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REPORT ON STRATEGIC NETWORK RESILIENCE IN THE CARIBBEAN

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The SubOptic Foundation is a charitable organization with a focus on education and research initiatives that lay the groundwork for a better future for the global fiber-optic subsea cable industry. This report is the culmination of a year of research on strategic resilience for the Caribbean subsea cable network and beyond.

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EXECUTIVE SUMMARY

This report outlines a new approach, strategic network resilience, to evaluate and enhance the resilience of the global fiber-optic subsea cable network, a system that currently transports over 99% of all transoceanic internet traffic.

Strategic network resilience is a proactive approach that recognizes the technical interdependency of subsea cables with a broader telecommunications network, energy systems, and other infrastructures. It takes into account market conditions that enable and constrain investments in infrastructure and in operational mitigations. It entails assessment of shared risk across a broad range of stakeholders, including operators, service providers, governments, regulators, and end-users. Critically, strategic network resilience necessitates a holistic and a regional focus, looking beyond single cable systems.

Guided by this approach, the Report on Strategic Network Resilience in the Caribbean describes the interconnected geographic, economic, infrastructural, political, regulatory, communication, and collaboration challenges in the region to subsea cable resilience and to digital infrastructure development and operation more broadly.

To address these challenges, the report outlines best practices in strategic network resilience. It recommends a series of pathways to a resilient cable network and digital infrastructure ecosystem in the Caribbean. Best practices span economic, geographic, and political domains, including the development of incentives for attracting cable development, the establishment of a supportive regulatory environment, and the formation of a regional group focused on subsea cable protection.

Photo by Iago Bojczuk (2024)

This report focuses specifically on the human dimension of resilience that is often underrepresented in technically-focused frameworks. It shows how facilitating collaboration and trust between individuals can not only enhance long-term resilience of Caribbean network infrastructure, but can also activate short-term resource sharing in the case of unexpected conditions. Public communication and awareness about critical infrastructure is also an important pathway to a resilient network. There is a pressing need to promote network resilience in education of the next generation who will design, build, operate, regulate, and use fiber-optic subsea cable systems. Ministries and Departments of Education across the Caribbean should consider digital infrastructure as the foundation for digital transformation and a salient topic for education today.

The Strategic Network Resilience Report is based on a year of intensive research conducted by an interdisciplinary team in the Caribbean. This included interviews with over seventy stakeholders in subsea networks, telecommunications, and information technology sectors. It draws insights from individuals with decades of experience in building, operating, and maintaining subsea cable networks, regulating telecommunications, and working in telecommunications-dependent industries. It also encompasses the analysis of quantitative datasets from infrastructure operators and third-party stakeholders.

This data-driven research suggests that network operators will also benefit from a collaborative framework. Leveraging metrics, analytics, and mitigation strategies, alongside market driven approaches allows operators to move from isolated competitors toward mutual support. Adoption of the strategic network resilience approach and what this report outlines as the next responders model enhances network stability, reinforcing the global subsea cable ecosystem.

For reasons of practicality and commonality, the report recommends a regional approach to collective preparedness. The specific pathways documented here can be used by stakeholders in government, industry, education, and other domains to develop collaborative, human-focused strategies that will enhance network resilience and improve digital connectivity in the Caribbean.

TOP TAKEAWAYS

TOP TAKEAWAYS

1

It's About People

Strategic network resilience has an important human dimension. Resilience can be achieved through investments in people and communities, in addition to the more traditional approaches through technology and regulation.

2

Formalize Collaborative Relationships

Relationships are underutilized tools for enhancing resilience. Collaboration and trust between people, as well as strong connections between individually-robust networks and infrastructures, already exist. Companies and organizations already work together informally to enhance resilience, but such relationships and practices can be supported through intentional structure.

3

Enhance Awareness of Critical Infrastructure

Communication and awareness about critical infrastructure is an important pathway to a resilient network. Resilience can often be improved simply by better exchange of information amongst stakeholders, from communication about new technological developments or pressing network constraints, to potential sources and means of funding.

4

Educate the Next Generation

There is a need to promote network resilience in education of the next generation who will design, build, operate, maintain, regulate, and use subsea cables. The formation of a digital infrastructure educational program with a concentration in subsea cable resilience could train a cohort of students across the Caribbean.

5

Form a Regional Subsea Cable Association

The creation of a regional subsea cable group, modeled after the European Subsea Cables Association (ESCA), could provide a non-commercial platform for collective advocacy. Such an association could act as a unified representative for cable protection and resilience, addressing the challenges identified in the report through a shared strategic framework rather than fragmented efforts.

6

Find the "Next Responders"

Best practices across the Caribbean demonstrate a move from a "first responders" model to a "next responders" model, or from a model where entities prioritize their own resources and capabilities to one that emphasizes collective awareness and proactive measures. Service providers can come together and collaborate during times of major network or service outages for the benefit of customers by utilizing each other's infrastructure assets with the support of regulators.

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BACK-GROUND

> Organizations, governments, and users are more dependent than ever before on digital infrastructure.

BACKGROUND

Why Resilience? Why Now?

Over the past decade, cloud-based technologies have spurred new economic opportunities, transformed business models, broadened consumer access to content, and reshaped government management of citizen data. Organizations, governments, and users are more dependent than ever before on digital infrastructure.

As a result, disruptions now cause much more substantial impacts to organizations and other users that depend on these networks. A single infrastructure disruption, whether caused by natural events or human actions, can severely hinder the provision of normal and emergency services and leave communities disconnected, with cascading effects that may take significant time to recover. These impacts are also much more public. The media now regularly covers outages and their financial effects.

We have also witnessed a surge of events tied to national security, including alleged cable cuts in areas of heightened geopolitical tension around the world. These incidents have exposed critical bottlenecks and have firmly placed resilience at the center of the spotlight for many stakeholders.

Consequently, global awareness of the need for network resilience has grown rapidly across the world's digital ecosystem. The concept of resilience now appears on nation state agendas, corporate strategies, and community priorities. This is a shift from viewing digital connectivity as a background utility to a pillar of technological sovereignty.

Network operators have always had contingency plans to restore systems impacted from disruptions but this can be costly and challenging. There is also a growing market awareness for resilience consultancy programs and a wider adoption of resilience plans, programs, and investment to ensure the stability of services that underpin everyday life.

Photo by Nicole Starosielski.

The Need for a Proactive and Multi-Sectoral Approach

Although it has recently gained more interest, network resilience is not a new idea. Since the 1970s, resilience has been an important topic for ecology, computer science, urban planning, and systems engineering, among other fields. Researchers and companies have generated diverse approaches to resilience evaluation.[1] Over the decades, key concepts such as reliability, stability, survivability, robustness, recoverability, redundancy, and adaptability have been incorporated into resilience frameworks. Today, many resilience concepts orient practical strategies for maintaining network services.

Distinctly, resilience approaches complement standard risk analysis by requiring continuous attention to evolving threats and opportunities, acknowledging that not all disruptions can be fully predicted or prevented, and designing systems to adapt and recover when unexpected events occur. Resilience frameworks depart from traditional design practices that assume complete foreknowledge of threats, instead emphasizing flexible, iterative, long-term strategies that can respond to uncertainty.[2]

In our view, network resilience is the capacity of a network to continue performing its intended functions, typically, delivering an acceptable level of service in the face of adverse conditions, disruptions, or fundamental structural changes.[3]

The study of network resilience has grown in scope and method over the years. However, there remain several gaps, especially when it comes to subsea cables. In public discussions and government strategies, network resilience is often treated as a catch-all term for a range of activities rather than evaluated as a specific system attribute.[4] This can make it difficult to measure and put resilience concepts into practice.

Of course, key proactive measures, including backup systems, restorative processes, and alternate, end-to-end routing strategies, have been implemented. After all, subsea cable systems are built for durability, typically engineered to last twenty-five years. System resilience is baked into every stage of the process, from technical specifications and route planning to physical protection such as cable burial and armoring. Even without formal regulations, subsea cable operators ensure reliability through geographic diversity and long-term maintenance agreements that guarantee quick repairs.

Despite this, when considering subsea cables within a broader technical and economic ecosystem, there are indications that holistic approaches to resilience remain limited in scope or fragmented across technical, commercial, and operational silos–especially when multiple industries, regulatory schemes, or industry practices are in play.[5] Perspectives on resilience can also vary as commercial, governmental, and operational stakeholders prioritize different aspects, leading to a fragmentation of resilience efforts across digital infrastructures.

While the development of new technologies and standards address these gaps in some regions, many current approaches to network resilience in the Caribbean lack such a proactive, holistic perspective that integrates social, economic, political, and technical domains.[6] In fact, subsea cable networks—despite forming the backbone of global connectivity—are often missing from broader studies of network resilience.

The aim of this report is to provide a more integrated perspective, incorporating political, economic, regulatory, and environmental considerations, among others, drawn from our research on the digital infrastructure that connects Caribbean nations and territories.

> **“Network resilience is the capacity of a network to continue performing its intended functions, typically, delivering an acceptable level of service in the face of adverse conditions, disruptions, or fundamental structural changes.”**

[1] Qi, X., & Mei, G. (2024). Network Resilience: Definitions, approaches, and applications. Journal of King Saud University - Computer and Information Sciences, 36(1), 101882. https://doi.org/10.1016/j.jksuci.2023.101882.
[2] Park, J., Seager, T. P., Rao, P. S. C., Convertino, M., & Linkov, I. (2013). Integrating risk and resilience approaches to catastrophe management in engineering systems. Risk Analysis, 33(3), 356–367. https://doi.org/10.1111/j.1539-6924.2012.01885.x
[3] Curt, C., & Tacnet, J.-M. (2018). Resilience of Critical Infrastructures: Review and Analysis of Current Approaches. Risk Analysis, 38(11), 2441–2458. https://doi.org/10.1111/risa.13166
[4] Klein, R. J. T., Nicholls, R. J., & Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? Environmental Hazards, 5(1–2), 35–45. https://doi.org/10.1016/j.hazards.2004.02.001
[5] Eriksson, B., Durairajan, R., & Barford, P. (2013). RiskRoute: A Framework for Mitigating Network Outage Threats. Available at: https://ix.cs.uoregon.edu/~ram/papers/CoNEXT-2013.pdf (Accessed 14 September 2024).
[6] Smith, P., Hutchison, D., Sterbenz, J. P. G., Schöller, M., Fessi, A., Karaliopoulos, M., Lac, C., & Plattner, B. (2011). Network Resilience: A Systematic Approach. IEEE Communications Magazine, 49(7), 88–97. https://doi.org/10.1109/MCOM.2011.5936160

Subsea Cables in the Global Spotlight

As part of a concern with network resilience globally, there has been increasing attention to the protection of subsea fiber-optic cables. There are roughly 600 active and planned subsea cables as of 2025.[7] These systems transport over 99% of international internet traffic, are essential to the continuity of global communications, and underpin national economic stability worldwide. Subsea cables not only enable consumer internet access but are essential for critical services and emergency communications.[8]

The dependence on subsea cables is particularly acute for island communities in the Caribbean, where a lack of redundant landing points can create single points of failure. Limited commercial incentive to expand infrastructure coupled with an increased frequency of environmental hazards creates a state of heightened vulnerability.

Fiber-optic subsea cables have a significant role in cloud architecture and the rising demand for data connectivity driven by AI. In a cloud-based model, data is no longer confined to on-premises storage but is decentralized and accessed from remote data centers in "availability zones." Subsea cables are more important than ever before in many places around the world, especially when cloud-based content is located offshore.

Despite the deployment of low-earth orbit (LEO) satellites, which alongside microwave serve as a complement to cable systems, their data transfer capacity is dramatically lower than that of subsea cables, and both operational costs and latency can be comparatively higher. This makes them much less viable for large-scale, affordable digital connectivity.[9] Reliance on satellites and microwave alone could relegate some locations to a second-tier internet, with far less bandwidth, higher costs, and potential sustainability issues.

The recent global focus on subsea cable protection, a topic that has long been a concern of the subsea cable industry, has been largely reactive rather than proactive. The sabotage of the Nordstream pipeline in September 2022 drew attention to the vulnerability of subsea infrastructures. This then created an environment where what would ordinarily have been unreported cable faults became the focus of media speculation, notably in the Baltic region and in the Red Sea (in 2024 and 2025).

Perhaps more relevant to the Caribbean, cable breaks caused by natural hazards in West Africa, affecting WACS, ACE, SAT-3, and MainOne, led to significant internet outages that impacted thirteen African countries.[10] These breaks and subsequent outages were widely publicized in the global media, drawing attention to the critical importance of this infrastructure for the countries and regions affected.

"The dependence on subsea cables is particularly acute for island communities in the Caribbean, where a lack of redundant landing points can create single points of failure."

[7] TeleGeography (2025). Submarine Cable Frequently Asked Questions. Available at: https://www2.telegeography.com/submarine-cable-faqs-frequently-asked-questions (Accessed 19 September 2024).
[8] Runde, D. F., Murphy, E. L., & Bryja, T. (2024). Safeguarding Subsea Cables: Protecting Cyber Infrastructure Amid Great Power Competition. Center for Strategic and International Studies (CSIS). Available at: https://www.csis.org/analysis/safeguarding-subsea-cables-protecting-cyber-infrastructure-amid-great-power-competition (Accessed 20 September 2024).
[9] Gordon, L. W., & Jones, K. L. (2022). Global Communications Infrastructure: Undersea and Beyond. Center for Space Policy and Strategy, The Aerospace Corporation. Available at: https://csps.aerospace.org/sites/default/files/2022-02/Gordon-Jones_UnderseaCables_20220201.pdf (Accessed 17 September 2024).
[10] Internet Society. (2024). 2024 West Africa Submarine Cable Outage Report. Available at: https://www.internetsociety.org/resources/doc/2024/2024-west-africa-submarine-cable-outage-report/ (Accessed 02 October 2024).
[11] European Commission (2024). Recommendation on the security and resilience of submarine cable infrastructures. Available at: https://digital-strategy.ec.europa.eu/en/library/recommendation-security-and-resilience-submarine-cable-infrastructures (Accessed 05 October 2024).

Following these breaks, subsea cable protection and resilience became more prominent in global policy arenas. In February of 2024, the European Commission issued its Recommendation on Secure and Resilient Submarine Cable Infrastructures,[11] highlighting the role of submarine cables in the EU's digital sovereignty, economy, and international connectivity. The recommendation called for a coordinated EU-wide approach to assess and mitigate vulnerabilities, streamline permitting processes, and promote high-level security standards among Member States. It introduced the concept of Cable Projects of European Interest (CPEIs) to strategically support the deployment or upgrade of critical cables, combining private financing with EU and national resources. It also stressed the importance of international cooperation with third countries, strategic partners, and the subsea cable industry.

In September of 2024, the Joint Statement on the Security and Resilience of Undersea Cables in a Globally Digitalized World included an agreement between fifteen UN member countries (United States of America, Australia, Canada, the European Union, the Federated States of Micronesia, Finland, France, Japan, the Marshall Islands, the Netherlands, New Zealand, Portugal, Republic of Korea, Singapore, Tonga, Tuvalu, and the United Kingdom) to improve the resilience of global subsea networks. However, over one hundred other nations did not participate.

The following month, the International Telecommunication Union (ITU), in partnership with the International Cable Protection Committee (ICPC), established The International Advisory Body for Submarine Cable Resilience, aiming to promote multi-stakeholder dialogue and collaboration.[12] The group's first in-person meeting was held at the International Submarine Cable Resilience Summit in Abuja (26–27 February 2025), where members adopted the "Abuja Declaration." This landmark document frames subsea cables as critical infrastructure and establishes a shared framework of commitments. The Caribbean Telecommunications Union (CTU) played a leadership role in this process as a member of the Advisory Body, with CTU Secretary-General Rodney Taylor being appointed co-facilitator of Working Group 3, "Fostering Connectivity and Geographic Diversity," alongside World Bank's Vice President for Digital and AI, Sangbu Kim.

In the United States, the Federal Communications Commission (FCC) launched a Notice of Proposed Rulemaking[13], marking the first major review of submarine cable regulations since 2001, to streamline cable deployment while addressing risks such as malicious activities, natural disasters, and spatial conflicts in marine environments. In December, the Department of Homeland Security (DHS) released a white paper, "Priorities for DHS Engagement on Subsea Cable Security & Resilience,"[14] outlining strategies to safeguard these systems through enhanced public-private coordination, expanded industry representation in engagement frameworks, and new forums for joint risk management.

