ITUPublications

International Telecommunication Union

Standardization Sector

ITU Focus Group Technical Report

(10/2025)

ITU Focus Group cost models for affordable data services

Supply chain of telecom/ICT infrastructure related to international internet connectivity costs enabling affordable data services, integrating the analysis of policy, economic, competition, regulatory, standardization and sustainability aspects

Working Group 2: International Internet Connectivity Cost

PREPUBLISHED

Version

Technical report on supply chain of telecom/ICT infrastructure related to international internet connectivity costs enabling affordable data services, integrating the analysis of policy, economic, competition, regulatory, standardization and sustainability aspects

Summary

This technical report identifies and analyzes the various layers and components that make up the Internet value chain. It examines the supply chain of telecom and ICT infrastructure with the aim of establishing a clear terminology and taxonomy linked to cost models for affordable data services. The report also integrates analysis of policy, economic, competition, regulatory, standardization, and sustainability aspects of international internet connectivity costs, providing a comprehensive perspective on both technical cost drivers and governance frameworks that shape affordability.

Keywords

Supply chain of telecom/ICT infrastructure, International Internet Connectivity Cost, competition, national backbone, interconnection and exchange infrastructure, infrastructure sharing, metro and middle mile networks, last mile access network,

Note

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Change Log

This document contains Version 1.0 of the ITU-T *Technical Report on supply chain of telecom/ICT infrastructure related to international internet connectivity costs enabling affordable data services, integrating the analysis of policy, economic, competition, regulatory, standardization and sustainability aspects* approved at the FG CD Meeting held online on 1 October 2025.

Acknowledgements

This Technical Report was written by the Editors below based on input documents received at the FG CD meetings, as a contribution to the ITU Focus Group on cost models for affordable data services (FG CD). If you would like to provide any additional information, please contact Vijay Mauree at tsbfgcd@itu.int

Editor:	Sathish Kumar MC India	**Tel:** +91-9444044400 **Email:** mc.sathish@gov.in
	Ashutosh Rai EY, India	**Tel:** +91-9739900007 **Email:** Ashutosh.Rai1@in.ey.com

CONTENTS

Page

1 Scope

The scope of this report is twofold:

- To identify the various layers and components that make up the value chain of the Internet and prepare a terminology and taxonomy of the supply chain of telecom/ICT infrastructure related to cost models for affordable data services. This includes providing clarification on related terms and concepts and analysing how each segment contributes to overall affordability.
- To study the policy, economic, competition, regulatory, standardization, and sustainability aspects of international internet connectivity (IIC) costs, especially in unserved and underserved areas, and to provide suitable recommendations. Comparative insights will be drawn from BRICS, G20, and BIMSTEC nations, with attention to South-South cooperation and long-term strategic plans for international internet connectivity.

By integrating these perspectives, the report aims to provide a comprehensive view that links supply chain cost structures with policy and regulatory frameworks, enabling more effective strategies to improve affordability and resilience of data services.

2 References

[1] Telecom Regulatory Authority of India (TRAI) – various directives, recommendations, and tariff regulations, including Telecom Tariff Orders and Interconnection Regulations.

[2] Department of Telecommunications (DoT) – Universal Service Obligation Fund Annual Reports; Guidelines for Grant of License for Establishing and Maintaining Landing Stations (2018).

[3] BharatNet project documentation and updates.

[4] National Internet Exchange of India (NIXI) – Peering Policy (2021).

[5] GSMA reports on infrastructure sharing and connectivity costs.

[6] World Bank (2021). World Development Report 2021: Data for Better Lives.

[7] World Bank Group (2020). International Internet Connectivity Costs.

[8] World Bank Group (2012). TEAMS Project (Kenya).

[9] Development Bank of Latin America (2019). South America Pacific Link (SAPL).

[10] International Telecommunication Union. ITU-T Recommendation D.50: Methodologies for calculating international connectivity costs.

[11] International Telecommunication Union (2020, 2022). Price Briefs on Data and Internet Affordability.

[12] European Commission (2018). European Electronic Communications Code.

[13] CGI.br (Brazilian Internet Steering Committee). IXP Best Practices Manual (2020).

[14] Communications Authority of Kenya. Regulations on Interconnection and Provision of Fixed Links (2017).

[15] Dell (2021). Clean to Green e-waste recycling program.

[16] ITU Journal (2020). Green Networking: A Step towards Sustainable ICT.

[17] Data Center Dynamics (2019). Indian data center providers experiment with solar power.

[18] Business Wire India (2018). Netmagic achieves LEED Platinum certification.

