allowing communities to manage their own electricity and reduce dependency on distant utility personnel/companies, provided they possess the technical capacity and regulations to permit such an arrangements.	**Examples of interventions.** Establish satellite-based communication hubs, community internet access points with digital education and telemedicine services, and culturally adapted platforms in Indigenous languages. Promote digital literacy and productive internet use. **Rationale.** The absence of fixed broadband or cellular signal leaves communities completely disconnected from all services and markets.

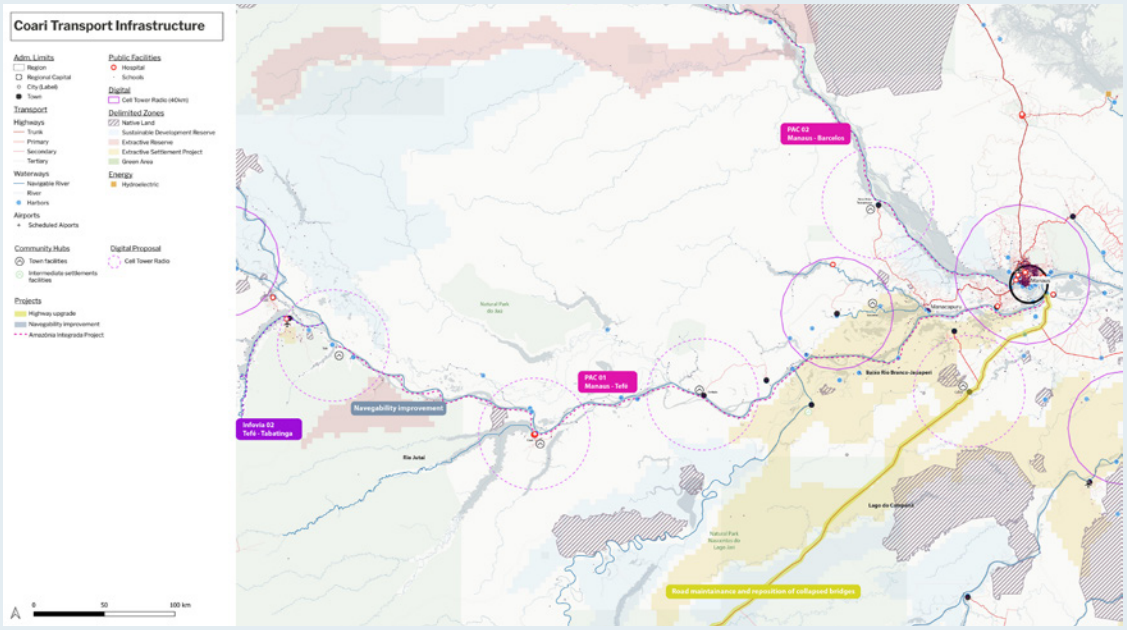
Source: Original compilation.

Box 3.1 Illustration of the place-based strategy

The central Amazon region surrounding Manaus serves as a prime example of the place-based strategy (map B3.1.1).

Manaus—the largest city in the Amazon region—serves as the region's main river port and a major logistics and freight hub, anchored by the Manaus Free Trade Zone, which hosts significant manufacturing and some agricultural and forest-product processing. Improving connectivity both within Manaus and to its peripheral areas is essential for remote communities to access opportunities. Economic growth also depends on stronger links between Manaus, regional cities, and international markets. However, the infrastructure strategies used to connect Manaus with urban centers such as Belem or Porto Velho should not be identical to those used to link Manaus with rural Manaquiri.

Map B3.1.1 Central Amazon place-based strategy applies different infrastructure strategies across Urban, Rural, and Deep Forest Amazon areas



Source: Original compilation.

Map B3.1.1 displays the Amazon/Solimões river corridor between Manaus, Tefé, and Tabatinga, which passes through Urban, Rural, and Deep Forest Amazon areas. A look at the existing cellular infrastructure, built roadways, navigable rivers, and important community centers (such as hospitals and schools) reveals key gaps to address.

The Amazon/Solimões river corridor is important for interregional transport of goods and for delivering services to dispersed riverine communities. Larger towns classified as Rural Amazon along the corridor serve as regional hubs, providing connectivity to the surrounding Deep Forest communities. Proposed interventions along this axis include: (1) improvements to river ports such as dock improvements and facilities for passengers and cargo (e.g., Coari); (2) implementation of fiber-optic cables and reinforcement of the digital backbone with cell tower radio systems to Tabatinga (Infovia 02); (3) installation of decentralized energy systems; (4) development of refrigerated storage and processing facilities; and (5) modernization of river fleet and transport services. These actions aim to integrate the regional hubs with smaller settlements that rely exclusively on river transport for mobility, fostering economic opportunities geared toward the export of açaí and fish products, which the region already specializes in.

Place-based principle #2: Leverage strategic development hubs to expand infrastructure and service coverage

The analysis confirms that the greatest challenge—and opportunity—for improving connectivity in the Amazon lies within the Rural and Deep Forest Amazon. Along with recommending infrastructure improvements while also protecting the environment, we provide an initial estimate of the investment needed to connect bioeconomy production zones with essential services and broader markets.

In line with the place-based approach, a package of interventions is envisioned that transforms existing ports across the Rural and Deep Forest Amazon into strategic development hubs, which integrate improved transport/logistics, energy, and digital solutions, and link decentralized production in the Rural and Deep Forest Amazon to processing hubs and urban centers. This investment framework serves as a starting point[38] for discussions on the scale and type of resources needed to close critical infrastructure gaps in the most underserved areas of the Amazon.

38 Estimating costs to close electricity access gaps is subject to uncertainty due to limited project-level data, absence of detailed engineering inputs, and the heterogeneity of conditions across the region. Cost adjustments for voltage class, terrain, logistics, or major river crossings can lead to significant under- or overestimation of investment requirements; thus, results should be interpreted with caution.

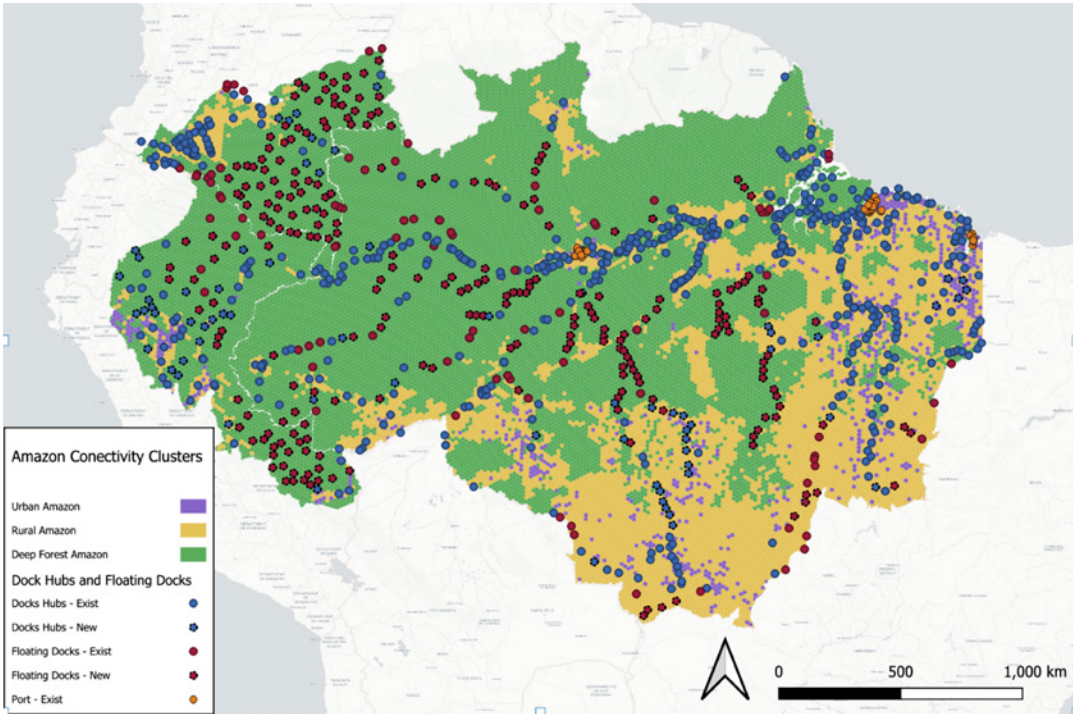
To address infrastructure gaps faced by bioeconomies across the Amazon, we conducted a comprehensive geospatial accessibility analysis. Each of the 730 mapped ports and docks is assumed to serve populations and bioeconomy activities within a 40-kilometer (km) catchment radius. River infrastructure needs were classified into two main categories based on geographic context and functional requirements:

- **Strategic development hubs:** Permanent river ports equipped with upgraded facilities for loading and unloading, cold storage, and connections to electricity and digital infrastructure. These hubs primarily target population centers in the Urban and Rural Amazon along river corridors.

- **Floating docks:** Modular, mobile infrastructure designed for Deep Forest areas, where terrain and hydrological conditions prevent permanent construction.

The results indicate that an additional 309 river facilities (see map 3.2)—comprising new strategic development hubs, and floating docks—are needed to provide adequate coverage for currently underserved bioeconomy in the Deep Forest, Rural, and Urban Amazon.

Map 3.2 New strategic development hubs, and floating docks can improve coverage for currently underserved bioeconomy



Source: Original compilation.
Note: The river infrastructure listed in the legend is overlaid over the three connectivity clusters being analyzed: the Urban Amazon (purple), Rural Amazon (gold), and Deep Forest Amazon (green). These clusters are defined based on levels of transport, energy, digital connectivity, access to services, and environmental characteristics. km = kilometer.

Costing strategic development hubs and docks

Given the heterogeneity of Amazonian contexts, any aggregate cost estimate is inherently approximate. More detailed project-level data will be needed for precise calculations than are currently available. To provide a general idea of costs within a standardized framework, we: (1) define access levels (low, medium, high) across the three connectivity clusters; (2) assume per unit investments for transport, energy, and digital infrastructure; and (3) aggregate the total costs across the clusters.

Energy systems: Cost estimate assumptions

Different energy access levels were defined using night light intensity as a proxy for energy access. Areas with very low or no visible night lights were categorized as low access, where only basic solar and battery systems could realistically meet basic needs for lighting, small refrigeration, and limited community services. Areas with intermediate night light intensity were categorized as medium access, requiring hybrid solar-diesel systems and larger battery storage to support higher loads such as cold storage, small productive activities, and digital connectivity. Finally, areas with high night light intensity were considered high access, reflecting proximity to the main grid and higher density of economic activity, justifying investments in grid connections, and sufficient supply to enable high-demand services such as vessel charging.

- **Low-access-level areas—proposed introduction of off-grid solar + batteries:** about 250–400 kW solar photovoltaic (PV) with 1–2 MWh battery storage. Capable of supplying basic lighting, refrigeration for health and fisheries, and limited digital services (400–600 MWh/year [enough for lighting for ~150 households + basic community services]). Estimated cost[39] is US$250,000–400,000 per hub for the solar generation and, including the battery storage, the total cost would be US$550,000 to US$1million.

- **Medium-access-level areas—proposed introduction of hybrid solar + diesel:** about 500–800 kW solar PV hybridized with diesel generation and 3–4 MWh of storage. Capable of powering productive uses including refrigeration, small-scale processing, and community-level internet (1,200–2,000 MWh/year [enough for about 500 households + refrigeration + digital nodes]). Estimated cost is about US$500,000–800,000 for solar PV and US$900,000–1,200,000 for battery storage.

- **High-access-level areas—proposed introduction of grid connection and cabling cost:** 1–2 MW peak demand with potential for vessel/vehicle charging, bioeconomy center facilities (4,000–6,000 MWh/year [sufficient for about 2,000 households or a small urban settlement, plus high-demand services such as e-charging]). Estimated cost, about US$500,000 for grid connection and US$1 million for 1MW solar per hub.

39 Cost estimate assumptions are based on a US$100,000 cost per 100 kW solar PV and US$300,000 for 1 megawatt (MW) battery storage.

Transport infrastructure: Cost estimate assumptions

- **Strategic development hubs:** Cost of civil works, passenger terminal, warehousing, and intermodal facilities estimated at US$2.0–2.4 million per hub, depending on remoteness.
- **Floating docks:** Estimated at US$200,000–300,000 per unit based on pilots in Amazonas State in Brazil.

Digital infrastructure: Cost estimate assumptions

The cost assumptions for digital infrastructure across strategic development hubs in the Amazon are grounded in standardized typologies and reflect the diverse connectivity conditions found throughout the region. Based on official data and implementation benchmarks from Brazil, the estimates consider the three distinct scenarios. These figures are intended to serve as approximate references and are subject to refinement as more detailed, project-level data become available.

- **Deep Forest Amazon:** Basic satellite internet (VSAT), about US$500 annually per hub.
- **Rural Amazon:** Community broadband with caching servers, about US$150,000–200,000 per hub.
- **Urban Amazon:** Fiber/4G/5G integration with Internet of Things nodes, about US$100,000–150,000 per hub.[40]

The cost analysis shows that establishing a network of 970 strategic development hubs and floating docks across the Amazon would require an estimated US$3.24 billion, reaching a projected population of nearly 13.9 million people, resulting in an average cost of US$233 per person. Unit costs vary considerably depending on location and energy access level: strategic development hubs range between US$3.1 and US$4.0 million per site, reflecting their higher needs for transport infrastructure, hybrid or grid-connected energy systems, and digital connectivity integration, while floating docks are less capital intensive, averaging US$500,000 per unit. Deep and Rural Amazon sites incur relatively higher energy-related costs due to their reliance on off-grid solar, hybrid systems, and storage, whereas Urban Amazon areas concentrate more resources on digital connectivity and grid integration. These results highlight the substantial investment needed to ensure transport nodes also serve as platforms for energy access and digital inclusion, with tailored solutions based on local demand and infrastructure conditions.

40 Using Brazil as a benchmark (source: https://www.gov.br/mcom/pt-br/arquivos/fust/caderno-de-projetos-cg-fust-2023-versao_final_aprovada.pdf).

Table 3.2 Projected bioeconomy growth in the Legal Amazon

Type	Cluster	Electricity	Total	Transport Cost Estimates per unit (US$)	Energy Cost Estimates per unit (US$)	Digital Cost Estimates per unit (US$)	Total per unit (US$)	Total (US$)
Development dock hubs	Deep	Low	87	2,400,000.00	1,100,000.00	500.00	3,500,500.00	304,543,500.00
	Deep	Medium	71	2,400,000.00	1,300,000.00	500.00	3,700,500.00	262,735,500.00
	Deep	High	8	2,400,000.00	2,000,000.00	500.00	4,400,500.00	35,204,000.00
	Rural	Low	49	2,100,000.00	800,000.00	200,000.00	3,100,000.00	151,900,000.00
	Rural	Medium	116	2,100,000.00	1,200,000.00	180,000.00	3,480,000.00	403,680,000.00
	Rural	High	37	2,100,000.00	1,500,000.00	150,000.00	3,750,000.00	138,750,000.00
	Urban	Low	66	2,000,000.00	650,000.00	150,000.00	2,800,000.00	184,800,000.00
	Urban	Medium	121	2,000,000.00	1,100,000.00	120,000.00	3,220,000.00	389,620,000.00
	Urban	High	84	2,000,000.00	12,000,000.00	100,000.00	14,100,000.00	1,184,400,000.00
Floating Docks	Deep	Low	203	300,000.00	250,000.00	500.00	550,500.00	111,751,500.00
	Deep	Medium	65	300,000.00	250,000.00	500.00	550,500.00	35,782,500.00
	Deep	High	4	300,000.00	250,000.00	500.00	550,500.00	2,202,000.00
	Rural	Low	16	250,000.00	250,000.00	200,000.00	700,000.00	11,200,000.00
	Rural	Medium	18	250,000.00	250,000.00	180,000.00	680,000.00	12,240,000.00
	Rural	High	7	250,000.00	250,000.00	150,000.00	650,000.00	4,550,000.00
	Urban	Low	5	200,000.00	250,000.00	150,000.00	600,000.00	3,000,000.00
	Urban	Medium	12	200,000.00	250,000.00	120,000.00	570,000.00	6,840,000.00
	Urban	High	1	200,000.00	250,000.00	100,000.00	550,000.00	550,000.00
	Total		970					**3,243,749,000.00**
					Population			**13,912,073.39**
					Cost per population			**233.16**

Source: Original compilation.

Costing digital connectivity expansion for bioeconomy areas

Capital expenditure estimates for digital connectivity in bioeconomy zones vary significantly across regions, reflecting differences in population density and the optimal technology mix suited to each context. In the Brazilian case, on average, population density in bioeconomy zones is approximately 25 people per square kilometer (km^2), with most municipalities having fewer than one inhabitant per square kilometer.

Also, leading bioeconomy production zones are concentrated in a few municipalities, notably Manaus, Limoeiro do Ajuru, Oeiras do Pará, Barcarena, and Belém. These areas are examples of a persistent digital divide in Brazil, where well-connected urban centers border underserved peripheries with limited connectivity. Improved digital connectivity will not only help bioeconomy communities integrate their production chains into the digital economy, but will also expand access to public services.

To ensure a consistent download speed of at least 50 megabits per second (Mbps) across the designated bioeconomy zones, an estimated investment of US$525 million would be required. This investment would primarily support the extension of optical fiber within a 10-kilometer radius of existing connectivity points, as well as the deployment of satellite solutions in more remote areas.

Zones currently experiencing limited connectivity (defined as download speeds below 25 Mbps) or lacking connectivity altogether would account for 69 percent of the total capital expenditure. The remaining 31percent would be allocated to areas with standard connectivity (download speeds between 20 and 50 Mbps). On average, approximately US$75 per person would be necessary to provide broadband infrastructure coverage across these regions.

Prioritizing regional infrastructure investments to support and connect strategic development hubs for the bioeconomy

Investing in infrastructure in the Amazon requires a structured, evidence-based approach that balances regional needs with environmental and social considerations. The infrastructure gap analysis provides critical insights into key investment priorities across the region, while the national infrastructure plans of Brazil, Colombia, and Peru outline a broad pipeline of proposed initiatives. A multicriteria evaluation ensures that these investments align with the priorities identified in the gap analysis—while assessing their potential impacts on local communities, traditional bioeconomies, and the environment, alongside considerations of project maturity (details in Annex A4).

Evaluation of projects proposed in national infrastructure plans

The sectoral priorities summarized earlier are also reflected in the existing infrastructure project proposals, defined in the National Plans of Brazil, Colombia, and Peru.

- **Brazil:** Growth Acceleration Program (PAC) 2023; National Logistics Plan (PNL) 2030; Medium-Term Electricity Operation Plan (PAR/PEL) for the National Interconnected System 2024; Electricity Transmission Concession Plan 2024; Integrated and Sustainable Amazon Program (PAIS) 2021; Technical Reports of the Energy Research Company (Empresa de Pesquisa Energética, EPE) since 2022.

- **Colombia:** Intermodal Transport Master Plan (PMTI) 2051; River Master Plan (PMF) 2022; Sustainable Amazonian Transport Plan (PATIS) 2024.

- **Peru:** Master Plan for Logistics Infrastructure and Services 2032; Amazon Fiber Optic Backbone Program, 2022 (private sector led with incremental regulatory clearances).

The infrastructure projects defined in these plans have been assessed for their potential impacts on communities, traditional bioeconomies, and the environment, as well as their maturity. The sections below summarize the findings of the proposed projects, which are justified based on their positive impact on the identified gaps, environmental impact, and project readiness as defined by the place-based approach and methodology discussed in this section.

Transport projects

High-priority projects typically have strong territorial and socioeconomic reach, align with high-volume bioeconomic corridors (particularly cacao and açaí), are ready to be implemented, and have low environmental risks.

Among the most aligned interventions are river navigation projects that bolster bioeconomy flows and support communities.

- **In Brazil**, improving navigation on the Madeira River benefits more than 600,000 people across 1,071 km, intersecting highly productive areas yielding 1.9 million tons of açaí and 2,566 tons of Brazil nuts. This corridor is included in PAC 2023 and traverses areas with moderate environmental risk. Another key corridor is the Tapajós River in Pará, serving approximately 380,000 people and over 300 km of community territories, supporting 54,475 tons of cacao, 951 tons of Brazil nuts, and 87 tons of pirarucu. Despite facing higher environmental pressure in certain sections, the corridor shows strong alignment due to its integration into productive and populated regions.

- **In Colombia**, enhancing navigation between Puerto Asís and Brazil on the Putumayo River (a corridor that stretches over 1,200 km) would benefit nearly 70,000 people and support the movement of 747 tons of pirarucu.

- **In Peru**, navigation corridors along the Ucayali River, particularly the stretch connecting to Pucallpa, would benefit about 800,000 people and intersect areas producing over 81,858 tons of cacao and 772 tons of pirarucu. Improving conditions along the Huallaga River and between the Amazon River and Pucallpa in Ucayali aligns well with the roadmap objectives.

Several road infrastructure projects exhibit alignment, particularly those in previously transformed landscapes with production potential. For instance, in Brazil, the Altamira-Medicilândia segment of BR-230 in Pará supports more than 190,000 inhabitants and traverses one of the most productive cacao corridors in the Amazon, with an annual output exceeding 121,000 tons, complemented by 376 tons of Brazil nuts. Located in a semiurbanized setting with existing right-of-way, this project demonstrates technical feasibility with limited environmental impact.

Conversely, some projects show lower alignment with the roadmap due to limited overlap with productive areas, low maturity, or elevated environmental risks. The BR-319 corridor, connecting Manaus to Porto Velho, serves a significant population (1.18 million) and intersects productive zones, but crosses extensive preserved forest areas and protected zones, resulting in high environmental pressure and potential land-use changes, which diminishes its suitability under the roadmap's sustainability criteria. Similarly, the BR-156 project in Amapá, which supports 43,082 people and intersects areas producing 48.7 tons of açaí, faces low technical maturity and high ecological sensitivity.

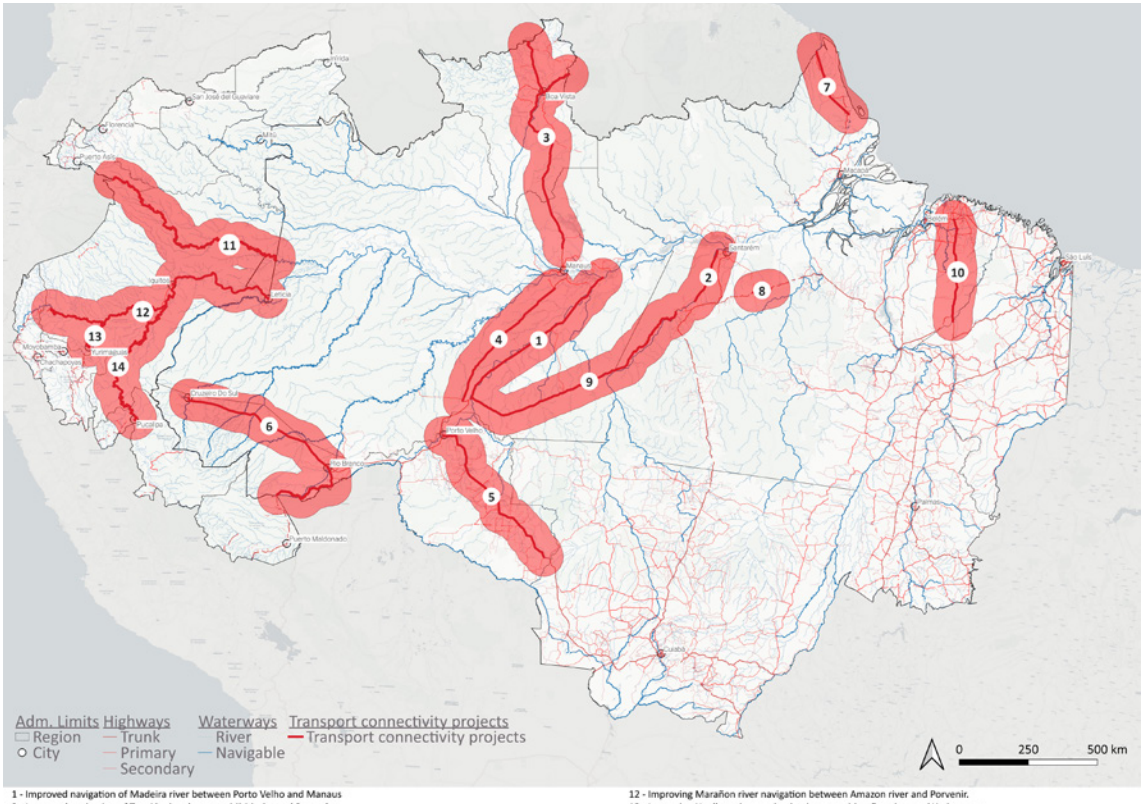
Certain existing projects present higher risks of land-use transformations and should be approached with caution. While road paving enhances transport conditions and reliability, and significantly reduces travel times, it may increase environmental pressure in well-preserved areas of the Amazon rainforest. Many local roads, including the majority of the Rural and Deep Forest road networks, suffer from poor quality. Road segments in protected forested areas or those crossing protected regions and Indigenous territories are considered less conducive to the roadmap's overall goals, especially when alternative river-based routes are available. River transport is less intrusive in these regions, but precautions are necessary when developing port and logistics infrastructure in pristine areas.