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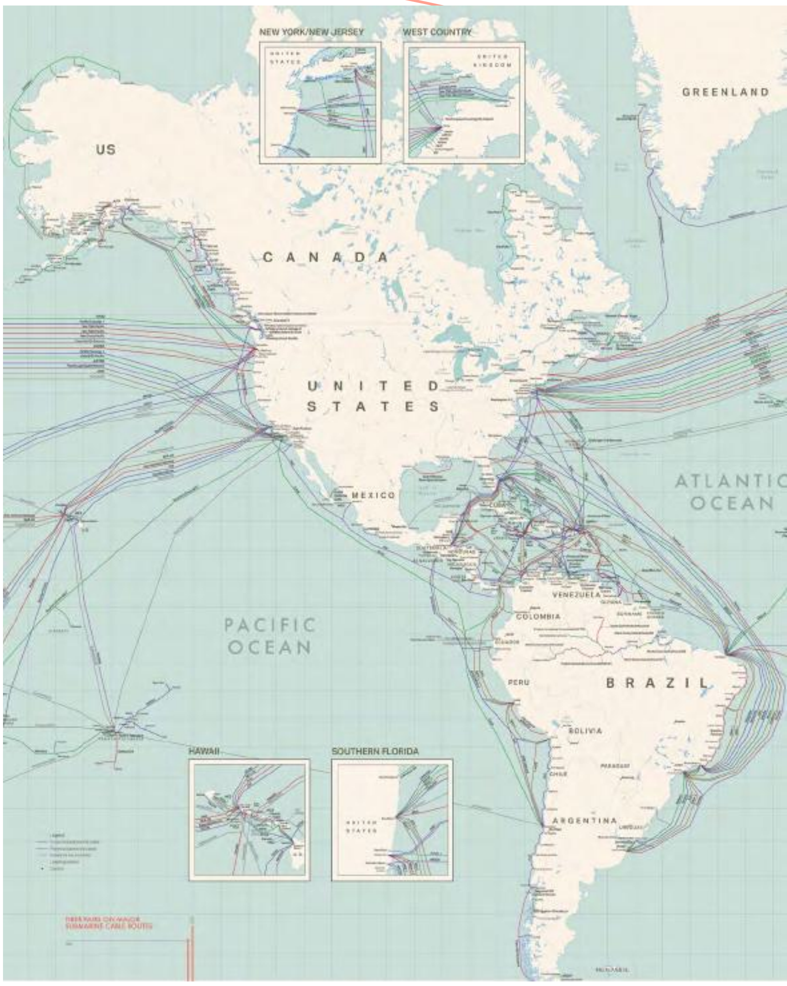
[12] International Telecommunication Union. (2024). Submarine Cable Resilience. Available at: https://www.itu.int/digital-resilience/submarine-cables/ (Accessed 13 December 2024).
[13] U.S. Federal Communications Commission. (2024). Review of Submarine Cable Landing License Rules and Procedures to Assess Evolving National Security, Law Enforcement, Foreign Policy, and Trade Policy Risks; Amendment of the Schedule of Application Fees Set Forth in Sections 1.1102 through 1.1109 of the Commission's Rules. Available at: https://docs.fcc.gov/public/attachments/FCC-24-119A1.pdf (Accessed 15 October 2024).
[14] U.S. Department of Homeland Security. (2024). Priorities for DHS Engagement on Subsea Cable Security & Resilience. Available at: https://www.dhs.gov/sites/default/files/2024-12/24_1218_scrc_Priorities-for-DHS-Engagement-on-Subsea-Cable-Security-Resilience_18-Dec-24.pdf (Accessed 24 December 2024).



Map by TeleGeography (2026).

"Without a deeper inclusion that translates global commitments into regionally-grounded support, existing inequalities in connectivity across the Caribbean are likely to widen. It is critical for underrepresented regions to move beyond mere participation toward direct influence in decision-making."

As these examples reveal, the protection and resilience of subsea cables is now seen as foundational to the global digital economy and to national security. Subsea cable protection and resilience activities now span multilateral agreements and declarations, regional strategies and funding mechanisms, as well as country-level regulatory reforms, and industry-specific standards. These activities recognize the multiple physical hazards that can occur to subsea cables, including natural disasters, inadvertent damage from ship anchors or commercial fishing equipment, and consider the potential for sabotage.

Caribbean stakeholders are increasingly participating in and expressing interest in these global discussions. The challenges facing the resilience of the region's networks, however, remain severe and include factors such as market dynamics that limit investment; worsening climate impacts in the Caribbean's archipelagic geography; and development pressures that escalate the social and economic costs of power or system outages.

Without a deeper inclusion that translates global commitments into regionally-grounded support, existing inequalities in connectivity across the Caribbean are likely to widen. It is critical for underrepresented regions to move beyond mere participation toward direct influence in decision-making. This ensures that global resilience strategies are tailored to reflect their specific circumstances and risk profiles.

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Existing Proactive Approaches

While for some around the world, subsea cable protection is a new topic, it has long been a concern of the global fiber-optic cable subsea cable industry. The industry has advanced many specific recommendations to enhance security, protection, and resilience of subsea networks. These generally focus on the most statistically significant risks to subsea cables.

The International Cable Protection Committee (ICPC), a non-profit organization formed to protect subsea telecommunications and power cables, has worked for over six decades to mitigate risks to subsea cables and has significantly advanced the resilience of marine route planning and maintenance. Its activities and recommendations have served as a cornerstone for governments, aligning with domestic laws and harmonizing with international legislative frameworks, such as the United Nations Convention on the Law of the Sea (UNCLOS) and related treaties. The Caribbean remains underrepresented in the ICPC.

In line with its mission and activities, the ICPC has outlined general principles for cable protection and developed recommendations for best practices for many aspects of installation, repair, and cable protection, which contribute to subsea cable resilience. Best practices for consideration by governments are detailed in the ICPC Best Practices (see Appendix).

Features that can enhance the resilience of a subsea system include cable awareness through education and training, updated nautical charts, cable burial, spatial separation measures such as designated protection zones, reduction of inconsistencies in permitting requirements, and robust domestic legislation to deter and penalize cable interference. The ICPC emphasizes inter-industry coordination and marine spatial planning integrates cable resilience into broader maritime governance frameworks. However, it does not include the assured provision of alternative cable capacity or routing, which are typically commercial matters for cable owners.

Subsea cable builders and operators have implemented a suite of these proactive measures to enhance system resilience and operational integrity.[15] For example, operators prioritize early engagement with ocean stakeholders and conduct thorough desktop studies and marine seafloor surveys to determine optimal routes. Collaborative mechanisms, such as cable/pipeline crossing agreements, can reduce conflicts with other ocean activities. Route planners focus on locating flat, stable seabeds while avoiding complex geographic features such as steep gradients, seamounts, vents, or fracture zones. Consequently, routes are adjusted to account for seabed characteristics and other ocean activities, with an emphasis on geographical diversity in routes and landing points to mitigate localized risks. In these, efficiency is sought by selecting the shortest viable routes between landing points, while also balancing operational needs with environmental considerations and geospatial factors.

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[15] This is highlighted in the repository of papers from the SubOptic Conference, a triennial industry event. Full list of conference proceedings can be found here: https:/suboptic.org/.

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In the past, some cable systems, such as Gemini, Japan-US, and TAT-14, were developed as "ring" architectures to ensure network resilience if one cable failed. This approach was later dropped because it required a doubling of the connectivity between two points. As more and more cables were laid on major routes, meshed networking allowed major operators to make their own arrangements for redundancy though acquiring capacity on other cable systems.

Resilience considerations do not disappear at the end of the planning stage of a network. Once cables are installed, resilience efforts continue through precautionary, regulatory, and security measures. Disseminating route information and engaging with stakeholders promotes awareness and cooperation. Physical risks are minimized through separation distances, cable protection zones, and marine spatial planning. Monitoring systems can also be used, including the maritime industry's Automatic Identification System (AIS), Distributed Acoustic Sensing (DAS), and technologies for external sensing such as SMART (Science Monitoring And Reliable Telecommunications) cables.

Fishing communities and cable planners/operators have proactively worked together in some parts of the world to ensure that cables are not damaged. Depending on the jurisdiction, the industry can also use available legal frameworks, including civil and criminal liability for damages.

In the Caribbean, small-scale fisheries are often geographically dispersed and, in many places, shaped by informal or locally organized arrangements. While fisherfolk organizations do exist—nationally in some states and regionally through the Caribbean Network of Fisherfolk Organisations (CNFO)—their coverage, resources, and regulatory influence vary widely across islands. This uneven institutional capacity can make sustained, region-wide coordination between fishers and subsea cable operators more challenging, especially around awareness and spatial planning.

As one cable consultant emphasizes, "resilience is not solely about the quantity of cables but also about the quality of the network's engineering." Resilience of subsea equipment, the cable landing station (CLS), and front-haul cable (cable from the CLS to the beach manhole (BMH)), has long been the focus of individual companies that typically have an economic incentive to ensure business continuity across individually-robust systems. Beyond route planning, operators invest in redundancy during repeater and branching unit design, redundant power feeds, automated failover mechanisms, fire hazard equipment, among others. The resilience of cable landing stations is also an important consideration in the design process. They are usually built in strategic locations and reflect the specific features of a place and its geography.

In addition, the resilience of the subsea network as a whole has advanced due to work on mesh networking and is a consideration for all operators who often have an economic incentive to offer multiple routes.

In short, the subsea cable industry has developed many proactive measures for both protection and resilience. Specifications, best practices, and pathways have been defined to support the resilience for an individual cable or network linking cable landing stations.

There remains no holistic evaluation of the Caribbean's digital resilience that accounts for the entire infrastructural stack. While progress is being made to identify individual risks, the region still lacks a unified picture of how subsea cables, landing stations, and terrestrial networks interconnect—leaving blind spots in how power dependencies and network failures might cascade across the region.

"Resilience of subsea equipment, the cable landing station (CLS), and front-haul cable (cable from the CLS to the beach manhole (BMH)), has long been the focus of individual companies that typically have an economic incentive to ensure business continuity across individually-robust systems."

STRATEGIC NETWORK RESILIENCE

STRATEGIC NETWORK RESILIENCE

This report introduces a paradigm to enhance the resilience of the subsea cable system: strategic network resilience. Moving beyond siloed approaches, this paradigm requires the identification and enhancement of features that will aim to make the entire network within a region more resilient. This broad view, which considers the collective needs and strengths of multiple communities, reveals challenges to resilience that cannot be remedied by design, equipment, route engineering, or building specifications alone.

This is necessary because digital infrastructures do not exist in a vacuum or under the control of a single organization. They are part of an interdependent ecosystem of diverse technologies and infrastructures, shaped by government interests, private sector companies, civil society, and regional organizations.

Four features of strategic network resilience differentiate this approach:

1 Technical Interdependency

Many analyses of the resilience of subsea cables limit their scope to the cable itself, assessing the route from cable landing station to cable landing station.[16] Strategic network analysis requires a holistic understanding of subsea cables' relationships to the broader internet infrastructure stack and other dependent systems.

2 Market Conditions

For each of these broader internet infrastructures there are different operators, equipment providers, and market conditions that shape how they are used. Strategic resilience requires consideration of commercial enablers and constraints, including how current market conditions either support or undermine resilience as well as how these dynamics are affected by regulation.

3 Shared Risk

Enhancing strategic resilience often requires looking beyond a single cable or single network. Considering multiple operators at once can help to identify sites of potential shared risk—nodes and links where a single point of failure could disrupt multiple services or offer the opportunity to enhance resilience.

4 Regional Approach

The features that will strategically advance resilience in one area of the world will not necessarily be translatable to other areas. Assessments of strategic network resilience are always regionally-specific. Rather than pursuing a one-size-fits-all model, efforts center on regionally or even sub-regionally contextualized solutions.

[16] Omer, M., Nilchiani, R., & Mostashari, A. (2009). Measuring the Resilience of the Trans-Oceanic Telecommunication Cable System. IEEE Systems Journal, 3(3), 295–303. https://doi.org/10.1109/JSYST.2009.2022570

RESILIENCE CHALLENGES IN THE CARIBBEAN

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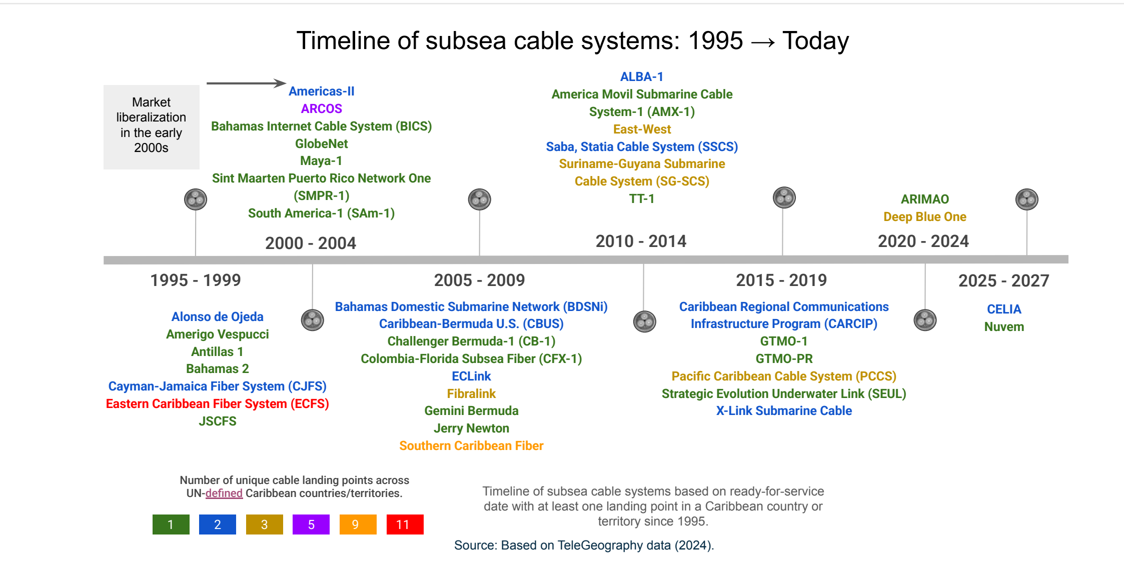
RESILIENCE CHALLENGES IN THE CARIBBEAN

A strategic, proactive approach to subsea cable resilience in the Caribbean has never been more critical than now, as stakeholders across the region are actively pushing cloud adoption and the presence of artificial intelligence (AI) is growing daily. Compared to regions such as North America and Europe, a shift to the cloud necessitates off-island data hosting as there are no cloud availability zones in the Caribbean.

This growing reliance makes island communities more dependent than ever on subsea networks. In the Caribbean, roughly thirty submarine cable systems (spanning local, regional, and international routes, with additional systems planned or under construction), underpin virtually all digital communications, from voice and basic internet access to cloud connectivity.

> "A strategic, proactive approach to subsea cable resilience in the Caribbean has never been more critical than now."



Timeline of subsea cable systems based on ready-for-service date with at least one landing point in a Caribbean country or territory since 1995. Based on TeleGeography data as of 2024.

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"Communication is a lifeline."

Bennette Thomas, former Director of Telecommunications and ICT Advisor to the Government of Dominica

For a region of over 44 million people, subsea cable systems enable economic activity, public services, education, and everyday social life. The consequences of their disruption can be national in scale, as Tonga's experience in the Pacific demonstrates. In January 2022 the Hunga Tonga–Hunga Ha'apai eruption severed the country's main undersea fiber-optic link, triggering a communications blackout and leaving Tonga largely offline for weeks.[17] Volcanic activity in the Caribbean has caused a few disruptions of subsea cables in recent years, including the eruption of Kick 'em Jenny in 2015 and La Soufrière in 2021. The impacts of these breaks were dramatically smaller in scale.

Most Caribbean islands have more than one cable route or landing point. Several smaller territories, however, remain dependent on a single primary system or landing site. Even when "redundancy" exists, it is often thinner than it appears. Cables, landing stations, and terrestrial backhaul frequently share common corridors, co-located facilities, or the same power dependencies. This concentration creates correlated risks, where a single localized event—such as a storm surge or a power grid failure—could shut down multiple systems simultaneously.

In interviews with stakeholders—including current and former government officials, port and customs authorities, utility companies, state agencies and organizations (environmental, ICT, security, tourism), university presidents, and financial institutions, as well as local telecom and IT professionals—almost all emphasized the essential nature of internet connectivity. "Communication is a lifeline," says Bennette Thomas, former Director of Telecommunications and ICT Advisor to the Government of Dominica. "If someone is sick in a remote part of the country, connectivity can be life-saving." In the case of natural disasters and climate-change related events, as the non-profit Télécoms Sans Frontières recognizes, connectivity is an essential part of emergency response.

