Resilient Broadband Expansion in Post-Pandemic America: Energy-Efficient Strategies for Sustainable Connectivity in Underserved Regions

Damilare Samson Olaleye[1]

[1]Apex Systems (Verizon Wireless), New York.

Publication Date: 2025/11/12

Abstract: A comprehensive review of resilient broadband expansion is important for advancing post-pandemic recovery while promoting equity and sustainability in underserved United States regions. This study examines the intersection of energy efficiency, digital inclusion, and infrastructure resilience, highlighting strategies that support scalable and environmentally responsible broadband deployment. The findings reveal that energy-efficient broadband reduces operational costs, lowers environmental impact, and strengthens access to essential services such as telehealth, remote education, and digital commerce. However, governance models emphasizing infrastructure sharing, affordability supports, and community engagement are critical for sustaining long-term outcomes. Energy-aware broadband design emerges as a cornerstone for sustainable development, enabling underserved communities to benefit from equitable connectivity while contributing to climate goals and national resilience. Therefore, adopting green deployment models ensures that broadband expansion fosters both social inclusion and environmental stewardship.

Keywords: *Broadband Equity, Energy Efficiency, Renewable Infrastructure, Sustainable Connectivity, Resilience, Rural Broadband.*

How to Cite: Damilare Samson Olaleye (2025) Resilient Broadband Expansion in Post-Pandemic America: Energy-Efficient Strategies for Sustainable Connectivity in Underserved Regions. *International Journal of Innovative Science and Research Technology*, 10(10), 3062-3068. https://doi.org/10.38124/ijisrt/25oct1413

I. INTRODUCTION

The necessity of broadband connectivity for daily activities and economic stability was made evident by the COVID-19 epidemic. The pandemic forced society to depend on technology for basic daily living including accessing basic goods, maintaining connections with others, working from home, and having the ability to complete schoolwork (Sanders and Scanlon 2021).

The pandemic has profoundly transformed the global energy sector, altering patterns of demand, disrupting supply chains, and reshaping market dynamics (Aljohani et al. 2025). The pandemic demonstrated that inadequate service is no longer just inconvenient; it may now be a crisis. Rural and underserved areas have long trailed behind in the deployment of broadband. According to Lai and Widmar (2021), a correlation exists between rurality and internet speed at the county level. As schools, jobs, and healthcare migrated online, many rural households saw an abrupt change from inadequate Internet service to a complete digital catastrophe. Prior to COVID, only roughly 50% of rural Americans had access to broadband that was fast to accommodate moderate consumption, compared to over 90% of urban households.

Broadband is now essential for public health and education as the epidemic increased demand for telehealth and remote learning. Telehealth use increased from 5% of people prior to the pandemic to 42% during it, according to a 2025 survey conducted in a Midwestern county that had just recently acquired fiber-optic connectivity (Salmon et al., 2025). The epidemic demonstrated that basic tasks like studying, job searches, and even telemedicine appointments become challenging or impossible in the absence of widespread high-speed Internet (Sanders et al., 2021; Lai et al., 2021).

Kostelnick et al. (2024) show how remote sensing and spatial analysis might direct the rollout of broadband in rural areas. Their techniques map vertical assets (trees, towers, etc.) and agricultural production in underserved areas to find high-elevation locations that are perfect for wireless transmitters as well as areas with economic necessity. This GIS-based method identifies low-cost "high points" from which to broadcast signals in addition to highlighting areas where connectivity will have the biggest economic impact (e.g., allowing precision farming to increase yields).