Many communities are already well served by their road networks (as illustrated by the Rural Access Index calculations highlighted in chapter 1). It has been well established that road transport plays a critical role for non-bioeconomy agriculture, primarily harvested in the Rural Amazon. Ensuring the maintenance and continued quality of major roadways that serve these regions and connect them to major urban hubs is essential. Additionally, in certain cases, maintaining local roads will also be vital for connecting isolated communities. In Deep Forest and in regions of the Rural Amazon where the forest is preserved, such maintenance

should prioritize promoting access to river networks, which naturally provide inter-regional connections, and must be accompanied by proactive environmental safeguards to limit negative impacts. In Colombia, best practices compiled by national agencies emphasize early intervention, environmental sensitivity mapping, and a hierarchy of mitigation measures—including avoidance, minimization, restoration, and compensation—to ensure that local road projects are planned, constructed, and maintained with careful attention to ecological connectivity, water resources, and community engagement.[41] These guidelines provide a comprehensive framework for integrating environmental and social safeguards throughout the life cycle of local road infrastructure.

41 See the following examples: Ministerio de Ambiente y Desarrollo Sostenible, WWF Colombia, and Fundación para la Conservación y el Desarrollo Sostenible (2021), "Lineamientos de Infraestructura Vial Verde," Bogotá, Colombia.; Ministerio de Ambiente y Desarrollo Sostenible (2019), "Guía de Manejo Ambiental para Vías Terciarias," Bogotá, Colombia.; Ministerio de Ambiente y Desarrollo Sostenible, WWF Colombia, and Fundación para la Conservación y el Desarrollo Sostenible (FCDS) (2021), "Guía ambiental de pasos de fauna silvestre en infraestructura lineal," Bogotá, Colombia.

Map 3.3 Transport projects proposed in national infrastructure plans, evaluated using four criteria



Source: Original compilation.
Note: Priority criteria include: potential impacts on communities, traditional bioeconomies, environment, and project maturity. km = kilometer.

Energy projects

The state of Amazonas is under analysis by Empresa de Pesquisa Energética, which periodically publishes technical and economic feasibility studies comparing the construction of transmission lines and substations with the costs of current diesel-powered plants. Projects that demonstrate positive feasibility advance to the Plano de Outorgas de Transmissão de Energia Elétrica (POTEE) for auction or authorization. Notable projects include the interconnection of Humaitá, located in southern Amazonas, to the national grid via a substation in Rondônia (Caladinho II), and reinforcements in the energy supply for Iranduba and Manacapuru near Manaus. These projects have a significant direct impact on local nut production (Humaitá) and particularly benefit the açaí and pirarucu industries (Iranduba and Manacapuru).

The most significant energy infrastructure project currently underway in the Legal Amazon is the final segment of the Tucuruí transmission line (720 km), which will connect Boa Vista, the capital of Roraima, to the national grid. This undertaking will benefit the 400,000 residents of Boa Vista by reducing their reliance on fossil fuels and on unreliable electricity imports from Venezuela. Roraima holds potential for bioeconomy products, including Brazilian nuts and cocoa.

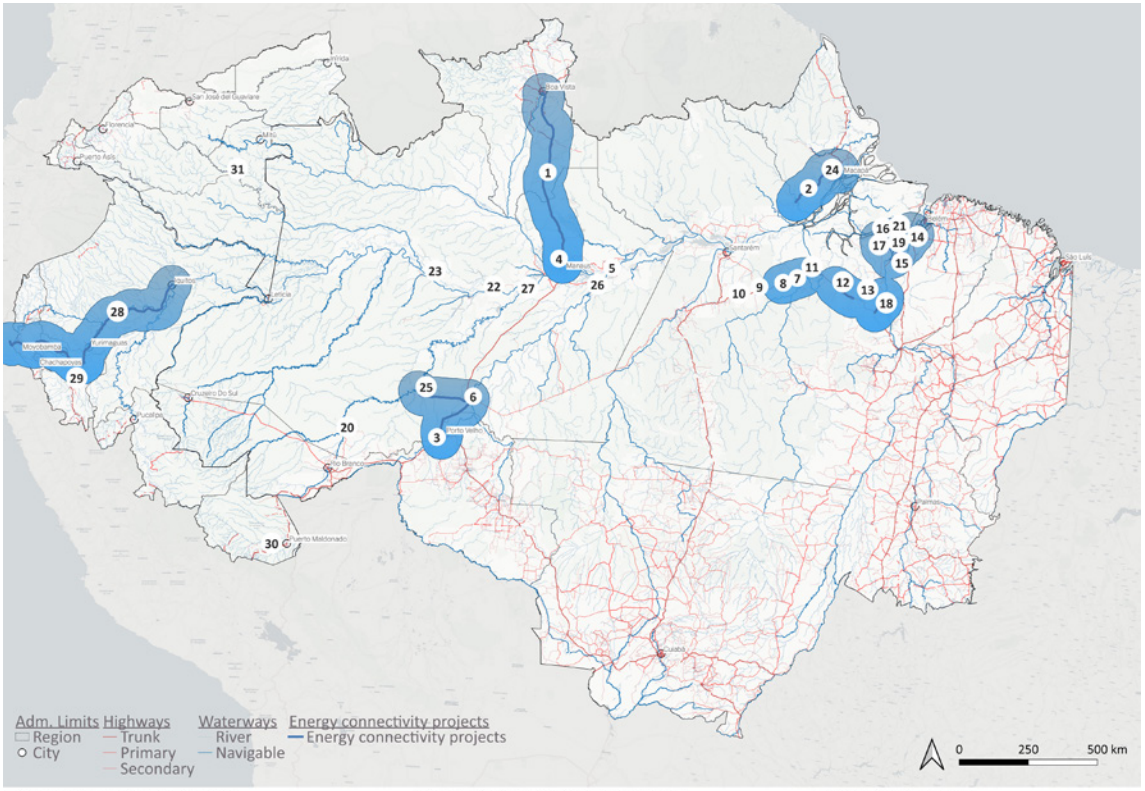
Another substantial project under construction is aimed at reinforcing the energy supply to Macapá. A new substation and transmission line are expected to become operational in 2027, addressing issues that led to extensive blackouts in 2020 and 2021. Since nearly all energy in Amapá is sourced from Macapá's infrastructure, this reinforcement will directly benefit the açaí and Brazil nut industries in the region.

In Peru, the connection of Iquitos to the Sistema Eléctrico Interconectado Nacional (SEIN) represents the longest planned transmission project in the country, set to serve over 600,000 people upon completion. Peruvian authorities have integrated features such as elevated transmission towers and cables above the trees, concurrent use of towers for fiber optics, and long-term demand growth models to accommodate a sixfold increase in energy consumption in Iquitos (from the current ~50 megawatts [MW] to 300 MW), with the aim of permanently eliminating energy shortages in the region.

Colombia is taking a different approach to bolstering energy supply in the Amazon. Instead of focusing on large transmission projects, its latest Plan Indicativo de Expansión de Cobertura de Energia Eléctrica (PIEC), published by the Unidad de Planeación Minero Energética (UPME) in April 2025, employed geospatial modeling to determine that most of the Colombian Amazon will remain disconnected from the national grid, relying instead on microgrids or individual installations.

It is worth noting that, for all three countries, smaller-scale renewable energy plants—particularly those combining solar, biomass, and batteries—offer a swift and autonomous pathway to energy accessibility, given the monumental challenges posed by transmission lines in the Amazon. As energy demand increases, private entities can develop or acquire their own energy projects, prompting governments to pursue more comprehensive and widespread solutions.

Map 3.4 Energy projects proposed in national infrastructure plans, evaluated using four criteria



Source: Original compilation.
Note: Priority criteria include: potential impacts on communities, traditional bioeconomies, environment, and project maturity. km = kilometer.

Digital connectivity projects

All digital infrastructure projects analyzed here are essential for enhancing connectivity in remote areas of the Amazon. High-capacity data connectivity is crucial not only for providing access to basic digital services but also for modernizing and integrating bioeconomic value chains, particularly in regions with limited physical infrastructure.

The prioritization of digital infrastructure projects significantly benefits territorial connectivity and productive ecosystems. However, this analysis reveals variations in scale, maturity, and bioeconomy impact that warrant prioritizing certain investments, especially within the Brazilian Amazon.

These projects are fundamental for unlocking market access, ensuring traceability, and enabling e-services, while also reinforcing territorial cohesion. Nonetheless, challenges such as energy insecurity, cost barriers, and institutional fragmentation continue to limit the transformative potential of digital infrastructure, particularly in the most isolated and underserved areas. Therefore, the roadmap emphasizes that investments in digital infrastructure must be accompanied by improvements in energy systems, affordability frameworks, and local digital literacy initiatives to achieve lasting impact.

Brazil leads in digital infrastructure development, with several fiber-optic corridors already deployed and operational. Among the proposed projects, the most strategic initiatives are concentrated in Brazil under the "Infovia" program. Specifically, Infovia 02 (Tefé-Tabatinga), Infovia 03 (Macapá-Belém), and Infovia 04 (Vila de Moura-Boa Vista) stand out as highly aligned with bioeconomy support objectives.

- Infovia 02 spans approximately 1,600 km, benefits an estimated 3.1 million inhabitants, and supports significant bioeconomic production, including 211,473 tons of açaí, 1,418 tons of castanha, 815 tons of pirarucu, and 222 tons of cacao annually. It is classified as highly aligned with bioeconomy support goals.

- Infovia 03, covering 496 km, impacts around 4.4 million people and supports a productive corridor yielding 343,986 tons of açaí, 61 tons of cacao, and 1,072 tons of pirarucu. This project is also classified as highly aligned.

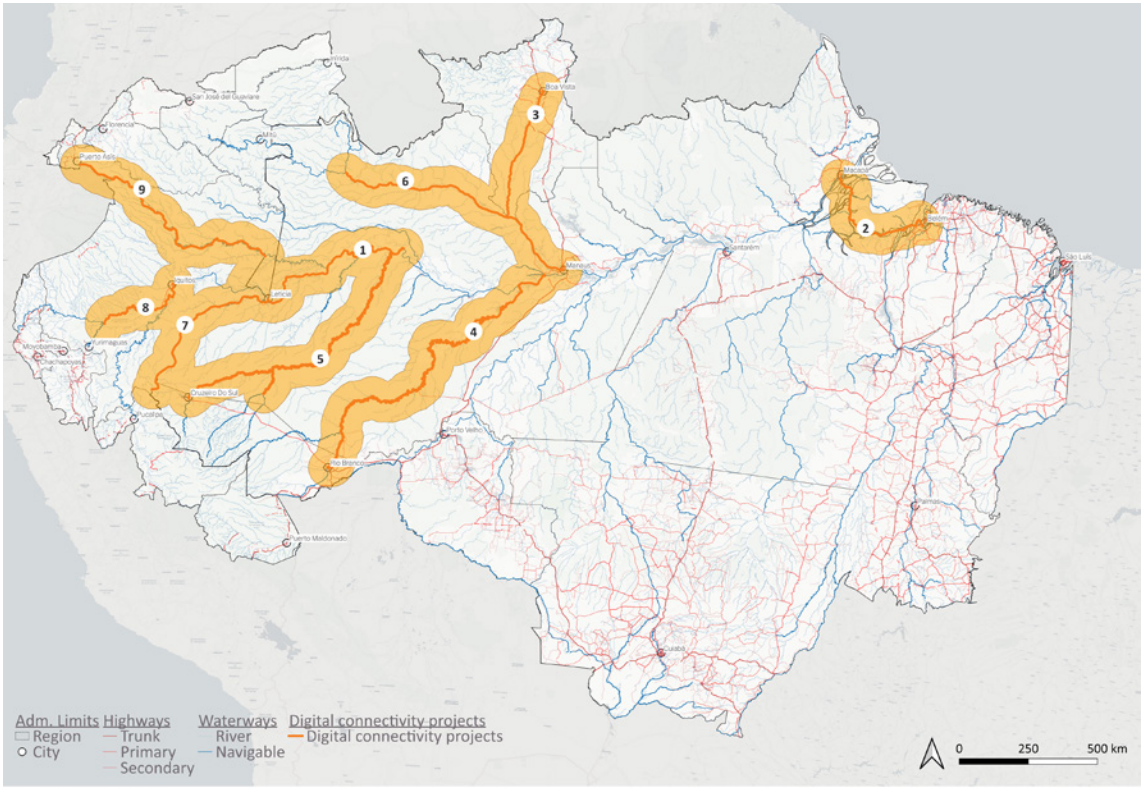
- Infovia 04 extends over 855 km, intersects a population of 3.03 million, and connects areas producing 193,308 tons of açaí, 698 tons of pirarucu, and 833 tons of castanha. It is similarly classified as highly aligned.

In Peru, the existing digital infrastructure in the Amazon includes fiber-optic deployments such as the Iquitos-Tabatinga and Yurimaguas-Iquitos segments, which form part of the National Fiber-Optic Backbone *(Red Dorsal Nacional de Fibra Óptica)*. This analysis has identified and included the proposed Pucallpa-Nauta fiber-optic corridor along the Ucayali

River, extending approximately 620 km through riverine and forested terrain. This project aligns technically with the existing network and aims to serve around 800,000 residents. The corridor traverses highly productive areas, including the departments of Ucayali and Loreto, where annual production reaches approximately 81,858 tons of cacao and 772 tons of castanha.

The Fibra Colombia–Río Putumayo project represents the most significant infrastructure initiative identified for improving digital connectivity in the Colombian Amazon. Spanning 714 km, it benefits 69,811 people and supports moderate levels of production—97.8 tons of Brazil nuts and 0.6 tons of pirarucu. Although smaller in scale compared to its Brazilian counterparts, this project addresses a critical connectivity gap along the Putumayo river. It is important to note, however, that this project is not currently included in Colombia's national digital infrastructure planning instruments or programs.

Map 3.5 Digital projects proposed in national infrastructure plans, evaluated using four criteria



Source: Original compilation.
Note: Priority criteria include: potential impacts on communities, traditional bioeconomies, environment, and project maturity. km = kilometer.

Place-based principle #3: Bundle projects to improve cross-sector coordination and optimize territorial impact

Combining infrastructure projects can increase the efficiency and relevance of investment implementation in the Amazon region by integrating complementary, and possibly multisectoral, solutions. This integration maximizes the impact of each dollar invested while minimizing environmental harm through consolidated interventions. In a region like the Amazon, where uncoordinated infrastructure expansion can accelerate deforestation, bundled projects offer a strategic approach to development that balances economic growth with ecological preservation. Moreover, integrated, locally adapted investments that combine energy, transport, and digital solutions to strengthen community-based production systems, enable processing closer to the source, and facilitate access to higher-value domestic and international markets. Combining targeted physical infrastructure with service provision can ensure that the entire Amazon community benefits from select interventions.

Examples of bundled, place-based investment strategies to boost bioeconomy activities and service access include:

1. **Complement port/dock infrastructure improvements with various other infrastructure.**

    - **Complement with energy, digital, and water infrastructure.** Such improvements can include solar panels, battery storage, rainwater harvesting, systems for clean drinking water, and internet connectivity. These are straightforward, scalable interventions that can immediately improve quality of life for communities currently lacking access to basic services like energy and water.

    - **Complement port/dock improvements with storage, refrigeration, and processing facilities.** Site selection should prioritize areas with existing quality electricity supply or those earmarked for energy upgrades. This would enable value-added activities for local bioeconomy products—increasing incomes for remote producers while bolstering the capacity of regional service centers.

2. **Pair river navigability improvements with energy and digital connectivity infrastructure.** Investments to enhance river navigability should be accompanied by complementary infrastructure that multiplies their developmental impact.

    - **Include the installation of underwater fiber-optic connectivity and subaquatic high-voltage transmission.** The construction of this infrastructure will help to promote reliable digital connectivity and energy access. These investments naturally follow the physical river routes that already connect urban hubs and regional service centers with the surrounding rural and Indigenous communities and are fully aligned with the place-based territorial development.[42]

42 Such solutions are already used in the Amazon: Iranduba and Manacapuru are connected to Manaus through a 69 kilovolt (kV) subaquatic line, as well as the Marajó Island is connected to Barcarena through underwater cables. Recent deployments of underwater fiber-optic cables have connected municipalities such as Leticia (Colombia), Tabatinga (Brazil), and Iquitos (Peru), enabling service to over 400 communities.

3. **Expand digital and cellular connectivity in the Rural and Deep Forest Amazon to improve the provision of regional social services.**

    - **Provide fixed wireless access (FWA) and TV white space technologies in the rural Amazon.** FWA using dedicated radio frequencies can deliver broadband internet over short-to-medium distances where line-of-sight connections are possible. In contrast, TV white space can be used to provide wireless internet for sparsely populated forested regions even in the presence of dense foliage.

    - **Support the development of e-commerce platforms for the bioeconomy.** This will allow to capitalize on the expanded digital coverage for other services. E-commerce platforms and digital marketplaces for Amazonian bioeconomy products will facilitate product traceability, product standardization, and market access, making the local production more appealing to downstream buyers.

4. **Develop electric mobility solutions along the Amazon river network.** The propulsion systems on the boats used in remote areas are optimized for shallow, vegetation-dense river channels. The largest portion of the fleet in the Amazon is propelled by small motors, thus offering a significant scale of motors to be transitioned.

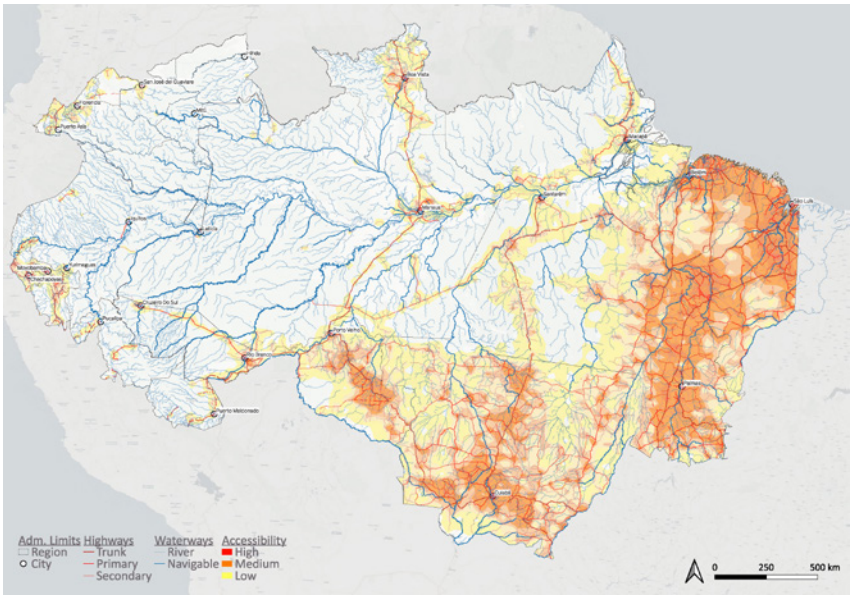
    - **i. Solar-powered charging stations.** Establishing riverbank and floating solar charging stations would reduce dependency on diesel, lower operational costs, and cut emissions. This infrastructure would improve river navigability while decreasing river pollution and promoting energy transition goals. In turn, this will support economic resilience by enabling access to schools, clinics, and local markets.

5. **Complement infrastructure investments in regional hubs with entrepreneurship support.** These can be initiatives to support incubators for bioeconomy start-ups and digital entrepreneurs and support the cooperatives that already lead community efforts in the bioeconomy. Thus, the regional centers will have the opportunity to grow into innovation hubs which harness digital tools and bioeconomy products, fostering inclusive economic development.

Local governments are best suited to conduct granular geospatial assessments to confirm the need and viability of specific investments and to ensure their successful design. As the place-based approach emphasizes, there is no one-size-fits-all solution for infrastructure investments in the Amazon. Jurisdiction-specific needs should be assessed at the local level. Such work will reveal important insights: Consider the variation captured in maps 3.6 and 3.7, which plot access to road and water transport infrastructure. Access varies substantially across the entire region, but also within individual states. Brazilian states along the periphery of the Amazon, like Tocantins or Maranhão, host the largest quantities of major roadways, and the density of such roadways is also highest in these jurisdictions. Yet, many communities are assessed as having only medium or low connectivity. How

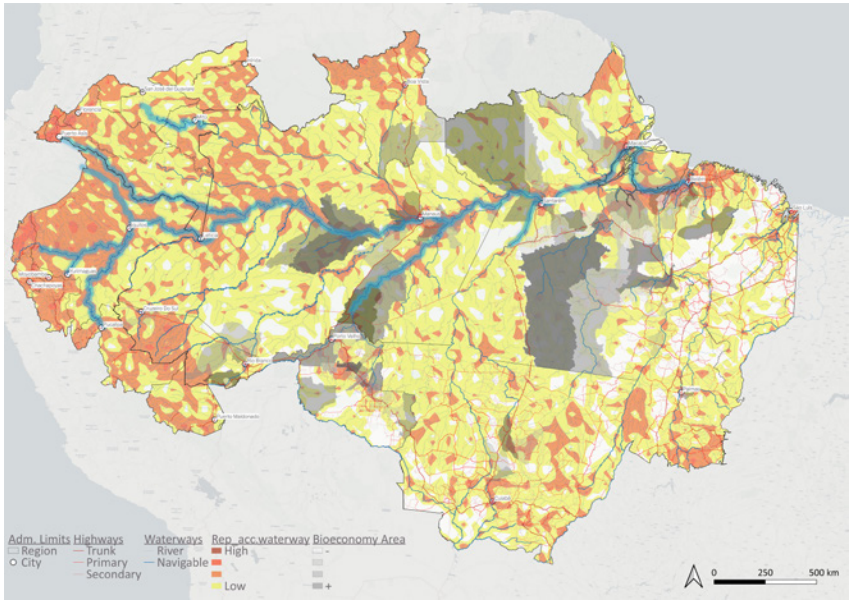
can the connectivity of these areas be improved, when infrastructure is already readily available? Answers to this and other questions can only be revealed through more detailed local investigations. A similar observation is available when considering river transport in the Colombian Amazon. Many communities are near rivers but lack sufficient infrastructure to capitalize on this location. Local governments are best suited to study the needs of their communities. Remotely assessed geospatial data can help serve as a guide to prioritize projects or interventions for further study.

Map 3.6 Road accessibility



Source: Original compilation.
Note: Red denotes the highest level of road access, and yellow the lowest.

Map 3.7 River accessibility



Source: Original compilation.
Note: Red denotes the highest level of road access, and yellow the lowest.

Place-based principle #4: Deploy innovative technologies and systems for inclusive and sustainable development

New, emerging technologies provide an important opportunity to promote bioeconomy development and improve the connectivity of communities in a spatially targeted manner. The opportunity is to improve access to services and markets, lower energy costs and emissions, and create resilient livelihoods while safeguarding ecosystems.

Several technologies are being piloted across different parts of the Amazon and in comparable remote, biodiverse regions globally and therefore have high potential for deployment across the Amazon (details are presented in the Annex A5):

- **Transport:** Electric boats and solar ferries reduce fuel and maintenance costs while improving service to riverine settlements. Floating docks and cargo platforms preserve logistics continuity despite fluctuating water levels. Amphibious aircraft extend reach for time critical services where waterways are the primary network.
- **Energy:** Hybrid solar battery microgrids and community energy hubs deliver reliable, least-cost power in remote areas. Floating PV and micro hydro leverage aquatic resources. Digital substations, FACTS, and grid forming inverters stabilize weak grids and integrate renewables. Biomass systems using bioeconomic residues convert waste to energy and reduce diesel dependence.
- **Digital:** Satellite/mobile connectivity and fixed wireless (including TV white space) bridge last mile gaps quickly for schools, clinics, and SMEs. Underwater fiber backbones provide high-capacity links along waterways. Drones, open digital mapping, and satellite monitoring supply real-time data for conservation, land use management, and disaster preparedness.
- **Bioeconomy production:** Modular processing (e.g., açaí) and mini factories increase local value addition and reduce post-harvest losses. Circular waste solutions lower footprints and input costs. E-commerce and blockchain enabled certification expand market access and reward ethical, sustainable supply chains.

The broader adoption of these technologies would benefit from targeted public sector incentives and regulatory adjustments. While several of the technologies are mature and technically proven, considering the challenges and remoteness across the Amazon, public sector support will be needed in initial phases.

In parallel, private sector actors, particularly those in logistics, bioeconomy value chains, clean energy, and digital services, are well positioned to lead investment initiatives where commercial viability is demonstrated. To unlock this potential, governments have an opportunity to consolidate these scattered pilots into a coordinated, large-scale investment package at the regional level, creating economies of scale, de-risking early investment, and attracting private sector participation under enabling and stable regulatory frameworks. Such an approach could accelerate the transition to a more integrated, sustainable, and inclusive development model for the Amazon.

Investment roadmap

The investment strategy focuses on raising productivity in urban and accessible rural areas with high population density and strong bioeconomy activity, while simultaneously establishing strategic development hubs and extending access through spoke investments—floating docks, feeder waterways/roads, renewable microgrids, and satellite- or fiber-backed internet—to maximize inclusion and minimize environmental footprint. The investment program proceeds in three steps:

- Years 1–5: Prioritize bioeconomy-dense urban and accessible rural hubs.
- Years 5–10: Consolidate rural networks and pilot solutions in the Deep Forest.
- Years 10–15: Achieve deep inclusion at scale with low-footprint technologies.