In recent years, essential connectivity has come to mean much more than basic Internet service. New cloud-based technologies and subsea systems connected to remote data centers are increasingly seen as essential. They are critical concerns for almost every sector. They are seen as necessary for enticing economic investment, especially in tourism. As one stakeholder responsible for attracting investments to an island state described: "Even the perception of connectivity can influence an investor's decision." Although many tourists visit the islands to "unplug," hotel owners and developers require cloud-based access for their clients. "If the Internet is unreliable," a head of an association focused on attracting tourism worried, "it defeats the purpose of being here, and visitors may speak negatively about their experience."

Members of educational institutions also spoke about the increased criticality of cloud-based technologies. A university president with decades of experience in higher education in the Caribbean region described that, given the limited resources on the island, the institution they lead relies extensively on telemedicine for healthcare. The operation of the university today, they noted, is "all very bandwidth-dependent."

Government operations across the region, ranging from the work of the port authority to environmental management, are currently being assessed for transition to the cloud. One government official working on the sustainable use of natural resources noted, "we are trying to make our internal department operations more digital, like applications and licensing processing."

They have "an overarching aim to make everything digital." Another official conveyed that their operations necessitated data storage, especially given their drone imagery and mapping of coastlines, coral reefs, mangrove habitats, and seagrass beds. This results in a significant amount of data. "A 12-terabyte or 15-terabyte external drive is not sufficient, and the cloud space or server space is something we are considering." An official with a key role in the supply chain and transportation sectors of one island described: "We want to be more than just a port. We want to actively engage with the community through platforms like YouTube, Twitter, and LinkedIn." This requires more than just an internet connection, it requires cloud access with a resilient international cable connection.

[17] Clare, M. A., Yeo, I. A., Nash, J., et al. (2025). Volcanic eruptions and the global subsea telecommunications network. Bulletin of Volcanology, 87(51). https://doi.org/10.1007/s00445-025-01832-1

It is imperative that we remain at the forefront of technological advancements.

Theresa Wankin, Secretary-General of CANTO

Financial transactions and the banking sector are dependent on international connections via cable, and at times via satellite. Banks may have multiple branches across islands, with most of their main IT and servers centralized in one country. Several banks recognized the need to expand the geographic distribution of networked ATMs, locations where people could withdraw money, particularly in rural or underserved areas. This would be necessary to improve resilience and access to banking services in times of crisis. This too, however, is dependent on connectivity.

While some are enthusiastic about the shift to cloud-systems, others remain skeptical. One regulator, responsible for the leadership and strategic direction of the agency, saw the internet as "an amplifier of practices." In Europe and America, he observed, it amplifies productivity. But in small island developing states like his island, "it amplifies consumerism."

Enthusiastic adopters and influencers on the islands are pushing the shift to twenty-first century telecommunications technologies and applications. Moving beyond the traditional regional touristic slogan of the Caribbean that is based on "sun, sea, and sand," the push for resilience is also about redefining the islands' engagements with the broader technology sector, ensuring that technology is deployed in ways that benefit people, businesses, and governments.

Theresa Wankin, the Secretary-General of CANTO, during the organization's opening conference ceremony in July 2024 argued that cloud infrastructure was one of the building blocks of the future
in the Caribbean: "it is imperative that we remain at the forefront of technological advancements," she stated.

A vice-president at a local energy provider mentioned that in delivering power, they also relied on cloud services, but were hesitant to expand them due to network limitations: "The perception of the limited resilience associated with a single point of communication with the external world significantly influences strategic decisions regarding the adoption of cloud services."

There remain many steps to fully realize the transition. An InterAmerican Development Bank report on the potential of cloud computing in the Caribbean identified several, including a need for investments in digital infrastructure, supportive policies, and strengthened collaboration.[18] A resilient subsea cable network, which makes reliable connectivity to the cloud possible, is essential to realizing this transition.

Given the heightened significance of the expanding digital economy, as well as the increased frequency of catastrophic events due to climate change, the islands in the Caribbean region which have only one international subsea connection will require a higher level of resilience than they currently have and the countries with two or more cable connections should be carefully monitoring both the physical condition and economic viability of their existing systems with a view to being ready when replacement becomes an imperative.

The following sections describe the critical challenges to ensuring this resilience.

[18] García Zaballos, A., & Iglesias Rodríguez, E. (2018). Cloud Computing: Opportunities and Challenges for Sustainable Economic Development in Latin America and the Caribbean. Inter-American Development Bank. Available at: https:/publications.iadb.org/en/cloud-computing-opportunities-and-challenges-sustainable-economic-development-latin-america-and?utm. (Accessed 14 November 2024).

Geographic Challenges

Many of our interviewees argued that the limited number of cables interconnecting Caribbean islands as well as connecting the Caribbean to the rest of the world is a primary challenge for island resilience. One former regulator for a Caribbean state lamented the "many bottlenecks around the region." Experts in the subsea cable industry agreed. One with decades of experience in the region elaborated: "The Caribbean's network infrastructure faces significant challenges in terms of physical resilience due to its primarily linear structure, with most islands relying on only one or two connections. Key pinch points, such as connections to the U.S., Panama, or Trinidad, increase the risk of network failures that could disrupt both sides of a ring, potentially disconnecting entire regions."

From a quantitative perspective, analysis revealed low redundancy and inefficient connectivity across the subsea communication infrastructure in the Caribbean. Such risk assessments identified the critical role of key cables, vulnerable locations where all subsea cables converge, and significant chokepoints that have high shared risk. Dependence on these single points of failure by multiple operators increases potential for service disruption.

Over-reliance on one hub can also concentrate resources in ways that may not benefit neighboring territories. In addition to the limited routes, there is also a lack of path diversity and redundancy of these routes when compared to many others around the world. Quantitative analysis showed that this further exacerbates the existing risks and vulnerabilities. In some cases, all service providers take the same route in and out of a country.

Key pinch points, such as connections to the U.S., Panama, or Trinidad, increase the risk of network failures that could disrupt both sides of a ring, potentially disconnecting entire regions.

Geography can be a driver of investment, but in the case of subsea cables in the Caribbean it has often been a deterrent to enhancing resilience. It has been difficult to achieve route diversity, in part, due to the archipelagic nature of the Caribbean as well as the orientation of the islands, with the eastern Caribbean chain running north to south, which makes direct connections from hubs to each island difficult.

Instead, cable routes typically begin in larger centers of connectivity, such as the Virgin Islands or Puerto Rico, then extend southward to Trinidad or Venezuela, requiring intermediate connections for the smaller islands along the chain, which complicates routing efficiency and increases logistical hurdles.

Photo by Iago Bojczuk (2024).

Beyond this, many Caribbean states are themselves composed of many domestic islands that often need to be connected via subsea cable. A representative of one island's Airport Authority, addressing the local challenges posed by the country's geography, emphasized that their top connectivity concern is the reliability of domestic links between islands, which currently rely on microwave systems that can fail, especially during storms. While international connectivity does come in via subsea cable, the lack of robust fiber-based infrastructure locally is the real bottleneck, and having domestic cables in place would be a "game changer" for ensuring uninterrupted communication and meeting future data needs.

A public servant within a department focusing on matters of technology and e-government services observed: "a lot of times, things that we experience now, latency issues, bandwidth issues, complete system loss are because of how we are situated geographically." Reaching communities within the country, he says, is the greatest challenge.

The specific topography of the submarine landscape in the Caribbean offers both opportunities and challenges for resilience. On one hand, subsea cables in the Caribbean are at lower risk for damage from human activities such as commercial fishing or dragged anchors compared to regions with shallower waters adjacent to the coast which may experience higher density of bottom trawling. This is because the seabed gets deep quickly off the islands. Submarine cables in the Caribbean face natural-hazard risks linked to regional tectonics and volcanism, and can also be affected by tropical cyclones that trigger landslides and sediment-driven seafloor flows capable of damaging subsea infrastructure (see section below, "The Compounding Effects of Climate Change").[19] Cable developers also ensure the resilience of the network by adding devices to protect coral reefs and the cable from each other.

> **"It has been difficult to achieve route diversity, in part, due to the archipelagic nature of the Caribbean as well as the orientation of the islands, with the eastern Caribbean chain running north to south, which makes direct connections from hubs to each island difficult."**

[19] PoPe, E. L., Talling, P. J., Carter, L., Clare, M. A., & Hunt, J. E. (2017). Damaging sediment density flows triggered by tropical cyclones. Earth and Planetary Science Letters, 458, 161–169. https://doi.org/10.1016/j.epsl.2016.10.046

Economic Challenges

Cost

Resilience is significantly hindered by economic barriers, stemming largely from the expense of building and maintaining subsea systems. Interviewees regularly commented on the "exorbitant cost" of subsea infrastructure. Subsea cables require substantial investment that many stakeholders find difficult to secure. The cost to manufacture and lay fiber optic subsea cables can be upwards of $55,000 per kilometer (based on 2025 estimates). Landing subsea cable systems can be in the tens of millions, as there are other costs such as surveying the seabed, building terrestrial front-haul and backhaul infrastructure, acquiring the land for and constructing the cable stations (which can be expensive if they are located on prime coastline property), among other expenses.

These are daunting figures for communities with limited financial resources. Additional resilience measures can further increase the cost. Improvements in cable landing stations, such as upgraded diesel generators, protective devices to prevent water intrusion into facilities, security, and access roads add to the price of the system. Beyond the cable landing station, the terrestrial backhaul route offers internet service providers and end-users access to the cable, but resilience here can entail the construction of additional cable routes.[20] In smaller markets, the cost of a new cable can be prohibitive even before additional resilience measures are considered.

Numerous experts in the subsea cable industry echoed the sentiment that there is often a lack of a positive business case for private investors in subsea networks in the region. Any cable system—regardless of its distance—represents a significant financial risk, especially given the high cost of private capital.

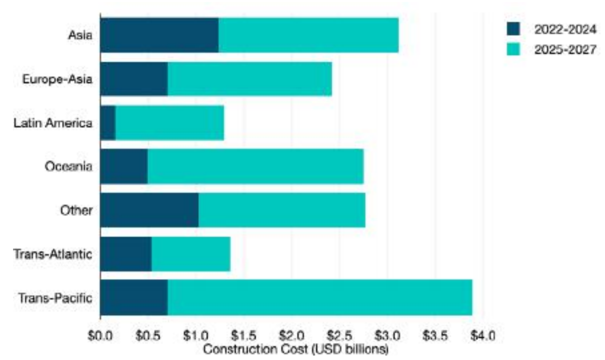
Many islands lack the economies of scale necessary to make such projects financially viable.[21] Cables are expensive anywhere in the world, but in the Caribbean they are particularly hard to justify. One subsea expert assessed, "money is a central challenge hindering resilience of subsea cable networks in the Caribbean. Without government funding, there is often no viable commercial business case for private companies to undertake the endeavor."

The lack of alignment between private investment goals and the region's infrastructure needs remains a significant challenge. Some experts pointed out that at times investors had shown some interest in Caribbean projects but found them "too small to justify their involvement." The banks, one prospective developer stated, "typically seek projects requiring $100 million or more, while small subsea cable projects in the region might only need around $20 million."

In short, there has been a lack of investment in new subsea systems compared to other parts of the world. This is a digital infrastructure divide extending far beyond the end-user.

Cost is also a challenge when it comes to operational expenditures to ensure the cable is powered, monitored, and maintained without disruption. Operators in the region described the business case for maintaining a resilient network as "difficult." One company sought grant funding to establish resilient operations and hurricane preparedness, including the purchase of backup generators and transfer switches to maintain network operations, but received only a fraction of the requested amount. "It's quite challenging, honestly," the operator reflected.

Construction Cost of New Submarine Cables Entering Service by Region



Source: © 2025 TeleGeography

[20] Caribbean Datacenter Association. (2024). Sun, Sea, Sand, and Submarine Cable Systems. Available at: https://caribbeandatacenters.com/wp-content/uploads/2024/07/State-of-the-Caribbean-Submarine-Cable-Ecosystem.pdf (Accessed 09 December 2024).
[21] Sutherland, E. (2009). Telecommunications in Small Island Developing States. SSRN. https://doi.org/10.2139/ssrn.1469243

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Scalability

The economic feasibility of alternative cable deployments is further constrained by the technology's lack of scalability. Subsea cable technology cannot be deployed at a small scale except where unrepeatered (i.e. short distance) systems can be used. This is possible on some inter-island links but eventually these must connect with longer repeatered systems which are much more expensive even if limited capacity is required.

The cost of a cable system does not scale linearly with its capacity. There is a financial inefficiency for smaller states or regions that do not require the capacity of larger systems. Given that the base cost required to deploy digital infrastructure is so high, for smaller or emerging entities the resources required to participate in expansive resilience-focused strategies may also be prohibitive.

The Value of Resilience

It is often difficult for developers and operators to monetize the benefits of enhanced resilience. Unlike traditional subsea cable deployments driven by clear demand for increased capacity or reduced latency, resilience-focused alternatives rely on less demonstrable benefits, such as reduced downtime or mitigated risk, which are harder to quantify and justify in a competitive market.

This issue is particularly pronounced in geographically isolated, economically disadvantaged, or demographically small markets, where the benefits of resilience are significant even though they may not translate into immediate financial gains. In our quantitative analysis we found that the potential user impact of any disruption is substantial in these regions. For example, for one island grouping with a minimum affected PoPulation of approximately 20,000 and a maximum affected PoPulation of over 40,000, the implications of a single point of failure were profound and the economic impact alone would be very significant.

Service providers typically face minimal economic incentives to invest in new infrastructure or upgraded maintenance, especially in non-growth markets where they profit from legacy infrastructure. This varied between providers and across islands. In some places, operators were resistant to making investment commitments and willing to take greater risks to establish connectivity more economically. Others, however, were more willing to invest whatever was necessary to adequately protect their infrastructure and especially their subsea cables.

Interviewees reported that these decisions often involve balancing cost, resilience, and time, with trade-offs being inevitable. Investors and governments weigh the affordability of the system against its resilience, knowing that reducing costs typically increases risks. This trade-off-driven approach poses challenges to building robust and resilient subsea networks in a financially constrained environment, where achieving long-term resilience may be deprioritized in favor of immediate cost reductions.

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Market Dynamics

Existing market forces and the level of regional competition directly shape the potential for network resilience. Caribbean telecommunications markets were historically monopolies, with a single provider determining all prices, which generally kept the cost of telecommunications high. These systems faced criticism from both local PoPulations and regulators.

When the markets diversified there was an element of competition introduced, although a few islands today still rely on only a single cable and a single operator for all international connectivity. On many islands, regulators continue to prioritize competition as a means to reduce consumer prices. However, the Caribbean today remains far less competitive than many other telecommunications markets globally and the Caribbean market for cloud and IT infrastructure is primarily dominated by local players.[22]

One regulator argued, "While prices haven't dropped significantly, having options is an improvement. This everyday competition helps keep prices in check." They credited competition with generating more innovation. At the same time, another former regulator observed, "Telecommunications companies are no longer the lucrative entities they once were; increasing bundling practices and heightened competition have led to declining revenues. Larger corporations are acquiring smaller ones, creating a competitive environment focused on survival."

Lower consumer costs often resulted in reduced revenue, and operators and builders noted that this meant less funds available for investments in new infrastructure, such as new subsea cables built for resilience purposes. As one subsea cable operator in the region reported, Caribbean markets face "a double-edged challenge: while monopolies can generate higher revenue to support infrastructure development, increased competition can drive prices down to a level where financial management becomes more complex, hindering the ability to invest in new projects."

In some instances, market conditions may even contribute to subsea cable failures, as highlighted in a recent report commissioned by the United Nations Institute for Disarmament Research (UNIDIR) and the European Union. This is particularly true when cost-reduction strategies lead to the use of lower-quality equipment and components in cable system construction.[23]

In many parts of the world, the subsea cable industry has also shifted, with the hyperscalers, largely Google and Meta, playing a large role in the market. A senior member in the cable industry observed, "the rise of hyperscaler services has shifted the digital landscape from predictable, linear growth to exponential growth, demanding networks that can handle this rapid scale." This shift and its full benefits, however, have yet to come to the Caribbean.

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[22] RocSearch. (n.d.). Market Size, Opportunity and Competitive Assessment: Caribbean Cloud Computing Market. Available at: https://www.rocsearch.com/wp-content/uploads/Caribbean-Cloud-Computing-Market.pdf (Accessed 25 September 2024).
[23] Kavanagh, C. (2023). Wading Murky Waters: Subsea Communications Cables and Responsible State Behaviour. United Nations Institute for Disarmament Research (UNIDIR). Available at: https://unidir.org/publication/wading-murky-waters-subsea-communications-cables-and-responsible-state-behaviour/ (Accessed 13 January 2025).