In general, broadband that uses less energy also supports more general sustainable economic growth, rural enterprises may run contemporary digital services (e-commerce, precision

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct1413

agriculture, remote monitoring) without burdening the local grid with dependable, environmentally friendly Internet (Emmanuel, 2025). Farmers can use IoT sensors and data analytics to optimize yields and reduce waste, enabling food security and incomes (Rajak et al., 2023). Telecommuters and entrepreneurs can remain in small towns if connectivity is affordable and dependable, education, long tied to local libraries and schools, becomes a door to lifelong learning anywhere. energy-efficient broadband networks offer a viable way ahead, and closing the digital divide is a social justice issue and a basic human rights and public health concern (Sanders and Scanlon 2021). In the post-pandemic recovery, then, investing in green, resilient broadband is investing in a more equitable and robust future one where underserved communities finally gain the digital access that undergirds telemedicine, education, and growth, without sacrificing environmental stewardship. Therefore, this review explores the intersection of energy efficiency, digital inclusion, and infrastructure resilience, highlighting strategies that support scalable and environmentally responsible broadband deployment.

II. OVERVIEW OF RESILIENT BROADBAND EXPANSION IN POST-PANDEMIC AMERICA

The COVID-19 outbreak highlighted the importance of broadband Internet to American culture. As such, schools, corporations, healthcare providers and families rely on high-speed connectivity for everyday life. Telemedicine grew widespread, social distancing policies revealed severe access disparities, and remote work and education increased (Stocker et al., 2023). The 2021 Infrastructure Law, for instance, allotted over $65 billion to extend high-speed Internet, with a focus on underserved, rural, and tribal communities (National Telecommunications and Information Administration 2022), this was an increase in investment by policymakers. Resilience is emphasised by planners to make sure that broadband infrastructure can withstand future shocks and to resolve long-standing gaps in equality.

➢ *Effects from the Pandemic: Telehealth, Remote Education, and Work-from-Home Imperatives*

The COVID-19 epidemic significantly altered how people obtained necessary services, emphasising broadband as a vital infrastructure supporting jobs, education, and health care. Lockdowns and social distancing measures accelerated the use of telehealth, enabling patients to consult doctors remotely. The use of telemedicine skyrocketed; in the first three months following March 2020, telehealth visits among commercially insured individuals increased by 766%, from 0.3% to 23.6% of visits (Shaver, 2022). Although this initial spike subsided, by late 2021, telehealth still accounted for about 5% of claims (Mulvaney-Day et al., 2022). Many patients now have better access to virtual care, but it also brought attention to the fact that those without dependable Internet were left behind. According to surveys, telehealth users are typically younger, wealthier, and more urban, and even before COVID-19, many rural or low-income patients lacked the bandwidth or devices required for video visits (Graves et al., 2021). Infrastructure, affordability, and digital literacy initiatives are all necessary to maintain the benefits of telemedicine.

Owing to this idea, schools and universities were compelled to adopt online learning, making dependable internet access vital for students and educators alike. In a 2021 study by the United States Institute of Education Sciences, nearly 60% of United States families with school-age children reported that their school or district had to provide computers or Internet service during the pandemic (Cortés-Albornoz et al. 2023). Even after the interventions, there were still notable disparities: minority and lower-income households were much less likely to have sufficient home Internet or devices (NDIA, 2022). In this regard, millions of American households had inadequate Internet connection in 2022, with rural households having a significantly higher rate of unconnection (NDIA, 2022).

According to Kelley & Sisneros, (2020), online education is becoming an increasingly common choice for both K-12 and college students. However, students without stable and high-quality internet access are unable to take part in virtual learning opportunities. Regardless of socioeconomic status, students who lack internet access at home tend to achieve lower academic performance, score worse on standardized exams, complete homework less frequently, and are less likely to pursue higher education (Hampton et al., 2020). Many of these students live in remote rural areas where academic support is limited (Reisdorf et al., 2019). These challenges were evident even before the COVID-19 pandemic forced schools to transition online.

These rapid transformations exposed and deepened existing digital divides, particularly for rural and low-income households, underscoring that connectivity has become indispensable for full participation in contemporary society. *Table 1* shows articles examining the impact of remote learning during the COVID-19 pandemic.