Following the principles of the place-based approach, bundled investments (transport + energy + digital) are used to optimize territorial impact and to avoid scattered, deforestation-inducing expansion.

The proposed investment roadmap recognizes that value chains "climb the ladder" of infrastructure—Deep → Rural → Urban. The approach adapts hub-and-spoke logistics to riverine geographies and sensitive ecosystems: strategic development hubs anchor logistics and services; small/floating docks and local paths act as spokes; and renewable energy plus digital access points ensure minimum-viable operations in production zones. This directly addresses spatial heterogeneity and uneven transport, energy, and digital provision across the region.

Through its phased structure, the roadmap proposes the sequencing of preparatory tasks—feasibility analyses, engineering designs, and permitting—in the early years, to build readiness for later investment stages, particularly those targeting more remote areas, ensuring continuity and implementation readiness over time.

Phased Investment Roadmap (5-10-15 years)

Years 1–5: Foundations at Hubs (Urban & accessible Rural Amazon)

Urban and accessible rural hubs already concentrate most of the Amazon population, services, and most of the bioeconomy flows (cacao, açaí, pirarucu, etc.). Upgrading these nodes and removing current bottlenecks, can bring important economic growth to the region and can most efficiently increase throughput, and quickly raise incomes. This phase focuses on high-maturity, large-scale infrastructure to increase capacity and productivity in urban and rural areas.



Transport — build reliable gateways
Upgrade urban ports in Manaus, Belém, Iquitos, and Florencia to expand cargo handling, add cold-chain facilities, and modernize safety signaling. Pair these works with a phased fuel transition at ports and last-mile fixes in urban logistics and public transport to lift city productivity and corridor reliability. In parallel, develop robust rural strategic development hubs (e.g., Codajás, San Vicente del Caguán, Caballococha) to ensure sheltered loading, temperature-controlled storage, and digital kiosks.



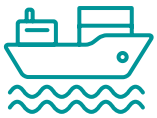
Energy — quality, reliability, and productive use at hubs
Reinforce high-voltage (HV) interconnections in urban areas and, where economic, add utility-scale storage to stabilize frequency and voltage for processing parks and cold chains. In rural hubs, commission medium-voltage (MV) hybrid systems—solar, biomass, and batteries—sized to productive loads (ice plants, freezers, pulping, drying). Advance the Humaitá–Caladinho II project and the Macapá reinforcement, complete the Tucuruí–Roraima link, and implement the Iquitos–SEIN interconnection to reduce diesel dependence and anchor industrial growth.



Digital — access that increase market outreach
Build the backbone and last mile together: deploy Infovia 02, 03, and 04, implement Pucallpa–Nauta, and complete feasibility/design for Fibra Putumayo, with redundancy engineered to reduce outages. Establish municipal broadband centers at urban ports and cooperative connectivity points at rural hubs (fiber or satellite backhaul) with default toolsets for traceability, e-commerce, and logistics management. Synchronize fiber/river works and power upgrades so refrigerated logistics and digital marketplaces are operational from day one.

Years 5–10: Rural Amazon Consolidation & Deep Forest Amazon Pilots

Extend the benefits of the foundations phase outward—linking more producers to hubs and testing low-footprint solutions for the most remote communities. Standardized spoke packages (floating docks, electrified river services, cold-chain, and connectivity) across rural basins, while piloting deep-forest access with modular infrastructure and technology. The goal is to convert scattered access into reliable, scheduled services, cut diesel dependence, and prove at scale what works in fragile geographies.



Transport — extend spokes and corridor reliability
From each rural hub, roll out standardized spokes: floating/community docks with sheltered loading and basic cold storage; scheduled feeder services aligned with hub departures; and priority electromobility routes for schools and clinics that also serve producers. Where roads already exist, apply targeted maintenance and stabilization (drainage, slope protection, all-weather surfacing) to reduce seasonal isolation without opening new fronts in intact forest. This will involve promoting all-season access for isolate communities and ensuring the continue efficient operations of major roadways for the Urban and Rural Amazons.



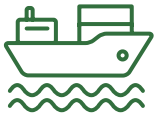
Energy — scale hybrids and anchor productive use
Scale MV hybrids across rural basins and deploy right-sized microgrids with grid-forming inverters in spoke communities for stable 24/7 basic service. Incentivize industrial bioenergy hubs (processing plants) to oversize hybrid generation and export surplus to nearby settlements via local grids or islanded microgrids under simplified feed-in rules. This raises power quality, displaces diesel, and ensures each new kilowatt enables cold chain, processing shifts, and digital services.



Digital — access that makes markets work
Provide last-mile access, pair hub centers with spoke connectivity points using a hybrid mix—fiber where feasible, fixed wireless (FWA) or TV white space (TVWS) at the forest fringe, and satellite backhaul deeper in. Provide default applications for traceability, e-commerce, payments, and logistics scheduling, with basic digital literacy and O&M training. Synchronize digital activation with transport timetables and reliable power so tele-health, school connectivity, refrigerated logistics, and market transactions operate from day one.

Years 10–15: Deep Forest Amazon Inclusion at Scale

Complete the value chain ladder (Deep → Rural → Urban) by delivering universal, low-footprint access for remote communities while safeguarding ecosystems. Scale standardized spokes basin-wide and embed technologies proven to work in forested, flood- and drought-prone geographies. The objective is that every deep community reaches a rural hub within predictable travel windows; essential services (health, education, payments) are reliable; and producers participate in formal markets—without triggering deforestation-inducing infrastructure.



Transport — low-footprint networks that reach everyone
Deploy floating docks with sheltered loading and small cold chains in deep communities. On short-haul, high-demand social routes, operate solar-electric boats on fixed schedules. For perishables and consolidated purchasing, run solar cargo floating market platforms with integrated cold chain. In the most isolated stretches or during climate extremes, use cargo drones for urgent, high-value/low-weight deliveries (e.g., medicines, diagnostics) and amphibious aircraft (seaplanes) for medical evacuation and time-critical trips—leveraging rivers as natural runways without heavy land infrastructure.



Energy — autonomous, smart, and community-owned
Adopt multi-source microgrids (solar PV + batteries + biomass, with efficient diesel for emergencies) governed by grid-forming inverters for stable, 24/7 service. Where water flows allow, add micro-hydropower. Operate productive clusters (açaí, fish, timber residues) as industrial bioenergy hubs, oversizing hybrid generation to export surplus to nearby communities under streamlined feed-in rules.



Digital — universal access and intelligence for services and markets
Establish satellite-based communication hubs, community internet access points with digital education and telemedicine services, and culturally adapted platforms in Indigenous languages. Promote digital literacy and productive internet use. In each spoke community, establish a connectivity point (school, clinic, or cooperative) with default toolsets for traceability, e-commerce, digital payments, logistics scheduling, and tele-services.

Table 3.3 Phased investment roadmap for the Amazon bioeconomies (5-10-15 years)

Time Horizon	2025–2030	2030–2035	2035–2040
Focus / Sector	**Strengthening the foundations at hubs in the Urban Amazon and the accessible Rural Amazon**	**Consolidation and scaling of enhancements in the Rural Amazon and piloting solutions in the Deep Forest Amazon**	**Scaling the inclusion of the Deep Forest Amazon**
Transport	• Develop rural strategic development hubs (e.g., Codajás, San Vicente del Caguán, Caballococha): sheltered loading, temperature-controlled storage, digital kiosks. • Upgrade urban ports (Manaus, Belém, Iquitos, Florencia): cargo handling, cold chain, safety signaling; phased fuel transition; last-mile urban logistics and public transport improvements.	• Roll out standardized spokes from hubs: floating/community docks with basic cold chain; scheduled feeder services aligned to hub departures; electromobility routes for schools/clinics that also serve producers. • Maintenance of existing roads to decrease seasonal isolation.	• Basin-wide floating docks; solar-electric boats/ferries on fixed schedules; solar cargo floating market platforms with integrated cold chain. • Cargo drones for urgent healthcare deliveries.
Energy	• Reinforce high-voltage interconnections; add utility-scale storage where economic. • Medium-voltage hybrid systems (solar/biomass/batteries) at rural hubs sized to productive loads (ice, freezers, pulping, drying). • Advance Humaitá–Caladinho II, Macapá reinforcement; complete Tucuruí–Roraima; implement Iquitos–SEIN to reduce diesel dependence.	• Scale medium-voltage hybrids across rural basins; deploy right-sized microgrids with grid-forming inverters in spoke communities for stable 24/7 basic service. • Incentivize industrial bioenergy hubs to oversize hybrid generation and export surplus via local/isolated microgrids under simplified feed-in rules.	• Universal multi-source microgrids (solar + biomass + batteries; efficient diesel only for backup); add micro-hydropower where feasible. • Expand community energy hubs (power + cold rooms + training) and industrial bioenergy hubs.
Digital	• Establish municipal broadband centers (urban ports) and cooperative connectivity points (rural hubs) with traceability, e-commerce, and logistics apps; synchronize with power/transport when they become operational.	• Extend last-mile access: hybrid mix—fiber where feasible, FWA/TV white space at forest fringe, satellite backhaul deeper in. • Default apps for traceability, e-commerce, payments, logistics; digital literacy and O&M training; align activation with transport timetables and reliable power.	• Satellite-based communication hubs and community internet access points supporting tele-education/telemedicine; culturally adapted platforms (Indigenous languages). • In each spoke, a connectivity point (school/clinic/cooperative) with tools for traceability, payments, logistics scheduling, and tele-services; promote digital literacy and productive use.

Financing: Investment landscape for sustainable infrastructure and bioeconomy in the Amazon

The Amazon region faces significant challenges in financing infrastructure, including regulatory hurdles, environmental degradation, and limited access to finance for local communities. However, innovative solutions like green bonds, biodiversity compensations, and debt refinancing can enhance capital flow and support sustainable development. The investment landscape varies across the region: the Legal Amazon benefits from mature investments from various governments and organizations, the Peruvian Amazon has limited private sector financing with a focus on agriculture, and Colombia relies on international initiatives due to a lack of nationally structured vehicles.

Financiers in the Amazon are divided into upstream and downstream capital providers, with a notable presence in the downstream market. Upstream providers, such as development finance institutions (DFIs), multilateral development banks (MDBs), government initiatives, international organizations, multilateral funds, pension funds, impact and thematic funds, NGOs, and family offices, focus on creating and mobilizing capital. Downstream providers, including impact investors, incubators, accelerators, corporate foundations, and philanthropy organizations, concentrate on distributing and utilizing capital, often offering complementary technical assistance. In the Amazon, these downstream providers include private sector companies, local financial institutions, and community-based organizations. They use instruments like philanthropic grants, equity, debt instruments, and guarantees to support various projects and initiatives, aiming for financial returns while addressing social and environmental goals. However, debt without de-risking mechanisms is not the main financing source in the Amazon due to revenue risk.

Table 3.4 highlights emerging partners that provide both capital and technical expertise for sustainability and reforestation initiatives in the region. These partners exemplify diverse efforts and financial instruments used to achieve sustainable development and conservation in the Amazon.

Table 3.4 Initiatives related to sustainable development and conservation in the Amazon region

Initiative	Description	Funding/Support
Amazon Fund	Created by the Brazilian government to support deforestation prevention, monitoring, and combating, as well as conservation and sustainable use of natural resources in the Amazon. It operates through grants focusing on forest management, protected area management, environmental law enforcement, and more.	Managed by BNDES, funded by donations from bilateral/multilateral agencies and the private sector.
Amazon Sustainable Landscapes Program (ASL)	A regional effort for conservation and sustainable development in the Amazon, supported by the Global Environment Facility (GEF). It includes national projects in several countries and aims to improve integrated landscape management and ecosystem conservation.	Supported by GEF with US$203.7 million in grant funding.
Amazon Region Protected Areas Program (ARPA)	A significant initiative aimed at protecting the Amazon rainforest, supported by the World Bank, Global Environment Facility, WWF, and the German Development Bank (KfW). ARPA focuses on expanding and consolidating protected areas, strengthening management infrastructure, and ensuring financial sustainability.	Supported by World Bank, GEF, WWF, and KfW.
Amazon Reforestation-Linked Bond	Mobilizes private capital to finance reforestation projects in the Brazilian Amazon, involving purchasing degraded farmlands and planting biodiverse native species trees. Carbon removal credits are sold to firms to meet climate commitments, integrating traditional knowledge and sustainable land management practices.	Funded by private sector capital market investors.

Infrastructure finance

Channeling innovative instruments and new investors focused on sustainability towards infrastructure projects can be challenging, as few existing downstream players cover the infrastructure sector, despite interest from Amazon-focused asset managers. Small-scale infrastructure projects (of less than $10 million) remain underserved due to a lack of specialized capital providers. Recently financed infrastructure projects with private capital are in renewable energy, where power purchase agreements (PPAs) provide lower revenue risk and leverage potential through long-term agreements with fixed prices, ensuring stable revenue streams for project developers and attracting more investors.

The Amazon region has relied on energy subsidies to support diesel-based electricity generation and access for remote communities. These subsidies have been crucial in ensuring electricity availability in isolated areas. As renewable energy and battery storage become more viable, there is potential for a shift away from diesel, allowing governments to reassess and accelerate electricity access programs. The rapid reduction in renewable energy costs presents an opportunity to optimize subsidy application in the sector. In Brazil for example, the electricity sector is mature and developed, with robust infrastructure primarily expanded through private investments over the last thirty years. In the Legal Amazon, all energy companies are privately owned, and public policies on energy access are implemented by private entities funded by consumer subsidies. Also, community funds, microfinance, and impact investing could be expanded to provide accessible financing for

equipment and infrastructure. Bundling investments across transport, energy, and digital sectors—such as pairing river navigability improvements with fiber-optic connectivity and high-voltage transmission—will maximize developmental impact and facilitate the emergence of e-commerce platforms and electric mobility solutions. The private sector may play a role in addressing energy gaps by investing in renewable energy projects, driving innovation in decentralized systems, and collaborating with governments through mechanisms like PPAs and public-private partnerships. MDBs can help expand access and improve energy quality by supporting infrastructure projects with lower economic viability or high perceived risk.

Though infrastructure investments are underrepresented compared to productive development, table 3.5 lists are two examples of how PPAs can work for energy infrastructure settings. A key insight is how the support of MDBs is crucial for project viability due to their financial support and technical assistance, as well as having a long-term PPA (off-take agreement) with a public entity, to address demand risk. Specifically on public and private financing, the Inter-American Development Bank (IDB) facilitated both public and private financing for sustainable infrastructure and bioeconomy projects including CAPEX and OPEX financing, as well as working capital financing.

Table 3.5 Examples of PPAs for energy infrastructure

Initiative	Access to Reliable and Clean Energy in Colombia's Amazon Region
Project	Development and financing of two solar energy plants with battery storage: *"Centenario"* in Puerto Leguizamo (Putumayo) *"Matakavi"* in Mitú (Vaupés)
Problems	Non-interconnected areas with reduced accessibility Diesel-powered electricity (8 to 10 hours per day) Complex logistics of transporting diesel by air or barge to communities Extreme poverty limits feasibility of individual billing
Solutions	Replace diesel use with solar energy, developing projects with battery storage in communities with limited access to electricity Planned installations are aligned with projected demand and expected population growth to ensure scalable expansion Power purchase agreement (PPA) entered with a public entity (i.e., electricity is subsidized)
Impact	Avoiding the use of approximately 2.21 million gallons of diesel per year, it will reduce greenhouse gas emissions, improve air quality and support the environmental health of the region These plants will provide clean energy 24 hours a day, reducing the need for diesel generators, to over 22,000 residents in Vaupés and 20,000 in Puerto Leguizamo
Sponsors	IDB Invest, DUE Capital and Services, BBVA, Bonus Asset Management and Financiera de Desarrollo Nacional (FDN) within a broader strategy inspired by Bloomberg Philanthropies' Climate Finance Leadership Initiative (CFLI)

Table 3.6 Summary of relevant revenue, risk mitigation and funding levers for infrastructure investments in the Amazon region

Projects **Infrastructure types**	Cost **Usual ranges in US dollars**	Revenue levers **Revenue capture options**		Risk mitigation levers **Available de-risking mechanisms**	Financing levers **Possible financing sources**	
River Transport (river ports, navigable, waterways)	5–50 million (small river docks ~$3-5 m; major river corridor improvements $50 M+)	• Tax-based • User-based	• Value capture	• Volume guarantees • Political risk guarantees • Profit-sharing agreements	• Government equity/debt • Project bonds	• Private equity/debt • MDB/ECA/ NDB loans/ debt fund
Land Transport (roads, rural highways)	5–100 million (depends on length and standard; ~\2-3 M per km for paved roads in Amazon)	• Tax-based • User-based	• Value capture	• Volume guarantees • Bundling	• Government equity/debt • Project bonds	• Private equity/debt • MDB/ECA/ NDB loans/ debt fund
Renewable Energy and Power (solar plants, biomass, microgrids)	5–50 million (range from community micro-grids to mid-sized generation)	• Tax-based • User-based		• Profit-sharin agreements • Financial guarantees • Hedging	• Government equity/debt • Green or project bonds • Asset platform	• MDB/ECA/ NDB loans/ debt fund • Private equity/debt • Commercial bank loans
Digital Connectivity (broadband towers, satellite links)	1–30 million (community networks at lower end, regional fiber backbone segments 20m-30m)	• Tax-based • User-based	• Data	• Hedging • Bundling	• Government equity/debt • Corporate investment (telecom industry)	• Private equity/debt • MDB/ECA/ NDB loans/ debt fund
Sustainable Transport Innovations (e-mobiity, drones)	0.5–5 million (pilots and small-scale deployments)	• User-based • Ancillary revenue	• Data*	• Bundling • Political and regulatory support	• Grants or concessional funding • VC or private equity	• MDB pilot programs
Industry and Supply Chain (logistic hubs, processing facilities)	1–20 million (small agro processing plants or logistics centers; larger industrial facilities can be more)	• User-based • Ancillary revenue	• Data*	• Volume guarantees • Bundling • Hedging	• Commercial bank loans • MDB/ECA/ NDB loans/ debt-fund	• Private equity/debt • Asset platform
Air Transport (rural airstrips, small airports)	5–50 million (ranging from simple airstrip upgrades to regional airport hubs)	• Tax-based • User-based	• Value capture	• Volume guarantees • Pre-completion insurance • Profit-sharing agreements	• Government equity/debt • Project bonds	• Private equity/debt • MDB/ECA/ NDB loans/ debt fund

Note: Cost figures provided are indicative and should be interpreted as approximate orders of magnitude only, given the variability across contexts. The listed levers are non-exhaustive and serve solely as illustrative references. ECA = export credit agency; MDB = multilateral development bank; NDB = national development bank; VC = value capture.

Proposed projects in the Urban Amazon include civil works that physically connect cities with each other via improved transport infrastructure. These projects share a similar investment profile. In terms of revenue generation, these projects can all offer opportunities for tax-based or user-based revenue sources. Tax-based revenue are availability payments, shadow tolls and tax breaks. They are a kind of payment stream with a lower risk rating than revenue streams exposed to commercial risks. As shown in table 3.7, this type of revenue is common amongst not only river and land infrastructure projects but also in renewable energy and power, and digital connectivity projects.

Scaling investment in sustainable infrastructure and bioeconomy demands more than just an enabling environment, it also requires effective, targeted financial tools. The funding levers include tax-based revenue, user-based revenue, ancillary revenue, value capture, and data monetization. Each type of funding lever is associated with specific infrastructure projects, such as community hubs, mobile hospitals, virtual education programs, airstrips, river navigability improvements, road and rail transport, waste and water management, logistic hubs, e-mobility innovations, renewable energy plants, and digital connectivity solutions. It is important to examine a variety of funding levers to ensure the successful financing of infrastructure projects, and design tailored financing structures based on the contextual characteristics of the Amazon region.

Table 3.7 Description of revenue levers to be considered for investment structuring

Funding levers	Suitable infrastructure
Tax-based revenue: availability payments shadow tolls and tax breaks. **Type:** Public **Description** Payment stream with lower risk rating than revenue streams exposed with commercial risks	• **River transport:** river navigability improvements, enlargement of ports, modernization of docks and harbors • **Land transport:** tertiary road improvements, corridors and access to ports • **Renewable energy and power:** solar plants, biomass plants, floating PV, isolated micro-grids, hydro-kinetic turbines • **Digital connectivity:** sub-aquatic broadband, fixed cables, 5G cell towers, satellite dishes • **Air transport:** airstrips
User-based revenue: toll revenues, tariffs on regulated utilities, unitary pricing, segment pricing and dynamic pricing **Type:** Private **Description:** Transfers a degree of commercial risk to the private sponsor of an infrastructure asset by enabling the operator to directly charge customers for services	• **River transport:** river navigability improvements, enlargement of ports, modernization of docks and harbors • **Land transport:** tertiary road improvements, corridors and access to ports • **Industry and supply chains:** logistic hubs (closer to extraction zones), and decentralized processing factories • **Sustainable transport and mobility innovations:** e-mobility, drones and unmanned aircraft • **Renewable energy and power:** solar plants, biomass plants, floating PV, isolated micro-grids, hydro-kinetic turbines • **Digital connectivity:** sub-aquatic broadband, fixed cables, 5G cell towers, satellite dishes • **Air transport:** airstrips

Funding levers	Suitable infrastructure
Ancillary, revenue: advertising, real estate revenues, energy solutions, commercial retail revenues or parking revenues **Type:** Private **Description:** Revenue-generating services that support or complement core operations; ability to generate ancillary is driven by the features the asset, population density, user income levels, and incentives for private participants or sponsors to offer non-core services	• **Industry and supply chains:** logistic hubs (closer to extraction zones), and decentralized processing factories • **Sustainable transport and mobility innovations:** e-mobility, drones and unmanned aircraft
Value capture: special district taxation, betterment levies, developer charges, stamp duties, tax increment financing, real estate taxation, general property tax **Type:** Public **Description:** Capture of spillover value created by an infrastructure asset	• **River transport:** river navigability improvements, enlargement of ports, modernization of docks and harbors • **Land transport:** tertiary road improvements, corridors and access to ports • **Air transport:** airstrips
Data **Type:** Private **Description:** modernization of operational and consumer data generated by an infrastructure asset	• **Digital connectivity:** sub-aquatic broadband, fixed cables, 5G cell towers, satellite dishes • **Industry and supply chains:** logistic hubs (closer to extraction zones), and decentralized processing factories • **Sustainable transport and mobility innovations:** e-mobility, drones and unmanned aircraft

Source: Original compilation (Global Infrastructure Hub, PPIAF, World Bank Group).

Table 3.8 Description of funding levers to be considered for investment structuring

Funding levers	Suitable infrastructure
Commercial bank loans (debt): senior long-dated facilities, partial and full recourse loans, bridge loans, equity bridge financing **Type:** Private **Description:** Long-term debt products essential to infrastructure projects where a commercial bank acts as a primary channel for loans secured against project cash flows (project finance) or corporate balance sheets (corporate finance). The maturity of the domestic banking market and internal risk management capacity drives the formation of project finance products	Suitable for projects with clear revenue-generating potential, strong cash flow, and established markets. Requires a solid business model and a proven ability to repay debt. Suitable for **land transport** tertiary road improvements and corridors (if there's a fee-based system in place), **renewable energy and power**, and **industry & supply chain**, logistic hubs and decentralized processing factories (if there's a contract or off-taker for goods or services)

Funding levers	Suitable infrastructure
Government debt **Type:** Public **Description:** "First dollar" or "last dollar" by using public debt in specific circumstances to fill liquidity gaps or to positively impact the business case of strategic projects. Government debt should act as a complement to private debt sources and is most commonly provided in the form of concessional loans	Especially important for strategic, long-term projects with limited immediate commercial viability. Critical projects in **social infrastructure, renewable energy and power, healthcare, and transport** are suitable infrastructure types, despite the challenges of revenue generation in remote and under-served areas
Government and general obligation bonds (debt): municipal bonds, green bonds, revenue bonds **Type:** Public **Description:** Fixed-income instruments backed by the issuing entity's general budget rather than the revenue of the project. Bonds are issued by central and local government bodies with borrowing rates dictated by the issuer's credit rating and some degree of explicit sovereign support. Government and general obligation bonds vary widely, but often feature tax exemptions, catalyzing investment	Suitable for **social infrastructure, healthcare, education: utilities**, among other, i.e.> projects that face serious challenges in attracting other financing sources
MDB/ECA/NDB debt: "A" and "B" loans: subordinated debt vendor financing and export credit mezzanine financing: local currency loans **Type:** Public **Description:** Multilateral development banks (MDBs) are prominent sources of corporate and project debt in emerging markets for governments and private sponsors. Export credit agencies (ECAs) can provide debt and risk management solutions to project sponsors if specific conditions are met around the use of capital and goods from the ECA's home market. National development banks (NDBs) provide a range of debt products to infrastructure projects that vary greatly according to the entity's mandate, rating, and similar factors	Loans are development-focused, with social and economic impact goals. Typically used for projects in emerging markets or regions where the financial risk is high and returns may take longer to materialize, they generally entail lower interest rates and longer repayment periods compared to commercial bank loans. Suitable for most of the envisaged infrastructure projects, including **social infrastructure, healthcare, education, utilities: renewable energy and power, river transport**
MDB/NDB debt fund: co-lending facilities **Type:** Public **Description:** Syndication platforms that create diversified portfolios of emerging market private sector loans enabling increased exposure or first-time entry into the asset class. MDB debt funds help investors overcome challenges with sourcing viable investment opportunities in emerging markets by delegating the selection, appraisal, and supervision of investments to deeply experienced NDB investors	Often used for projects in under-served regions with limited commercial viability but significant public and developmental value. Suitable for **social infrastructure, utilities, transport, renewable energy** and **power, healthcare,** among other
Project bonds (debt): with credit enhancement, backed by cash flow only, private activity bonds **Type:** Mixed **Description:** Fixed-income instruments sold to investors where the proceeds are used to provide debt to an infrastructure project. Project bonds are tradable, rated, and directly linked to the cash flows of individual projects	Typically for large, capital-intensive projects that are expected to generate steady long-term revenue, often tied to specific revenue streams like fees or government contracts. Suitable for **transport** (including air, rail and river) and **renewable energy and power**

Source: Original compilation (Global Infrastructure Hub, PPIAF, World Bank Group).