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Infrastructure Challenges

Aging Subsea Systems

Challenges to resilience also exist at the level of infrastructure. For the subsea cable network, one upcoming risk is the fact that many subsea systems were constructed in the late 1990s or early 2000s, meaning they are now approaching or have exceeded their theoretical lifespan of twenty-five years. There will be significant replacements and upgrades required within the next decade.

Critically important in the Caribbean, the assumed lifetime of twenty-five years does not apply to unrepeatered systems. These systems are shorter links that carry the signal end-to-end without amplification and they lack underwater electronic components (repeaters). Unrepeatered systems may operate for much longer than twenty-five years. Provided the fiber itself has not suffered multiple repairs and the cable landing stations have been properly maintained and upgraded, terminal equipment upgrades allow owners to increase capacity on these networks as new technology becomes available. Some regional fiber networks are nearing thirty years of operation and continue to be essential for many islands.

In general, economics determines the lifespan of a submarine fiber-optic system rather than its physical durability. This is particularly noticeable in markets where there is strong competition. In those locations, systems are likely to be replaced much sooner as more efficient technology becomes available, in part because a low capacity legacy system might incur the same marine maintenance costs as a modern high capacity system while delivering far less capacity.

In contrast to this, many Caribbean routes operate under different market conditions. Smaller traffic volumes and concentrated control of landing stations often reduce the competitive pressures that might lead cable owners to retire older systems quickly. In addition, many shorter inter-island links are unrepeatered, and thus may operate much longer than twenty-five years.

A critical factor in determining the economic life of a subsea fiber-optic system is the cost of maintenance. There has been an uptick in construction and margin pressure exerted on marine maintenance providers by hyperscalers and other cable owners. Cable ships are in short supply and day rates have risen sharply. Whether served by a cable maintenance club or by a private marine maintenance provider, there is a significant cost in keeping a vessel in port awaiting call-out for a repair. The cost of the repair itself may exceed US$1M in each instance. There has been at least one case in which a subsea cable developed a fault very soon after commissioning but was left inoperable for years because the system owner did not have the funds to effect the repair.

It is not possible to eliminate the risk of damage to a subsea fiber-optic cable. There are over 200 faults per year across the world on less than 600 commercial submarine systems in operation, suggesting that every cable system operator should plan and budget for a fault at least once every three years. On this basis, it can be seen that, although the age of a system is a relevant factor, the key issue is how much redundancy exists in each of these Caribbean island markets. One system is clearly insufficient and even two-system redundancy has been shown to be inadequate in some cases.

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Energy

The subsea cable system and the many layers of the network stack above it all depend on electricity for their operation. Interviewees across sectors expressed concern about the current and future energy capacity for supporting resilient digital infrastructure. One interviewee from the subsea cable industry described how the robustness of energy networks and energy dependency now forms "a more critical element of the resilience of the subsea cable network" than before.

Energy dependency is significant for the entire network, from the subsea segment all the way to the end-user. There are many instances in which the subsea cable might continue to be powered, but the lack of end-user power for devices inhibits connectivity. A faculty member at one island university noted that load-shedding of the electrical infrastructure had substantially affected students' ability to attend online classes on time and access cloud-based content, since not everyone had access to electricity or a generator.

"Power is always a risk factor," observed one information technology consultant. It's not only the grid, but the diesel backup generators and battery systems, which are "not immune to disruption." During Hurricane Maria, the lack of preparedness for diesel distribution to the subsea cable landing station on one island created significant challenges for operation. On another, the generator room of a major CLS was completely flooded and in a third instance, lack of regular maintenance meant that the generators did not start when they were needed.

Energy regulation plays a role in resilience. The majority of the islands have government-owned and operated electrical utilities. In a few cases, the power generation, transportation, and distribution sectors are privately owned and lack sufficient government oversight, allowing companies to supply high, low, or no voltage without oversight. The high cost of electricity can create barriers to establishing and maintaining key mission-critical infrastructures such as data centers and PoPs (Point of Presence) that facilitate cloud infrastructure. Notably, energy capacity, regulation, and cost are not uniform throughout the Caribbean, creating a variable terrain for the development of telecommunications services.

Cybersecurity

As organizations and sectors consider moving to cloud-based systems, they often face increased cybersecurity threats. This requires increased, mostly human, resources. It is a known fact amongst cybersecurity specialists that the Caribbean region has emerged as a key target for cyberattacks, driven by increasing digital connectivity and significant vulnerabilities in its infrastructure.

One way that is being measured is through the ITU's Global Cybersecurity Index (GCI), which measures countries' commitment to cybersecurity at a global level.[24] When comparing the GCI scores against GDP per capita, a pattern emerges where nations with lower GDP, such as many small island states in the Caribbean, often exhibit lower cybersecurity capabilities and commitment. In parallel, many interviewees noted that cybersecurity was indeed a significant challenge for network resilience.

[24] This index evaluates each country across five pillars: (i) Legal Measures, (ii) Technical Measures, (iii) Organizational Measures, (iv) Capacity Development, and (v) Cooperation, aggregating them into an overall score. International Telecommunication Union. (2024). Global Cybersecurity Index 2024 (5th Edition). Available at: https://www.itu.int/epublications/publication/global-cybersecurity-index-2024 (Accessed 16 December 2024).

Political and Regulatory Challenges

Fragmented Political Landscape

The Caribbean is not a unified social or political environment. In addition to market fragmentation, lasting colonial legacies have had an impact, with six official languages spoken in the region and many more unofficial languages. The Caribbean is one of the most ethnically diverse regions on the planet with Indigenous peoples, Africans, Indians, Europeans, and Chinese all inhabiting the islands. [25]

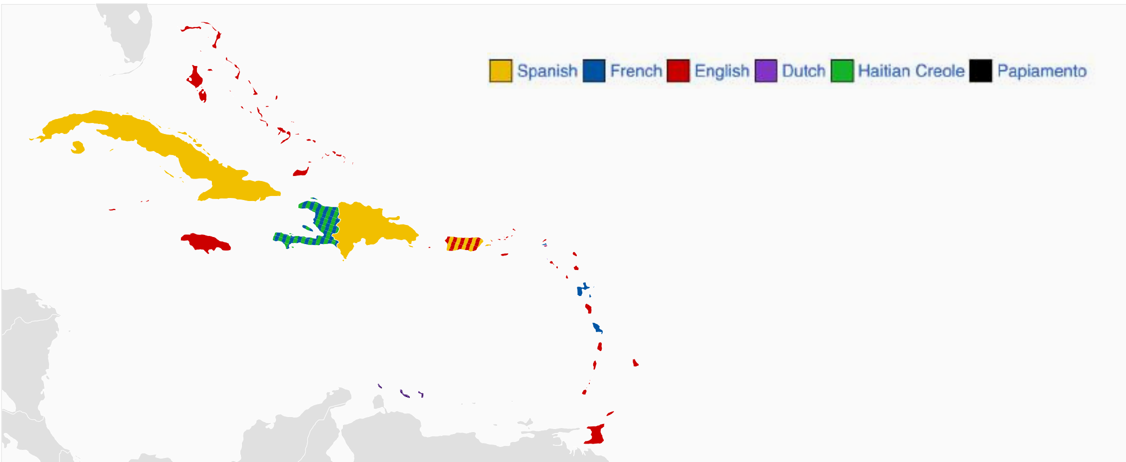
The contemporary Caribbean comprises thirteen sovereign states and twenty additional political entities, including dependencies and overseas territories. Despite their small size and geographic proximity, Caribbean states and entities are very independent and have their own historical, cultural, and economic challenges and dynamics. The region is also governed by national entities and former colonial powers on a bi-lateral basis and as such is affected by political influence of France, the Netherlands, the United Kingdom, and the United States. This gives the region a unique geo-political complexity.

This complexity is reflected in how infrastructure networks have been developed, financed, and organized in the region. It also can be seen in their varied limitations. One interviewee with decades of experience managing submarine networks observed that states in the Caribbean lack a unified and harmonized way of deploying region-wide infrastructures, differing from archipelagic countries like Indonesia. A telecommunications regulator commented: "The islands have their unique situations, and you cannot apply a one-size-fits-all solution. It is important to consider local circumstances before making any sweeping regulatory changes." As a result, resilience strategies have to be locally-tailored.

> "The islands have their unique situations, and you cannot apply a one-size-fits-all solution. It is important to consider local circumstances before making any sweeping regulatory changes."

Interviewees suggested that there may be opportunities for Caribbean island states with commonalities, e.g. geographic proximity, language and culture, political governance, or similar industrial bases, to collaborate in enhancing their network resilience but purely pan-regional initiatives are largely unfeasible.

Official Languages Spoken in the Caribbean



[25] CARICOM. (n.d.). Our People. Available at: https://caricom.org/our-community/who-we-are/our-people/ (Accessed 07 December 2024).

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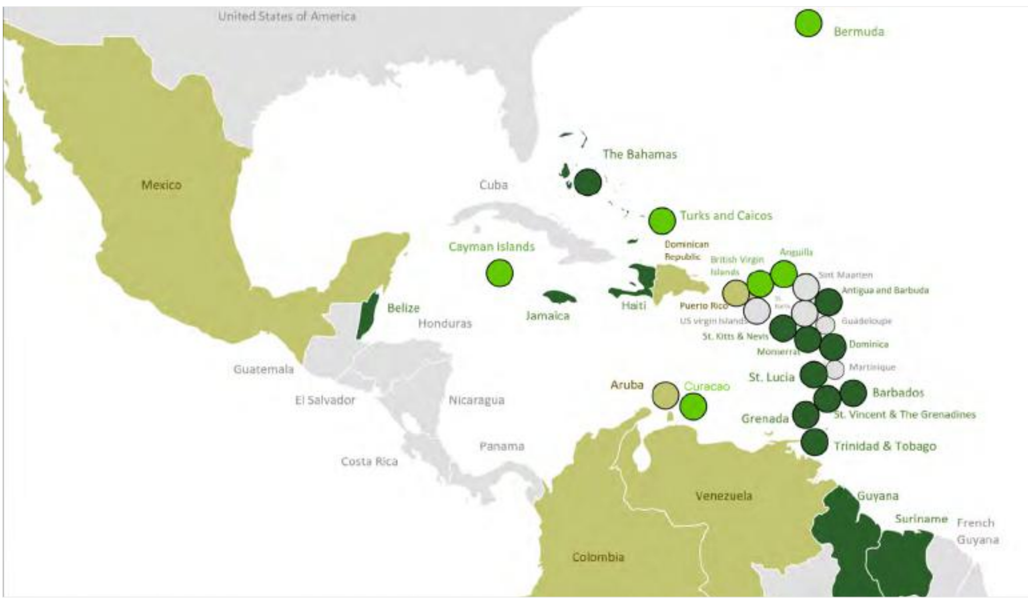
Complex Regulatory Regimes

In part due to this geo-political complexity, multiple regulatory bodies for telecommunications have authority in the region. Many Caribbean territories rely on distinct national regulatory frameworks, such as Jamaica's Office of Utility Regulation (OUR). The Eastern Caribbean Telecommunications Authority (ECTEL) regulates telecommunications for five islands—Dominica, Grenada, St. Kitts and Nevis, St. Lucia, and St. Vincent. Barbados, which currently maintains its own regulatory regime, is considering joining ECTEL. Antigua features a unique setup where the government-run Antigua Public Utilities Authority (APUA) competes with private providers like Digicel and Flow, remaining outside of ECTEL's jurisdiction. In the Turks and Caicos Islands, the Turks and Caicos Telecommunications Commission oversees all regulation and licensing, and Puerto Rico is subject to the United States' Federal Communications Commission. There are many other bodies across the region that have different sets of activities and competing priorities depending on the local context.

As a result, islands across the Caribbean have many different telecommunications acts. One former regulator notes that while these are similar, they also have subtle but important differences. On the whole, he argues, over time these regulations have not been able to grapple with the new dynamics posed by internet development. In the Eastern Caribbean, the new Electronic Communications (EC) Bill was passed in 2024 to repeal and replace existing telecommunications acts with legislation that could encompass a broader scope of internet communications in the ECTEL States. The regulator states that although "this represents a significant change in the regulatory process" the EC Bill was first promulgated in 2009. It is also worth noting that ECTEL represents PoPulations amounting to just over 1% of the Caribbean region.

In addition to formal regulatory bodies, there are also several intergovernmental and trade organizations for whom network resilience is a concern. The Caribbean Community (CARICOM) is an intergovernmental organization established in 1972 with fifteen member states and five associated members. Heads of government meet annually or biannually to discuss and make policy decisions on regional issues. One key topic of discussion is the importance of Internet resilience to the region. These meetings aim to address issues collectively and foster a collaborative approach to enhance the region's overall infrastructure and policies.

Member states of the Caribbean Community



Within CARICOM, the Council for Trade and Economic Development (COTED), has focused specifically on information and communication technology. In July 2024, the Community advanced and approved a digital resilience strategic framework, encompassing "digital integration, infrastructure and connectivity, skills workforce development and capacity-building, government, e-services and sectors, and the policy regulatory environment."

The Caribbean Telecommunications Union (CTU), established by the CARICOM Heads of Government in April 1989, is the policy decision arm of CARICOM for technical matters. In 2005, the Caribbean Internet Governance Forum (CIGF) was first convened by the CTU to provide a platform for synthesizing Caribbean views on Internet policy.

One telecommunications regulation expert describes the challenge posed by the fragmented regulatory structure: it can create problems due to the different bodies' competing interests. This can in turn impact consumer prices and services. Another regulator described that at times individual states were not even aware of what regulation might be needed to support a resilient network.

Ineffective Regulation and Lack of Oversight

Many Caribbean states have encountered regulatory hurdles that limit market entry for new participants in the telecommunications and digital infrastructure sectors. For example, some communications licenses may have been granted in perpetuity and with little detail. This has often resulted in minimal competition and elevated costs for consumers. Interviewees described numerous outdated regulations. Coupled with a lack of clear frameworks for investment and licensing, these now function as impediments to the region's potential for widespread, affordable, and resilient connectivity. A current telecommunications regulator observed that they currently had no visibility for "practices associated with subsea cables. In terms of just transparency and policy issues, that hinders resilience considerably because it undermines small players in the market."

There is legislation in place on many islands, which offers structure, yet many interviewees pointed out that such regulations are not necessarily effective in practice. In some places, the issue is that there is not a clear "demarcation line between the government and the regulator in the region." As a former regulator described: "Often, the regulators must have the backing of the government. This does not necessarily mean they will be biased, but it complicates clear-cut decision-making. Regulators might hesitate, thinking, 'I don't want to upset this person.' Even though on paper it is an independent regulatory structure, in reality, it is not."

Many interviewees pointed out that insufficient regulatory frameworks for resilience itself often result in minimal investment by private telecommunications operators, leaving infrastructure vulnerable. These vulnerabilities had been raised to governments as matters of national security, yet as the regulator observes, "nothing has been done as of now." The adoption of a strong resilience plan can be very challenging to achieve, especially where there is a limited market, a lack of government support, and different stakeholders with varying interests.

Without oversight mechanisms, interviewees pointed out that there is a heightened risk of conflicts of interest, where the status quo leaves the broader PoPulation relying on these services vulnerable and dependent on insufficient infrastructure that fails to meet current demands.

Notably, many of these regulatory issues are not unique to the Caribbean, which opens avenues to draw best practices and insights from other regions.

Political Influences

No matter what the region, subsea cable resilience is strongly influenced by political dynamics. This is the case more broadly for many infrastructure projects that require substantial funding and enable the functioning of dependent sectors. Although the need for additional cables to bolster resilience is widely acknowledged by many in the Caribbean region, the reality is that political drivers shape investment decisions, as politicians seek projects that enhance their public image.

One subsea cable consultant with extensive experience in the Caribbean reports, "it makes the politicians look good if they bring a new submarine cable, regardless of what the experts think about whether it's needed or not." However, election cycles and conflicts of interest can delay or complicate these initiatives, with decision-making often stalling near election periods: "When you get close to election time... politicians get nervous about making any decisions to spend money."

Ultimately, the political cycle in the Caribbean plays a pivotal role in subsea cable investments, influencing both the timing and justification of projects. This is particularly challenging given the slow pace of development. One interviewee reports: "you might start a project at the very beginning of an election cycle... but because of the slow development of decision making, you can easily use up four years, five years, and suddenly the election's upon you." Infrastructure developments are moving pieces connected to the political priorities of each individual island state.

Permitting

Around the world, licensing and permitting can also be a challenge for the development of new subsea cable networks. However, one Caribbean operator reflected that this was not necessarily true for all islands. "The regulatory and permitting regime in the Caribbean, particularly on the smaller islands, is quite good for the installation and maintenance of cables. They understand that their countries rely 100% on these cables, so they are more than happy to bring new ones in."