[19] CtrlS and NxtGen. Solar-powered data centre initiatives in India.

3 Terms and definitions

3.1 Terms defined elsewhere

This Technical Report uses the following terms defined elsewhere:

3.1.2 International Long Distance (ILD) Operator [DoT License Guidelines, 2018]: An operator licensed to provide international connectivity services.

3.1.2 Internet Exchange Point (IXP) [CGI.br Manual, 2020]: A physical infrastructure where different ISPs and networks exchange internet traffic.

3.2 Terms defined here

This Technical Report defines the following terms:

3.2.1 Supply chain of telecom/ICT infrastructure: The layered structure of international, national, and local network components, including supporting passive and customer equipment, that together enable affordable broadband connectivity.

3.2.2 Meaningful Connectivity: A state of broadband access that is affordable, reliable, and of sufficient quality to enable effective participation in the digital economy, aligned with ITU and IGF definitions.

3.2.3 Cost optimization strategies: Policy, technical, and operational measures aimed at reducing capital and operating costs across the ICT supply chain, while maintaining service quality and sustainability.

3.2.4 Sustainability aspects in ICT: Environmental and energy-related measures, such as e-waste management, renewable integration, and green networking, that influence both costs and long-term resilience of telecom infrastructure.

4 Abbreviations

Abbreviation	Expanded form
APEC	Asia-Pacific Economic Cooperation
BCP	Best Current Practice
BRICS	Brazil, Russia, India, China, South Africa
CAK	Communications Authority of Kenya
CPE	Customer Premises Equipment
DoT	Department of Telecommunications (India)
DSL	Digital Subscriber Line
FTTH	Fiber-to-the-Home
GSMA	GSM Association
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IGF	Internet Governance Forum
IIC	International Internet Connectivity
ILD	International Long Distance
ISP	Internet Service Provider
ITU	International Telecommunication Union
LEED	Leadership in Energy and Environmental Design
MEO	Medium Earth Orbit
NIXI	National Internet Exchange of India
OpEx	Operational Expenditure
REC	Renewable Energy Certificate
SPV	Special Purpose Vehicle
TRAI	Telecom Regulatory Authority of India
USF	Universal Service Fund
WDR	World Development Report

5. Introduction

The digital economy and modern information society fundamentally depend on robust, high-quality, and affordable broadband connectivity. At the heart of this connectivity lies the multi-layered telecom and ICT infrastructure supply chain, encompassing the physical and logical components that facilitate seamless data and voice transmission. This infrastructure not only forms the backbone of national and international communication networks but also underpins inclusive digital participation and economic development.

Despite its critical role, the affordability of data services remains constrained by a complex interplay of cost drivers, technological bottlenecks, and regional disparities across the supply chain. These challenges are further compounded in emerging and underserved markets, where limited competition and fragmented infrastructure exacerbate cost pressures.

At the same time, information asymmetry continues to hinder universal internet connectivity worldwide. The World Bank's World Development Report 2021: Data for Better Lives called for closer international cooperation to harmonize regulations and coordinate policies at bilateral, regional, and global levels. The ITU emphasizes "Meaningful Connectivity," while the World Bank highlights five pillars for resilient, inclusive growth: Connectivity, Affordability, Access through devices, Digital Skills, and Trust.

Global policy forums have also advanced conceptual frameworks for digital equity. The United Nations' Internet Governance Forum (IGF) promotes the "3A" model—Access, Affordability, and Ability—to ensure that no one is left offline. UNESCO has similarly underscored the urgent need for meaningful connectivity, encouraging governments to comply with global accessibility standards, set national targets, and promote digital public goods to bridge the digital divide.

This technical report builds on these perspectives by integrating a supply-chain cost analysis with policy, regulatory, and sustainability considerations, offering a comprehensive understanding of how both infrastructure and governance shape the affordability of data services.

6. Defining the Telecom/ICT Infrastructure Supply Chain

The telecom and ICT infrastructure supply chain consists of interconnected layers, each with distinct roles and cost implications:

- **International Connectivity** – Encompasses submarine fiber-optic cables and satellite systems that link countries and continents to the global internet. It provides high-capacity gateways for international data transport.
- **National Backbone Networks** – Extends connectivity from international landing points to regional hubs through long-haul terrestrial fiber and cross-border links. It forms the backbone of national data transit infrastructure.
- **Interconnection and Exchange Infrastructure** – Includes Internet Exchange Points (IXPs), peering hubs, and regional gateways. It facilitates efficient data exchange within and between networks, reducing dependence on costly international transit.
- **Metro and Middle-Mile Networks** – Comprises metropolitan fiber rings and wireless backhaul solutions such as microwave and millimetre-wave links. It aggregates data traffic within urban and suburban areas, bridging the backbone and access networks. It also incorporates edge data centres and local caching to optimize content delivery and reduce latency.
- **Last-Mile Access Networks** – Delivers broadband connectivity directly to end-users through fixed (FTTH, DSL, cable) and wireless (2G to 5G) access technologies. It includes innovative community networks and alternative access models in underserved areas.