Table 3.9 Description of funding levers to be considered for investment structuring (continued)

Funding levers	Suitable infrastructure
Private debt fund: co-facilities, conventional product loans, mezzanine project loans **Type:** Private **Description:** Unlisted funds that pool money from institutional investors and provide debt to infrastructure projects (often substituting commercial banks). Private debt funds have fewer regulatory constraints and less internal bureaucracy than commercial banks, enabling them to provide debt with fewer covenants	Typically for projects that are commercially viable but not large enough or do not meet the risk profile for a commercial bank. Suitable for **transport industry & supply chain investments and renewable energy and power**
Securitized debt: collateralized loan obligations (CL Os) **Type:** Private **Description:** Tradable securities backed by the cash flows of pooled debt from a portfolio of infrastructure projects. It provides investors with a platform to gain exposure to the debt of operating assets without taking a direct position in the project's structure	Used for projects that can generate steady and predictable cash flows. Suitable for **renewable energy and power and utilities**
Government equity: transferable capital contribution, transferable operating contribution **Type:** Public **Description:** Evolving product that can function as both a potential subsidy, and a traditional equity contribution. Like government debt, government equity is viewed as a 'first dollar, or 'last dollar, strategy to catalyze participation from private financing source	Projects that may not have immediate commercial returns particularly relevant when commercial financing is scarce. Suitable for **social infrastructure, healthcare, utilities, education** and **transport**, among other
Direct equity institutional: SPV equity contribution, JV equity contribution, private sale **Type:** Private **Description:** Foundational source of equity for infrastructure markets with an increasing number investing equity directly into project structures. Given currency fluctuation risk and high standards of fiduciary duties, domestic institutional investors are likely the main source of direct institutional equity investment. Institutional equity can be provided in to multiple project structures	Used for larger-scale projects where investors seek significant ownership in exchange for funding. Investors are willing to take more risk in exchange for higher returns and longer-term involvement in the project. Suitable for **renewable energy and power** (with off-take agreements in place), **sustainable transport innovations**, and **industry & supply chain investments**
Direct equity operating: SPV equity contribution, JV equity contribution, private sale **Type:** Private **Description:** Operators are a foundational source of equity for infrastructure markets, providing a unique combination of capital and operating capabilities	Similar to institutional direct equity, but more focused on operational involvement, hence, the investor provides equity in the operating entity and expects to be involved in its management. Suitable for **land transport** (under PPP models), and **utilities**

Funding levers	Suitable infrastructure
Listed trust investments: infrastructure investment trusts (InvITs), yield company (YieldCo), real estate investment trusts (REITs) **Type:** Private **Description:** Collective investment scheme into a portfolio of projects enabling investors to hold tradable equity securities linked directly to projects. They act as a 'white label' platform to aggregate operating assets with stable yield profiles across different sectors and regions	Pooled investment vehicles that attract revenue-generating infrastructure projects, such as toll roads, utilities or power generation projects. Suitable for **renewable energy and power** and **utilities**
Private equity: general project equity (SPV or JV), general project equity co-investment (SPV or JV), open-ended structure, securitized loans **Type:** Private **Description:** Unlisted infrastructure funds pool money from institutional investors for equity investment in infrastructure projects seeking returns over various horizons. Funds enable their Limited Partners (LPs) to gain exposure directly to project capital structures without the need for building in-house investment capabilities. These funds do not invest in all markets as they are constrained by LP requirements and project alignments, with targeted risk-weighted returns	**Suitable for high-risk, high-reward**, with an exit-period of 5 to 7 years approximately. Suitable for **sustainable transport innovations, industry & supply chain digital connectivity, transport** and **renewable energy and power**
Asset platform investments **Type:** Private **Description:** Platforms that aggregate infrastructure assets of specific criteria and allow investors to purchase equity in that portfolio. Asset platform investments give investors exposure to specific asset types while diversifying away some risk by holding equity in multiple assets	Entails managing multiple assets or projects in a specific sector, often related to infrastructure or real estate. Suitable for **renewable energy and power**, and **utilities**

Source: Original compilation (Global Infrastructure Hub, PPIAF, World Bank Group).

Bundling combines smaller projects or those with different risk profiles into larger ones to achieve economies of scale and align with private investor appetite. Additional risk mitigation levers are outlined in Table 3.10. For Urban Amazon river and land-based transport projects, volume guarantees ensure a minimum level of usage, mitigating demand risk and allowing investors to repay high initial costs for long-term concessions. Coordinating projects across sectors can increase the effectiveness of this lever by ensuring that increases in one mode benefit the other.

Table 3.10 Description of risk management levers to be considered for investment structuring

Funding levers	Suitable infrastructure
Profit-sharing agreements: cap, and cap & collar **Type:** Mixed **Description:** Distribution of profits from infrastructure assets to specific parties under return scenarios	These agreements are best suited for infrastructure projects with shared ownership (public and private) and long-term revenue generation, in particular: **transport infrastructure (air, river, land and rail), renewable energy and power** and **utilities (waste and water management)**
Political and performance guarantees: including expropriation, war, terrorism, and civil disturbance, breach of contract, change or sale of ownership restrictions, step-in rights, performance bond, security over assets **Type:** Public **Description:** Provide protection against losses resulting from the failure of a sovereign, sub-sovereign, or state-owned enterprise to fulfill contractual obligations, excluding payment obligations. Typically provided by multilateral development banks or governments to facilitate foreign direct investments in emerging markets	Necessary when political risk is significant and the project's success depends on the support and stability of the government. **Social infrastructure** (community hubs, public space improvements), **healthcare** (mobile hospitals), and **education** (virtual education), among others
Volume guarantees: minimum volume or revenue **Type:** Private **Description:** Formal assurances that a party will receive a minimum level of revenue during a concession period. Volume guarantees mitigate demand risk and allow investors to gain enough revenue to repay high initial investment costs for long-term concessions	Suitable for projects where a minimum level of usage or demand is essential for financial liability; including **transport infrastructure** (airstrip, roads, river ports) **utilities** (waste management, water treatment), and **industry supply chains** (logistic hubs, processing factories)
Financial guarantees: non-honoring of financial obligations, currency inconvertibility and transfer restrictions, conditions precedent clauses, bank guarantee or letter of credit **Type:** Private **Description:** Provide protection against losses resulting from an arrangement of risks that lead to the failure of a sovereign, sub-sovereign, or state-owned enterprise to make a payment when it is due under an unconditional financial payment obligation (defined as a credit enhancement product) or guarantee	Useful when there is a need for protection against unforeseen financial shortfalls to assure investors that funds will be available even if revenues fall bellow expectations. Suitable projects include **transport infrastructure, renewable energy and power utilities**, among others

Funding levers	Suitable infrastructure
Hedging: currency or raw material price, among others **Type:** Private **Description:** Investment position intended to mitigate currency risk in the event of significant exchange rate fluctuations. Critical for foreign institutional investors and insurers in markets with high foreign exchange (FX) risk	Appropriate when there are currency, commodity price or inflation risks that could affect project financing or operations. Suitable projects include **transport infrastructure, renewable energy and power industry and supply chain (logistic hubs)**, among others
Bundling **Type:** N/A **Description:** Combining several smaller projects or projects with different risk profiles (for example brownfield and greenfield), into a single larger project or program to achieve economies of scale and/or a project risk-return profile that is more aligned to private investor appetite	Becomes particularly relevant in projects that require scale to become feasible, or that for other bankability reasons are put together (crown or most attractive asset with less attractive assets)
Pre-completion insurance **Type:** Private **Description:** Arrangement where one entity provides formal assurances of guaranteed compensation in the event of specified losses, damages or delays. Insurance mitigates execution risks for investors, but may be expensive – particularly in emerging markets and for greenfield projects	All infrastructure types; important for projects in challenging environments or those requiring high upfront investments. Suitable projects include **transport infrastructure renewable energy and power utilities**, among others

Source: Original compilation (Global Infrastructure Hub, PPIAF, World Bank Group).

Policy recommendations for the bioeconomy and infrastructure in the Amazon

Setting the next generation of policy approaches requires a holistic approach that embodies the current needs and opportunities of the Amazon. Prioritizing policies that strengthen infrastructure and the bioeconomy is key to finding synergies and obtaining optimal results.

One innovative strategy is revenue stacking, which involves integrating bioeconomy players as energy providers. Bioeconomy hubs have the potential to decentralize energy generation, maintenance, and billing, addressing key challenges faced by utilities such as logistics and payment defaults. By integrating renewable energy systems, these hubs can provide stable electricity to their own operations and surrounding communities, reducing dependency on centralized power grids and improving overall energy accessibility. This model allows local players to sell surplus energy, further strengthening community empowerment and financial resilience. By treating energy as a commercially viable product, bioeconomy hubs can enhance local economic stability ensuring sustainable business models while contributing to regional electrification efforts.

Equally important is the recognition of territorial needs and the active participation of local communities in policy and infrastructure planning. Strengthening community participation involves respecting the autonomy of Indigenous and Afro-descendant individuals, addressing their unique needs, and promoting inclusive development. By establishing community-based monitoring systems and local service committees with real decision-making power, we can bridge the gap between government authorities and local realities. This participatory approach, grounded in ancestral knowledge and rights, ensures that policies are context-specific and effectively implemented. By prioritizing strategic bioeconomy hubs and fostering community involvement, we can unlock the potential of local product chains, enhance economic stability, and contribute to regional electrification efforts.

To further enhance community engagement and support the bioeconomy, it is essential to establish community digital hubs with energy autonomy. These hubs will serve as anchors for digital literacy, public services, and bioeconomy formalization. Additionally, decentralized intercultural community hubs should be established and strengthened as physical and digital spaces for citizen engagement, service delivery, and governance. Co-designed with communities and equipped with satellite internet and renewable energy, these hubs will host civic activities, vocational training, digital learning, and public services, particularly in isolated areas.

Infrastructure-related policies

- **Data and infrastructure planning:** To effectively identify and prioritize infrastructure gaps, it is essential to improve data on service access and infrastructure coverage. This requires investing in coordinated data collection efforts, ensuring that information is regularly updated and disaggregated by territory, population group, and service type. Additionally, coordinating energy and digital infrastructure planning is crucial, as the lack of reliable electricity, particularly in remote communities, poses a significant barrier to stable internet connectivity. Therefore, it is necessary to plan both the energy and telecommunications infrastructure together. In the digital sector, efforts should also focus on improving digital connectivity through digital skills programs, considering affordability schemes for digital connectivity, and expanding affordable digital services in rural areas.

- **Strengthen climate resilience across all sectors:** In transport, apply risk-informed design standards (e.g., upgraded drainage, slope stabilization), prioritize maintenance and asset management as "no regret" actions, and build redundancy at choke points—including nature-based solutions—while deploying adaptable river infrastructure such as floating docks and all-season local access roads to keep communities and value chains connected. In energy, diversify and decentralize with renewables and mini-grids in remote areas, harden critical grid elements, improve vegetation management and substation flood protection, and add operational redundancy and automation to speed restoration. In digital infrastructure, reduce single points of failure via route diversity and elevated/armored assets in floodplains, use satellite backhaul where fiber is not available, and power sites with solar battery hybrids to cut diesel dependence. Crucially, embedding resilience up front in new investments is far more cost effective than retrofits.

- **Consider legal and regulatory updates to promote sustainable infrastructure: Strengthen enforcement and monitoring** via satellite and other remote sensing solutions for surveillance and to enhance enforcement. **Promote policy coherence** by integrating sustainability criteria and incentivizing green infrastructure. **Establish concrete guidelines** for infrastructure design, construction, and operations. **Standardize weather monitoring and data sharing** through unified databases for real-time weather monitoring. **Clarify legal responsibilities and incentivizing sustainable practices** by establishing clear legal frameworks and regulatory incentives for proactive vegetation management to enhance grid reliability and attract private investment. Incorporate sustainability in investment programming by emphasizing sustainability criteria in public and private investment projects. **Public-private partnerships (PPPs)** should be used to leverage private sector investment and expertise in infrastructure development.

- **Ensure stakeholder engagement: Early and continuous community engagement** in project planning can help ensure projects reflect community interests, reduce conflicts, and improve project acceptance and success. **Strengthen stakeholder participation** by institutionalizing inclusive decision-making for Indigenous and traditional communities through formal consultations and capacity building. **Enhance transparency and accountability** through stakeholder engagement via digital platforms and multiple communication channels, with regular reporting and public hearings. **Decentralize oversight and monitoring** by creating regional and local offices for closer and more efficient oversight and monitoring, with financial incentives to attract qualified professionals

- **Use coordination mechanisms: Establish centralized coordination mechanisms** to streamline decision-making and improve policy efficiency through interagency committees or centralized authorities; **cooperation and information sharing**; **cross-sectoral coordination and joint planning** to integrate ecological and climate resilience criteria; **technology and digitalization** platforms combined with advanced project management tools to improve project efficiency; **capacity building and training** programs for agency staff to ensure they have the skills and knowledge to manage complex projects and collaborate effectively.

- **Technical capacity:** Strengthen technical capacity at subnational levels to plan, deliver, and manage infrastructure assets better, and increase private participation.

- **Transport sector:** To enhance mobility, it is crucial to improve river signaling, passenger services, and road infrastructure maintenance, while investing in resilient infrastructure. Introducing electromobility in river transport for motorized canoes and passenger vessels can reduce costs, improve reliability, and decrease environmental impact. Investing in signage systems, especially in curved sections or narrow passages, will facilitate safe night navigation and ensure compliance with safety regulations. Providing cartographic information and ensuring vessel monitoring are also essential. Improving river passenger services, particularly in tributary rivers in Brazil and Peru and throughout Amazonian rivers in Colombia, will increase freedom of movement and transport reliability. More reliable transport services, supported by governments, will benefit people and goods across the region. Prioritizing road infrastructure maintenance will lead to future cost savings and should include a focus on building resilient infrastructure.

- **Energy sector:** It is essential to prioritize policies to increase the quality of electricity. Examples include transitioning from diesel dependency to renewable energy sources, customizing energy planning to each region, expanding the use of small-scale renewable energy plants, and ensuring reliable, decentralized, and climate-resilient energy systems. Focusing on quality of electricity and ensuring it allows a wider range of productive uses are needed as the next steps after public programs for energy access universalization. The sustainable development of both infrastructure and the bioeconomy requires addressing the higher energy demand of small processing and industrial plants and considering how they can, in turn, generate energy from biomass byproducts.

However, expanding energy access in the Amazon must go beyond infrastructure provision to actively enable productive use. To unlock the full potential of new energy infrastructure, policy must ensure that communities have access not only to electricity but also to the equipment and financing necessary for productive activities. To ensure the productive use of energy, policy should promote access to equipment and financing. This includes expanding microfinance and community funds to empower cooperatives and small-scale producers, facilitating the purchase of processing machinery and cold storage units. Blended finance mechanisms—combining public and private resources—can de-risk investments and attract capital for sustainable infrastructure.

Also, technically, standardized and modular designs for renewable energy systems (solar PV, micro-hydro, biomass gasifiers) should be developed to suit Amazonian conditions, facilitating easier deployment and maintenance. Local capacity building through vocational training programs will empower communities to install, operate, and maintain these systems and associated productive equipment, reducing reliance on external technicians and fostering local ownership.

Finally, regulatory reforms are needed to streamline licensing and permitting for decentralized renewable energy systems and small-scale processing facilities. Simplified processes could accelerate deployment and reduce barriers for communities. Environmental guidelines tailored for small-scale renewable projects will ensure sustainability, while strengthened frameworks for product certification and traceability will improve market access and consumer trust.

- **Water access:** Improve access to safe water in rural areas, considering electricity availability and quality. Rainwater harvesting systems can be a viable alternative.

Bioeconomy-Related Policies

- **Sustainable development:** To ensure the long-term health of the Amazon's ecosystems, it is critical to emphasize sustainable development practices. This includes promoting agroforestry, sustainable agriculture, and the use of non-timber forest products. Prioritizing strategic bioeconomy hubs can unlock the potential of all product chains by allowing the installation of processing and refrigerating industrial plants, which increases the longevity and value of locally produced fruit and fish. Investing in human capital is also essential. Implementing vocational training programs in sustainable production, agro-processing, ecotourism, and solar panel maintenance will support this goal. To reach remote communities, establishing Mobile Training Units for Trades can provide these training programs.

- **Research, innovation, and capacity building:** Investing in research and innovation to develop new bio-based products and technologies. This includes supporting local research institutions and fostering partnerships between academia, industry, and government. Collaborating with universities and NGOs will facilitate knowledge transfer and technological innovation, ensuring that local populations benefit from the latest advancements in sustainable development. To be able to enhance the capacity of local communities and institutions to engage in and benefit from the bioeconomy involves providing education, training programs, and technical assistance. Strengthening regulatory frameworks, certification, and branding is also essential. Developing clear regulations and certification schemes, such as Fair Trade, organic, and origin labeling, will improve product marketability and foster consumer trust in bioeconomy products.

- **Policy integration:** Ensuring that bioeconomy policies are integrated with other relevant policies, such as those related to climate change, biodiversity conservation, and rural development.

- **Monitoring and evaluation:** Establishing mechanisms for monitoring and evaluating the impacts of bioeconomy policies. This includes setting up indicators and benchmarks to measure progress and ensure accountability.

References

ANNEL (Agência Nacional de Energia Elétrica). 2024.

—— *Base de Dados das Tarifas das Distribuidoras de Energia Elétrica.* https://portalrelatorios.aneel.gov.br/luznatarifa/basestarifas.

—— *Base de Dados Geográfica da Distribuidora (BDGD).* https://dadosabertos.aneel.gov.br/dataset/base-de-dados-geografica-da-distribuidora-bdgd.

—— *Qualidade do Fornecimento de Energia Elétrica.* https://www.gov.br/aneel/pt-br/assuntos/distribuicao/qualidade-do-fornecimento-de-energia-eletrica.

—— *Relatório de Perdas de Energia.* https://git.aneel.gov.br/publico/centralconteudo/-/raw/main/relatorioseindicadores/tarifaeconomico/Relatorio_Perdas_Energia.pdf.

—— *Subsidiômetro.* https://app.powerbi.com/

Allen, Treb, and Costas Arkolakis. 2022. "The Welfare Effects of Transportation Infrastructure Improvements." *The Review of Economic Studies* 89 (6): 2911–57.

Amazonas 365. 2025. "Litro da gasolina é vendido a R$ 7,29 em Manaus e a mais de R$ 8,49 nos municípios." https://amazonas365.com.br/municipios/litro-da-gasolina-e-vendido-a-r-729-em-manaus-e-a-mais-de-r-849-nos-municipios/.

ANATEL (Agência Nacional de Telecomunicações). 2025. "Banda Larga Fixa." https://informacoes.anatel.gov.br/paineis/acessos/banda-larga-fixa.

Arakaki, Agustín. 2023. "La Matriz y el Modelo Insumo-Producto." In *Cuentas Nacionales e Indicadores Socioeconómicos: Metodologías, Debates Críticos y Aplicaciones a la Economía Argentina*, edited by Juan Martín Graña. Florencio Varela: UNM Editora.

Arakaki, Agustín, Javier Morales Sarriera, and Lourdes Rodríguez Chamussy. 2021. "Jobs and Distributive Effects of Infrastructure Investment: The Case of Argentina." Working paper.

Arnold, J. E. Michael, and M. Ruiz Pérez. 2001. "Can Non-Timber Forest Products Match Tropical Forest Conservation and Development Objectives?" *Ecological Economics* 39 (3): 437–447. https://caribbeanclimatehub.org/wp-content/uploads/2019/08/CanNonTimberForestProductsMatchTropicalForestConservationandDevelopmentObjectives_JA2001.pdf.

Atkin, David, and Dave Donaldson. 2015. "Who's Getting Globalized? The Size and Implications of Intra-National Trade Costs." *NBER Working Paper* 21439. Cambridge, MA: National Bureau of Economic Research. https://www.nber.org/papers/w21439.

BBC News Brasil. 2023. "Starlink, de Elon Musk, domina internet por satélite na Amazônia com antenas em 90% das cidades." *BBC News Brasil,* October 20, 2023. https://www.bbc.com/portuguese/articles/cv2edkw84zmo.

Cambio Colombia. 2023. "La odisea para que un galón de gasolina logre llegar hasta Leticia." https://cambiocolombia.com/economia/la-odisea-para-que-un-galon-de-gasolina-logre-llegar-hasta-leticia.

Charity, S., N. Dudley, D. Oliveira, and S. Stolton, eds. 2016. *Living Amazon Report 2016: A Regional Approach to Conservation in the Amazon.* Brasília and Quito: WWF Living Amazon Initiative, World Wide Fund for Nature (WWF).

Cosar, Karem, and Banu Demir. 2016. "Domestic Road Infrastructure and International Trade: Evidence from Turkey." *Journal of Development Economics* 118 (January): 232–44.

CPI (Climate Policy Initiative). 2022. *Rivers of Diesel in the Amazon: Why Does the Region with Brazil's Biggest Hydroelectric Plants Still Rely on Expensive, Dirty Fuel?* Rio de Janeiro: CPI. https://www.climatepolicyinitiative.org/wp-content/uploads/2022/06/REL-Rios-de-Diesel-EN.pdf.

CPR LATAM (Communications Policy Research Latin America). 2024. "Conectividade Significativa na Amazônia: Uma análise sobre o Programa Amazônia Integrada e Sustentável." *CPRLATAM Conference 2024.* https://www.cprlatam.org/conference.

DANE (National Administrative Department of Statistics). 2023. *Encuesta Nacional de Calidad de Vida (ECV) 2023.* https://www.dane.gov.co/index.php/estadisticas-por-tema/salud/calidad-de-vida-ecv/encuesta-nacional-de-calidad-de-vida-ecv-2023.

DANE. 2024. *National Quality of Life Survey 2024.* Bogotá, Colombia. https://www.dane.gov.co/index.php/estadisticas-por-tema/salud/calidad-de-vida-ecv/encuesta-nacional-de-calidad-de-vida-ecv-2024.

Duranton, Giles, Peter Morrow, and Matthew Turner. 2014. "Roads and Trade: Evidence from the US." *The Review of Economic Studies* 81 (2): 681–724.

El Tiempo. 2025. "Sube el precio de la gasolina y el ACPM para febrero: Así quedó el valor del combustible en las principales ciudades de Colombia." *El Tiempo*, February 2025. https://www.eltiempo.com/economia/sectores/sube-precio-de-la-gasolina-y-el-acpm-asi-quedo-el-valor-del-combustible-en-las-principales-ciudades-de-colombia-3423439.

EPE (Empresa de Pesquisa Energética). 2024. WEBMAP EPE – *Sistema Interativo de Geoinformação do Setor Energético Brasileiro.* https://gisepeprd2.epe.gov.br/WebMapEPE/.

Escate Lay, C. Z., J. da Cruz, C. Blair-Matos, J. A. A. Luzeiro, and M. C. de Oliveira. 2021. "Traditional Knowledge of Açaí (*Euterpe precatoria* Mart. – ARECACEAE) Usage in the Sustainable Development Reserve – RDS Piagaçu Purus – Amazonas – Brazil." *International Journal of Environment, Agriculture and Biotechnology* 6 (1): 128–35. https://ijeab.com/upload_document/issue_files/17IJEAB-101202118-Traditional.pdf.

Farrokhi, Farid, Elliot Kang, Heitor S. Pellegrina, and Sebastian Sotelo. 2025. *Deforestation: A Global and Dynamic Perspective. NBER Working Paper Series No. 34150.* Cambridge, MA: National Bureau of Economic Research. https://www.nber.org/papers/w34150.

Ferreira Filho, J. B. S., and A. L. Fachinello. 2015. "Employment and Income Generation in the Brazilian Amazon Forest: A Social Account Matrix–Based Multiplier Approach." *International Forestry Review* 17 (S1): 85–96. https://doi.org/10.1505/146554815814669007.

Ferreira Filho, J. B. S., and A. L. Fachinello. 2019. "About Trees and People: What Works for Development in the Amazon? A SAM and CGE Analysis." *Revista de Economia Bageense* 12 (13).