On other islands, there are more difficulties. There have been reports that significant delays in the approval, installation, and repair of subsea cables have been created by the need to acquire permits. This then amplifies the economic challenges of cable development. As research by the Global Digital Inclusion Partnership observes: "Investors are less likely to land a cable in a country whose regulatory environment is unsettled, anti-competitive, and/or overly burdensome. Countries with a poor regulatory landscape would thus be deprived of the economic benefits that subsea cables would otherwise bring."

> **"The political cycle in the Caribbean plays a pivotal role in subsea cable investments."**

Communication and Collaboration Challenges

Across these many examples, there is a common challenge: communication and collaboration around network resilience, especially when it comes to subsea cables.

The Caribbean's geographic and political complexity produce a fundamental challenge to collaboration across diverse island contexts. Regional competition will impact how collaborative parties are prepared to be. The economic difficulty of justifying a business case is often tied to the challenge of communicating the value of resilience. The value of resilience and the significance of subsea cables are difficult and yet essential to communicate as investments are affected by political dynamics and public sentiment. However, there is little understanding of network development timelines (their long lead time and the benefits of connecting to systems already moving through the area).

These communications and collaboration issues likewise make it difficult to develop education about subsea cables across the islands, which can in turn ensure a workforce capable of developing resilient networks.

Despite their importance, subsea cables often remain outside public debates on investment priorities, climate resilience, and internet access, leading to the circulation of misinformation and ineffective policymaking.

We describe this as the first responders model for network resilience. The first responders model is a single entity-focused approach that functions as a zero-sum game. In this framework service providers and governments prioritize individual gains over collective resilience, fostering a competitive rather than collaborative environment. This mindset influences how subsea cable operators and governments strategize and implement resilience measures, potentially at the expense of shared security and operational robustness.

Photo by Iago Bojczuk (2024).

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One key feature of this model is the dominance of business competition. Providers primarily perceive one another as rivals, competing for market share and profitability rather than recognizing opportunities for mutual benefit. This adversarial outlook can limit the potential for collaborative resilience-building initiatives that strengthen the regional subsea network.

Another characteristic of the first responders model is the prevalence of isolated resilience strategies. Each operator independently seeks to maximize their own individually-robust networks and revenue by maintaining exclusive control over their infrastructure assets. Governments, when they do define network resilience, tend to do so domestically rather than in international collaboration. This siloed approach has at times resulted in duplicated efforts and missed opportunities to leverage shared resources for enhanced security and efficiency.

While there are mechanisms for cooperation, such as peering and restoration agreements, these are largely driven by revenue considerations rather than proactive resilience planning. These agreements, while providing short-term financial benefits, inadvertently increase shared risks by creating interdependencies that are not supported by comprehensive, joint risk management strategies.

In a competitive and siloed approach, entities prioritize their own resources and capabilities in preparation for crisis situations. While this model emphasizes self-reliance, there is a need for a more integrated, cooperative framework to address the growing challenges to the resilience of regional subsea infrastructure. In fragmented markets like the Caribbean, true resilience requires more than just operator investment; it requires streamlined regional cooperation to overcome logistical and bureaucratic bottlenecks.

> **"The first responders model is a single entity-focused approach that functions as a zero-sum game."**

BEST PRACTICES IN STRATEGIC NETWORK RESILIENCE

Photo by Iago Bojczuk (2024).

BEST PRACTICES IN STRATEGIC NETWORK RESILIENCE

In the face of these challenges, this section outlines some best practices in strategic network resilience in the Caribbean. These are drawn from our team's extensive research across several Caribbean islands as well as recommendations identified by the International Cable Protection Committee (ICPC) and other key reports.

Such changes in resilience can be incremental and should be holistic. Developing more resilient subsea cable systems can stretch across layers of the network and infrastructure, from design and power management, to ensuring cables land in different locations, to harmonized regulations and streamlined permitting processes. Many opportunities for enhancing resilience bridge network layers but will take coordination to enact.

In numerous cases, we found stakeholders—including governments, technology providers, state agencies, and community organizations—forming effective alliances, creating engagement strategies, and addressing vulnerabilities often via communication and collaboration. Many of the below strategies prioritize coordination, knowledge-sharing, and proactive planning.

Through such measures, it is possible to enhance an interconnected ecosystem that not only addresses current risks but also adapts proactively to the evolving demands and threats faced by the broader digital infrastructure sector.

Resilient Pathways: Lessons from the ITU

One example of a notable early and forward-thinking approach to resilience is Resilient Pathways: The Adaptation of the ICT Sector to Climate Change (2014), a report released by the International Telecommunication Union (ITU), in collaboration with the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Educational, Scientific and Cultural Organization (UNESCO).

The report identifies that adoption of resilience pathways requires moving beyond generic contingency and risk management measures. It adopts a broad, system-wide perspective that transcends specific actors and isolated climatic threats. The report recognizes the sector's capacity not only to "adjust" but also to transform in response to climatic stressors and emerging opportunities.[26] It identifies key resilience attributes of the ICT sector.

Resilient pathways: Linkages between resilience attributes and potential (adaptive) responses by the ICT sector according to ITU (2014)

Resilience Attribute	Definition	ICT Sector's Potential Response
Robustness	The ability to maintain performance amidst environmental shocks and fluctuations, spreading risks to retain overall consistency.	Strengthen physical assets (e.g., flood barriers, cooling systems, infrastructure).
		Review governments', regulators', and market roles in addressing climate risks.
		Adopt measures to ensure ICT structures continue to operate amidst climatic stress.
Self-organization	The ability to rearrange processes and functions independently in response to external disturbances to withstand, adapt, and recover.	Foster collaborative mechanisms among stakeholders to address sector vulnerabilities at regional, national, and international levels.
		Facilitate access to resources (financial, technical infrastructure, social resources, data).
		Encourage collaboration among major telecom providers to build the business case for addressing climate risks.
Learning	The capacity to gain or create knowledge, strengthen skills, and innovate through experimentation and discovery.	Support research on ICT-climate change linkages and risks throughout the supply chain.
		Review evidence from past weather events to draw best practices.
		Encourage experimentation and innovation to develop responses for climatic conditions.
Redundancy	The availability of interchangeable systems, processes, or components to ensure continuity in case of failure or disruption.	Promote surplus systems, interoperability, and response pathways to avoid complete collapse.
		Foster multi-sector approaches to address operational gaps during climatic events.
		Encourage functional overlap of contingency measures to ensure ICT service and network continuity.
Flexibility and Diversity	The ability to undertake diverse courses of action and utilize resources while adapting to changes or uncertainties.	Improve financial mechanisms for rapid savings, credit, and insurance to respond to extreme events.
		Ensure swift access to information for short-term decision-making.
		Strengthen coordination between governments, local authorities, and ICT providers for emergency responses.
Scale	The ability to access a breadth of assets across multiple levels to overcome, recover from, or adapt to disturbances.	Strengthen cross-sectoral and multilevel collaboration with broader support networks (e.g., governments, regulators, market players).
		Provide mechanisms for ICT infrastructure and service providers to access financial, human, and other resources.
		Foster cross-government collaboration to address interdependency issues.

The strategic network resilience approach draws from the approach of the ITU's adaptation framework to strengthen core resilience attributes, even if subsea cables are not addressed there.

[26] Ospina, A. V., Faulkner, D., & Dickerson, K. (2014). Resilient Pathways: The Adaptation of the ICT Sector to Climate Change. International Telecommunication Union. Available at: https://www.itu.int/en/ITU-T/climatechange/Documents/Publications/Resilient_Pathways-E.PDF (Accessed 25 October 2024).

Geographic Pathways

Three geographic pathways to a more resilient subsea network include laying additional subsea cables to underserved regions, diversifying the routes of subsea cables, and developing new hubs for subsea networks. As one interviewee stated, "creating geo-redundant systems within the Caribbean is essential."

For such projects to be successful, those in the subsea cable industry believe there must be a balance between technical feasibility, collaboration that effectively navigates regional politics, and communication of the need for redundant and diverse subsea connections to potential funders.

One of the simplest ways to achieve such redundancy, which is often overlooked, is to add a branch to an existing cable or ideally a cable still under development. There are several cables recently laid and under development that are designed to cross the region which aim to enhance bandwidth, ensure redundancy, and strengthen connectivity between Central America and both North and South America, due to a renewed interest in the region.

In order to connect to these systems, island stakeholders should become sufficiently aware of what is happening in the regional subsea space to identify potential opportunities when they arise. This means being more engaged with the subsea fiber-optic industry than most Caribbean governments are today. In addition, subsea cable builders should also be engaging with island stakeholders.

Governments should also be aware that timing is critical. There is a very short window for islands to propose participation and acquire funding to connect to a cable system in development. It is always disruptive and usually cost-prohibitive to install a branch to connect to a subsea cable once it is in operation.

> **"One of the simplest ways to achieve such redundancy, which is often overlooked, is to add a branch to an existing cable or ideally a cable still under development."**

Economic Pathways

Establish Government Support

Developing and diversifying new cable routes is dependent on "scaled investment in the right places," as one expert in the region's subsea networks observed. "This is a key component to increasing resilience of the network."

Many stakeholders in the Caribbean suggested that domestic government funding would be crucial for the delivery of stable and cost-effective subsea cable connectivity. This is a deviation from the dominant model of subsea cable development, where private entities build projects alone or in consortia, but it is becoming more prevalent. Several suggested that governments could leverage lower capital costs via low-interest loans and would be in the position to co-fund and even lead such projects. In such a model, several interviewees emphasized, individual nations could address their specific infrastructure needs proactively.

> Domestic government funding would be crucial for the delivery of stable and cost-effective subsea cable connectivity.

There are some island governments that have begun to consider funding subsea cable networks and have even undertaken studies. The Honorable Erwin Jay Saunders, Deputy Prime Minister of the Turks and Caicos Islands, described their domestic fiber-optic cable as "the highest priority"--the only way to increase the network resilience of the islands. Pedro Ariza, Chairman of the Board of Directors for the Grand Turk Enhancement and Sustainability Agency (GTESA), "governments in the Caribbean may need to assume ownership of critical infrastructure, as the Internet serves as a fundamental pillar of modern economies." This, as other interviewees noted, "takes the vulnerability away from their profit-driven service providers." In other words, the role of the government is to underwrite that part of the commercial risk in a submarine cable project that cannot be mitigated by profitability projections.

Regional governments can also offer targeted incentives to providers for economically unviable resilience efforts. These might include financial support for the construction of physically diverse cables which reduce the risk of simultaneous failures during disasters or other disruptions, or provision of services to underserved communities. Many saw such interventions as necessary to guarantee the resilience of these island networks in the long term.

Develop Strategic Collaborations

Another path toward funding involved strategic collaborations through multinational funding or international support. In other parts of the world, external funding and subsidies have been oriented to resilience. In the Caribbean, the British and French governments have demonstrated a significant interest in influencing how public funds are allocated. France has adopted a more proactive approach, actively supporting the development of infrastructure, including funding subsea cables with European Union or national resources. In contrast, the United Kingdom's stringent financial management requirements ensure disciplined spending but can also create delays in project implementation.

In the Pacific region, where strategic competition among major global powers has intensified, increased international support has been directed toward subsea cable projects in small Pacific Island states. In several cases, such support has enabled new or additional fiber-optic connections that may have been difficult to deliver through commercial investment alone, given high deployment costs and limited market size. This has not yet occurred in the Caribbean.

Several stakeholders emphasized that countries might coordinate effectively to secure financing for a backbone cable system, which could have branches to multiple islands, or a ring around the Caribbean. The latter option had been examined as one of the most cost-effective solutions for bringing resilience to the region even as it was still a massive investment. As one industry expert commented, "Cooperation between nations seems like an obvious approach. Historically, cables were often built by consortia... that model could be very applicable in the Caribbean, where nations can identify and act on shared interests."

Interviewees identified cases where a shorter and relatively inexpensive additional unrepeatered path could prove valuable in enhancing resilience for some islands.

One key consideration in potential collaboration between governments on a specific subsea cable is the comparative timing of planning and budget cycles. This must be a long-term effort given that the timing of budget priorities between small island developing states and with the cable build payment cycle must be coordinated. Debt financing (i.e. government bonds) could provide the necessary bridge between budget cycles and cable construction phases. Governments should recognize that the opportunity to connect to the backbone of a system passing through the Caribbean is likely to be a once-in-a-generation opportunity. If the opportunity is missed, the ship has literally sailed.

Communicate the Value of Resilience

Communicating the value of resilience is central to strategic collaboration. One consultant stated that a cable system might work from a networking point of view, but it could only from a Caribbean politics point of view if people were made aware of the true benefits of resilience. What resilience can do needs to be actively demonstrated in financial and other terms.

Another industry expert echoed this: "I think you have to sell resilience first. You have to say that there's no easy solution. Is what you've got really adequate? And are you willing to look at something? Which means everybody needs to make compromises." Emphasizing the tangible benefits of resilience helps stakeholders adopt shared strategies for more robust routing, as evidenced by recent investments in routes designed for redundancy and expanded bandwidth—crucial steps in safeguarding connectivity throughout the region.

> **This isn't just a technical matter; it's an economic issue that will affect all countries in the region. The economic viability of each country is closely tied to ICT and Internet resilience.**

As another interviewee succinctly put it: "There needs to be a meeting of the minds to make everyone understand that this isn't just a technical matter; it's an economic issue that will affect all countries in the region. The economic viability of each country is closely tied to ICT and Internet resilience. For example, every one of the seventeen UN Sustainable Development Goals includes some aspect of ICT resilience."

Infrastructure Pathways

In many cases, our research found that resilience efforts were often limited to ensuring individually-robust operations within a single layer or sector. Addressing this, best practices for resilience include increasing communication and collaboration entities across the entire infrastructure stack. Subsea cables must work in tandem with other digital infrastructures (including data centers, points-of-presence (PoPs), cellular networks, terrestrial fibers, etc.) as well as non-digital infrastructures (such as the electrical grid) to sustain connectivity. Even a reliable water supply and drainage is essential.

Structure Stakeholder Communication

In our interviews we discovered numerous cases in which stakeholders communicate informally, both in the moment of crisis and in everyday operations, to enhance resilience. Proactive communication has enabled the recognition of shared risks, which in turn leads to practical opportunities for collaboration: infrastructure owners/operators, governments, and service providers can act to structure maintenance if needed, collaborate on data sharing, and jointly develop rapid response strategies to accelerate repairs when failures occur.

> **If such communication was structured, this would pave the way for multiple stakeholders to work together to create robust infrastructure rather than inadvertently reinforcing single points of failure.**

As one example, we found that when service providers and energy suppliers were in regular contact, this facilitated opportunities for mutual benefit. Following the impact of a hurricane on one island, direct contact was established between one network operator and with the energy supplier, which now recognizes the facility as critical infrastructure. This relationship has, in some cases, reduced downtime by over an hour during power outages in the area. Another measure implemented was the generation of contracts for diesel distribution in the case of emergency.

Adhering to international norms, especially in energy efficiency and environmental sustainability, is increasingly seen as vital. Global pressure is mounting for greener operations. Aligning with recognized benchmarks may help Caribbean operators avoid subjective decision-making and ensure consistent service quality. These standards also open the door to potential foreign investment and partnerships. International stakeholders are often inclined to support operators who uphold proven sustainability metrics. In some cases, financial institutions now require demonstration of sustainability measures.

Resilience-enhancing communication is possible not only between network operators and energy providers, but between dependent sectors. One police department, for example, secures fuel for their network's operations through a dedicated provider that reserves a large tank exclusively for critical services, ensuring network resilience during emergencies.

Several stakeholders suggested an easy first step: establish a designated domestic point of contact to oversee not only the development of subsea cable projects in a country or territory but also their long-term sustainability and restoration. This point of contact could be a person or a government department tasked with responsibility for subsea cable policy overall. One regional expert suggested, "this role requires a comprehensive understanding of the entire process, from fiber installation to the ongoing maintenance." Such a point of contact can facilitate communication within and between governments. It can also give the industry a department to communicate with to help to streamline activities. This has worked very effectively elsewhere and assists with policy coherence.

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> Enhancing stakeholder communication can facilitate operational synergy.

Find Operational Synergies

Enhancing stakeholder communication can facilitate operational synergy and help providers to work together to achieve outcomes that would be unattainable individually. By coordinating efforts—whether in resource sharing, risk assessment, or emergency response planning—operators can realize significant efficiency gains.

These collaborative efforts can lead to more robust infrastructure, quicker recovery times during disruptions, and ultimately, greater trust and reliability in regional communication networks. One telecommunications expert in the region comments that "companies operate independently, focusing on their own interests. Greater collaboration could allow for shared investments and better cable protection."