- **Passive Infrastructure** – Encompasses supporting physical structures such as towers, poles, ducts, conduits, and power systems. It provides the foundation for deploying active network components across the supply chain.
- **Customer Premises Equipment (CPE)** – Consists of modems, routers, and optical network terminals that establish connectivity within homes and businesses. It serves as the essential interface between the access network and the end-user.

This layered breakdown forms the foundation for analyzing the cost components, operational dynamics, and potential optimization strategies in the subsequent sections.

7. Cost Components & Considerations

The affordability and sustainability of broadband connectivity rely on a nuanced understanding of the cost components across each layer of the telecom and ICT infrastructure supply chain. Each layer introduces unique technical, operational, and economic challenges that collectively shape the final cost of delivering data services to end-users.

This section provides a detailed analysis of the cost structures associated with the major layers of the supply chain. For each layer, it covers aspects such as **capital expenditures (CapEx), operational expenditures (OpEx), energy costs, regulatory and licensing fees, and market structure dynamics.**

7.1 International Connectivity

International connectivity is the foundational layer of the telecom and ICT infrastructure supply chain, enabling cross-border data transport. It primarily relies on submarine fiber-optic cables and satellite systems, each introducing distinct capital and operational cost considerations that shape the affordability of downstream services.

Capital expenditure for submarine cable systems includes the manufacture and deployment of fiber-optic cables, optical amplifiers, and landing station infrastructure. Costs are driven by the system's design capacity (fiber pairs, amplifier count), route complexity, and seabed topology. Satellite connectivity involves satellite manufacturing, launch services, and the construction of ground station facilities, with costs influenced by the satellite's orbital configuration (GEO, MEO, LEO) and transponder capacity.

Operational expenditure in submarine cable systems centres on periodic maintenance and repairs. Specialized cable ships and consortia arrangements spread these costs among participating operators. For satellites, operational costs include ground station operation and satellite fleet management. Capacity leasing for international bandwidth, whether from cable operators or satellite providers, constitutes a recurring expense for downstream ISPs.

Energy consumption is a notable operational factor. Submarine cable landing stations and satellite gateways require continuous power for optical or RF transmission systems and climate control, with higher costs in regions with unreliable grid access.

Licensing and regulatory compliance impose costs related to maritime permits, environmental clearances, and spectrum or orbital slot coordination. Navigating these requirements adds to project timelines and introduces additional financial commitments.

Market structure has a direct impact on transit prices. In regions with limited international connectivity routes, capacity prices remain high, constraining downstream affordability. Competitive landing environments and multiple submarine cable options can reduce unit costs and create more favourable market conditions.

Key cost levers:

- Collaborative financing and ownership models (consortia) to reduce individual capital investment burdens
- Maintenance sharing agreements to lower operational repair costs
- Adoption of energy-efficient power and cooling systems at landing stations and ground facilities
- Establishment of multiple landing points and route diversity to improve resilience and reduce dependency costs
- Clear and predictable regulatory frameworks to avoid project delays and cost escalation
- Promoting competitive wholesale markets by encouraging new submarine or satellite systems to enter underserved regions

Regulatory Aspects of International Internet Connectivity Costs

Regulators provide various economic and fiscal incentives to encourage operators to expand international internet connectivity to underserved regions. These include Special Purpose Vehicles (SPVs), Universal Service Funds (USF), and tax incentives.

TRAI (India): Issued directives and tariff regulations for international bandwidth and interconnection agreements to ensure fair competition, transparent pricing, and efficient traffic exchange.

Department of Telecommunications (DoT, India): Issues licenses to International Long Distance (ILD) operators with conditions on pricing, quality of service, and compliance with international standards. Monitors ILD operators for compliance and service quality.

Asia-Pacific Economic Cooperation (APEC): Provides guidelines to promote competition, efficiency, and affordability in international connectivity.