Freitas, Madson A. B., José L. L. Magalhães, Carlos P. Carmona, Víctor Arroyo-Rodríguez, Ima C. G. Vieira, and Marcelo Tabarelli. 2021. "Intensification of Açaí Palm Management Largely Impoverishes Tree Assemblages in the Amazon Estuarine Forest." https://ui.adsabs.harvard.edu/abs/2021BCons.26109251F/abstract.

Freitas, Madson Antonio Benjamin, Ima Célia Guimarães Vieira, Ana Luisa Kerti Mangabeira Albernaz, José Leonardo Lima Magalhães, and Alexander Charles Lees. 2015. "Floristic Impoverishment of Amazonian Floodplain Forests Managed for Açaí Fruit Production." *Forest Ecology and Management* 351: 20–27. https://ui.adsabs.harvard.edu/abs/2015ForEM.351...20F/abstract.

GICE (Grupo Interinstitucional de Conectividade na Educação). 2022. "Nota Técnica: Qual a Velocidade de Internet Ideal para Minha Escola? Como Definir o Plano de Internet Baseado em Parâmetros Técnicos e Pedagógicos." São Paulo: GICE. https://medicoes.nic.br/media/nota-tecnica-velocidadeescola.pdf.

Giga. 2023. "Guidelines for ISPs to Connect Schools to the Internet through Competitive Bidding Process." *Giga Connect*, April 26, 2023. https://giga.global/10-school-connectivity-guidelines/.

Gonzalez-Navarro, Marco, Román David Zárate, Rémi Jedwab, and Nick Tsivanidis. 2024. "Land Transport Infrastructure." *VoxDevLit*. https://voxdev.org/sites/default/files/2023-12/Land_Transport_Infrastructure_Issue_1.pdf.

Google Research. 2024. "Open Buildings: Global Building-Footprint Database (v3) [Data set]." Accessed May 30, 2025. https://sites.research.google/gr/open-buildings/.

Government of Brazil. 2024. "Average per Capita Income in Brazil Surges by 11.5% to Reach 12-Year High." *News*, April 20, 2024. https://www.gov.br/planalto/en/latest-news/2024/04/average-per-capita-income-in-brazil-surges-by-11-5-to-reach-12-year-high.

GSMA and IFC (International Finance Corporation). 2014. Tower Power Africa: *Energy Challenges and Opportunities for the Mobile Industry in Africa.* https://www.gsma.com/solutions-and-impact/connectivity-for-good/mobile-for-development/wp-content/uploads/2014/11/Africa-Market-Report-GPM-final.pdf.

Guerra, A. C. B., A. N. D. Jesus, and M. L. S. Martins. 2021. "A Cadeia Logística do Açaí e Sua Importância para o Estado do Pará." In *XII Fateclog—Gestão da Cadeia de Suprimentos no Agronegócio: Desafios e Oportunidades no Contexto Atual,* Fatec Mogi das Cruzes, Mogi das Cruzes/SP, Brasil, June 18–19, 2021.

Halla, M., org. 2022. *Cadeia de Valor do Açaí: Dos Territórios Indígenas aos Mercados.* Iniciativa Comunidades e Governança Territorial da Forest Trends (ICGT-FT).

Hanusch, Marek, ed. 2023. *A Balancing Act for Brazil's Amazonian States: An Economic Memorandum.* Washington, DC: World Bank. http://hdl.handle.net/10986/39778.

Herrera Dappe, Matias, Mathilde Lebrand, and Aiga Stokenberga. 2025. *Shrinking Economic Distance.* Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/08128e98-55c4-42e8-9a88-0027cd88cbb7.

Homma, Alfredo. 2017. "Plant Extractivism in the Amazon: Limitations and Possibilities." https://philip.inpa.gov.br/publ_livres/Other%20side-outro%20lado/Extractive%20reserves/homma%20Plant%20extractivism.pdf.

Hsu, C., C. Liu, A. Mostafavi, E. Ivarsson, and L. Sekerinska. 2025. "Leveraging Heterogeneous Data and Machine Learning for Mapping Connectivity and Infrastructure Provision in Amazon." *Environmental Research: Infrastructure and Sustainability*. https://iopscience.iop.org/article/10.1088/2634-4505/ae0f4f.

Humanitarian OpenStreetMap Team. 2025. "HOTOSM Brazil, Colombia & Peru – Waterways and Roads Exports [Data sets]." Accessed May 30, 2025. https://data.humdata.org/group/.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2019. *População dos Municípios com Base nos Dados do Censo Demográfico 2022*. https://www.ibge.gov.br/estatisticas/sociais/populacao/22827-censo-demografico-2022.html?edicao=35938&t=resultados.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2023.

—— *Municipal Livestock Survey (PPM) 2022. Production of Plant Extraction and Forestry (PEVS), by Major Regions and Federation Units, According to the Type of Aquaculture Product.* Rio de Janeiro: IBGE.

—— *Municipal Livestock Survey (PPM) 2022. Aquaculture Production in Brazil, by Major Regions and Federation Units, According to the Type of Aquaculture Product.* Rio de Janeiro: IBGE.

—— *Pesquisa Nacional por Amostra de Domicílios Contínua (PNADc).* https://www.ibge.gov.br/estatisticas/sociais/populacao/9171-pesquisa-nacional-por-amostra-de-domicilios-continua-mensal.html.

Imazon (Instituto do Homem e Meio Ambiente da Amazônia). 2023. *Amazônia 2030: Bases para o Desenvolvimento Sustentável.* Belém, PA: Imazon. https://amazonia2030.org.br/wp-content/uploads/2024/03/Amz2030-Livro.pdf.

INEI (National Institute of Statistics and Informatics). 2023. Peru: *Evolution of Monetary Poverty, 2014–2023.* Lima: INEI.

INEI. 2024a. *Peru: Education Indicators According to Departments 2013–2023.* Lima: INEI.

INEI. 2024b. *Indicators of Basic Services and Digital Connectivity by Department, 2023.* Lima: INEI.

INEI-ENAHO (Instituto Nacional de Estadística e Informática – Encuesta Nacional de Hogares). 2023. *National Household Survey, Peru, 2023.* https://proyectos.inei.gob.pe/microdatos/.

Instituto Pólis. 2024. "Justiça Energética: Pesquisa de Opinião Pública." São Paulo, Brasil: Instituto Pólis. https://polis.org.br/wp-content/uploads/2024/06/justica-energetica.pdf.

IPSE (Instituto de Planificación y Promoción de Soluciones Energéticas para las Zonas No Interconectadas). 2023. *Informe Mensual de Telemetría – Noviembre de 2023.* https://ipse.gov.co/documentos_cmn/documentos/informes_mensuales_de_telemetria/2023/noviembre/INFORME_MENSUAL_TELEMETRIA_NOVIEMBRE_DE_2023.pdf.

IPSE (Instituto de Planificación y Promoción de Soluciones Energéticas). 2024. *Caracterización de las Zonas No Interconectadas (ZNI).* https://ipse.gov.co/cnm/caracterizacion-de-las-zni/.

Lima, N. R. O., B. F. A. de Oliveira, I. H. da Silveira, I. N. de Oliveira, R. F. V. de Sousa, and E. Ignotti. 2025. "Health in the Legal Amazon: An Analysis of Morbidity and Mortality Indicators Between 2010 e 2021." *Ciência & Saúde Coletiva* 30 (1): e03722023.

Lopes, D. B., A. Euler, J. Ferreira, J. Valentim, L. H. O. Wadt, M. Kanashiro, R. Porro, and S. L. L. de Gois. 2023. "Visões sobre Bioeconomia na Amazônia: Oportunidades e Desafios para a Atuação da Embrapa." https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1155733/1/Visoesbioeconomia-Amazonia-doc-2023.pdf.

Lopes, E., B. Soares-Filho, F. Souza, R. Rajão, F. Merry, and S. Carvalho Ribeiro. 2019. "Mapping the Socio-Ecology of Non-Timber Forest Products (NTFP) Extraction in the Brazilian Amazon: The Case of Açaí (*Euterpe precatoria* Mart.) in Acre." *Landscape and Urban Planning* 188 (August): 110–17.

Mapbox. 2025. "Mapbox Movement Activity Index (v4) [Data set]." Accessed May 30, 2025. https://www.mapbox.com/.

Marengo, J. A., and C. M. Souza. 2018. *Changes in Climate and Land Use over the Amazon Region: Current and Future Variability and Trends.* São Paulo: Springer Nature.

Meta Data for Good. 2025. "Movement Range Maps: 'Movement Between Places During Crisis' [Data set]." Accessed May 30, 2025. https://dataforgood.facebook.com.

MINEM (Ministerio de Energía y Minas). 2023. *Diagnóstico de Brechas* 2025–2027. https://cdn.www.gob.pe/uploads/document/file/5058945/Diagnóstico%20de%20Brechas%202025-2027%20-VF.pdf.

Ministry of Environment and Sustainable Development. 2020. *Guia de Manejo Ambiental para Vias Terciarias. Bogotá,* DC, Colombia: Ministry of Environment and Sustainable Development. https://www.minambiente.gov.co/wp-content/uploads/2022/07/15.-Guia-de-manejo-ambiental-para-vias-terciarias.pdf.

MMA (Ministry of the Environment), Brazil. 2024. *First Biennial Transparency Report of Brazil to the United Nations Framework Convention on Climate Change.* Brasília: MMA Technical Series.

MME (Ministério de Minas e Energia). 2023. "Tarifa social: saiba como funciona e quem pode pedir desconto." https://www.gov.br/mme/pt-br/assuntos/noticias/tarifa-social-saiba-como-funciona-e-quem-pode-pedir-desconto.

Nobre, Carlos A., Rafael Feltran-Barbieri, Caroline Medeiros Rocha Frasson, Paulo Camuri, and Carolina Genin. 2023. *New Economy for the Brazilian Amazon.* São Paulo: WRI Brasil. https://wribrasil.org.br/nova-economia-da-amazonia.

NOAA Nightlight Data. 2024. "VIIRS Night-time Lights (VNL v2.2), Annual and Monthly Composites [Data set]." Accessed May 30, 2025. https://eogdata.mines.edu/products/vnl/.

Oliveira, R. F. P. 2023. *O Desenvolvimento da Biotecnologia Industrial nos Processos de Produção no Estado do Amazonas.* Doctoral dissertation, Federal University of Amazonas. https://tede.ufam.edu.br/handle/tede/9459.

OSINERGMIN (Organismo Supervisor de la Inversión en Energía y Minería). 2024. *Indicadores de Calidad de Suministro de las Empresas de Distribución Eléctrica a Nivel Nacional (SAIDI, SAIFI).* https://datosabiertos.gob.pe/dataset/indicadores-de-calidad-de-suministro-de-las-empresas-de-distribuci%C3%B3n-el%C3%A9ctrica-nivel-0.

OSINERGMIN. 2025. *Precios de Referencia de Combustibles.* https://www.osinergmin.gob.pe/seccion/institucional/regulacion-tarifaria/precios-de-referencia-banda-de-precios/precios-de-referencia-de-combustibles.

Pereira, Cinthia Nazario. 2023. *Aproveitamento Energético de Resíduos do Açaí nos Sistemas Isolados.* Federal University of Rio de Janeiro. http://www.repositorio.poli.ufrj.br/monografias/projpoli10040492.pdf.

Pokorny, Benno. 2013. *Smallholders, Forest Management and Rural Development in the Amazon.* London: Routledge.

Poli, N., M. Cenamo, and C. Koury. 2021. *Gargalos e Oportunidades: Diagnóstico – Cadeia do Açaí no Amazonas.* Manaus, Brazil: Instituto de Conservação e Desenvolvimento Sustentável do Amazonas (Idesam).

Potiguar, M. R. S., and H. J. Sá de Oliveira. 2016. *Planejamento Estratégico para o Fortalecimento do Arranjo Produtivo Local da Cadeia de Valor do Açaí do Marajó: Uma Construção Coletiva e Territorial.* Belém: Instituto Peabiru.

RealTime1. 2023. "Vazante pode causar apagões em 23 municípios do Amazonas." RealTime1, August 30, 2023. https://realtime1.com.br/vazante-pode-causar-apagoes-em-23-municipios-do-amazonas/.

Rodrigues, D. L., and D. N. Silva. 2023. "Poverty in the Brazilian Amazon and the Challenges for Development." *Cadernos de Saúde Pública* 39 (10): e00100223.

Schaeffer, R., R. Barrantes, A. Klautau, A. Malky, A. C. Oliveira Fiorini, A. M. Durán Calisto, A. Abelem, C. Simmons, L. Chermont, M. Okamura, M. Arteaga, O. L. Heredia Flores, R. Delgado, and R. Soria. 2023. *Una Nueva Infraestructura para la Amazonía.* Sustainable Development Solutions Network (SDSN). https://doi.org/10.55161/ROYG4225.

Schaeffer, R., J. A. Marengo, A. Koberle, A. Lucena, C. Simoes, and E. Lèbre La Rovere. 2023. *Climate Risks to Infrastructure and Connectivity in the Brazilian Amazon.* Rio de Janeiro: Fundação Getulio Vargas.

Serviço Geológico do Brasil (SGB). n.d. https://www.sgb.gov.br/.

Sinchi – Instituto Amazónico de Investigaciones Científicas. 2015. Asaí (Euterpe precatoria): *Cadena de valor en el sur de la región amazónica.* Bogotá. https://www.sinchi.org.co/files/publicaciones/publicaciones/pdf/asaipubli.pdf.

Soares-Filho, B. S., A. Alencar, D. Nepstad, G. Cerqueira, M. C. V. Diaz, S. Rivero, L. Solórzano, and E. Voll. 2004. "Simulating the Response of Land-Cover Changes to Road Paving and Governance along a Major Amazon Highway: The Santarém–Cuiabá Corridor." *Global Change Biology* 10 (5): 745–764. https://doi.org/10.1111/j.1529-8817.2003.00769.x.

SSPD (Superintendencia de Servicios Públicos Domiciliarios). 2019. *National Report on the Coverage of Public Water and Sewerage Services.* Bogotá: SSPD.

SSPD. 2023. *Diagnóstico de la Calidad del Servicio de Energía Eléctrica en Colombia 2022.* Bogotá: SSPD. https://www.superservicios.gov.co/sites/default/files/inline-files/Informe-de-Calidad-del-Servicio-de-Energia-2022.pdf.

UPME (Unidad de Planeación Minero Energética). 2024. *Geoportal UPME – Shapes.* https://geoportal-upmeonline.opendata.arcgis.com/pages/shapes.

Van Loon Maritime Services B.V. n.d. "3,955/2,868 DWT Sea/River Bunker/Oil Tanker (2 Sisters)." https://www.vlmaritime.com/product/i0019-sea-river-bunker-tanker/.

World Bank. 2006. "Individuals Using the Internet (% of Population) — Brazil, Colombia, Peru, Bolivia, Ecuador, Venezuela, RB." https://data.worldbank.org/indicator/IT.NET.USER.ZS?end=2023&locations=BR-CO-PE-BO-EC-VE&start=2006.

World Bank. 2016. *Measuring Rural Access: Using New Technologies.* Washington, DC: World Bank. http://hdl.handle.net/10986/25187.

World Bank. 2023. *Cierre de Brecha Digital en el Departamento Amazonas*. Washington, DC: World Bank. https://documentos.bancomundial.org/es/publication/documents-reports/documentdetail/099507509282332734/idu0ce839d000e6c004d0c09cdb0a83b7b0d036e.

World Bank and Nommon. 2024. *Data-Driven Methodology to Quantify Travel Demand in the Amazon Region in Brazil and Colombia Using Mobile Phone Data*.

WRI (World Resources Institute). 2023. *New Economy for the Brazilian Amazon*. WRI Brasil and New Climate Economy.

XM Compañía de Expertos en Mercados S.A. E.S.P. 2024. *Capacidad de Generación.* https://paratec.xm.com.co/paratec/SitePages/generacion.aspx?q=capacidad.

Zodhya. 2023. "How Much Power Does a Cell Tower Consume?" *Medium*, August 5, 2023. https://medium.com/@zodhyatech/how-much-energy-does-a-cell-tower-consume-7efc2c8cdfbf.

A1. Compiling an open-source data inventory: Mapping transport, energy, and digital infrastructure in the Amazon region

The World Bank Group initiated the mapping of all existing infrastructure belonging to the transport, energy, and digital sectors in the Brazilian, Colombian, and Peruvian Amazon. The project utilized a variety of open-source data sets and data provided by government entities. Aggregation and centralization of this information produced a large data set, which can be visualized online and is available for use by third parties for further analysis. Given the nature of the exercise and the type of data processed, all deliverables are formatted as geospatial packages, which can be used with third-party software such as QGIS. At the issuance of this report, the delivered data set consisted of 1,100 individual files for a total size of about 15 gigabytes.[43]

The area of interest (AOI) for the data collection and mapping encompasses roughly 6.48 million square kilometers (km^2), covering large parts of Brazil, Colombia, and Peru, and can be decomposed into 24 territories (map A1.1). Boundaries were obtained using sources such as Instituto Brasileiro de Geografia e Estatística (IBGE) for Brazil, Office for the Coordination of Humanitarian Affairs (OCHA) for Colombia, and Infraestructura de Dados Espaciales del Perú (IDEP) for Peru. In Brazil, this area encompassing the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins, Mato Grosso, and part of Maranhão is designated the "Legal Amazon," which is our AOI. In Colombia, the Amazon region consists of six fully Amazonian departments—Amazonas, Caquetá, Guainía, Guaviare, Putumayo, and Vaupés—accounting for 84 percent of the country's Amazonian territory, while four additional departments—Cauca, Nariño, Meta, and Vichada—include Amazonian portions, making up the remaining 16 percent. In Peru, the Amazon region includes the departments of Amazonas, Loreto, Madre de Dios, San Martín, and Ucayali, forming a significant portion of the country's extensive rainforest coverage.

43 A large number of files is at times due to the necessity to break down some of the maps according to some nonspatial characteristics, such as per year or per month. Such a breakdown appeared as a necessity, especially for freight and trips data (to measure traffic intensity). A decision was also made to split the four largest files (road network, presence of pavement, pavement condition, and interconnecting roads) into 24 subsets each—one for each of the specified territories—so that they could be used when focusing on a particular region, and the size of the layers, which could slow down the visualization process (for instance, the road network file alone is of approximately 1.5 gigabytes), could be managed.

Map A1.1 Area of interest, broken down by country and with territories bound



Source: Original compilation.

Road infrastructure

To measure the quantity and quality of the road infrastructure in the Amazon region, we rely on vector data, used to reconstruct or "map" the network, as well as satellite imagery, used to assess the presence of pavement and its condition for the entire AOI. The following sources were used for the entire road mapping workflow:

- OpenStreetMap (OSM)
- Open Mapping at Facebook (OMF)
- Microsoft Bing Maps (MBM)
- Sentinel-1 synthetic aperture radar (SAR) for radar imagery—used to assess pavement quality
- Sentinel-2 multispectral instrument (MSI) for optical imagery—used to assess the presence of pavement on roads
- The Global Roads Inventory Project (GRIP) candidate data source was discarded, being redundant and less comprehensive than the combination of those sources.

Mapping of the road network represents the first step of the analysis and is key to the estimation of other features. Since the network's extraction is mostly based on open-source data sets with continental coverage (OSM, OMF, and MBM), the breadth and state of the road infrastructure in the Amazon region can be measured to a very high degree of accuracy. In practice, the team extracted information from the three largest databases of road infrastructure currently available online: OSM,[44] OMF,[45] and MBM.[46]

After collecting data sets over the AOI, a conflation routine had to be implemented. In the context of a geographic information system (GIS), conflation is defined as the process of merging or combining geographic vector information from overlapping sources to retain the most accurate data, minimizing redundancy and reconciling data conflicts. The conflation method follows these steps:

- **Data preparation.** The geographic data to be conflated are prepared for use in the conflation process. This may include the removal of invalid geometries and the conversion of the data into a compatible format.

- **Matching.** Data are compared to identify matching features between different sources. This is done using automatic matching algorithms that use road geometry and its features to establish candidate vectors for the next step.

- **Merge.** Once matches are identified, the data are combined to create a new data set. Information from candidate sources is either deleted or added to our base vector (the OSM data set). So, a portion of a road vector can be erased, or fused into another road vector.

- **Validation.** The result is checked to ensure that it is logical and consistent. Errors are corrected and incomplete information is filled in if necessary.

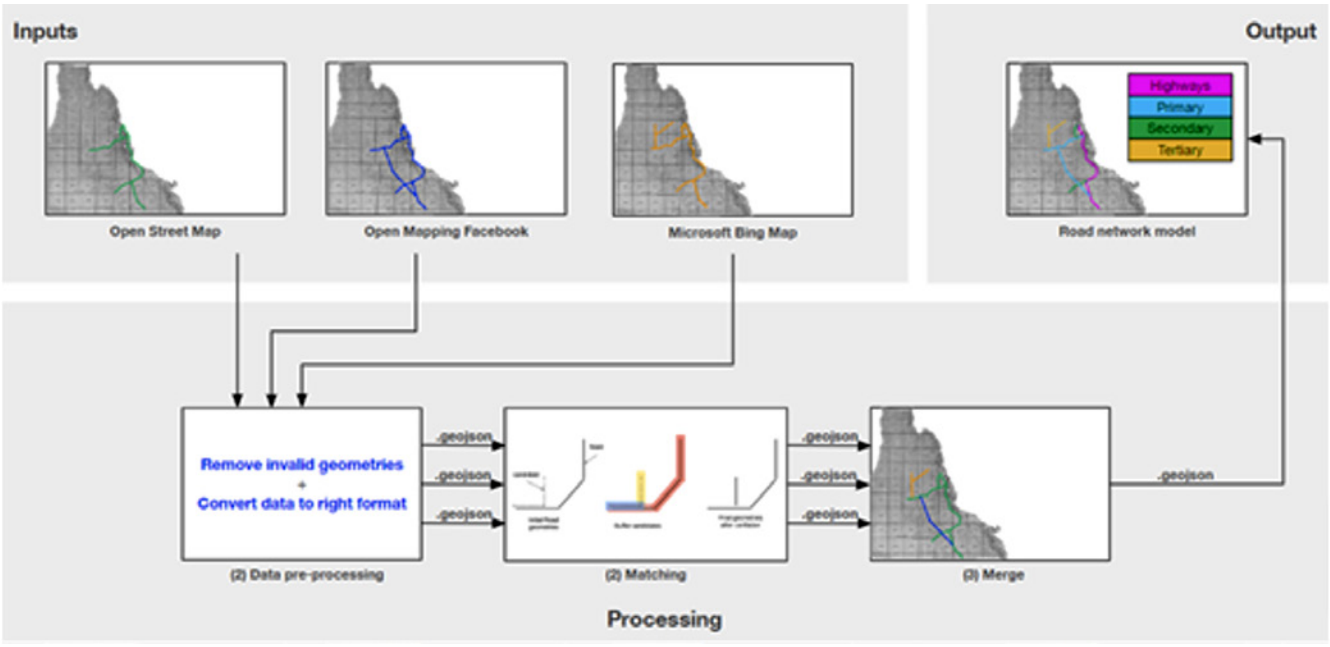
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44 OSM is an open-source collaborative project in which, like Wikipedia, users can create and modify vector features in an online platform to create a map of a city or even an entire country. It is the most used service online for tasks of this type and is quite accurate and complete in urban zones, where users have more incentives to collaborate to provide a complete description of their neighborhoods. However, a collaborative map of this type can be incomplete in rural zones. They could also exclude some connections between villages where roads are not paved and/or rarely used.

45 The objective is to have a platform to edit maps like OSM but with modern artificial intelligence capabilities added. The initial roads are created using a geospatial neural network trained on high-resolution satellite images. Users can then edit these roads online. While the neural network can be used to make predictions about roads anywhere in the world, even in remote locations, the position of roads tend to be inaccurately predicted: errors in path can be of several meters, and in urban environments, the predictions tend to be less complete than the OSM. The collaborative project faces competition from OSM, which has many more users and a more established application programming interface and tutorials for the community.

46 This project is another geospatial neural network, like OMF, that uses high-resolution satellite images to make predictions on road positions. It is very similar to OMF but with some geometrical improvements on the model, but has the same limitations.

Figure A1.1 Schematic of the conflation routine workflow



Source: Original compilation by Alteia.

The ability to characterize whether a road is paved or not, and the proportion of paved roads in the network, is an essential indicator of network development and a crucial source of information for further road planning. Given the scale of the analysis, approximating that metric using satellite imagery remains the best approach. The pavement classification workflow used multispectral optical data from Sentinel-2 to determine the presence of pavement on road vectors. Normalized difference indexes were computed to distinguish between paved and unpaved roads.

Road quality was approximated using the International Roughness Index and synthetic aperture radar (SAR) imagery from Sentinel-1.