Best practices in strategic network resilience already in place include the generation of capacity-sharing agreements amongst subsea cable operators as well as mutual restoration agreements. As one operator observed, "companies already use each other's infrastructure for redundancy." Where both providers have two cables, redundancy can be achieved independently without reliance on the other. In most cases, the operator noted, "capacity is shared between providers' cables through commercial agreements. These arrangements are not direct swaps but involve partial exchanges supported by negotiated commercial deals, reflecting a practical approach to ensuring connectivity."

There is also a need to bridge the gap between subsea cable operators and Internet Service Providers (ISPs). Finding common ground, several interviewees noted, typically at network interconnection points, is critical to foster collaboration to enhance network resilience and efficiency. There are many examples of collaborations between operators during times of crises, such as cable restoration, roaming agreements and resource sharing following a natural disaster. Such agreements can be proactively designed and developed ahead of the next crisis.

Changes are often implemented after times of crisis. As one example, in Dominica following Hurricane Maria, a fiber-optic ring around the country was created. A backup system was built so that, if the company that won the bid to provide the primary service failed, there was an option to switch to their competitor to maintain services. Apart from fiber-optic cables, satellite communication, microwave communication, and a service called air fiber (a type of microwave service), were implemented specifically for resilience, alongside regulations ensuring emergency telecommunication service.

The need for coordinated assessment across systems was often articulated in discussions between stakeholders about terrestrial fiber systems. As one former regulator discussed: "Hurricane Maria taught us that fiber is not invincible. Both overhead and underground fibers were damaged, causing a complete communication breakdown." While overhead fiber was susceptible to wind damage, underground fiber–typically the more secure technology–could be washed away by heavy rains.

> Hurricane Maria taught us that fiber is not invincible. Both overhead and underground fibers were damaged, causing a complete communication breakdown.

Proactively Monitor and Maintain Infrastructure

All operators agreed that careful, proactive monitoring and maintenance was an essential best practice for resilience. A proactive maintenance program and monitoring of physical risks (including simple issues like vegetation growth) not only helps mitigate the risk of disruptions but can also extend the operational life of infrastructure and related equipment.

A best practice in collaboration on subsea cable maintenance is the presence of collective cable maintenance services, such as the Atlantic Cable Maintenance Agreement (ACMA), which serves the Caribbean. This ensures that maintenance vessels are on standby at all times in the case of a subsea cable break. The Agreement includes a "priority assessment" in the event of coincident failures.

Political and Regulatory Pathways

Industry-led initiatives are critical for protecting subsea cable assets but this remains insufficient without complementary government actions.[27] In regions such as the Caribbean, ensuring network resilience requires sustained and structured government involvement— ranging from interagency engagement to cross-disciplinary dialogue with telecommunications and infrastructure providers.

Harmonize Regulatory Regimes

Resilience can be enhanced by adhering to the International Cable Protection Committee (ICPC) Government Best Practices for Protecting and Promoting Resilience of Submarine Telecommunications Cables (see Appendix). As emphasized in the ICPC recommendations, states should regulate marine activities that pose threats to subsea cables and implement spatial planning requirements within their jurisdictions.

> “States should regulate marine activities that pose threats to subsea cables and implement spatial planning requirements within their jurisdictions.”

Establishing liability frameworks for cable damage is essential, alongside regulatory regimes that promote infrastructure diversity and enable swift repairs—which remains a big financial challenge for operators.[28] These changes assume that governments can also explore a more active coordination with neighboring states, international bodies, and institutions to address regional and global activities impacting subsea cable networks, ensuring a cohesive and comprehensive approach to resilience.

Subsea cable experts have repeatedly assessed that streamlined and clear regulation is key to implementing subsea projects successfully. A strong regulatory environment supports many aspects of the subsea ecosystems and enables them to thrive. One cable developer asserted: “One thing that kills submarine projects faster than cost is lack of certainty in process. If you want a cable to come by and connect, make it easy for them, make it easy to do business. You are rolling out the red carpet, not the red tape.” We found key examples in the Caribbean where legislative frameworks helped to create certainty in the process and facilitated infrastructure diversity.

Governments can streamline permitting processes for infrastructure development, ensuring that providers face fewer bureaucratic delays. This means reducing administrative bottlenecks and limiting avoidable delays for providers. These measures create a win-win scenario, enhancing regional connectivity and resilience while benefiting providers through reduced costs and accelerated deployment timelines. When well-designed, these reforms strengthen regional connectivity and resilience while simultaneously lowering costs and shortening deployment timelines.

However, the pace of subsea cable deployment—and, more critically, repair—is not shaped by permitting alone. In practice, friction often emerges in adjacent policy domains that were not designed for the operational realities of a globally mobile cable fleet. For instance, customs and importation regimes may require the formal “import” of a vessel or specialized equipment before urgent work can begin. This often triggers sizable bonds, duties, and clearance procedures that compound network outage times. Similarly, cabotage rules, while serving legitimate domestic shipping and labor objectives, can inadvertently prevent foreign-flagged repair ships from operating quickly in territorial waters.

[27] Bressie, K. (2021). Best Practices for Submarine Cable Protection and Resilience. Presented at the International Cable Protection Committee (ICPC) Workshop, Sines, Portugal, 28 May 2021. Available at: https:/www.anacom.pt/streaming/Kent_Bressie.pdf?contentId=1642841&field=ATTACHED_FILE (Accessed 09 November 2024).
[28] Dzieza, J. (2024). The Invisible Seafaring Industry That Keeps the Internet Afloat. The Verge. Available at: https:/www.theverge.com/c/24070570/internet-cables-undersea-deep-repair-ships (Accessed 15 September 2024).

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> **Regulatory certainty and efficiency has been shown to attract investment.**

Most importantly, network resilience requires coherence across these policy areas. If subsea cables are critical infrastructure, government action must align with rhetoric. If there is a single, empowered point of contact with resources and political backing to coordinate permitting, customs, cabotage, and maritime security, this will ensure fast-track implementation for subsea network planning and emergency repair.

Narrowly tailored exemptions or fast-track provisions for cable vessels, spares, and repair equipment can prevent delays without undermining the broader intent of maritime regulation. To this end, joint "stress-testing" exercises between Caribbean governments and the cable industry are particularly productive: they identify where seemingly minor administrative requirements might cascade into significant operational disruptions. As one regulator noted: "We need to modernize the laws. Best practice regulation… needs to be updated to ensure a functioning ecosystem that can address these challenges."

Regulatory certainty and efficiency has been shown to attract investment. Singapore exemplifies this, where the country has no direct or indirect foreign equity limits for those seeking telecommunications licenses. Singapore's regulatory regime has also promoted open and cost-effective landing stations. Research demonstrates that having "cost-based open access to competing backhaul providers and cost-based interconnection" is important in building a resilient system.[29]

National governments are not the only stakeholders that can support resilient development of subsea cables. Municipal authorities can also play a key role in supporting this. As one example outside of the Caribbean, the Port of Marseille planned in advance for new infrastructure such as manholes for easy maintenance access and neutral landing infrastructure that encourages competition. Such a case illustrates the role that municipal and national-level authorities can play in supporting infrastructure deployment and long-term, strategic planning.

Currently, the CTU is working to establish a common, harmonized regulatory regime, similar to the European Union. Non-profit organizations such as CANTO, an association of operators, organizations, companies, and individuals in the telecommunications sector, can likewise be a site for the discussion of Caribbean telecommunications regulation and policy.

Stakeholders reinforced that such region-wide regulatory shifts are most effective when there is a strong separation between commercial entities, the government, and the regulatory wing in each island context. One telecommunications expert explained that in order for any island government to adequately support resilience projects, it is key to have a strong oversight mechanism in place. "We need to strengthen the oversight body. That's first and foremost." Another telecommunications expert agreed that a domestic monitoring process is necessary "to ensure that everything is implemented correctly. Without monitoring, there could be lapses or mismanagement.

Recognize Subsea Cables as Critical Infrastructure

To date, not all states recognize subsea cables as critical infrastructure and do not participate in facilitation of data sharing on incidents and threats to strengthen resilience, another recommendation of the ICPC Best Practices. In the Caribbean, several stakeholders suggested that governments could benefit from an improved database for managing critical infrastructure, including subsea cables.

In other regions, researchers have recommended maintaining an up-to-date regional database that captures details on cable ownership, cable ship bases, and each country's relevant policies and regulations. Such a resource could aggregate data in a single location and offer much-needed visibility for policymakers, ultimately strengthening the region's ability to develop and safeguard its subsea cable networks.[30]

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[29] Jorge, S., & Namara, E. (2024). Good Practices for Subsea Cables Policy: Investing in Digital Inclusion. Global Digital Inclusion Partnership. Available at: https://globaldigitalinclusion.org/wp-content/uploads/2024/01/GDIP-Good-Practices-for-Subsea-Cables-Policy-Investing-in-Digital-Inclusion.pdf (Accessed 26 October 2024).

[30] Noor, E. (2024). Subsea Communication Cables in Southeast Asia: A Comprehensive Approach Is Needed. Carnegie Endowment for International Peace. Available at: https://carnegieendowment.org/research/2024/12/southeast-asia-undersea-subsea-cables?lang=en (Accessed 10 January 2025).

You get resilience by having strong partners—partners that have a long-term vision.

Develop Regional Resilience Frameworks and Organizations

Defining national or regional resilience frameworks could allow providers to pool resources, share risks, and respond more effectively to disruptions. Facilities such as towers and backhaul transmission systems are expensive to build and maintain but, with regulatory frameworks that mandate or incentivize sharing, operators could significantly reduce costs here as well. Ideally, these savings could be passed on to consumers, while also accelerating network expansion into underserved markets. Shared facilities lower barriers to market entry and promote more equitable access across the region.

As one example of this, proposals for carrier-neutral subsea cable landing stations may offer a platform where multiple operators can interconnect under fair terms. By removing operator-specific barriers, these stations encourage competition and reduce the cost of international bandwidth.

If an administration sets a policy for resilience, service providers must comply, regardless of their profit motives. The policy ensures that even if infrastructure fails, communication and services continue. This approach could be driven at the highest political levels, in places such as CARICOM, and implemented by respective prime ministers.

Policies targeting resilient network infrastructure could in turn play a vital role in safeguarding subsea cables. As one non-Caribbean example, Ghana's critical information infrastructure policy serves as a notable case, in which subsea cables were incorporated into the nation's cybersecurity framework and cable operators were engaged to enhance network resilience and defense against cyberattacks. Policymakers aiming to implement similar measures might consider comparative practices.[31]

Such work is already beginning. The Commission on Caribbean Communications Resilience (CCCR) emerged in 2017 to recommend strategies for Caribbean governments to improve the resilience of the region's communications infrastructure in the face of natural disasters. With contributions from stakeholders across the region, the CCCR's Strategies for Strengthening Caribbean Communications Resilience report stated that collaboration is paramount, recommending that public policies prioritize foster collaboration among relevant agencies and partners at the national, regional, and international levels.[32] While the report does not provide much granularity on the kinds of technologies (or the segments of the network they refer to), it does report the need to specify minimum standards for technologies that are mission-critical in nature.

Leverage Strong Leadership

Political leadership is integral to advancing resilience frameworks, agenda-setting, and advancing cable projects. One subsea cable expert argued that a high-ranking official, such as a premier, vice premier, or finance minister, needs to publicly champion these projects to gain momentum. Leaders need to be able to communicate the importance of resilient network infrastructure to those in the government as well as constituents. As one described, "You can have all the great ideas that you like. But unless you have got the political will to make this happen, it goes nowhere." Similarly, the effectiveness of resilience policy often depends on such clear and decisive leadership.

For cable developers, generating substantive relationships with partners, including political leaders, is also essential. As a relatively unknown industry, governments face challenges in understanding the complexities of the subsea cable world. Industry members directed attention to the value of a concierge-style approach to guide political leaders through the process as well as the critical importance of building trust. This reassurance helps foster confidence and transparency in decision-making. One expert in the subsea cable industry explicitly stated: "You get resilience by having strong partners—partners that have a long-term vision."

[31] Jorge, S., & Namara, E. (2024). Good Practices for Subsea Cables Policy: Investing in Digital Inclusion. Global Digital Inclusion Partnership. Available at: https://globaldigitalinclusion.org/wp-content/uploads/2024/01/GDIP-Good-Practices-for-Subsea-Cables-Policy-Investing-in-Digital-Inclusion.pdf (Accessed 26 October 2024).
[32] Caribbean Telecommunications Union. (2019). Strategies for Strengthening Caribbean Communications Resilience. Commission for Communications Resilience. Available at: https://ctu.int/wp-content/uploads/2021/05/CCCR-Report-Jan-2019-3.pdf (Accessed 04 November 2024).

Communication and Collaboration Pathways

Communication and collaboration are key to many of the resilience practices outlined above. They are also important components of many ICPC Best Practices. The ICPC recommends, for example, that governments ensure accurate, up-to-date charting of subsea cables and then use charts to communicate cable awareness to fishermen. Mandating the use of Automatic Identification Systems (AIS) and Vessel Monitoring Systems (VMS) on vessels at all times can also assist in cable protection.

The ICPC also encourages direct engagement between cable operators and fishing communities, including the formation of fishing-cable committees. A successful example of this comes from Oregon where the Oregon Fishermen's Cable Committee (OFCC) promotes cooperation between local fishermen and cable companies. This body helps to reduce the potential financial risks of fishermen entangling their equipment with the cable infrastructure, while also negotiating clear terms and responsibilities for cable companies to reduce potential damage.[33]

A practical illustration of these principles in action is the Kingfisher Information Service - Offshore Renewable & Cable Awareness project (KIS-ORCA) project, which is specifically designed to reduce the risk of cable damage by improving situational awareness among other sea users.

KIS-ORCA contributes to subsea cable resilience by providing mariners with accurate, positional information on the location of subsea cables as well as emergency contacts and procedures in case of snagging. By making this information readily accessible, the system enables fishermen, offshore operators, and other mariners to plan and conduct their activities in a manner that avoids interaction with cable infrastructure. This proactive avoidance is a critical risk-reduction measure, as it directly lowers the likelihood of cable strikes, snagging, or other forms of accidental damage arising from normal maritime operations.

Complementing this static positional awareness is the Kingfisher Bulletin hazard alert, which delivers live notifications via email and SMS to registered users. These alerts provide timely information on offshore activities such as cable installation and repair operations, allowing sea users to adjust their plans in real time. The result is improved coordination between cable operators and other maritime stakeholders, reducing the potential for conflict and enhancing safety during periods of heightened offshore activity.

Three final areas that cut across all of the above pathways, where communication and collaboration can significantly magnify resilience include the creation of a regional subsea cable association, a shared vision for network resilience, and offer subsea cable education. These less-often recognized human dimensions are crucial because they often allow for enhancements in resilience that are not as expensive as new technical systems but nonetheless bring tangible benefits.

"These less-often recognized human dimensions are crucial because they often allow for enhancements in resilience that are not as expensive as new technical systems but nonetheless bring tangible benefits."

[33] Jorge, S. and Namara, E. (2024). Good Practices for Subsea Cables Policy Investing in Digital Inclusion. Global Digital Inclusion Partnership. Available at: https://globaldigitalinclusion.org/wp-content/uploads/2024/01/GDIP-Good-Practices-for-Subsea-Cables-Policy-Investing-in-Digital-Inclusion.pdf (Accessed 13 December 2024).

SUBOPTIC FOUNDATION

Form a Regional Subsea Cable Association

Several interviewees suggested the formation of a regional subsea cable association. A standing Caribbean subsea cable forum could routinely convene governments, regulators, coast guards and port authorities, and industry operators to coordinate resilience practices across jurisdictions.

Such a forum could be structured along the lines of the European Subsea Cable Association (ESCA), the Association of Submarine Cable Operators of Indonesia (ASKALSI), the Danish Cable Protection Committee (DKCPC), the North American Submarine Cable Association (NASCA), the Oceania Submarine Cable Association (OSCA), the Association of Submarine Cable Operators of Nigeria (ASCON), and the Africa Subsea Ecosystem Forum (ASEF), among other leading examples.

An association or other parallel forum could foster collaboration around shared protocols for communication, incident reporting, and stakeholder engagement, while also "stress-testing" where non-cable policy areas (such as customs or maritime rules) may inadvertently slow repair and restoration. Over time, it could also serve as a regional hub for cable awareness and education, helping translate best-practice guidance into locally workable arrangements.