Standardization Aspects of International Internet Connectivity Costs

Non-standardized pricing models have created challenges such as lack of transparency, inequitable costs for developing countries, and barriers to competition. Standardization efforts address these issues by establishing benchmarks, methodologies, and regulatory alignment.

Cost Models and Benchmarking: ITU's Recommendation ITU-T D.50 outlines methodologies for calculating international connectivity costs, including submarine cables, terrestrial infrastructure, and operations.

Regulatory Frameworks: Regional frameworks such as the European Electronic Communications Code harmonize cross-border access and pricing rules, fostering fair competition.

Peering and Interconnection Guidelines: IETF's Best Current Practice 38 (BCP 38) provides standards for secure and efficient interconnection, reducing risks like IP spoofing while promoting stable, cost-effective connectivity.

By integrating regulatory and standardization dimensions, this section expands beyond infrastructure costs to show how policy, incentives, and harmonized standards directly shape affordability and equitable access to international bandwidth.

Case Studies on International Connectivity Costs

India

The Telecom Regulatory Authority of India (TRAI) has introduced tariff directives and interconnection regulations for international bandwidth to prevent monopolistic practices and ensure transparency. The Department of Telecommunications (DoT) issues licenses to International Long Distance (ILD) operators with conditions relating to fair pricing and service quality, while monitoring compliance. The BharatNet project provides an example of government-driven cost models for rural fiber deployment, demonstrating standardized approaches to estimating connectivity costs.

Kenya

The East African Marine System (TEAMS) submarine cable has been central to Kenya's international connectivity. A standardized pricing model for TEAMS bandwidth, developed collaboratively by government and ISPs, reduced costs for operators and consumers. The Communications Authority of Kenya (CAK) also introduced regulatory guidelines, aligned with ITU recommendations, to promote non-discriminatory access and fair pricing.

Brazil

Brazil collaborated with neighbouring countries on the South America Pacific Link (SAPL) submarine cable. Cost-sharing agreements among participants were standardized, ensuring equitable distribution of costs by usage. Brazil also invested in Internet Exchange Points (IXPs), reducing reliance on costly international transit. The Brazilian Internet Steering Committee (CGI.br) established IXP guidelines that foster efficient traffic exchange and cost savings.

7.2 National Backbone Networks

National backbone networks extend international connectivity to regional and urban hubs across a country. This layer primarily consists of long-haul terrestrial fiber infrastructure and, where relevant, cross-border links to neighbouring countries. The cost profile of national backbone networks is shaped by geography, deployment methods, and operational requirements.

Capital expenditure in this layer is dominated by the costs of fiber deployment. Trenching and duct installation are significant cost drivers, with expenses determined by the length of fiber routes, terrain (urban vs. rural), and the cost of securing rights-of-way. Construction in densely populated areas often involves higher compensation costs for land and disruptions, while remote areas face challenges due to limited supporting infrastructure.

Operational expenditure includes maintenance and repair of fiber routes, particularly in areas prone to damage from construction activity or environmental conditions. Regular inspections, repair work, and fiber route security measures are necessary to ensure network uptime and service continuity.

Energy consumption in national backbone networks is primarily associated with active network equipment (e.g., optical amplifiers and regeneration sites) located along fiber routes. These sites require continuous power supply and environmental controls, with costs dependent on grid access and local electricity pricing.

Licensing and regulatory costs include permits for right-of-way access, compliance with safety standards, and adherence to national infrastructure guidelines. Delays or inconsistencies in right-of-way approvals can significantly impact project costs and deployment timelines.

Market structure and competitive dynamics directly influence backbone network costs. In regions with multiple competing backbone operators or open-access fiber models, capacity leasing prices tend to be more competitive, reducing downstream service costs. In contrast, areas with limited backbone infrastructure can face elevated wholesale rates and restricted expansion options for downstream ISPs.

Key cost levers:

- Efficient right-of-way access and streamlined permitting processes to reduce delays and compensation costs
- Use of existing utility corridors (e.g., power lines, railways, highways) to minimize civil works expenses
- Infrastructure sharing agreements (ducts, fiber pairs) to spread capital costs across operators
- Deployment of energy-efficient optical equipment to reduce ongoing power costs

- Competitive backbone leasing and open-access models to mitigate market concentration risks

7.3 Interconnection and Exchange Infrastructure

Interconnection and exchange infrastructure plays a critical role in ensuring efficient data flow within and between networks. This layer includes Internet Exchange Points (IXPs), regional peering hubs, and gateway facilities. It directly impacts the cost and quality of downstream data services by reducing reliance on costly international transit and improving network performance.