Table 1 Impact of Remote Learning During the COVID-19 Pandemic

Impact of remote learning during COVID-19 lockdowns	**Domains**	**References**
Academic performance	Mathematics, Reading, Language and spelling, Biology	Oostdam et al., (2023)
Emotion and behavior	Resilience, Emotional regulation, Attention, Inhibition, Mood disorders, Willingness to study	Zhang et al., (2019)
Population perception	Children with intellectual disabilities, Children with neurotypical development	Cortés-Albornoz et al., (2023)

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct1413

➢ *The Digital Divide: Equity Challenges in Rural, Tribal, and Low-Income Regions*

According to Sanders & Scanlon (2021), despite significant public and private investment in recent years, the United States continues to face a persistent and unequal digital divide. As of 2022, nearly one-quarter of households still lacked home broadband access (NDIA, 2022). Infrastructure gaps, affordability challenges, and barriers to adoption converge most acutely in rural, tribal, and low-income communities. Broadband access has therefore become a central policy concern, as the digital divide threatens to marginalise these populations further. Federal Communications Commission (FCC) estimates indicate that around 9.3 million rural residents remain without adequate broadband (FCC, 2021), while a Congressional Research Service report found that approximately 24% of people living on tribal lands lack broadband, compared with 7% nationwide (Congressional Research Service, 2021).

According to Allen (2025), there are still significant differences in broadband access between income levels and racial and ethnic groups. In 2022, the median cost of high-speed internet service for households earning less than $10,000 annually was more than 9% of their income (NDIA, 2022). Lower-income families and members of Black, Indigenous, and Hispanic communities continue to have lower broadband adoption rates. Cost is the main barrier; according to the Government Accountability Office (GAO), approximately one-third of Americans who have not adopted broadband believe it is "too expensive" (GAO, 2023). Even though federal programs like the FCC's Affordable Connectivity Program (ACP) aim to reduce this burden through subsidies, by the end of 2022, only about one-third of eligible households had enrolled (FCC, 2022). An often-overlooked aspect of the divide is that many low-income urban neighborhoods also lack quality service.

➢ *Broadband as Critical Infrastructure for National Resilience*

The federal government stated that the Infrastructure Investment and Jobs Act (2021) explicitly treated broadband such as other infrastructure and committed approximately $65 billion to its expansion (Valentín-Sívico et al., 2023). Broadband networks are now integral to emergency response, telemedicine during crises, virtual schooling if schools close, and telework during future disruptions. For example, when hurricanes or wildfires hit, Internet service allows governments to coordinate evacuations, households to stay informed, and businesses to keep running remotely. Conversely, communications outages can exacerbate disasters (Seneviratne et al., 2024).

Broadband has become a critical driver of economic activity, serving as essential infrastructure for both the modern supply chain and the labour market. Rural manufacturing, agriculture, and small businesses are increasingly dependent on digital connectivity, with research showing that rural broadband can enhance economic output and create jobs (Valentín-Sívico et al., 2023). In this way, expanding robust networks strengthens national resilience by fostering productivity and innovation across diverse regions.

➢ *Scalable Models for Deployment in Marginalized Areas*

Bridging the remaining connectivity gaps demands scalable business models supported by sustainable funding mechanisms. One emerging approach is the expansion of rural cooperatives and community-led broadband providers, which have proven effective in reaching underserved populations. Public–private partnerships (PPPs) and municipal networks are another scalable model. For instance, Vermont's ECFiber is a community-driven co-op that collaborated with private firms to connect dozens of rural towns. States have also used federal stimulus funds to incentivize private buildout (Adebayo & Joseph, 2025).

Federal and state grant programs underpin these models. The USDA's ReConnect program has funded hundreds of rural projects: since 2021 it has awarded about $4.4 billion to connect roughly 680,000 rural Americans (USDA, 2024). Similarly, NTIA's Broadband Equity, Access, and Deployment (BEAD) grants will finance last-mile projects in unserved areas (NTIA, 2022). Importantly, many programs now reserve funds for cooperatives, tribes, or non-profits, recognizing that these entities are often the only hope for the most remote places.