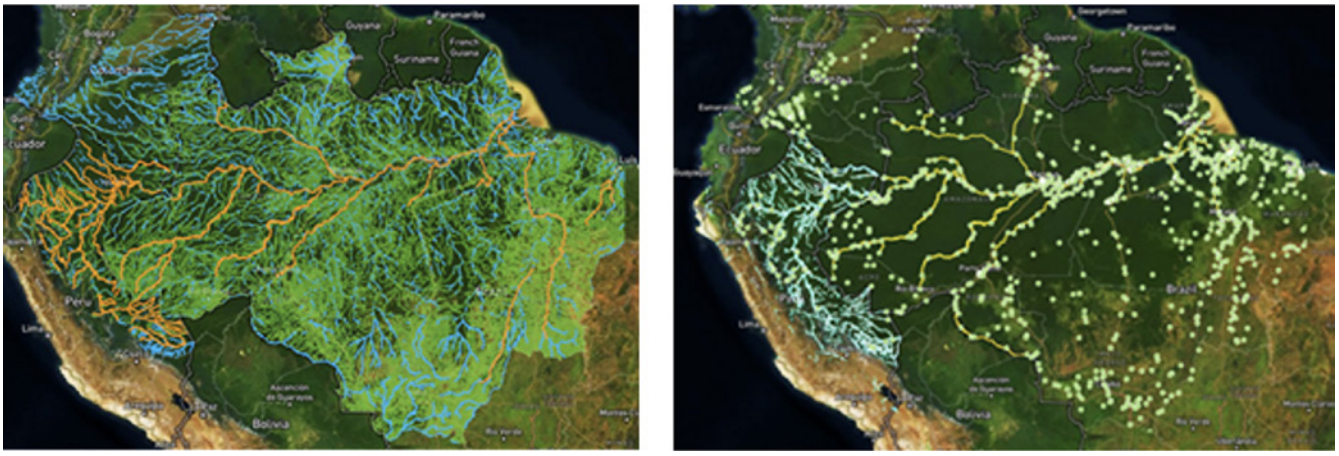
Several transport-related information, including the type of traffic on a given road section or its intensity, can help understand the state of development of the road network. Where no comprehensive, granular, and open-source traffic data on the AOI were available, several alternatives were explored and integrated into the infrastructure geo-spatial database.

Road infrastructure

River mapping was conducted using a combination of the following data sources: (1) for Brazil: IBGE and *Agência Nacional de Transportes Aquaviários* (ANTAQ); (2) for Colombia: OSM through Humanitarian Data Exchange (HDE); (3) for Peru: GeoGPS and *Infraestructura de Datos Espaciales del Perú* (IDEP); and (4) for all three countries: the Surface Water and Ocean Topography (SWOT) mission of the National Aeronautics and Space Administration (NASA). The *Plan Amazónico De Transporte Intermodal Sostenible* (PATIS) data set also contains a dense river network mapping over the AOI.

Combining the above sources, along with port infrastructure, generates a very comprehensive mapping of rivers over the Amazon region (map A1.2).

Map A1.2 Left: River network using PATIS (green) and NASA (blue), and rivers categorized by navigability level (orange). Right: Economically navigated rivers (yellow), the Peru hydrography data set (cyan), and ports and docks (green)



Source: Original compilation.
Note: NASA = National Aeronautics and Space Administration; PATIS = Plan Amazónico De Transporte Intermodal Sostenible.

Navigability conditions were proxied using synthetic indicators provided by government sources. For Brazil, classifications were taken from *Departamento Nacional de Infraestrutura de Transportes* (DNIT). For Peru, classifications were taken from *Autoridad Nacional del Agua* (ANA).

A total of 511 ports were inventoried. An important part of data processing was the removal of duplicates when combining sources, in part because several names may be used for the same ports. The data sources used were as follows: (1) for Brazil: *Banco de Informações de Transportes* (BIT); (ii) for Colombia: *Instituto Geográfico Agustín Codazzi* (IGAC); and (3) for Peru: *Ministerio de Transportes y Comunicaciones* (MTC).

Docks (e.g., jetties and wharfs) enable small population settlements[47] in remote areas usually lacking road infrastructure to access rivers and trade opportunities with the rest of the region. Since no data set was available on the AOI, the presence of docks was inferred by crossing information on population settlements with river locations: if a small population settlement was found in remote areas and in the vicinity of a river, the likelihood of a dock, even of small size, was considered high. The final mapping can be considered rather extensive, since we relied on (1) dense riverway mapping data sets and (2) the WorldPop—Population Counts data set, which is also considered extensive in its coverage, to locate settlements close to rivers. The Peruvian government supplied an additional data set (terminals and wharfs) that complemented port and dock mapping.

Passenger volumes on rivers were estimated based on ticket sales and ferry traffic statistics. Where no aggregated ferry passenger volume data were available, an estimate can be derived using ferry trip schedules (either actual or planned trips) and ferry capacity, thus giving an upper bound for passenger volume. The final estimate was built by (1) collecting ferry trips data and matching them to our mapped rivers, (2) collecting maximal or nominal capacity details for ferries, and (3) building a final layer by providing the actual or maximal (theoretical) passenger volume.

Freight volumes on rivers were approximated using the following data sets: (1) ANTAQ for Brazil and (2) MTC for Peru. Minor port usage data are available for Peru and are therefore reported. However, the data do not follow the breakdown used in Brazil. Finally, no similar and suitable data source was found for rivers in Colombia.

47 A settlement was identified when population was above 100 inhabitants/km^2. For the distance to rivers, a 5 km buffer was applied to all settlements.

Airport infrastructure

The following sources were used to map airports: (1) for all three countries: *OurAirports*; (2) for Brazil: IBGE; (3) for Colombia: OSM through HDE; and (4) for Peru: MTC.

Airport size was defined based on the passengers the airport processed. The following data sets on passenger volume were used: (1) for Brazil: *Agência Nacional de Aviação Civil* (ANAC); (2) for Colombia: Aeronáutica Civil; and (3) for Peru: MTC, *Corporación Peruana de Aeropuertos y Aviación Comercial* (CORPAC), *Movimiento General Aeroportuario Internacional* 2022. The resulting layers were built per year, or per month.

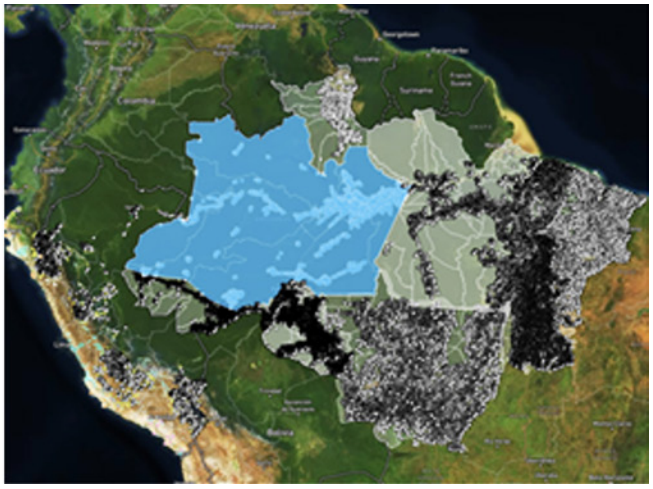
Electricity infrastructure

Power transmission and distribution networks were mapped using open-source data sets from OSM, OpenInfraMaps, MapBiomas, and *Operador Nacional do Sistema Elétrico* (ONS), as well as government data. Additional data from *Agência Nacional de Energia Elétrica* (ANEEL) were used for utilities within the AOI. Mini grids and off-grid systems were also inventoried.

The final power transmission and distribution maps (map A1.3) accurately and comprehensively reveal the spatial distribution of the transmission and distribution infrastructure in the Amazon region, allowing them to be used as overlay with other infrastructure, and with biodiversity and population layers, to analyze gaps.

Map A1.3 Power transmission data (left) and power distribution data (right)





Source: Original compilation.

A data set on mini grids from ANEEL in Brazil was also integrated into the final energy mapping. However, this data source shows a rather low penetration for this type of infrastructure within the AOI. Inventory results for off-grid systems were taken from *Empresa de Pesquisa Energética* (EPE) data.

For hydropower and dam locations, these data sets were used: (1) for Brazil: ANEEL; (2) for Colombia: *Rede Amazônica de Informação Socioambiental Georreferenciada* (RAISG); and (3) for Peru: *Organismo Supervisor de la Inversión en Energía y Minería* (ONISERGMIN).

The *Rural Electrification Study* in Peru was leveraged by extracting information from the report, along with an indication of the region of interest—in our case, the regions belonging to the AOI, specifically, Amazonas, Loreto, and Ucayali. The layer attributes provide information on the population coverage of electrical power, for example, town centers without electricity service (expressed as a percentage population) or the count of electrified homes in the region.

Digital infrastructure

The scope of the digital mapping analysis was primarily focused on internet and mobile telecommunication infrastructure. However, some data for land phones/lines were also included.

As with power lines, it should be noted that information on telecommunication networks is highly sensitive and not easily disclosed by mobile and broadband service providers. Other constraints, such as commercial strategies, taxation regimes, or regulatory environments, among others, can also play a role in the lower availability of data in this sector.

However, open-source connectivity test data is a robust alternative and can proxy for actual coverage levels. Once combined with other data sets, these data can also generate a proxy for broadband coverage. As with other mapping efforts in the project, the coverage per country is uneven and relies heavily on the supply of government sources.

Mobile networks were mapped using the *Ookla data set* (all countries). Ookla is a crowdsourced data source, which captures speed tests and has data available for all regions, for both mobile and fixed networks. Available years span from 2019 to 2024. The available properties pertain to average *upload* and *download speed, latency, number of tests, and number of devices*. The raw data, consisting of around 50 vector files, was processed, producing a layer for each year and each type of network (mobile or fixed).

Moreover, the *Agência Nacional de Telecomunicações* (ANATEL) data set provides coverage-related information for Brazil using mobile network propagation models, which report signal breadth and strength. The raw data set is originally made up of 58 vector files, which represent combinations of three fields: operator, technology, and power. Technology refers to 2G, 3G, 4G, or 5G. Power refers to the maximum signal strength (Received Signal Strength Indicator in decibels relative to a milliwatt [RSSI dBm] and quality attributes). The final data set was aggregated by operator and technology. This processing was conducted for the entire Brazil AOI.

The team crossed the above aggregated data with the WorldPop population data set to estimate the population in the covered areas (the layer is called *ANATEL x World Pop*). The union of all technologies (2G, 3G, 4G, and 5G) provides the most accurate estimate.

The *OpenCellID* data set was integrated. The data set consists of a database of cell towers across the world, which provides geolocation and basic information on mobile tower technology. In addition, the Peruvian government supplied a data set on mobile coverage. The data set from ANATEL (Brazil) was also integrated.

To map the internet/fiber-optic network, the following data were used: (1) For *transmission links and nodes*, a data set from International Telecommunication Union (ITU) for Brazil covering major parts of the country and providing high-level network details was used; (2) *internet* exchange points for the years 2020 and 2024 from Packet Clearing House and the World Bank were integrated; and (3) other data sets, such as the Internet Coverage data set for Peru, the Broadband Beneficiaries data set illustrating locations benefiting from the *Proyectos de Banda Ancha* program in Peru, and the Backhaul data set for Brazil, were used.



Logistical chains

Data sets for logistical chains and nodes are not fully available, making it difficult to transfer them into georeferenced data or maps. Given the importance of understanding the logistical corridors, three separate data sources from Peru, Colombia, and Brazil were consolidated into a single database. This integration enables a best-effort mapping of the logistical corridors across the region. The data sources considered are:

- **NLP 2035 (Brazil).** The National Logistics Plan provides highly valuable information on logistics in Brazil. It also provides essential information on future development for logistical corridors. Integrating this information into the mapping effort was hence made a priority. The base scenario from 2017, along with several future scenarios.

- **PATIS (Colombia).** The PATIS data set handles the integration and complementarity of transportation modes and means to guarantee intraregional connectivity in Colombia. The data set consists of a diversity of information, such as land register data, corridors, and sectoral information. In total, 246 layers were integrated, and a categorization was made to sort the data by domain, for example, corridors, industrial sectors, and climate risk layer.

- **PATS (Peru).** The Peruvian government provided the *Programa de Apoyo al Transporte Subnacional* (PATS) data set, which has two layers, PATS I and II. Only layers where at least one segment intersects with or is within the regions of interest in Peru were kept. A layer represents road segments, along with information on plans for each segment (e.g., maintenance status) or the status of projects (e.g., under construction).

Connectivity and access

Interconnecting roads are broadly defined as roads that connect population settlements of significant size. Using WorldPop data, a layer consisting of roads along with the population count in the vicinity of road segments was created based on road network conflation. This layer also contains an attribute stating whether a road segment is classified as urban, depending on whether it crosses areas with at least approximately 100 inhabitants per square kilometer (the population density resolution of the WorldPop data set is approximately 1 km^2). Through this layer, users are able to filter (out) intraurban road networks, which mainly consist of city streets, which are very dense, making the road data set increasingly larger and slowing down visualization on the platform. More importantly, city streets are not critical for assessing the connectivity of a given settlement to the rest of the Amazon region.

The local communities layer—created using the WorldPop population data set—presents the settlements of local communities, indicating the community's name for related Indigenous territory, the name of the ethnic group, and the population count in the area. A separate layer, using the data set for peasant and native communities provided by the Peruvian government (*Secretaría de Gobierno y Transformación Digital*), complements the mapping of local communities.

Mapping of health care and education facilities utilized open-source data for hospitals and open-source data for schools: For hospitals—(1) in Brazil: OSM; in Colombia: *Registro Especial de Prestadores de Servicios de Salud* (REPS) and OSM; in Peru: *Ministerio de Salud* (MINSA) from GeoPeru and OSM. For schools—(1) in Brazil: GigaMaps, OSM, and ITU; (2) in Colombia: United Nations Office for the Coordination of Humanitarian Affairs (OCHA), GigaMaps, and OSM; and (3) in Peru: *Ministerio de Educación* (MINEDU), GigaMaps, and OSM. The attributes pertain to education level (primary, secondary) or facility type (clinic, hospital).

Challenges and limitations related to the infrastructure mapping

Several challenges were encountered during the infrastructure mapping, including access to clean and readily available data sets, the scale of the project, and engineering issues related to the manipulation of very large data sets. However, for projects of this type, publications without access to original, raw data represent the most important limitation.

Among the main challenges was access to clean and readily available data sets. Although the team compiled a preliminary list of potential open-source data before the data collection started, efficient mapping required more than just open-source data. While large swaths of critical information pertaining to all types of infrastructure are technically available online, most are in the form of reports and publications, which cannot be processed as is. Moreover, links to portals are not always publicly accessible, and access to raw data is often restricted. Publications without access to original, raw data, therefore, still represent the most important limitation for projects of this type.

The scale and nature of the project required working with regions in three countries (Brazil, Peru, Colombia). This added to the heterogeneity in terms of data format, completeness, and quality, which needed multiple steps to address. In general, data in Brazil were more readily available and more comprehensive, followed by data in Peru and data in Colombia. The extensiveness of the final mapping reflected this heterogeneity. Managing a multicountry, multi-infrastructure project implies accommodating a variety of formats and flexible approaches to ensure everything can be read in a single environment. In general, vector data had to be converted. In other cases, data had to be aggregated under a certain scheme. Where data were not georeferenced, they had to be reconciled with an already mapped data set.

Issues related to the sheer size of the final data set emerged, given the scale of the project. Researchers interested in similar studies should anticipate, for visualization and manipulation, heavy investments in platforms capable of handling very large data sets with complex geometries simultaneously.

A2. Leveraging big data and machine learning for infrastructure and mobility planning in the Amazon

The World Bank applied cutting-edge data science methods to provide an integrated, evidence-based picture of infrastructure provision and mobility patterns across the Amazon region. By combining heterogeneous data sets with machine learning techniques, this initiative seeks to unlock new possibilities for inclusive infrastructure planning and targeted investment.

This study utilizes diverse data sources, including government official data sets, satellite imagery, OpenStreetMap (OSM) data, Ookla internet speed metrics, Meta (Facebook) Movement Data, Mapbox mobility data, and mobile network records, for a comprehensive assessment of connectivity and infrastructure challenges across the Amazon region. Combining machine learning and spatial analytics, the World Bank team classified regions in the Amazon based on transport infrastructure (roads, rivers), digital connectivity, energy, and access to essential public services (schools, hospitals) using K-means clustering. SHapley Additive exPlanations (SHAP) analysis identified the dominant factors shaping connectivity patterns, revealing that rivers and internet availability are key determinants. Additionally, we introduce an Infrastructure Provision Index (IPI), highlighting high-, medium-, and low-provision areas using multiple indicators, enabling data-driven targeted investments in infrastructure and policy making.

Data sources and novel data sets

The World Bank team maximized the use of open data, satellite imagery, and the World Bank Development Data Partnership. Various novel data sets that provide unique perspectives on infrastructure and mobility in the Amazon were integrated:

- **Google buildings footprints data set.** It provides a detailed inventory of buildings footprints across the Amazon, extracted from high-resolution satellite imagery. The data set includes 1.8 billion building detections spanning 58 million km^2, covering Latin America, Sub-Saharan Africa, and South and Southeast Asia, and it offers valuable insights for infrastructure planning and urbanization studies in remote and rapidly developing regions (Google Research 2024).

- **The Humanitarian OpenStreetMap Team.** The Humanitarian OpenStreetMap Team (HOT), via the Humanitarian Data Exchange (HDE), includes detailed information on rivers and road networks within Brazil, Peru, and Colombia, covering the Amazon region. OSM is a collaborative project that creates a free, editable map of the world. Volunteers build the map based on Global Positioning System (GPS) data, aerial imagery, and other free sources (Humanitarian OpenStreetMap Team 2025).

- **Nighttime lights (NOAA VIIRS Data).** The nighttime lights data set, developed by the National Oceanic and Atmospheric Administration's Earth Observation Group, captures human-generated lighting patterns across the Amazon. The data set is derived from satellite observations collected by the Visible Infrared Imaging Radiometer Suite (VIIRS). The data set serves as a proxy for economic activity, energy access, and urban expansion, offering critical insights into disparities in regional development (NOAA Nightlight Data 2024).

- **Meta (Facebook) Movement Data.** Meta's Movement Between Places During Crisis data set tracks anonymized mobility patterns of Facebook users who have enabled location services. The data set provides real-time insights into population movements by comparing crisis period activity to baseline mobility trends. Metrics such as percent change and z-scores help quantify mobility fluctuations while ensuring user anonymity. The data set aids in crisis response, infrastructure planning, and transport demand analysis (Meta Data for Good 2025).

- **Mapbox.** The Mapbox Movement data set aggregates over 30 billion daily location updates from 700 million active users across more than 45,000 applications. It offers high-resolution mobility insights. Mapbox normalizes raw location data to generate an Activity Index. It applies strict privacy safeguards, including de-identification and cloud-based aggregation. The data enable granular analysis of movement trends (Mapbox 2025).

- **Mobile phone data.** Anonymized mobile network data from operators such as Claro Brasil (Brazil) and Tigo (Colombia) were utilized to construct origin-destination matrices. These matrices categorize travel demand by mode—road, river, and air—identifying key mobility corridors and infrastructure gaps. By integrating mobile network data with census records, land-use data, and transport surveys, this data set improves the accuracy of mobility analyses, supporting sustainable transport planning across the Amazon.

Building upon these emerging data sources, among others, this study addresses a critical knowledge gap in infrastructure and mobility patterns for the Amazon region. The synergy between novel data streams underpins our subsequent analysis, providing the foundation for evidence-based mobility planning in the Amazon region.

Connectivity and access

The study applies advanced spatial analytics and machine learning to characterize regional connectivity and infrastructure gaps:

- **H3 Spatial Indexing.** The Amazon is divided into Level-5 H3 hexagons (roughly 0.25 km² each), allowing uniform aggregation of features such as road length, proximity to schools, or average download speed.

- **K-means clustering.** Regions are classified into four clusters based on multidimensional indicators of infrastructure provision. This unsupervised technique groups together areas with similar connectivity profiles (e.g., urban hubs, rural low-connectivity zones).

- **SHAP.** It is applied to interpret machine learning models and identify which features (e.g., road access, digital connectivity) most influence the classification of infrastructure levels.

- **IPI.** It is a composite score computed using weighted, normalized infrastructure indicators. SHAP values inform the relative weight of each feature in the IPI, enabling mapping of infrastructure hotspots and deficits.

Based on these data sets, the indicators mentioned in table A2.1 were built to calculate the infrastructure gaps in and connectivity challenges of the Amazon region.

Table A2.1 Summary of indicators

Technology	Description	Data sources	Variables (unit)
Building density	Density of buildings footprints within a hexagon	Google Open Buildings v3	Building density (buildings per square kilometer [km²])
Navigable rivers density	Linear density of navigable rivers inside a hexagon	World Bank navigable waterways layer; HydroSHEDS river network	River density (km per km²)
Density of river or seaport docks	Density of river or seaport docks located in the hexagon	World Bank port inventory (2023)	Dock density (docks per km²)
Density of roads	Road network length per hexagon area	OpenStreetMap road layer (2024-04 extract)	Road density (km per km²)
Road accessibility	Distance from hexagon centroid to the nearest road	Derived from OpenStreetMap road layer	Distance to road (km)
River accessibility	Distance to the nearest navigable river	World Bank navigable waterway layer	Distance to river (km)
Dock accessibility	Distance to the nearest dock	World Bank port inventory (2023)	Distance to dock (km)
Digital access	Mean cellular download speed within a hexagon	Ookla Speedtest Intelligence (2023)	Average download speed (kilobits per second [kbps])
Access to any infrastructure	Minimum of road, dock, or river accessibility distances	Composite of the three accessibility layers above in the table	Minimum accessibility distance (km)
School accessibility	Distance to the nearest school	World Bank education facility database	Distance to school (km)
Accessibility of hospitals	Distance to the nearest hospital	World Bank health facility database	Distance to hospital (km)
Electricity availability	Night time light radiance (proxy for electrification)	Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (2022 annual composite)	Radiance (nanowatts per square centimeter per steradian [nW/cm²/sr])
Connectivity clusters	Clustering of areas (hexagons) based on their connectivity features (various connectivity features)	Various connectivity features/indicators listed above in the table	Classification level of connectivity
Infrastructure Provision Index	A machine learning–based computed index determining the extent of infrastructure provision based on various infrastructure features/indicators	Various infrastructure features/indicators listed above in the table	A unitless indicator; 0 indicating no infrastructure and 20 indicating significant infrastructure development

A3. Methodology for the digital infrastructure gap analysis

Connectivity and access

The digital gap analysis utilized geospatial data sets, infrastructure registries, and bioeconomic production statistics to map and assess connectivity barriers across Brazil, Peru, and Colombia. Connectivity data, including average download/upload speed, latency, and test density across both fixed and mobile networks (2019–24), were derived from Ookla The Global Broadband Speed Test, at a resolution of 600 x 600 meter (m) tiles. Population distribution was mapped using the Copernicus Global Human Settlement Layer (GHSL) raster data set at 3 arcsecond (approximately 100 m) resolution. Infrastructure mapping encompassed known terrestrial and subfluvial fiber-optic routes, cell tower locations, and river port installations. It utilized national telecom registries and satellite imagery. Production data for açaí, cacao, castanha, and pirarucu were sourced from *Instituto Brasileiro de Geografia e Estatística's* (IBGE 's) *Produção Agrícola Municipal* (PAM) and *Pesquisa Especial de Atividades Florestais* (PEVS) in Brazil and expert-informed estimates in Peru and Colombia, where municipal-level data are not available.

All data were processed and visualized in geographic information system (GIS) environments. Data were normalized across a common grid system to allow spatial overlays between infrastructure availability, service quality, and productive zones.

Spatial overlay and territorial gap typology

To assess territorial mismatches, a spatial overlay was created using a combination of:

- Ookla speed and coverage maps;
- GHSL population density grids;
- Infrastructure layers (fiber optics, towers, ports); and
- Municipal bioeconomy production volumes.

Spatial overlay analysis was performed using QGIS, an open-source GIS. Infrastructure layers, including mobile coverage grids from Ookla, mapped fiber-optic corridors, and known cell tower locations, were imported and georeferenced alongside raster layers of population density (GHSL) and municipal production data for bioeconomy. Using QGIS's Raster Calculator and Zonal Statistics tools, analysts aggregated average internet speeds and coverage density by municipality and then cross-referenced these with bioeconomic production volumes through an analysis of a 75 km buffer around fiber routes and ports. The "Intersect" and "Join Attributes by Location" functions were used to quantify how many high-production municipalities lacked proximity to digital infrastructure.

The analysis outlined above allowed the identification of municipalities with high productive potential but no digital connectivity at key nodes, particularly river ports. The analysis found that over half of these productive municipalities lacked any internet-connected port infrastructure, confirming a territorial disconnect between the digital and economic layers.

Broadband access, service quality, and isolation metrics

To quantify digital exclusion, Ookla speed data were aggregated at the municipal level and stratified into quality quintiles. The analysis showed that:

- Large rural areas, especially in Acre, Amazonas, Loreto, and Putumayo, remain outside any fixed or mobile network coverage;
- Even where signal is present, over 15 percent of household income may be spent on low-speed or unstable internet (download speeds below 5 megabits per second); and
- Remote zones without grid electricity or road access rely almost entirely on expensive satellite or informal mesh networks, which causes high latency and diminishes reliability.

This step confirmed the compounding effect of energy and transport limitations on digital service quality.