Capital expenditure in this layer includes the establishment of physical exchange facilities, including data centre space, switching equipment, and high-capacity routing infrastructure. The costs depend on the scale of the exchange, the level of redundancy and security measures incorporated, and the need for specialized hardware to handle high traffic volumes.

Operational expenditure consists of ongoing facility management, maintenance of routing and switching equipment, and interconnection service management. Regular upgrades are necessary to accommodate traffic growth and ensure low latency and high reliability.

Energy costs are significant for large exchange facilities, driven by the continuous operation of high-capacity routing equipment and cooling systems to maintain optimal environmental conditions. In high-cost electricity markets, this contributes directly to the operational cost burden.

Licensing and regulatory considerations are typically less burdensome in this layer compared to international connectivity, but IXPs must still comply with local data centre regulations, security mandates, and peering policy requirements. In some cases, regulatory support for neutral IXPs can lower entry barriers for smaller ISPs, enhancing competition.

Market structure is a central factor influencing interconnection costs. In well-developed markets, neutral IXPs enable multiple operators to exchange traffic directly, reducing transit fees and improving network efficiency. In markets with limited or no neutral IXPs, operators may rely on expensive upstream transit arrangements, increasing costs for downstream data services.

Key cost levers:

- Promoting the establishment of neutral IXPs to enable direct peering and reduce reliance on costly upstream transit
- Efficient facility design and high-density equipment to minimize energy and space costs
- Shared facility models and public-private partnerships to spread capital and operational expenditures

7.4 Metro and middle-mile networks

Metro and middle-mile networks provide the critical link between national backbones and last-mile access networks. They aggregate and distribute data traffic within cities and connect regional hubs, shaping both service quality and cost structures.

Capital expenditure in this layer involves the deployment of metropolitan fiber rings and the installation of wireless backhaul solutions, such as microwave and millimetre-wave links. Costs are influenced by the density of urban infrastructure, the need for secure and redundant paths, and the integration of edge caching or content delivery points to improve data flow efficiency.

Operational expenditure includes routine maintenance of fiber routes, wireless backhaul equipment, and aggregation points. Urban environments often pose challenges due to frequent construction activities that can damage fiber assets, increasing the need for proactive maintenance.

Energy costs in metro networks are driven by active network elements, such as aggregation switches and wireless backhaul equipment, as well as cooling and environmental control systems at central and regional aggregation sites. Efficient design and equipment selection play a direct role in containing these energy costs.

Licensing and regulatory compliance can include local permits for rights-of-way, adherence to municipal infrastructure guidelines, and compliance with safety and environmental standards. Delays in municipal approvals or restrictive local policies can significantly add to deployment costs and timelines.

Market structure in metro and middle-mile segments typically includes multiple operators and, in some cases, shared or wholesale-only fiber networks. Competitive markets and open-access middle-mile infrastructure can lower leasing costs for downstream ISPs, while limited competition can maintain high costs and reduce service availability.

Key cost levers:

- Strategic use of existing urban infrastructure (e.g., ducts, utility poles) to reduce civil works costs
- Adoption of high-capacity wireless backhaul and edge caching to minimize fiber extension needs
- Infrastructure sharing agreements and open-access policies to lower per-operator costs
- Efficient energy management at aggregation sites to contain operational expenditures
- Streamlined municipal permitting and rights-of-way processes to accelerate deployment

7.5 Last-Mile Access Networks

Last-mile access networks are the final link in the telecom and ICT infrastructure supply chain, delivering data services directly to end-users. They include fixed broadband (such as fiber-to-the-home, DSL, and cable) and mobile radio access networks (2G to 5G), as well as community and alternative access solutions in underserved areas.

Capital expenditure in this layer involves significant investments in physical infrastructure and customer-facing equipment. Fixed broadband deployments require fiber drop cables, customer premises installations, and network termination devices. Mobile access networks involve the installation of radio base stations, sector antennas, and supporting backhaul connections. Terrain, building density, and technology choice directly influence these deployment costs.

Operational expenditure covers ongoing maintenance of network elements, such as fiber drop connections, wireless base station equipment, and local switching infrastructure. Maintenance challenges vary between dense urban areas and dispersed rural deployments, impacting the scale and frequency of interventions.

Energy costs in last-mile networks are driven by active equipment at base stations and fiber access nodes. In mobile networks, energy demand increases with densification (e.g., small cells) and the introduction of higher-capacity technologies (4G, 5G). In fixed access networks, energy consumption is linked to customer premises equipment and local distribution nodes.