➢ *Geospatial Planning for Smart Deployment*

Maximizing impact requires careful geospatial planning. Planners use detailed data to target investments and design networks that are efficient and resilient. Key considerations include:

- Data Inputs: The FCC's new Broadband DATA maps provide a nationwide baseline of reported service (FCC, 2023). States augment this with surveys, speed tests, and census data.
- Prioritization Frameworks: Locations that are unserved and underserved (below 100/20 Mbps) are given priority under BEAD (NTIA, 2022). Schools, libraries, and clinics are examples of community anchor institutions that serve as focal points (NTIA, 2022).
- Terrain and Climate Factors: Geography and climate shape network design. States are required to overlay NOAA disaster-risk maps on broadband projects to ensure resilience (Islam et al., 2025). Based on UNISDR's framework, the Indonesian National Agency for Disaster Management incorporated the core principles of effective early warning systems (EWS) into its community-based EWS guidelines. *Figure 1* illustrates the key components of an effective EWS as defined in the guidelines.
- Anchor Institutions: Schools and hospitals serve as hubs for community access, and BEAD grants require connectivity planning for these institutions (NTIA, 2022).

By integrating these elements, planners can direct funds where gaps are greatest and returns are highest.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct1413

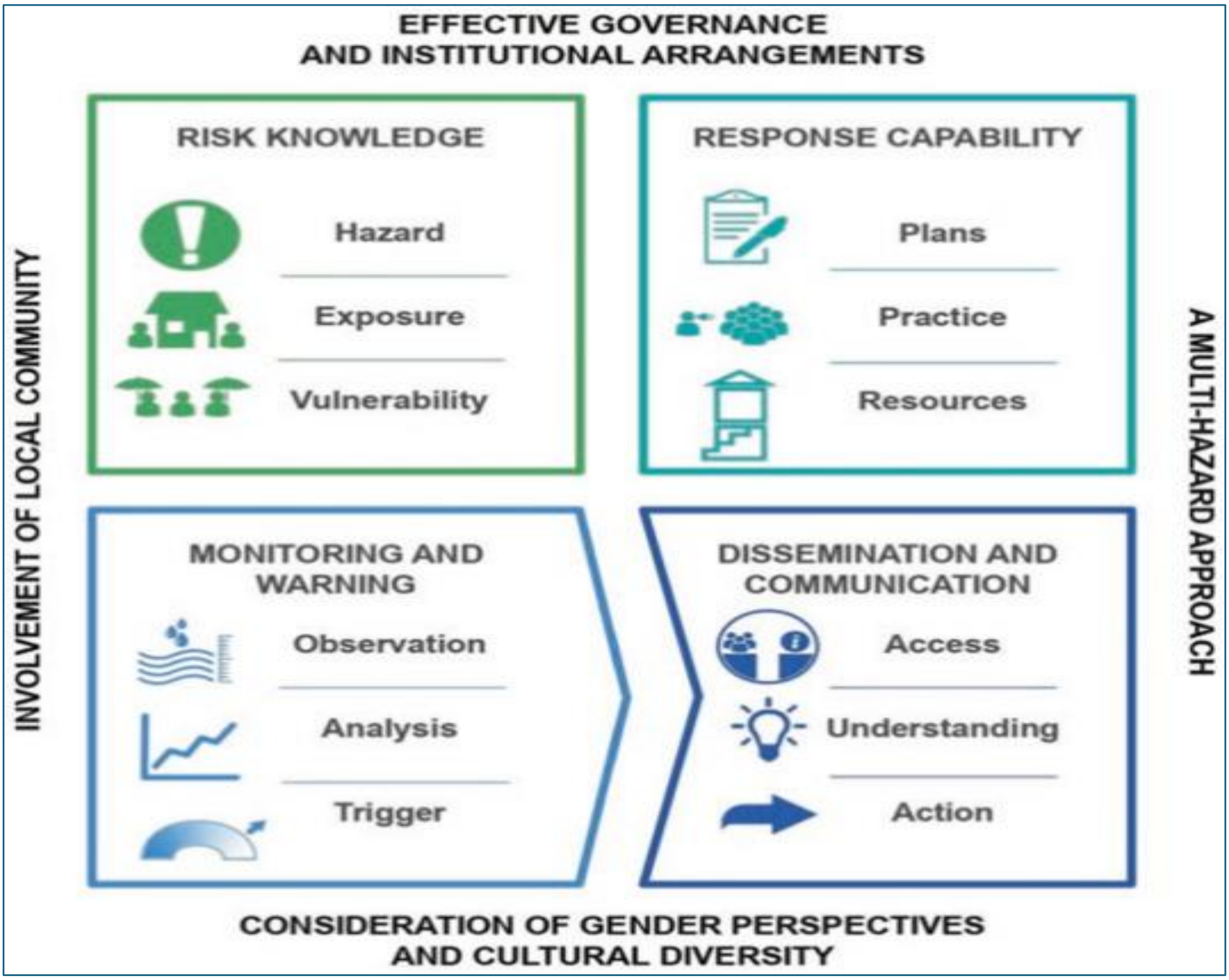

Fig 1 Key Components of an Effective Early Warning Systems (EWS) (Islam et al., 2025)

III. ENERGY-EFFICIENT STRATEGIES FOR SUSTAINABLE CONNECTIVITY IN UNDERSERVED REGIONS

The expansion of broadband in rural and marginalized areas of the United Statess is not only a matter of digital equity but also of sustainability. In addition to the growing concerns over climate change, energy costs, and the need for resilient infrastructure, energy efficiency has emerged as a central pillar in broadband deployment strategies. The COVID-19 pandemic further highlighted the urgency of providing reliable and affordable connectivity in underserved communities while minimizing environmental and economic costs (Valentín-Sívico et al., 2023).

➢ *Geospatial Planning*