> **"A standing Caribbean subsea cable forum could routinely convene governments, regulators, coast guards and port authorities, and industry operators to coordinate resilience practices across jurisdictions."**

Develop a Shared Vision

Even in fragmented geographic and political circumstances, enhancing communications requires building a unified narrative around the need for network resilience. This in turn necessitates aligning governments, service providers, local communities, and the public under a shared vision. Such efforts would improve information sharing about the various factors affecting cable resilience, including national security, geopolitical considerations, and strategies for mitigating disruptions.

Engaging with local journalists and media producers is a critical part of countering misinformation about subsea cables and distancing the projects from the negative associations tied to political decision-making. Rather than avoiding media involvement, direct engagement can help create a more informed public narrative and build broader support for critical investment in network resilience.

A collective approach based on transparent engagement can also help to build public trust. Equally essential is forging alliances and communications pathways among operators, regulators, and policymakers.

Educate the Next Generation

Many interviewees agree: education is a fundamental pillar of resilience. As one stakeholder succinctly articulated: "Education is seen as fundamental to driving progress, both in terms of human resources and broader economic development." Training staff to be able to locally engage with technological evolution, this person observed, should be the priority.

> Education is seen as fundamental to driving progress, both in terms of human resources and broader economic development.

Another island stakeholder also identified human resource capacity as an area of distinct concern: "We need to foster interest among students to explore the potentials within telecommunications," they stated. "Some experts are nearing retirement, and we need a new generation of engineers who understand the science, including ocean-related aspects."

A cable builder echoed this sentiment: "You want to have strong, resilient local partners because you will rely on them for various services, such as cable landing station operations. These organizations provide essential skills and resources, and you will need trained personnel, which will naturally come from the local community."

One stakeholder argued for the establishment of "vocational schools to implement a fiber optic program or certification.... We could then recruit individuals straight out of high school. I am advocating for this." For example, Puerto Rico's Smart Island Connectivity Plan, a five-year initiative aimed at improving connectivity, encompasses an educational component of the plan in which 2,500 individuals are trained in broadband infrastructure.

Some expressed confidence at the prospect of training the next generation. "It might not be too difficult," another stakeholder described: "There are young people coming out of college, but the critical factor is often their attitude and willingness to learn. We may have to provide some specialized industrial training, even if they have a background in electronics or computer programming."

Others remained sceptical: "Local recruits lack the hands-on experience we gained in telecoms, even in basic networking. So, yes, we have that challenge. In fact, 99.9% of engineering students wouldn't understand undersea cables and their role as the lifeblood of the Internet...there's a clear need for hands-on technical knowledge."

There was a need articulated not simply for technical education, but for training in the many areas that could shape and would be impacted by network resilience. These included fields such as business and economics, politics and regulation, environmental studies and management, and media and journalism, among others. Through the development of a shared language around network resilience, interviewees expressed optimism that the next generation would be well-positioned to effectively assess and work to meet their own islands' infrastructure.

THE NEXT RESPONDERS MODEL

THE NEXT RESPONDERS MODEL

Our quantitative research on strategic resilience introduces a transformative approach that redefines how resilience is conceptualized and implemented for subsea cable infrastructure. This proposed paradigm shift moves away from the existing zero-sum game, where individual gains are often achieved at the expense of collective resilience. Instead, it advocates for a positive-sum game in which all stakeholders benefit through shared collaboration and mutual reinforcement. The "next responders" model is a metrics-based forward-looking framework that prioritizes collective preparedness and coordinated responses to challenges.

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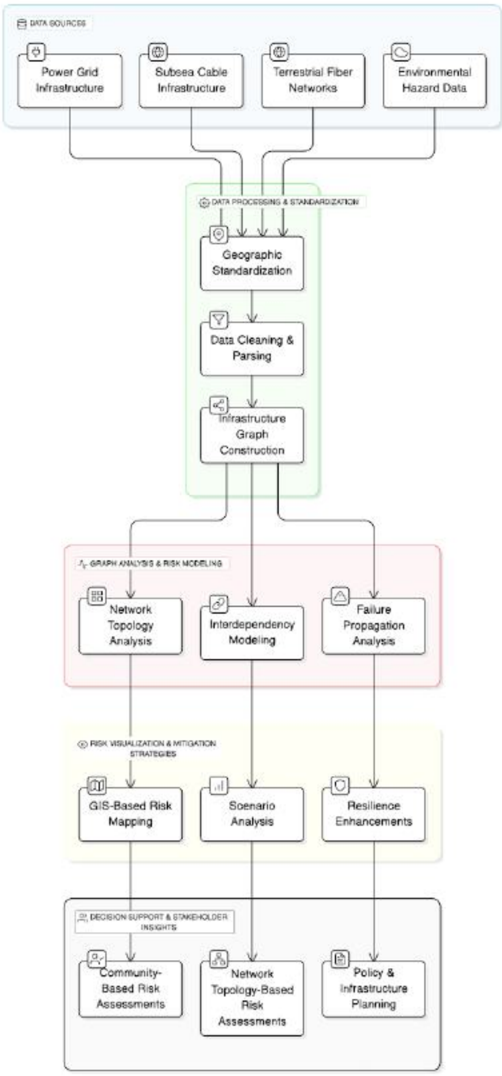
Unlike the "first responders" model, which emphasizes individual efforts to manage crises, the next responders model envisions stakeholders in the network, including subsea cable operators, as an interconnected network of mutual support. In this model, operators work together to anticipate risks, pool resources, and create shared contingency plans. This collective approach not only enhances the ability to respond to disruptions but also mitigates systemic vulnerabilities by fostering trust and cooperation across the industry.

By adopting the next responders model, stakeholders in the network can transition from isolated, competitive resilience strategies to a unified, proactive system. The model underscores the importance of building resilience as a shared responsibility, ensuring that the industry as a whole becomes stronger and more adaptive in the face of emerging threats.

Next Responder Model



Why the Next Responders Model?

The next responders model provides a scientific, data-driven approach to transforming the traditional competitive dynamics of the subsea cable industry into a framework of regional cooperation. By leveraging quantitative insights, this model seeks to address the limitations of the current zero-sum paradigm. It encourages operators to work together to build resilience at a regional level, where the interdependence of subsea cable systems makes collective action not just beneficial but essential. This shift toward cooperation fosters an environment where mutual gains are prioritized, enhancing both operational security and economic efficiency.

Adopting the next responders model offers providers a range of tangible benefits that go beyond what is achievable through isolated resilience strategies. One critical advantage is the ability to access backup capacity during disruptions. With resource sharing agreements, operators can utilize each other's infrastructure to maintain service continuity, reducing downtime and minimizing financial losses. Additionally, the model facilitates the pooling of resources—such as expertise, technology, and operational tools—enabling providers to optimize their resilience strategies without duplicating efforts.

Another significant benefit is the capacity for coordinated responses to disruptions. By establishing regional frameworks for joint action, network operators can respond more effectively to crises, whether caused by natural disasters, technical failures, or security threats. Coordinated responses not only expedite recovery times but also help mitigate systemic risks, ensuring that the subsea infrastructure network remains robust and reliable.

Motivation for Metrics and Analytic Pipelines

Why Metrics are Essential

Metrics play a fundamental role in building and maintaining resilient subsea cable networks by offering a structured, data-driven approach to evaluating vulnerabilities and guiding strategic improvements. Robust metrics enable subsea operators to quantitatively assess the weaknesses and strengths of their networks, and provide a clear understanding of where vulnerabilities exist. This quantitative evaluation is crucial for addressing risks proactively rather than reacting to failures as they occur.

One of the most significant benefits of effective metrics is their ability to generate actionable insights for identifying and mitigating critical points of failure, such as choke points or vital network links. By analyzing metrics on physical deployments (e.g., topology, redundancy, etc.) and environmental risks (e.g., hurricanes, earthquakes) on a map interface, network operators can pinpoint specific locations or systems that, if disrupted, could lead to widespread service outages. This granular understanding allows providers to prioritize investments in reinforcement and redundancy measures, significantly enhancing the strategic resilience of subsea networks.

Metrics can play a pivotal role in informing strategic planning. By comparing data from existing network configurations with projections for proposed deployments, operators can make evidence-based decisions about where to allocate resources. For example, metrics can assess the potential impact of adding new routes or deploying alternative infrastructures, helping stakeholders weigh the costs and benefits of these investments. This ability to simulate and evaluate "what-if" scenarios ensures that strategic plans are grounded in measurable outcomes rather than speculation.

Ultimately, metrics are not just tools for evaluation. They are essential to fostering a culture of resilience. By providing the data needed to make informed decisions, metrics empower providers to transition from reactive approaches to proactive, strategic planning. This shift is critical for addressing the complex challenges of subsea cable operations in a way that maximizes reliability, minimizes risks, and supports the growing demands of global connectivity.

> "Metrics can play a pivotal role in informing strategic planning."

Why Analytic Pipelines are Necessary

Analytic pipelines enable the transformation of raw metrics into actionable intelligence for effective decision-making. There are vast amounts of metric data that one can consider when planning resilience strategies, including but not limited to: performance metrics, topology-based metrics, capacity related metrics, failure rates, and environmental risk indicators. Without structured analytic pipelines, this data will remain fragmented and underutilized. Analytic pipelines provide a systematic framework to process, analyze, and interpret the data, converting raw numbers into meaningful insights that drive strategic actions. This transformation empowers stakeholders to make informed decisions, anticipate vulnerabilities, and implement targeted interventions that enhance resilience.

A key application of analytic pipelines is the creation of risk profiles and rankings that holistically evaluate threats to network resilience. By integrating metrics related to network structure, regional factors, and exposure to natural hazards, analytic pipelines offer a comprehensive view of where the network is most vulnerable. For instance, they can identify chokepoints in high-risk seismic zones or routes with limited redundancy. These profiles enable decision-makers to prioritize investments and allocate resources effectively, focusing on mitigating the most significant risks while optimizing costs.

Analytic pipelines also play an important role in supporting multi-stakeholder collaboration. Resilience in subsea networks often requires coordinated efforts among diverse entities, including service providers, regulatory bodies, and regional governments. Transparent, data-driven justifications for interventions—such as the need for new infrastructure, the reconfiguration of existing routes, or enhanced cross-provider agreements—help align these stakeholders toward shared goals. Analytic pipelines provide the transparency and objectivity needed to build trust, ensuring that all parties work from a unified evidence base and can clearly understand the rationale behind proposed actions.

In sum, analytic pipelines are not merely tools for processing data—they are the backbone of a proactive, collaborative approach to subsea network resilience. By transforming raw data into actionable intelligence, creating comprehensive risk assessments, and fostering transparent, data-driven decision-making, these pipelines can ensure that the subsea cable industry can effectively navigate the complex challenges of a dynamic global environment.

SUBOPTIC FOUNDATION

A Decision Support Framework for Strategic Network Resilience

Translating the next responders model into an operational prototype requires a systematic approach to decision-making at three distinct levels —who, why, and how.

First, it is necessary to determine who is the best next responder for an established provider or infrastructure. This involves identifying other providers or infrastructures within the region that have the capability to step in and support the incumbent in times of disruption or crisis. Factors such as geographical proximity, technical compatibility, and capacity for resource sharing must be considered to ensure that the chosen responder can effectively mitigate risks and maintain service continuity.

The second level of decision-making involves understanding why a provider or infrastructure should act as a next responder. This step requires a clear rationale for collaboration, driven by mutual benefit and shared resilience goals. Providers need to assess how supporting an incumbent's operations will also enhance their own resilience and market positioning. These reasons may include access to backup capacity, improved risk management, or the potential for establishing long-term strategic partnerships. A framework must be developed to evaluate the incentives for each provider to participate in the cooperative response system.

Finally, the third level of decision-making concerns how a provider or infrastructure should act as a next responder. This involves defining the operational processes and procedures for collaboration, including how resources will be shared, how responsibilities will be divided, and how disruptions will be communicated and managed. Clear protocols for coordination, emergency response, and resource allocation must be established to ensure that each provider is prepared to act swiftly and effectively when required. These protocols should be flexible enough to adapt to different scenarios while ensuring that all parties involved have a shared understanding of their roles and commitments.

By addressing these three levels of decision-making—who, why, and how—the next responders model can be operationalized to support regional cooperation to enhance the resilience of subsea cable infrastructure.

SUBOPTIC FOUNDATION

Challenges in Prototyping the Next Responders Model

To effectively implement the next responders model, there is a need for practical yet simple metrics that can answer the critical question of "who" is the best next responder. These metrics should be designed to assess the readiness and capabilities of potential responders in real-time, factoring in variables such as geographic proximity, infrastructure capacity, and historical performance during disruptions.

The goal is to provide clear, quantifiable indicators that enable providers to quickly and accurately identify which infrastructure or provider is most capable of stepping in to support an incumbent's operations during a crisis. By simplifying this process through accessible metrics, the model can be operationalized more efficiently across diverse regions and network configurations.

In addition to metrics, the next responders model necessitates a shift from informal "social networking" to data-driven, principled analytic capabilities to answer the question of why a provider should act as a next responder.

In our qualitative, interview-based research, we found that current practices often rely on informal, ad-hoc relationships between operators, where decisions are driven more by established connections than by objective data. This can lead to suboptimal responses in times of crisis. To address this, a data-driven approach can evaluate the motivations behind collaboration. This may involve using predictive analytics to assess the mutual benefits of cooperation, such as the potential for reduced downtime, shared resource costs, and enhanced service reliability. Establishing such analytic capabilities will help providers make more informed, strategic decisions about which partnerships will deliver the greatest value during disruptions.

Furthermore, current models for deployment strategies often fail to take a holistic view of the question of how to implement the next responders model. Traditional approaches tend to focus narrowly on infrastructure deployment without considering the full range of factors that could impact resilience. To address this, comprehensive deployment strategies must be developed that encompass a broad spectrum of considerations. For example, this might include the availability of backhaul, such as terrestrial infrastructure, is crucial for ensuring seamless connectivity during disruptions.

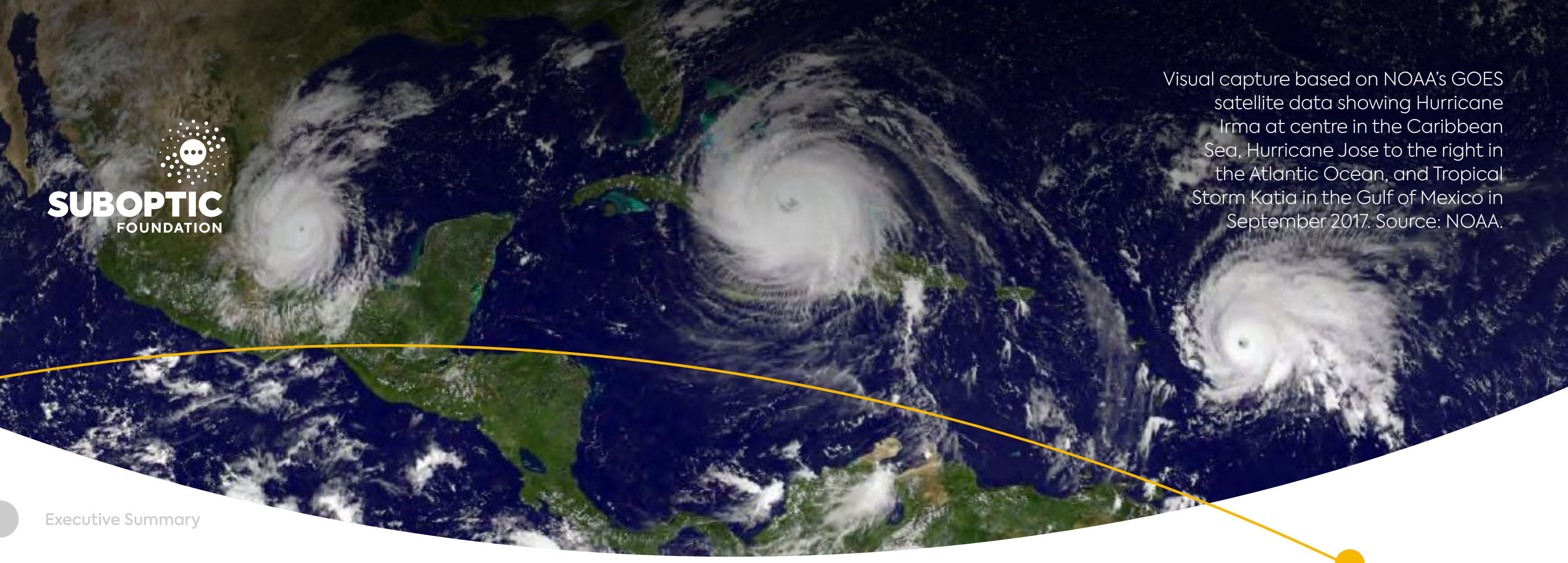
Additionally, both optics (e.g., restorative agreements) and IP (e.g., peering arrangements) must be evaluated as part of a coordination strategy, as these elements determine the resilience of data flow between interconnected networks. The business case for collaboration should also be considered, ensuring that there is sufficient demand from users and that the cost structures are viable for all parties involved.