Infrastructure prioritization and corridor mapping

Spatial prioritization involved ranking digital corridors and municipalities based on:

- Access deficit—distance to the nearest fiber-optic backbone or mobile tower;
- Population served—based on a 75 km buffer around proposed corridors;
- Production density—volume of bioeconomy output within this buffer;
- Project maturity—alignment with national digital programs (e.g., Infovia, Red Dorsal); and
- Environmental sensitivity—proportion of Indigenous territories and protected areas intersected.

These multicriteria inputs were synthesized into a gap typology:

- Type A: partially connected zones with poor-quality service.
- Type B: fully unconnected areas with no infrastructure.
- Type C: underserved zones in Indigenous and riverside communities, which remain outside service coverage despite proximity to infrastructure.

With this methodology, high-impact corridors, such as the Pucallpa-Nauta segment in Peru, Infovias in Brazil, and the Putumayo digital spine in Colombia, all of which intersect bioeconomy-intensive areas with poor or no connectivity, could be strategically selected.

A4. Multi-criteria assessment of infrastructure projects prioritized in national plans

This annex details the methodology followed for assessing the relative alignment of transport, energy, and digital infrastructure projects, which aim to support the traditional bioeconomy and enhance life quality for communities in the Amazon territories.

Data sources and projects analyzed

The review focused on government-led plans and national programs that detail infrastructure interventions across the three countries. The following sources were consulted:

- **For Brazil.** Growth Acceleration Program (PAC2, 2023), National Logistics Plan (PNL, 2030), Medium-Term Electricity Operation Plan (PAR/PEL), Electricity Transmission Concession Plan (2024), Integrated and Sustainable Amazon Program (PAIS, 2021), and technical publications by the Energy Research Company (EPE).
- **For Colombia.** Intermodal Transport Master Plan (PMTI 2051), River Master Plan (PMF, 2022), and Sustainable Amazonian Transport Plan (PATIS, 2024).
- **For Peru.** Master Plan for Logistics Infrastructure and Services (2032) and Amazon Fiber Optic Backbone Program (2022).

The projects analyzed were as follows:

- Transport projects
    - **Brazil.** Madeira river (Porto Velho–Manaus), Tapajós river (Mirituba–Santarém), BR-174 (Manaus–Boa Vista), BR-319 (Humaitá–Manaus), BR-364 (Vilhena–Porto Velho and AC section), BR-156 (Macapá–French Guiana), BR-230 (Mirituba–Medicilândia and Mirituba–Humaitá), PA-415/PA-256 (BR-010 to Port of Barcarena), and AM-176 (BR-319 to Novo Aripuanã).
    - **Colombia.** Putumayo River (Puerto Asís–Brazil).
    - **Peru.** Marañón river (Amazon–Porvenir), Huallaga river (Marañón–Yurimaguas), and Ucayali river (Amazon–Pucallpa).
- Energy projects
    - **Brazil (grid).** Roraima connection; Macapá supply reinforcement; Humaitá-Lábrea-Iranduba-Manacapuru grid extensions; supply to ports in Itacoatiara; and high-voltage networks in Medicilândia, Brasil Novo, Uruará, Placas, Vitória do Xingu, Anapu, Pacajá, Barcarena, Cametá, Limoeiro do Ajuru, Oeiras do Pará, Novo Repartimento, and Mocajuba.
    - **Brazil (off-grid).** Hybrid solar-biomass-battery plants near Boca do Acre, Muaná, Codajás, Tefé, Afuá, Lábrea, Autazes, and Beruri.
    - **Peru.** Iquitos grid connection and energy supply improvements in San Martín and Madre de Dios.
    - **Colombia.** Hybrid microgrids in isolated areas.
- Digital connectivity projects
    - **Brazil.** Infovía 02 (Tefé–Tabatinga), Infovía 03 (Macapá-Belém), Infovía 04 (Vila de Moura–Boa Vista), Infovía 05 (Itacoatiara–Porto Velho), Infovía 06 (Manacapuru–Rio Branco), Infovía 07 (Barcelos–São Gabriel da Cachoeira), and Infovía 08 (Juruá–Cruzeiro do Sul).
    - **Peru.** Ucayali fiber backbone.
    - **Colombia.** Putumayo fiber backbone.

Methodology

Each project was assessed based on the consolidated RICE approach, a framework used to prioritize projects by evaluating them across four dimensions: Reach, Impact, Confidence, and Effort. Reach estimates the potential magnitude of the beneficiaries of the initiative, while Impact measures how much each beneficiary's experience will improve. Confidence reflects how certain estimates are or how consolidated a project is, and Effort accounts for the technical and organizational viability to complete a project. RICE was implemented using a composite score by applying the formula Score = (A × ((B + C)/2) × D) / E:

- **Increase in territorial connectivity (A).** This criterion assesses the extent of each project's contribution to improving physical access and overcoming isolation in the Amazon. The untapped connectivity potential was rated *low*, *moderate*, or *high* based on a project's ability to reduce travel distances or connect previously isolated areas. It represents the Impact component of the RICE methodology.

- **Population benefited (B) and bioeconomy benefited (C).** A project's area of influence was calculated using a 75 km buffer along the planned or existing infrastructure corridor. Population density within this buffer was used to estimate the number of inhabitants potentially benefiting per kilometer of infrastructure. The volume of bioeconomy production (cacao, açaí, castanha, and pirarucu) within the 75 km buffer was also considered. This volume was calculated using regional production statistics from 2022. These two components represent the Results component of the RICE methodology.

- **Project maturity (D).** This criterion refers to a project's status within national and regional investment programs. Projects formally included in government-approved plans, under implementation, or with secured financing were scored higher than early-stage proposals. This component represents the Confidence component of the RICE methodology.

- **Environmental sensitivity (E).** Each project was analyzed in relation to the environmental characteristics of the territory it crossed. Territories were classified as *preserved forest, pressured forest, transformed,* and *urban*. Scores were higher if projects were set up in more fragile territories. The existence of protected natural areas or Indigenous lands in the project implementation area was also considered an additional environmental constraint and pushed up the environmental sensitivity score. This component represents the Effort component of the RICE methodology.

To operationalize the multicriteria method, each project was evaluated based on the criteria outlined above. For each project category—A, B, C, D, and E—project scores were normalized on a scale from 0 to 1, and then aggregated to produce a final score, reflecting the degree to which each project aligns with the bioeconomy objectives.

A5. Technology catalog and use cases

Table A5.1 Transport

Technology	Description
Electric boats	The electrification of small-scale vessels used by Amazonian communities is being accelerated via two types of propulsion systems: (1) **outboard electric motors** with power outputs ranging from **6 kilowatts (kW) to 20 kW**, and (2) **long-tail propulsion systems** ranging from **5 kW to 15 kW**. These systems are optimized for shallow, vegetation-dense river channels and are currently the most widely adopted form of e-mobility by riverine households in Brazil. Coupled with solar charging infrastructure, these technologies reduce fuel costs, improve navigability, and support economic resilience by enabling access to schools, clinics, and local markets.
Solar-powered ferries	Solar-electric catamarans, capable of transporting up to **100 passengers** with **2 crew**, are deployed on predefined short-haul river routes. Each vessel reduces emissions by approximately **770 kilograms (kg) of diesel per day**, providing both environmental and operational cost benefits. The integration of solar arrays with battery-electric propulsion supports full-day autonomous operation, and such systems have been co-developed with Indigenous governance structures to ensure community ownership and long-term sustainability. These systems directly target emission reduction goals and help decouple mobility from fossil fuel dependency in deforestation-prone river basins.
Solar cargo floating market platforms	High-capacity cargo rafts (balsas) with onboard cold chain systems are increasingly deployed to transport perishables such as fruits and frozen açaí pulp. A typical unit has a carrying capacity of **20 tons of fresh fruit** and **12 tons of frozen pulp**, supported by a hybrid energy system combining **solar panels, diesel generators, and B-box batteries**. These platforms operate across major tributaries of the Amazon river (e.g., Solimões, Japurá, Juruá, Purus, Madeira) and significantly reduce postharvest losses while facilitating decentralized trade flows.
Floating dock systems	Floating piers provide resilient port infrastructure that can adapt to river level fluctuations caused by seasonal droughts or climate anomalies. These structures are particularly critical for maintaining logistics continuity in high-variability environments. For example, flexible docking platforms such as the **Itacoatiara Floating Pier** mitigate disruption risks when major carriers (e.g., Maersk, CMA CGM) suspend operations due to insufficient draft near Manaus.
Amphibious aircraft (seaplanes)	Seaplanes use existing river transport infrastructure, bringing financial gains without the need for massive investment in airport infrastructure. Amphibious aircraft equipped for medical evacuation have conducted over 290 rescue missions in the Amazon in a one-year period , transporting over 200 patients and addressing critical health emergencies.

Table A5.2 Energy

Technology	Description
Digital substations	Digital energy substations are those with advanced electronic-based architecture that utilize the International Electrotechnical Commission's IEC 61850–based digital communication, replacing traditional analog signals with fiber-optic connections.This design integrates **intelligent electronic devices, merging units, and process/station buses** to perform real-time monitoring, protection, and control, and it boosts system reliability; reduces copper wiring; minimizes substation footprint; and enables automation, faster commissioning, and improved maintenance efficiency. New substations worldwide are designed with either full or partial digitalization elements.
Flexible alternating current transmission systems (FACTS)	FACTS are power electronics–based solutions that **enhance the controllability, stability, and efficiency of alternating current (AC) transmission networks**. They dynamically regulate voltage, impedance, and phase angle to optimize power flow, reduce losses, and improve grid stability. Key devices include **static VAR compensators (SVCs), static synchronous compensators (STATCOMs), thyristor-controlled series capacitors (TCSCs), and unified power flow controllers (UPFCs)**, each serving specific functions like reactive power compensation and line impedance control. FACTS support higher transmission capacity and renewable integration without new lines, working well with digital substations.
Subaquatic high-voltage transmission	Subaquatic high-voltage transmission lines are **underwater cables designed to carry electricity across rivers or other water bodies**, connecting power grids where overhead lines are impractical or environmentally sensitive. These systems typically employ high-voltage alternating current or high-voltage direct current technologies, with cables insulated and laid on or beneath the riverbed to ensure safety and reliability. Such solutions are **already used in the Amazon**: Iranduba and Manacapuru are connected to Manaus through a 69 kV subaquatic line; also, as the Marajó Island is connected to Barcarena through underwater cables.
Hybrid solar-battery energy systems	The combination of photovoltaic (PV) generation with energy storage aims to enhance reliability, flexibility, and energy autonomy. Solar panels generate electricity, which can be stored in batteries for use during low irradiance, even at night, or peak demand. These systems enable **load shifting, peak shaving, and backup power** and can operate in both grid-connected and off-grid modes. Advanced inverters manage energy flow between PV, storage, loads, and the grid, optimizing performance and resilience. Solar-battery hybrid systems are the most common solution for microscale, single-consumer, isolated energy installations across the Amazon, with programs such as Luz Para Todos (these installations are called Sistema Individual de Geração de Energia Elétrica com Fonte Intermitente [SIGFI]) in Brazil and Programa Masivo Fotovoltaico in Peru. Peru also has a several private sector initiatives, notably related to Novum Solar (https://novumsolar.com/soluciones/microrredes).
Floating photovoltaic (FPV) energy plants	FPV plants are **solar systems installed on water bodies like reservoirs, lakes, or dams**. They offer key advantages over ground-mounted systems: they preserve land for other uses, reduce water evaporation, and benefit from lower panel temperatures due to water cooling, which improves efficiency. FPVs are ideal for regions with limited land, high land costs, or high environmental sensibility on land and can be co-located with hydroelectric plants to share infrastructure and boost energy output stability. Recently, FPV pilot projects were announced by the Brazilian government for the reservoirs of the Balbina hydroelectric power plant Balbina, Amazonas.
Biomass energy plants from bioeconomic residues	Through combustion, gasification, or anaerobic digestion, these **residues are converted into usable energy**. This approach adds value to local bioeconomy chains, reduces waste, lowers emissions, and supports distributed, renewable generation, especially in rural or agro-industrial regions with abundant biomass availability. The use of açaí seeds as a biomass energy source in the Amazon is already underway by the private sector, including by Coca-Cola and Votorantim. Larger-scale applications for açaí residues are the object of research by local universities such as Universidade Federal do Pará; preliminary findings point to a **potential 160 megawatts of energy per million tons of açaí**, providing a relevant secondary source of income to producers and communities if such potential is further developed.

Technology	Description
Micro-hydropower plants	Micro-hydropower plants generate electricity from small-scale water flows, typically under 100 kW, using **turbines or water wheels**. Advantages include low operating costs, long system lifespan, minimal environmental impact, and stable, continuous energy generation; they are ideal for rural or off-grid areas with consistent water sources, and their use worldwide predates nearly all other energy generation technologies. When **integrated with other sources in hybrid systems**, micro-hydro enhances reliability and reduces dependence on fossil fuels or intermittent renewables such as solar.
Multi source energy plants	A multisource energy system integrates diverse generation sources, such as **solar PV, biomass, diesel generators, and battery storage**, to ensure continuous, reliable, and efficient power supply. By combining intermittent renewables with dispatchable sources and storage, these hybrid systems optimize energy availability, reduce fuel dependency, and lower emissions. Advantages include improved resilience, reduced operational costs, flexible load management, and the ability to adapt to variable resource availability, especially in isolated or off-grid regions. Colombia's government agency Instituto de Planificación y Promoción de Soluciones Energéticas (IPSE) is developing a pilot multisource project in the Indigenous community of Papayó, Chocó, combining solar, hydro, sugarcane biomass, and diesel to provide energy to 146 families.
Grid-forming inverters and batteries	The traditionally used grid-following inverters rely on an existing grid signal and cannot operate in stand-alone mode. Grid-forming inverters, however, actively **establish and regulate voltage and frequency**, allowing them to operate independently of an external grid. When **paired with batteries**, they provide stable power, enable black start capability, and support microgrids or weak grids dominated by renewables, effectively eliminating the need for synchronous machines (mechanical generators) to establish a power grid.
Community energy hubs	Community energy hubs are **decentralized centers that combine renewable energy generation** (usually solar and batteries) and **digital services** to support local development. They provide reliable electricity, internet access, education, health care, and training, especially in remote or underserved areas. A key example is Dell's Solar Community Hubs in the Amazon, built from solar-powered shipping containers.
Microgrids	Energy microgrids are localized power systems that can operate **independently or in coordination with the main grid** in order to distribute energy to more than one consumer. They integrate various energy sources, such as solar, hydro, wind, biomass, diesel, and batteries, to supply electricity to a defined area, like a community or facility. Microgrids are already used for **collective energy needs in government programs** such as Luz Para Todos (called Microssistema Isolado de Geração e Distribuição de Energia Elétrica [MIGDI]) in Brazil and Comunidades Energéticas in Colombia.
Smart grids	Smart grids are modernized electrical networks that use digital technologies, sensors, and automated controls to **monitor and manage electricity flows in real time**. They enable two-way communication between utilities and consumers; improve grid efficiency, reliability, and flexibility, and support the integration of distributed energy resources like solar, wind, and batteries. Smart grids also enhance fault detection, demand response, and energy forecasting, making the power system more resilient and sustainable.
Real-time automatic meter reading (AMR)	Real-time AMR systems enable the **remote collection of energy consumption data** from meters using communication technologies such as **radio, power-line communication, or cellular networks**. Unlike manual or periodic readings, real-time AMR provides continuous monitoring, allowing utilities to detect anomalies, manage loads, and bill accurately. It enhances operational efficiency, reduces human error, supports demand response, and enables faster detection of outages or energy theft, being a key component to smart grids and the digitalization of billing.

Using industrial bioenergy hubs to expand community energy access and drive sustainable development

It is important to shift away from small-scale, household-only electrification efforts by leveraging regional industrial plants—particularly those focused on processing bioeconomy products—as central sources for both energy generation and community development. By combining renewable energy from sources like biomass, solar, and batteries, these industrial hubs can cover their own power needs and actively supply surplus electricity to surrounding communities. This approach aims to create a sustainable, reliable, and affordable energy ecosystem that anchors local economic growth and improves livelihoods across the region.

A comprehensive set of measures is needed to leverage the Amazon's bioeconomy potential while expanding energy access and supporting local development. This includes identifying priority locations where bioeconomy industrial clusters—such as açaí, fish processing, and also timber and sustainable livestock—can be combined with renewable, decentralized energy systems. At the facility level, projects should focus on designing hybrid energy systems that use biomass residues (e.g., bark, husks, waste oil, and fish by-products) as fuel, complemented by solar PV, battery storage, and efficient diesel for backup. To attract investment, public-private financing mechanisms will be essential to incentivize industrial operators to oversize generation capacity and supply surplus power to nearby communities through local grids or isolated microgrids. In parallel, governments and development partners should scale up successful regional pilots—such as açaí processing plants using biomass gasification—by integrating them into larger public programs supported by concessional funds and climate finance.

For these efforts to be sustainable and socially impactful, complementary policies and safeguards must be in place. Regulatory reforms should simplify licensing and feed-in processes for distributed generation, making it easier for industrial producers to supply neighboring areas. To avoid creating incentives for deforestation through biomass use, robust monitoring systems are needed. Finally, expanding energy access should go hand in hand with social infrastructure investments, to ensure increased electrification brings real improvements in education, health care, digital connectivity, and economic opportunities for local populations.

Table A5.3 Digital

Technology	Description
Satellite-to-cell connectivity	Satellite-to-cell technology enables direct communication between satellites in low Earth orbit (LEO) and standard mobile phones, bypassing the need for ground-based infrastructure in remote areas. Systems such as LEO satellite constellations can deliver **speeds up to 220 Mbps**. Integration with terrestrial networks enables hybrid 4G/5G expansion via satellite backhaul, reducing dependence on fiber and supporting fast deployment in hard-to-reach locations. Medium Earth orbit (MEO) and geostationary orbit (GEO) satellites offer wider coverage but incur higher latency, making them better suited for less-time-sensitive applications.
Fixed wireless access (FWA)	FWA uses dedicated radio frequencies (e.g., 2.4 gigahertz [GHz], 5 GHz, 60 GHz) to provide broadband internet over short-to-medium distances. It is particularly effective in peri-urban or forest-fringe zones where fiber deployment is cost prohibitive. FWA systems offer **high throughput with moderate latency**, and their performance depends on line-of-sight conditions and backhaul capacity. They can be deployed quickly and scaled modularly, supporting both household and institutional connectivity.
TV white space (TVWS)	TVWS technology exploits unused television broadcast spectrum (typically **470–698 megahertz [MHz]**) to deliver long-range wireless internet. It is low cost, low bandwidth, and ideal for sparsely populated rural regions. The extended range and good foliage penetration allow deployment in forested terrain without extensive antenna infrastructure. TVWS has been used successfully in Sub-Saharan Africa and Latin America as an affordable solution for community networks and digital inclusion.
Aerial remote sensing (drones)	Unmanned aerial vehicles are used for high-resolution environmental data acquisition. Professional-grade drones, which can fly for 3.3 hours on the on-board battery and 2.7 hours on external power, can transport **payloads up to 30 kilograms** over distances of **16 km at 70 km/hou**r, with **flight duration of 3.3 hours (internal battery) and 2.7 hours (external)**. Charging requires **USB-C input with** capacity of **65 watts or more**. Drones equipped with red, green, and blue **(RGB); multispectral; and light detection and ranging (LiDAR) sensors** enable accurate orthomosaics, forest health assessments, and land-use monitoring. These technologies support precision mapping, reforestation planning, and environmental accountability in conservation projects.
Open digital mapping platforms	Open-source mapping hubs compile geospatial data on built infrastructure and environmental assets across the Amazon Basin. These platforms facilitate **emergency planning, deforestation monitoring,** and **resource allocation** by aggregating citizen-contributed and institutional data sets. By engaging local mappers, these tools enhance spatial literacy and governance capacity while supporting initiatives such as sustainable land management and protected area surveillance. For instance, Amazon Mapping is an initiative of the Open Mapping Hub of Latin America and the Caribbean that seeks to map built elements and environmental conditions in the Amazon, facilitating emergency management and sustainable forest management.
Underwater fiber-optic connectivity	Subfluvial fiber networks provide high-capacity, low-latency internet to remote Amazonian towns by following riverbeds. Recent deployments have connected municipalities such as Leticia (Colombia), Tabatinga (Brazil), and Iquitos (Peru), enabling service to over **400 communities**. These systems bridge the digital divide by offering urban-grade connectivity to otherwise isolated regions, supporting telemedicine, e-learning, and e-government applications with reliable bandwidth.
Satellite-based environmental monitoring	High-resolution Earth observation satellites combined with **artificial intelligence–driven change detection algorithms** enable near-real-time deforestation alerts. Systems use both **optical and radar imaging** to detect canopy loss and land cover changes under cloud cover. Platforms such as Planet Labs or Global Forest Watch are already integrated into regional conservation strategies, providing governments and nongovernmental organizations with **daily monitoring capabilities and predictive analytics** to anticipate illegal activity and ecosystem degradation.

Table A5.4 Bioeconomy production

Technology	Description
Circular waste management	Integrated circular economy models in bioeconomy production focus on minimizing waste and maximizing resource recovery, particularly from nontimber forest products like açaí. Açaí production chains exemplify this model, transforming not only fruit pulp but also seeds, peels, and processing residues into cosmetics, fertilizers, and bioenergy, reducing pressure on primary forest resources while supporting local livelihoods.
E-commerce in bioeconomy	E-commerce platforms and digital marketplaces facilitate the commercialization of Amazon-based bioproducts—ranging from natural cosmetics to medicinal plants and agroforestry produce—by strengthening the **market access, product development,** and **investment readiness** of small-scale producers. These systems include **capacity building in sustainability**, traceability, and product standardization, and often include on field assessments (e.g., market mapping studies) to identify **high-potential bio-businesses** across multiple countries. They serve as critical scaling tools to move from subsistence production to commercially viable green value chains. The Rainforest Alliance, in partnership with Inter-American Development Bank, is leading the first phase of the Amazon Bioeconomy Marketplace initiative to support sustainable bio-businesses in the Amazon.
Modular açaí processing facilities	Industrial-scale pulp extraction systems with capacities exceeding **5 tons/hour**, powered by **50 kW electrical systems**, can be deployed in a **20x30 meter footprint**. These modular facilities are designed for **semi-industrial rural settings**, allowing upstream processing closer to harvest sites, which reduces product deterioration and increases local value retention. However, due to stringent sanitation requirements from downstream buyers, there is a growing preference for decentralized pulp processing to ensure quality and traceability.
Blockchain-based ethical supply chain certification	Distributed ledger technologies such as **blockchain** are applied to certify and trace products like timber, fruits, or minerals from source to consumer, ensuring compliance with deforestation-free and fair-trade standards. These systems record immutable data on origin, handling, and environmental impact, enabling companies to verify that their supply chains are not contributing to illegal deforestation or social exploitation. Blockchain-based certification is increasingly required for export markets and environmental, social, and governance reporting.
Bioeconomy technology transfer and mini-factory installations	Hybrid models integrating **local knowledge systems** with **digital fabrication and processing technologies** aim to boost **community-level value addition**. These “laboratory-factory” prototypes are equipped for small-scale processing of oils, resins, fibers, and food products, tailored for biodiversity-rich contexts. Initial deployments require minimal grid access and emphasize **training and technology transfer**, often run through mobile or relocatable units. These models are critical for scaling bioeconomy entrepreneurship while preserving ecological integrity and cultural traditions.

A6. Econometric model for value chain projections

The growth of municipal gross domestic product (GDP) for each producing municipality (encompassing over 350 municipalities) was estimated using individual econometric regression models with a trend component for each municipality. These models were developed using the ordinary least squares (OLS) method and relied on historical data published by IBGE for the period 2010–21. The standard classical model applied is presented below:

$$GDP_i = a + b.TREND$$

Where:

- GDP_i represents the gross domestic product of municipality **i**,
- **a** is the estimated constant,
- **b** is the estimated coefficient, and
- **TREND** refers to the annual trend (e.g., 1, 2, 3…).

All monetary values were adjusted for inflation using the General Price Index – Internal Availability (a.k.a. 'IGP-DI'), calculated by the Fundação Getulio Vargas.

Using the parameters derived from the regression models for each municipality, annual GDP projections were generated for the period 2022–50. These projected GDP values were subsequently incorporated into the gravitational model each year, along with projected production data. This integrated approach enabled the simulation of product flows and, consequently, the projection of demand for bioeconomy products.

Scenario development

The analysis of intermunicipal trade flows for bioeconomic products in the Legal Amazon region explores three distinct scenarios to project growth trajectories from 2022 to 2050: tendential, optimistic, and pessimistic. These scenarios are simulated using a gravitational model and focus on aggregated flows across key value chains.