Licensing and regulatory compliance can involve spectrum fees for mobile services, municipal permissions for fiber or cable deployments, and adherence to building safety codes. In some cases, licensing complexity can delay deployment and increase financial risk.

Market structure plays a decisive role in last-mile costs. In competitive markets, multiple access network operators can create downward pricing pressure on both wholesale and retail services. In rural or remote areas with limited competition, costs remain high due to low customer density and the need to recover investments across fewer subscribers.

Key cost levers:

- Efficient deployment strategies tailored to urban density and rural sparsity to control civil works and equipment costs
- Use of alternative technologies (e.g., wireless or hybrid solutions) in low-density areas to reduce fiber extension costs
- Infrastructure sharing models (active and passive) to reduce per-operator CapEx and OpEx burdens
- Energy-efficient access node and small-cell deployments to lower recurring power expenses
- Competitive wholesale and retail environments to mitigate monopolistic pricing and expand service reach

7.6 Passive Infrastructure

Passive infrastructure includes the physical structures and systems that support active network components across the telecom and ICT supply chain. Key elements include towers, poles, ducts, conduits, and power systems, all of which are essential for reliable service delivery.

Capital expenditure in this layer covers the construction and installation of these structures. Towers and poles require significant upfront investment in site acquisition, civil works, and materials. In urban areas, costs are influenced by limited availability of suitable sites and stringent municipal guidelines. In rural areas, terrain and distance from utility corridors can increase site preparation and transport costs.

Operational expenditure involves routine site maintenance, security, and inspections to ensure the structural integrity and safety of passive assets. Harsh environmental conditions and ongoing urban construction activities can accelerate wear and increase maintenance demands.

Energy costs in passive infrastructure are driven by the need to power active network equipment at tower and aggregation sites. In regions with unreliable grid access, diesel generators and hybrid power systems are often used, introducing ongoing fuel costs and logistical complexities.

Licensing and regulatory costs include securing construction permits, land use approvals, and compliance with environmental standards. Inconsistent or delayed municipal approvals can increase project costs and extend deployment timelines.

Market structure and ownership models significantly shape cost outcomes in this layer. Shared passive infrastructure, such as tower co-location and duct sharing, enables operators to spread costs and reduce duplication. In markets with fragmented or proprietary infrastructure ownership, redundant deployments can raise sector-wide costs and limit affordable access for end-users.

Key cost levers:

- Promotion of tower and duct sharing arrangements to reduce duplication and lower total deployment costs
- Utilization of existing urban structures (buildings, utility poles) to minimize new construction expenses
- Deployment of energy-efficient power systems to reduce fuel dependency and operational costs
- Streamlined permitting and regulatory processes to contain civil works expenses and avoid delays
- Robust asset management and maintenance practices to extend asset lifespans and ensure efficient operation

7.7 Customer Premises Equipment (CPE)

Customer Premises Equipment (CPE) forms the final link in the telecom and ICT infrastructure supply chain, connecting the end-user to broadband services. It includes devices such as modems, routers, optical network terminals (ONTs), and wireless access points installed at homes, businesses, and institutions.

Capital expenditure in this layer involves the procurement of CPE devices and their installation at customer premises. While unit costs for CPE have declined over time due to mass production and technology standardization, the cumulative capital outlay remains significant for service providers, particularly in large-scale deployments.

Operational expenditure covers ongoing device management, firmware updates, troubleshooting, and in some cases, equipment replacement cycles. These costs are essential to maintain service reliability and quality, especially as customer expectations for seamless connectivity grow.

Energy costs for CPE are relatively modest compared to other supply chain layers but still contribute to household and small-business energy usage. Efficient device design and low-power standby modes help minimize these impacts.

Licensing and regulatory considerations typically focus on device certification and compliance with national telecom standards and compatibility requirements. Regulatory delays or fragmented standards can complicate procurement and deployment strategies, adding indirect costs.

Market structure and equipment sourcing models shape the cost dynamics of this layer. In some markets, operators supply and manage CPE as part of bundled service offerings, absorbing device costs within subscription fees. In other contexts, end-users procure their own CPE, shifting the upfront financial burden away from operators.