Finally, environmental and topographical factors, such as disaster resilience and the impact of geographic features (e.g., marine protected areas), must be integrated into resilience deployment strategies to ensure that infrastructure is robust against both natural and man-made disruptions. By considering these diverse factors, providers can develop more effective, comprehensive deployment plans that strengthen the overall resilience of subsea cable networks.

While the technical details of the next responders model are beyond the scope of this report, publications that specify processes for implementation of the model are forthcoming.

> **"To effectively implement the next responders model, there is a need for practical yet simple metrics that can answer the critical question of "who" is the best next responder."**

COMPOUNDING EFFECTS OF CLIMATE CHANGE



Visual capture based on NOAA's GOES satellite data showing Hurricane Irma at centre in the Caribbean Sea, Hurricane Jose to the right in the Atlantic Ocean, and Tropical Storm Katia in the Gulf of Mexico in September 2017. Source: NOAA.

COMPOUNDING EFFECTS OF CLIMATE CHANGE

Climate Impacts on Caribbean Networks

Given the many challenges facing Caribbean networks, climate change has already caused numerous disruptions in internet services, directly impacting emergency management and business continuity. Between 2016 and 2019, a series of devastating hurricanes severely impacted telecommunications infrastructure and led to significant outages across multiple nations. In 2017 alone, Hurricanes Irma and Maria caused widespread damage to networks in ten Caribbean countries, resulting in debilitating delays in critical services.[34]

Direct impacts on the networks in the region include:

In October 2016, Hurricane Matthew struck Haiti as a Category 4 hurricane, causing extensive flooding and mudslides that damaged road infrastructure and buildings, as well as electricity and water shortages. The storm disrupted the electrical grid, leading to widespread power outages, and damaged communication lines, causing significant outages.[35]

In September 2017, Hurricane Irma hit the British Virgin Islands as a Category 5 hurricane, causing widespread damage to road infrastructure, buildings, ports, telecommunications, electrical infrastructure, as well as other critical emergency facilities. The destruction of networks led to significant outages, hampering emergency responses and isolating communities.[36] Telecommunications systems, VHF radio networks, and the National Emergency Operations Centre (NEOC) headquarters were destroyed. The total cost of Hurricane Irma in the British Virgin Islands was estimated at $2.3 billion, including damages, revenue losses, and debris removal, with damages alone accounting for $1.6 billion.[37]

During Hurricanes Irma and Maria in 2017, Digicel's telecommunications infrastructure in the Turks and Caicos Islands sustained significant damage, leading to service disruptions that took months to recover.[38] The hurricanes caused extensive destruction not only to the operators' microwave antenna in the islands but also to the emergency communications infrastructure.[39] In response, Digicel deployed teams of engineers and technicians to restore services, introducing transportable cellular towers, known as Cells on Wheels (COWs), to deliver service to areas severely affected by the hurricanes. These efforts were crucial in helping first responders and agencies like the Department of Disaster Management and Emergencies (DDME) stay connected during the emergencies.[40]

In Dominica, Hurricane Maria made landfall as a Category 5, also causing widespread devastation. The island's communication networks were severely damaged, leading to a near-total loss of connectivity. Broadband connectivity was mainly available in the capital, Rouseau, and sparsely in some regions, leaving rural communities without access. According to an Internet Society report, the estimated damage and losses in Dominica amount to $1.3 billion USD, equivalent to 200% of the country's GDP.[41]

In Puerto Rico, Maria struck the country as a high-end Category 4 hurricane, causing catastrophic destruction to the power grid and communication networks. The storm broke power lines and toppled telecom towers, taking out 95.6% of cell sites and leaving residents scrambling for a signal.[42] A year after the hurricane, telecommunications infrastructure problems persisted, with phone calls dropping and internet speeds significantly slower than the average in the continental United States. Since the event, discussions amongst stakeholders have continued to focus on the challenges pertinent to electricity, given that the island's natural geography and historic planning make energy supply tricky.[43]

In September 2019, Hurricane Dorian made landfall in The Bahamas as a Category 5 hurricane, causing flooding and mass destruction on the islands of Abaco and Grand Bahama. The hurricane knocked out power, water, telecommunications, and sewage services, leaving many parts of The Bahamas offline. Network data showed some restoration of communications in the days following the hurricane, but many areas remained without connectivity.[44] Later, a report by the Inter-American Development Bank reports that Hurricane Dorian caused approximately $3.4 billion in damages, equivalent to 25% of The Bahamas' GDP. In the telecommunications sector alone, damages were estimated at $42.1 million, with losses reaching $54.4 million.[45]

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Climate events have directly impacted the resilience of networks and critical infrastructure across the Caribbean, resulting in the tragic loss of human life and significant financial costs during both crisis and recovery phases.

Even in contexts where telecommunication operators have implemented substantial resilience initiatives under relatively harmonized regulatory frameworks, as in Puerto Rico, significant vulnerabilities remain. A 2018 Internet Society report points to a lack of coordination, the absence of an overarching entity with execution power, the need for structural fundraising, insufficiently robust telecommunications infrastructure (e.g., antennas not designed to withstand higher wind categories), and outdated electricity distribution systems.

Although Caribbean stakeholders may be well-versed in disaster management, the unprecedented frequency and severity of recent storms have exceeded expectations. This underscores the need for a phased approach that weaves resilience into every aspect of planning and collaboration around digital infrastructures.[46]

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Intensified Resilience Challenges

The above challenges will be exacerbated by the increased frequency and intensity of severe weather events, including hurricanes, flooding, and tropical storms due to climate change.[47] Existing studies of network resilience have documented the effects of natural disasters and weather-related events, but many ignore subsea cables entirely.[48] Our quantitative risk analysis reveals current annual probabilities of 7-9% for a major hurricane, 3-5% for an earthquake, and 5-8% for subsea cable and Internet infrastructure failure due to power-related failures and shared infrastructure risks.

A lack of resilient network infrastructure makes smaller Caribbean nations particularly susceptible to climate disruptions, amplifying economic and developmental consequences that are harder to recover from compared to larger economies.[49] As Small Island Developing States (SIDS), Caribbean countries have already experienced the effects of climate change firsthand, as highlighted by multiple reports by the United Nations in recent years.[50] A 2020 study found that climate change damages in the Caribbean are projected to increase from 5 percent of GDP in 2025 to more than 20 percent of GDP by 2100 if no regional action is taken to mitigate or adapt to climate change.[51] As the catastrophic effect of hurricane events such as Irma and Maria on networks across the region reveal, these trends are only set to increase.[52]

A 2019 World Bank report, Lifeliness: The Resilient Infrastructure Opportunity, offers a peek into the current and future climate risks for the different kinds and layers of network infrastructure.


Photo by Iago Bojczuk (2024).

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Climatic events and their impacts on telecommunications infrastructure

Infrastructure	Inland and Coastal Floods	Earthquakes	Tsunamis	Sea-level Rise	High Temperatures	Water Scarcity	High Winds and Storms
Submarine cable (deep sea)	L	H	M	L	L	L	L
Submarine cable (near shore)	L	H	H	L	L	L	L
Landing station	H	H	H	H	L	L	L
Terrestrial cables (underground)	M	H	L	L	L	L	L
Terrestrial cables (overland)	L	M	L	L	L	L	M

Note: L = low; M = medium; H = high
Source: World Bank (2019), based on previous data and research by Adams et al. (2014); Dawson et al. (2018); Fu, Horrocks, and Winnie (2016); and U.S Department of Homeland Security (2017).[53] It is important to note that there are variations from these assessments depending on region, cable landing site, and other geographic factors.

This is not an issue only relevant for the Caribbean region. Around the globe, governments—particularly regulatory agencies—are increasingly recognizing the need to address how climate-related events expose network vulnerabilities and, in turn, threaten service continuity. Some key conclusions from the World Bank report, drawing from cases worldwide include:[54]

- **First-mile infrastructure is critical for global connectivity, yet highly vulnerable to seismic and environmental risks such as earthquakes, tsunamis, and submarine landslides.** Despite improvements in the resilience of landing stations through modern construction techniques, natural events pose direct challenges to these critical facilities.
- **Middle-mile infrastructure, which connects PoPulation centers within a country** that a break in one segment does not entirely disconnect downstream areas. However, this infrastructure—whether aerial or underground—is vulnerable to earthquakes, landslides, strong winds, and coastal flooding, particularly in regions where connectivity routes run along exposed coastlines.
- **Last-mile infrastructure, consisting primarily of poles and antennas, is the most exposed to environmental risks but is physically resilient and can be recovered quickly.** Mobile antennas can endure winds of up to 250 kilometers per hour, and terrestrial cables are often protected in underground ducts or supported by poles in urban areas.

Conditions remain uneven around the globe and strategies largely reactive. In Ireland, a 2022 assessment study showed that different weather conditions can create varying pressure points for operators, yet few explicitly list climate change as a primary risk—focusing instead on designing resilience into their networks broadly and monitoring upcoming weather on a case-by-case basis. At the same time, backup power capabilities differ significantly, from systems able to operate independently for two days to those prone to immediate shutdown.[55]

Echoing these concerns, a study by the UK's National Infrastructure Commission reported the importance of governments, regulators, and infrastructure providers collectively setting and meeting resilience standards to anticipate shocks and address failures pre-emptively.

Finding the right balance between short-term cost-savings and "gold plating" of infrastructure—over-investing in resilience and burdening consumers—remains a challenge, especially as most essential infrastructure (energy, water, digital, roads, rail) is privately delivered.[56] Because private operators rarely bear the full cost of catastrophic failures, there is often little incentive to invest in resilience, leaving governments responsible when disruptions occur.

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CONCLUSION

CONCLUSION

Full and equitable participation in our digital world begins with resilient digital infrastructure. In the Caribbean region, subsea cable systems form the backbone of connectivity, carrying almost all international data traffic and enabling the cloud-based services on which governments, universities, businesses, and emergency services increasingly depend.

Strengthening subsea cable resilience in the region not only reduces the risk of service outages. Reliable, redundant connectivity can also position Caribbean islands as a more viable location for network technologies, whether regional cloud availability zones or future AI inference edge nodes.

The Strategic Network Resilience Report documents the challenges to establishing resilient regional subsea infrastructure, especially given the broader economic, technical, and political forces at play in the Caribbean islands. Drawing upon extensive interviews, site and facility visits, and quantitative data-driven research, the report outlines a suite of best practices that stakeholders can consider as they work toward network resilience.

In short, the report finds that the long-term resilience of Caribbean digital infrastructure will depend on people as much as technology. Realizing a resilient network will require sustained connections and collaboration between governments, industry, and regional institutions.

While long timelines, high capital costs, and complex regulatory environments often deter development of subsea cable infrastructure, governments can work proactively to streamline permitting, harmonize regulatory frameworks, and support new policies that foster subsea cable resilience. Network operators and the subsea industry also have a role to play. Companies can work to structure collaboration, whether by formalizing existing cooperative exchanges, by adopting the next responder model, or by forming a regional subsea cable association where resilience can be proactively addressed.

Regional institutions can facilitate collaborative initiatives across governments and industry. They can also support the education of a workforce capable of designing, maintaining, regulating, and sustaining digital infrastructures, including subsea cables. Educational development in this area, from technical training in subsea and telecommunications engineering to broader digital infrastructure curricula, will ensure network resilience initiatives are not a temporary effort, but a long-term commitment.

Addressing the vulnerabilities outlined above requires prioritizing network preparedness to operate despite changing climatic and political conditions. As many interviewees described, there is not a one-size-fits-all approach to network resilience. Moving away from fragmented efforts involves both the strategic recognition of local conditions and the investment in people that can translate, coordinate, and implement network resilience across their different contexts. This approach supports local agency in decision-making within the islands while also fostering the creation of a strong and resilient network infrastructure across the Caribbean.

APPENDICES

APPENDICES

Author Biographies

Nicole Starosielski, Professor of Film and Media at the University of California-Berkeley and the Berkeley Center for New Media, conducts research on global internet infrastructure, with a focus on the subsea cables that carry almost 100% of transoceanic internet traffic. Starosielski is author or co-editor of over thirty articles and five books on media, infrastructure, and environments, including: The Undersea Network (2015), which chronicled the subsea telecommunications cable network from the 1800s to today. Dr. Starosielski has been working with the SubOptic Association and Foundation to develop research and educational programs focusing on the subsea cable industry. Starosielski is the creator and co-chair of the SubOptic Association's Sustainable Subsea Networks Working Group and has served as a Principal Investigator on a SubOptic project to enhance the strategic resilience of subsea cables in the Caribbean.

Iago Bojczuk is a Research Associate at the Berkeley Center for New Media (BCNM) within the College of Engineering at the University of California, Berkeley. His research focuses on digital infrastructures, science and technology policy, and the governance of large-scale complex systems. Drawing from Science and Technology Studies, his PhD research at the University of Cambridge examined Brazil's data center ecosystems by tracing how their expansion intersects with urban inequality, political economy, and compounding climate risks, and by situating these dynamics within wider debates on digital infrastructure research in the Global South. His work has been published in Convergence: The International Journal of Research into New Media Technologies; Media, Culture, and Society; Global Media and Communication; Submarine Telecoms Forum; e-flux Magazine; and official UN publications. Most recently, he was a visiting scholar at Koç University in Istanbul, Türkiye. Prior to Cambridge, Iago earned a Master of Science from the Massachusetts Institute of Technology (MIT), where he was a Lemann Fellow, and a Bachelor of Arts (Phi Beta Kappa) from the University of Oregon.

Hannah Ellis holds a master's degree from the School of Information at the University of California, Berkeley, where her research focused on local networks, community broadband, and digital public infrastructure. She has worked at the intersection of technology and human rights for the last five years, including as a manager on the technology and human rights team at Business for Social Responsibility (BSR). Before BSR, Hannah worked at the Human Rights Foundation and the Berkman Klein Center for Internet and Society at Harvard University.

John Hooft Toomey holds a B.S. in Computer Science with Departmental Honors from the University of Oregon. His research interests lie at the intersection of Machine Learning, Geospatial Information Systems (GIS), and critical infrastructure resilience. Toomey has contributed to the development of unsupervised ML frameworks for network anomaly detection at the Oregon Networking Research Group. Most recently, as a Geospatial Software Engineer at Net Intel Inc., he co-authored research on Caribbean subsea cable resilience (SubOptic '25) and developed risk analysis frameworks for power and network infrastructure.

Ram Durairajan is an Associate Professor in the School of Computer and Data Sciences at the University of Oregon, and a Chief Scientist at Link Oregon. Ram earned his Ph.D. and M.S. degrees in Computer Sciences from the University of Wisconsin - Madison and his B.Tech. in Information Technology from the College of Engineering, Guindy (CEG), Anna University. Ram has been leading a team of graduate and undergraduate students in federal, university, and industry research projects. He has published over 90 peer-reviewed papers in prestigious conferences, journals, and workshops. His research has been recognized with several awards including the NSF CAREER award, NSF CRII award, Ripple faculty fellowship, UO faculty research award, UO Golden Egg Innovator award, best paper awards from ACM CoNEXT and ACM SIGCOMM GAIA, and has been covered in several fora (NYTimes, MIT Technology Review, among others). His resiliency research has been recognized among the "100 Greatest Innovations," influenced FCC's Spectrum Frontiers 2d Report and Order, and won awards including PoPular Science's ``Best of What's New" in security.

ICPC Best Practices

The International Cable Protection Committee Government Best Practices for Protecting and Promoting Resilience of Submarine Telecommunications Cables

General Principles:

- Focus on statistically-significant risks where government action could have the greatest impact on risk reduction;
- Promote commercial and regulatory environments that encourage multiple and diverse (both with domestic and foreign landings) submarine cable landings within the state's territory;
- Observe and implement treaty obligations (particularly under the United Nations Convention on the Law of the Sea ("UNCLOS")) and customary international law defining state jurisdiction over, and protection of, submarine cables;
- Promote transparent regulatory regimes that expedite cable deployment and repair according to well-established timeframes;
- Consult closely with industry to understand industry technology and operating parameters and to share data regarding risks;
- Complement existing industry best practices;
- Recognize that laws and government policies themselves can sometimes exacerbate risks of damage and reduce resilience; and
- Engage with other states on a global and regional basis, as other states' actions can greatly affect an individual state's own connectivity.

ENDNOTES

ENDNOTES

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