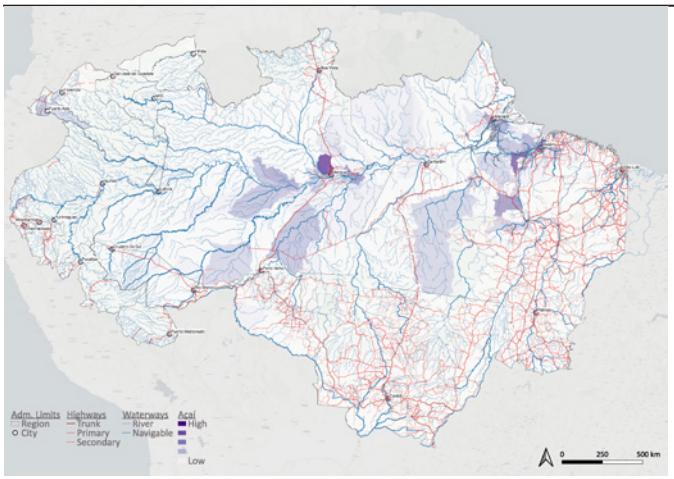
It should be noted that among the bioeconomy value chains—wild-harvested açaí, Brazil nuts, pirarucu, and cocoa—the greatest projected growth across all scenarios involves pirarucu and cocoa. In the case of pirarucu, growth is assumed to rely primarily on aquaculture expansion, given that its wild fishing activities are strictly regulated by the Brazilian Institute of Environment (IBAMA) to prevent overexploitation of the species (Normative Instruction No. 34, issued on June 18, 2004, by IBAMA establishing general regulations for pirarucu fishing (*Arapaima gigas*) in the Amazon River Basin).

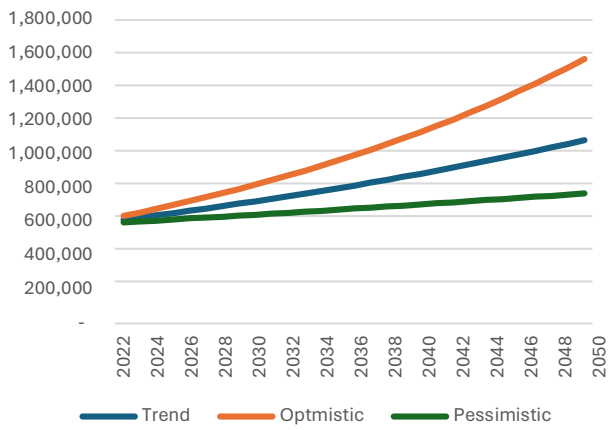
For cocoa, projected growth is driven both by its cultivation method and rising international demand favoring South American cocoa over African cocoa. In Pará—the largest cocoa-producing state in Brazil—production, although based on a native species, is primarily achieved through new plantations established in previously deforested areas. This practice has allowed cocoa production in Pará to steadily increase over recent years, surpassing traditional Brazilian cocoa-growing regions such as the state of Bahia. According to an interview with Gencau, a manufacturer of cocoa-derived products, this heightened demand stems from a strategic shift among major global chocolate producers, who are increasingly sourcing cocoa from South America rather than Africa noting South Africa's greater institutional stability.

Table A6.1 Scenario values for total flows (demand) of harvested açaí and cocoa

Production	Flows

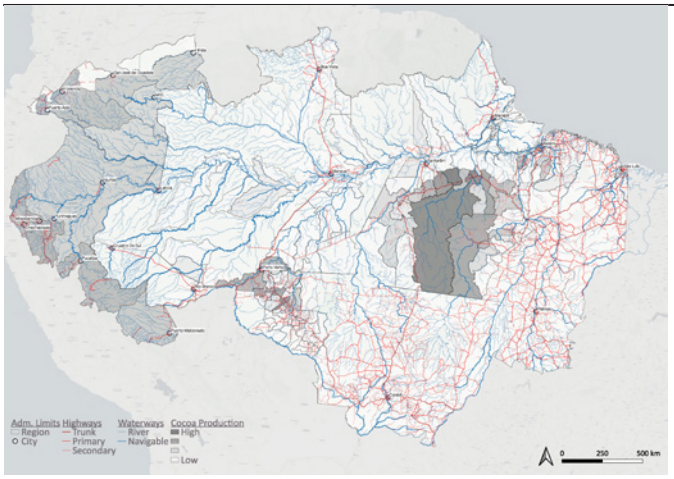
Açaí

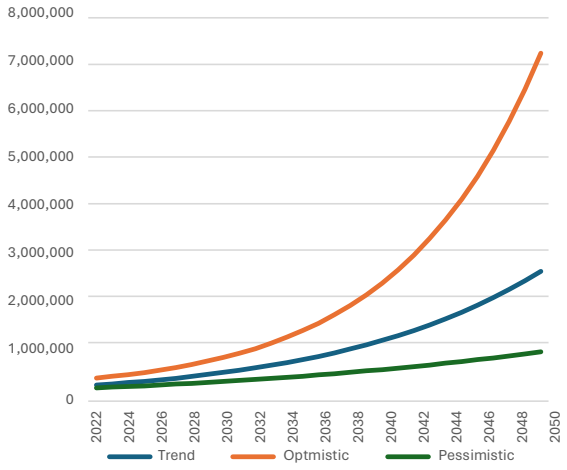




Scenario	Initial volume (2022) (tons)	Final volume (2050) (tons)	Average growth rate	Comparison to tendential
Tendential	601,361	1,087,384	2.25%	Baseline
Optimistic	609,010	1,568,834	3.27%	+44%
Pessimistic	594,299	772,016	0.95%	−29%

Cocoa





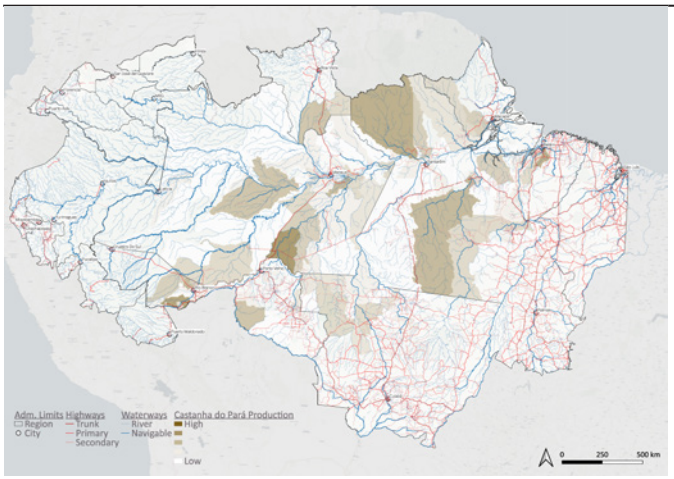
Scenario	Initial volume (2022) (tons)	Final volume (2050) (tons)	Average growth rate	Comparison to tendential
Tendential	260,365	2,708,634	7.29%	Baseline
Optimistic	264,481	7,261,253	10.06%	+168%
Pessimistic	251,824	1,029,705	4.37%	−62%

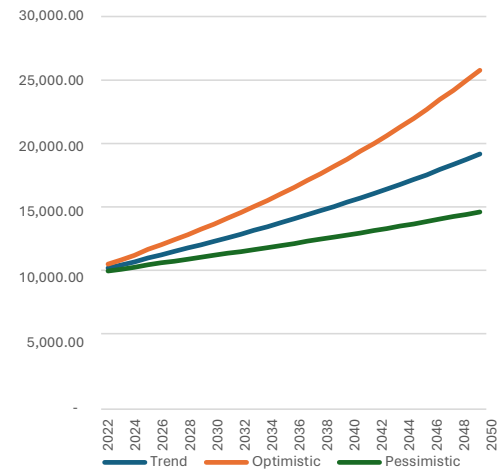
Source: Original compilation.

Table A6.2. Scenario values for total flows (demand) of Brazil nuts and pirarucú

Production	Flows

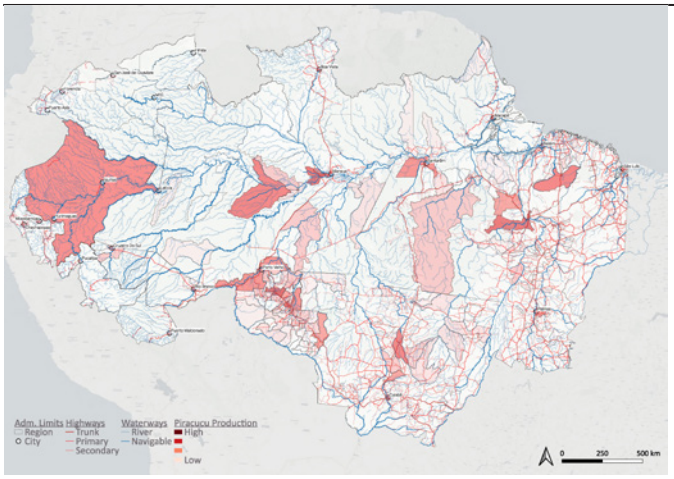
Brazil Nuts

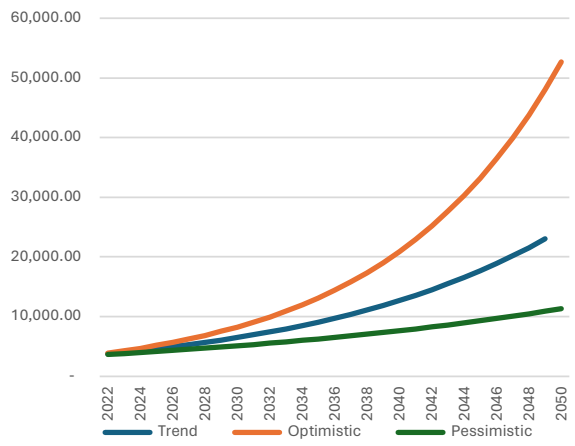




Scenario	Initial volume (2022) (tons)	Final volume (2050) (tons)	Average growth rate	Comparison to tendential
Tendential	10,504	19,495	2.03%	Baseline
Optimistic	10,607	25,892	3.44%	+33%
Pessimistic	10,411	15,065	1.23%	-23%

Pirarucu





Scenario	Initial volume (2022) (tons)	Final volume (2050) (tons)	Average growth rate	Comparison to tendential
Tendential	3,674	24,623	6.68%	Baseline
Optimistic	3,874	52,677	9.42%	+114%
Pessimistic	3,224	11,340	3.96%	-46%

Source: Original compilation.

A7. Legal and regulatory review

Brazil

Brazil's environmental legislation is among the most comprehensive globally. It includes mechanisms for protecting the environment and mitigating deforestation. The Forest Code mandates land use requirements for private rural properties, mandates maintaining a Legal Reserve and Permanent Preservation Areas, and introduced the Rural Environmental Registry to monitor compliance with environmental regulations. The National Environmental Policy lays the foundation for managing the environment. It established principles of sustainable development and created the National Environmental System to coordinate policies across federal, state, and municipal levels. *Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis* (IBAMA)[48] and *Instituto Chico Mendes de Conservação da Biodiversidade* (ICMBio)[49] enforce these regulations federally, while local agencies handle implementation. The National Water Policy introduces watershed-based governance. Water is recognized as a public good, and a system of charging for water use encourages conservation. The National System of Conservation Units provides a legal framework for creating and managing conservation units, facilitating biodiversity conservation and sustainable resource use. The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon addresses deforestation drivers and impacts and supports the coordination of government actions across multiple sectors.

Brazil's energy sector is a key player in the global energy transition. A significant portion of its electricity matrix is renewables based. Hydropower, wind, and biomass are the largest renewable sources in Brazil, while natural gas, oil, and coal constitute the nonrenewable segment. Brazil's hydropower potential is among the largest globally. Hydropower developments are classified into three types based on energy generation capacity. Strategic policies and programs, such as *Programa de Conservação de Eletricidade* (Procel) and *Programa de Incentivo a Fontes Alternativas de Energia Elétrica* (Proinfa), promote energy efficiency and the use of alternative energy sources. Procel aims to combat electricity waste, while Proinfa increases the share of renewable sources in electricity production. The program has facilitated the commissioning of numerous projects, significantly reducing greenhouse

48 IBAMA handles licensing for activities with significant environmental impact at the regional or international level, while state and municipal environmental agencies handle licensing for activities with local impacts.

49 ICMBio's instructions ensure federally protected ecosystems and species are conserved.

gas emissions. Tariff reductions for using grid electricity have promoted renewables-based energy generation, helping solar and wind power to grow exponentially in the electricity matrix. The National Interconnected System links regions through a network of transmission lines that meet almost 99 percent of Brazil's electricity demand.

Despite comprehensive legal structures, effective implementation of environmental protection and mitigation of deforestation continue to face challenges. The reliance on hydropower for energy presents both opportunities and challenges. Brazil's strategic policies aim to expand renewable energy sources, modernize the electricity sector, and fulfill international climate commitments, but factors such as political will, economic interests, and enforcement limitations hinder progress. Stronger governance, adequate funding of enforcement agencies, and more transparent environmental policies are crucial for improving compliance and advancing Brazil's environmental and energy goals.

Environmental protection in Brazil is a shared responsibility. The federal government sets the general guidelines, which states and municipalities supplement with local regulations. Entities within the national environmental system (*Sistema nacional do meio ambiente*, SISNAMA) manage the environmental licensing process. IBAMA oversees significant regional or international impacts, and state and municipal agencies handle local impacts. This structure ensures national oversight while preserving local autonomy, enabling tailored responses to environmental and infrastructure challenges across Brazil. While efforts have been made to build climate resilience, their overall effectiveness is impacted given enforcement and policy stability continue to be significantly inadequate. Resilience improvement requires stronger governance, clearer policy commitments, and the integration of climate adaptation into development strategies.

Brazil's climate legislation incorporates resilience measures through different frameworks and policies that have national and subnational adaptation and mitigation as the objective. States are empowered to develop their own policies. The National Policy on Climate Change (*Política Nacional sobre Mudança do Clima*, PNMC) provides a foundational legal structure for integrating climate resilience into development plans, promoting low-carbon technologies and sustainable practices. However, enforcement gaps and the absence of binding commitments weaken the policy's effectiveness. The National Water Resources Policy complements these efforts by emphasizing sustainable water management, though challenges like pollution and regional disparities persist. The National Green Growth Program seeks to align economic growth with environmental sustainability but lacks enforcement mechanisms. Federal Decree No. 11,550/2023 established the Interministerial Committee on Climate Change to coordinate national policies, yet its success hinges on political will and interministerial cooperation. The Brazilian Greenhouse Gas Emissions Trading System, introduced by Federal Law No. 15,042/2024, aims to reduce emissions through a regulated carbon market, though effective monitoring and integration with existing policies remain

crucial. In the road transportation sector, guidelines for highway concession contracts promote resilient infrastructure and emission mitigation but apply to new projects only. The electricity sector faces challenges from climate impacts, necessitating investment in resilient infrastructure and renewable energy diversification. Despite legislative advancements, Brazil struggles with inconsistent enforcement, regulatory instability, and limited integration of resilience measures. Stronger governance and continuous investment are needed to effectively address the impacts of climate change.

Brazil needs investment and to leverage private sector expertise to meet its infrastructure needs. For this, it can use concessions, public-private partnerships (PPPs), and contracts for general work and services. Legal and financial mechanisms, such as guarantees and performance bonds, protect investments and ensure continuity of projects. The Brazilian Public Procurement and Administrative Contracts Law and the Concessions Law support effective risk allocation and performance guarantees, giving private investors confidence. However, political and economic instability, along with the unique conditions of the Amazon biome, can affect that confidence. Governance practices and legal security must be enhanced continuously. Advancing Brazil's infrastructure and environmental goals requires more robust cooperation between regulatory and environmental agencies, promoting public participation in infrastructure projects, and developing specific policies for climate resilience and environmental sustainability.

Colombia

Colombia has comprehensive legislation for protecting the environment and mitigating deforestation. Environmental considerations are integrated into economic activities through its constitution and various laws. Key legislation in this regard includes Law 99 of 1993, which established the Ministry of Environment and mechanisms for Environmental Regulation, and the Forest Law, which designates forest reserves and promotes sustainable forest management. The National System of Protected Areas (*Sistema Nacional de Áreas Protegidas,* SINAP) and Decree 622 of 1977 further protect biodiversity and regulate national parks. Law 165 of 1994 ratified the Convention on Biological Diversity, while Decree 2811 of 1974 sets guidelines for sustainable resource use. The National Council for Economic and Social Policy (*Consejo Nacional de Política Económica y Social,* CONPES) and the National Development Plan (*Plan Nacional de Desarrollo,* PND) integrate environmental sustainability into economic planning. Indigenous communities are protected through prior consultation rights, ensuring their involvement in decisions affecting their lands. Despite these frameworks, challenges such as weak enforcement, illegal activities, and land tenure issues hinder effective implementation.

Colombia's environmental licensing process, regulated by Decree 2041 of 2014 and overseen by *Autoridad Nacional de Licencias Ambientales* (ANLA) and *Corporaciones Autonomas Regionales* (CARs),[50] ensures projects undergo thorough environmental assessments. Decree 1076 of 2015 consolidates environmental regulations, promoting sustainable practices and compliance. Projects must include environmental impact assessments for evaluating potential impacts and involve public participation to ensure accountability. Colombia's climate change legislation, notably Law 1931 of 2018, aligns with international commitments like the Paris Agreement. It established the National Climate Change System (Sistema Nacional de Cambio Climático, SISCLIMA) to coordinate mitigation efforts. The Amazon Vision Program and the National Plan for the Integral Management of the Amazon focus on mitigating deforestation and promoting sustainable development in the Amazon. However, Colombia's forests are threatened by, among other challenges, illegal logging, mining, and infrastructure projects, highlighting a need for stronger enforcement, resource allocation, and integration of ecological considerations into development planning.

Colombia's approach to climate resilience is integral to its strategy for addressing the impacts of climate change, including extreme weather, shifting precipitation patterns, and rising temperatures. The country has embedded climate resilience into its legislation through key instruments like Law 1931 of 2018, the National Climate Change Policy (La Política Nacional de Cambio Climático, PNCC), Nationally Determined Contributions (NDCs), and Decree 1076 of 2015, which emphasize including climate resilience in national planning and development strategies, especially for infrastructure projects. The PNCC, with support of the SISCLIMA, coordinates resilience measures across sectors, ensuring sustainable development and effective adaptation strategies. The NDCs set ambitious emission reduction targets and outline sector-specific actions to achieve low-carbon transition, boost ecosystem resilience, and improve water management. Financial mechanisms and capacity-building initiatives support these efforts, while monitoring and evaluation ensure accountability and inform policy decisions. However, implementation and enforcement remain inadequate, requiring enhanced technical capacity, coordination, and financial resources. Public participation and transparency are encouraged, for inclusiveness and to empower local communities to plan for climate resilience.

The transformation of the National Institute of Concessions into the National Infrastructure Agency (*Agencia Nacional de Infraestructura,* ANI) through Decree 4165 of 2011 marks significant institutional advancements in Colombia's infrastructure sector. This transformation endowed ANI with enhanced technical capabilities to structure projects and concession agreements under international standards, thereby professionalizing the management of infrastructure projects. This institutional strengthening was crucial for attracting both domestic and international investors, ensuring their investments are managed

50 ANLA is Colombia's national authority for granting environmental licenses. It specifically deals with large-scale projects. *Corporaciones Autónomas Regionales* are regional bodies responsible for smaller projects and sustainable development. They operate with administrative autonomy. Both agencies ensure environmental compliance.

through clear, fair, and competently structured contracts. The enactment of Law 1508 of 2012, known as the PPP Law, further bolstered infrastructure development by providing a comprehensive framework for PPP projects. Recognized internationally for its robustness, this law supported the development of ambitious road concessions specifically for improving Colombia's transportation infrastructure.

Further legislative advancements, including Laws 1682 of 2013 and 1882 of 2018, collectively known as the infrastructure laws, address critical aspects that have historically hindered infrastructure projects in Colombia. These laws create a more predictable investment environment by streamlining administrative processes, in turn reducing bureaucratic delays and accelerating project implementation. The PND for 2022–26 emphasizes infrastructure as a key driver of economic growth, social equity, and environmental sustainability, aiming to improve connectivity through integrated regional and national planning frameworks. Nevertheless, challenges persist, for example, a need for innovative financing mechanisms and improved governance. The Fifth Generation (5G) of concessions aims to address these challenges by promoting sustainable and resilient infrastructure development. Environmental regulations, including Decrees 1076 of 2015 and 2041 of 2014, ensure projects proceed efficiently while respecting the environment, considering the community, and reducing risks of conflict. Overcoming implementation challenges and ensuring effective legislative support for sustainable infrastructure development in Colombia require enhanced institutional capacity, greater transparency, and better interagency coordination.

Building on its experience in road projects, Colombia published the "Guidelines for Green Road Infrastructure in Colombia" in 2022 and the "Tertiary Roads Environmental Management Guide" in 2023 (Ministry of Environment and Sustainable Development 2020). These documents provide practical guidance for sustainable and resilient road development. The Guidelines for Green Road Infrastructure in Colombia (*Lineamientos de Infraestructura Verde Vial,* LIVV) was collaboratively developed by different ministries and organizations. It offers technical guidance for sustainable transport infrastructure. The guidelines aim to integrate environmental, social, and technological elements into road projects to mitigate adverse impacts and promote biodiversity conservation. These guidelines were distributed to relevant agencies and governorates to improve environmental management and planning in road infrastructure projects. Complementing these guidelines, the Environmental Management Guide for Tertiary Roads serves as a reference for planning and executing environmental management in third-order road projects. It assists in early identification of legal, technical, environmental, and social requirements; estimating costs and timelines; and implementing environmental management measures. The guide includes public policy guidelines, legal frameworks, and instructions for identifying environmental impacts and project influence areas. It features a cartographic tool for assessing environmental sensitivity and alerts for protected areas and ethnic territories. The guide focuses on existing road interventions, mandating environmental licenses for new constructions, and it offers recommendations for dismantling roads that threaten environmental conservation.

Peru

Peru's environmental legislation is comprehensive, promoting environmental protection across all activities carried out by individuals, companies, and the state. The 1993 Constitution guarantees the right to a balanced environment. It is supported by the General Environment Law, Law No. 28611, which ensures continuous environmental management to enhance quality of life and improve sustainable development. The National Environmental Policy for 2030, specifically addresses loss of ecosystem services due to loss of biodiversity, pollution, and deforestation, and outlines actions for government entities, the private sector, and civil society to address environmental challenges. Its objectives are reducing biodiversity loss, deforestation, and pollution, and improving waste management, and it aims to reduce ecosystem fragility, conserve biodiversity, and recover ecosystem services. Protected Natural Areas (*Áreas Naturales Protegidas,* ANP) are a key conservation tool, governed by Law No. 26834. Protected areas are categorized into national, regional, and privately administered units to conserve biodiversity and support sustainable development. Each ANP has a master plan, developed through participatory processes, to guide management and resource use. Under the National System of Environmental Impact Assessment (*Sistema de Evaluación de Impacto Ambiental,* SEIA), projects must have environmental certification and measures to prevent environmental damage. Regulations specific for the transport, communications, and energy sectors further support environmental management, with supervision and sanctioning mechanisms ensuring compliance.

Peru's legal framework requires regional and local policies to align with national directives, even though regional governments have autonomy within their geographical boundaries. Regulatory and autonomous entities operate independently, chiefly managing supervision and planning. Key ministries, such as Economy and Finance, Energy and Mines, Transport and Communications, Environment, and Development and Social Inclusion, play crucial roles in promoting sustainable infrastructure and development. Additionally, specialized bodies like the National Infrastructure Authority, sectoral supervisory agencies, and the National Center for Strategic Planning contribute to strategic planning and oversight, ensuring environmental, social, and economic sustainability. The National Service of Natural Protected Areas and the National Forest and Wildlife Service specifically work on conservation and the sustainable development of natural resources. These institutions work collectively to address infrastructure gaps and promote investment in less developed regions of Peru, thereby improving quality of life and fostering sustainable growth nationwide.

Peru has a legal framework regulating forest resource access and management, under which activities impacting forests are supervised and brought under sanctions, with environmental offenses penalized according to the country's criminal code. Indigenous peoples in Peru, defined by their descent from precolonial populations and self-identification, have distinct legal regimes and the right to prior consultation under Convention 169 of the International Labor Organization. They must be included in decision-making processes for

measures affecting their rights. Indigenous Peoples in Isolation and Initial Contact (*Pueblos Indígenas en Aislamiento y Contacto Inicial,* PIACI) live in remote jungle areas, protected by Law No. 28736, which establishes Indigenous reserves to safeguard their rights and habitat. These reserves are intangible, prohibiting settlements other than those of the Indigenous inhabitants. Peru's approach to Indigenous rights and environmental protection reflects a commitment to sustainable development, balancing conservation with the needs of local communities and ecosystems.

Peru, highly vulnerable to climate change due to its unique geographical, ecological, and social characteristics, actively participates in international climate efforts, as demonstrated by its commitment to the United Nations Framework Convention on Climate Change. The country has developed a robust institutional regulatory framework, highlighted by the National Strategy for Climate Change, which guides state actions toward adaptation, resilience, and carbon neutrality, and emphasizes sectoral adaptation and greenhouse gas reduction. The framework is implemented by sector authorities, regional governments, and municipalities. The Framework Law on Climate Change, Law No. 30754, further articulates public policies for managing climate change adaptation and mitigation, aiming to reduce vulnerability and leverage low-carbon growth opportunities. The Ministry of Environment leads this effort, coordinating with various stakeholders, including Indigenous peoples, to integrate climate change measures into public and private investments. The legislation promotes the use of international climate funds, access to information, citizen participation, and the inclusion of climate change topics in education, fostering research and innovation while valuing Indigenous knowledge.


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