Key cost levers in customer premises equipment:

- Bulk procurement and standardized device models to achieve scale economies and reduce unit costs
- Efficient device lifecycle management to minimize replacement and maintenance expenses
- Adoption of low-power, energy-efficient CPE designs to lower household energy costs and environmental impacts
- Regulatory streamlining and alignment to reduce compliance complexity and procurement delays
- Flexible sourcing strategies (operator-supplied vs. user-supplied) tailored to market preferences and competitive dynamics

8. Cost Optimization Strategies Across the Supply Chain

The cost structures identified across the telecom and ICT infrastructure supply chain require targeted strategies to ensure affordable and sustainable data services. Industry stakeholders and policymakers have implemented a range of practical measures to manage capital and operational expenditures, streamline deployment, and improve service resilience. These strategies are shaped by both technological innovation and regulatory frameworks, with examples drawn from global best practices.

8.1 International Connectivity

Global strategies to optimize international connectivity costs focus on collaborative investment, technology innovation, and regulatory streamlining:

- **Carrier consortium models**: Major cables like SEA-ME-WE-4 (built by 16 operators) and ACE (serving 24 countries) exemplify how shared funding minimizes individual capital burden for multi-continent cable systems.
- **Maintenance-sharing agreements**: Joint contracts support shared deployment of repair vessels, distributing maintenance costs across all consortium participants and reducing OPEX per operator.
- **Advanced transmission technologies**: Cables like Equiano and Dunant use space-division and wavelength multiplexing to dramatically increase capacity while lowering per-unit costs and deferring total system replacement.
- **Energy efficiency at landing sites**: Modern landing stations and satellite ground hubs are optimized with efficient cooling and power systems and increasingly deploy hybrid or solar solutions to lower recurring energy expenses.
- **Regulatory harmonization**: Regional coordination in permitting and licensing—across coastal nations—is reducing deployment timelines and avoiding redundant regulatory costs and delays.
- **Market competition**: Entry of new cables on major routes has led to wholesale bandwidth price reductions of over 20% annually, preventing any single operator from controlling transit pricing.

8.2 National Backbone Network

Strategies to optimize national backbone network costs focus on infrastructure sharing, efficient deployment methods, and supportive regulatory frameworks:

- **Duct and corridor sharing**: Coordinating fiber deployment with road, rail, and utility projects minimizes repeated trenching and reduces civil works costs.
- **Aerial fiber deployment**: In areas where existing utility poles are available, aerial installations are leveraged as a cost-effective alternative to underground fiber, particularly in suburban and rural areas.
- **Open-access and wholesale backbone models**: Shared backbone networks promote fair access for ISPs, preventing monopolistic pricing and supporting broader market competition.
- **Energy-efficient backbone upgrades**: Amplifier and regeneration sites are increasingly equipped with modern, energy-saving equipment and, in some areas, hybrid or renewable energy solutions to reduce long-term power expenses.
- **Supportive regulatory frameworks**: Policies that enable and incentivize infrastructure sharing have proven crucial to avoiding duplication and reducing both capital and operational costs.
- **Competitive backbone leasing markets**: Where multiple backbone providers operate under clear regulatory guidelines, capacity leasing costs for downstream ISPs are contained, supporting lower end-user tariffs.

8.3 Interconnection and Exchange Infrastructure

Efficient interconnection and exchange infrastructure is vital for reducing wholesale transit costs and supporting local data exchange, with optimization strategies focusing on neutral platforms and shared facilities:

- **Neutral Internet Exchange Points (IXPs)**: Neutral, carrier-agnostic IXPs enable direct traffic exchange between networks, reducing reliance on expensive international transit and improving routing efficiency.

- **Shared facilities and peering hubs**: Co-location and facility-sharing agreements lower capital and operational costs by pooling data centre resources and network equipment in centralized exchange points.
- **Energy-efficient facility design**: Modern IXPs and peering hubs use efficient cooling and power systems to contain operational expenses, particularly in regions with high energy costs.
- **Supportive regulatory and policy frameworks**: Policies that recognize and promote neutral IXPs and shared facilities help reduce administrative costs and encourage more ISPs and content providers to participate.
- **Market-driven peering and interconnection models**: Competitive interconnection environments, including vibrant local IXPs, lower peering and transit costs, supporting more affordable downstream services.

8.4 Metro and Middle-Mile Networks

Metro and middle-mile networks form the crucial link between backbone systems and last-mile access networks. Strategies for optimizing costs in this layer emphasize reuse of existing assets, efficient backhaul solutions, and local content delivery:

- **Use of existing urban infrastructure**: Leveraging existing ducts, utility poles, and municipal infrastructure minimizes civil works costs and reduces deployment disruptions.
- **High-capacity wireless backhaul**: In areas where fiber deployment is challenging or cost-prohibitive, microwave and millimetre-wave wireless backhaul solutions offer a lower-cost, high-capacity alternative.
- **Edge caching and local content delivery**: Deploying edge data centres and caching servers reduces long-haul traffic demand, improving performance and lowering overall transport costs.
- **Infrastructure sharing**: Shared middle-mile fiber and wireless assets spread capital and operational expenses across multiple operators, reducing per-operator costs and improving service affordability.
- **Streamlined municipal permissions**: Efficient permitting processes for metro and middle-mile projects help avoid costly delays and minimize project risk, especially in dense urban environments.

8.5 Last-Mile Access Networks

The last-mile segment is the final bridge between network infrastructure and end-users. Strategies for cost optimization focus on matching deployment models to geography and leveraging flexible technologies:

- **Deployment models tailored to urban and rural contexts**: In high-density urban areas, fiber-to-the-home (FTTH) and small-cell solutions maximize capacity and service quality. In rural or low-density areas, wireless or hybrid solutions reduce deployment costs and improve feasibility.
- **Active and passive infrastructure sharing**: Shared towers, poles, and fiber drops help reduce both capital and operational expenses, avoiding redundant investments.
- **Use of alternative technologies**: In low-density or remote areas, fixed wireless and hybrid fiber-wireless solutions offer more cost-effective connectivity options compared to full fiber builds.

- **Competitive wholesale and retail models**: Policy frameworks that encourage multiple last-mile providers and wholesale access ensure competitive pricing, improving affordability for end-users.

8.6 Passive Infrastructure

Passive infrastructure including towers, poles, ducts, and power systems supports active network equipment throughout the supply chain. Strategies for cost optimization focus on sharing models, efficient use of physical assets, and sustainable practices:

- **Infrastructure sharing models**: Tower and duct sharing arrangements reduce redundant deployments, lowering both capital and operational costs for all operators.
- **Use of existing structures**: Reusing existing buildings, utility poles, and other municipal assets minimizes new construction needs and reduces site acquisition costs.
- **Energy-efficient power solutions**: Deploying hybrid or renewable power systems at tower sites and aggregation points lowers fuel costs and improves operational sustainability, especially in areas without reliable grid access.
- **Streamlined permitting and regulatory processes**: Clear guidelines and efficient municipal approvals reduce deployment delays and associated costs.
- **Proactive maintenance practices**: Robust asset management and preventive maintenance extend the lifespan of passive infrastructure and help avoid expensive emergency repairs.

8.7 Customer Premises Equipment (CPE)

CPE devices—such as modems, routers, and optical network terminals—form the end-user interface with the broadband network. Strategies for optimizing costs in this layer focus on procurement, management, and technology choices:

- **Bulk procurement and standardized device models**: Operators leverage bulk purchasing and standardized models to reduce unit costs and streamline logistics.
- **Efficient device lifecycle management**: Proactive device upgrades and lifecycle planning minimize replacements and help reduce long-term costs.
- **Flexible sourcing models**: Allowing users to choose between operator-supplied and user-owned CPE can optimize affordability and improve market fit.

8.8 Sustainability Aspects of the Telecom/ICT Supply Chain

In addition to economic and technical factors, sustainability is increasingly shaping cost models for data services:

Green Networking: ISPs and telecom operators are adopting energy-efficient equipment, dynamic power management, and network virtualization to reduce both operational costs and environmental impact.

E-Waste Management: The rapid turnover of IT equipment generates large volumes of e-waste. Effective recycling and Extended Producer Responsibility (EPR) frameworks, such as India’s E-Waste (Management) Rules 2016, encourage sustainable product design and responsible disposal.

Renewable Energy Integration: Data centres and network hubs are major energy consumers. Companies like CtrlS and NxtGen in India are investing in solar-powered data centres. The Ministry of New and Renewable Energy supports the use of Renewable Energy Certificates (RECs) to offset carbon footprints.

Efficient Infrastructure Design: LEED-certified data centres and energy-efficient building practices are reducing long-term costs while meeting sustainability goals.

These practices demonstrate how environmental sustainability aligns with economic efficiency. Reducing energy use and waste lowers operational expenditures while also supporting regulatory compliance and corporate social responsibility objectives.

9. Conclusion

This report has highlighted the key cost drivers and optimization strategies across the telecom and ICT infrastructure supply chain. Addressing these challenges requires coordinated action that combines technology upgrades, regulatory simplification, and shared infrastructure use. Competitive markets and energy-efficient practices also play crucial roles in lowering costs and ensuring affordability. By adopting these targeted approaches, stakeholders can build robust, inclusive broadband networks that support sustainable digital growth