Kostelnick et al., (2024) developed GIS-led workflows that combine LiDAR/terrain layers, land-use and economic value mapping to identify existing vertical assets and routes that minimize tower heights and backhaul lengths; the authors demonstrate how such siting reduces both capital and operational energy when compared to naïve routing or random site selection (Kostelnick et al., 2024). Valentín-Sívico et al. (2023) empirical evaluation of a Missouri wireless deployment corroborates this: locating base stations near community anchor institutions and natural elevations improved service quality and adoption, which in turn raised energy-per-impact (more useful sessions per kWh) versus widely dispersed, low-utilization nodes. The crucial conclusion is that demand forecasts and geographic optimisation must be combined; careful placement that disregards user clustering runs the danger of underutilized capacity and subpar energy-to-outcome ratios.

➢ *Renewable On-site Generation and Hybrid Microgrids for Resilient Nodes*

In many underserved United States sites, grid reliability is weak or absent; peer-reviewed United States work emphasizes pairing modest renewable systems (solar PV and storage) with low-power network nodes sized to duty-cycled operation. Chattopadhyay, Sauer, and Witmer (2024) analyze solar electrification efforts on the Navajo Nation and argue that technically feasible PV and battery solutions must be co-designed with local institutional supports, maintenance pathways, and productive uses to be sustainable in the long run; oversizing or purely technical drop-in approaches fail

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25oct1413

when social systems are not built concurrently. Engineering models demonstrate that building PV and storage specifically for duty-cycled radios, as opposed to high-power operation continuously, lowers capital costs while providing the uptime needed for school schedules or telehealth hours. Thus, renewable integration is feasible and cost-effective if the energy demand profile is matched to low-power network strategies and community governance.

➢ *Energy-Aware Network Operations*

Energy savings accrue not only from hardware selection but from operational practices. Literature documents that dynamic RAN features (cell sleep modes, adaptive transmit power), edge caching for school/clinic content, and virtualization of core functions measurably reduce energy per bit. Masanet et al.'s (2020) exploration of ICT energy accounting underscores the value of measuring and reporting energy intensity and highlights how software and architectural optimizations (virtualization, caching, efficient cooling in other ICT contexts) reduce net energy demand; these principles translate to rural broadband nodes: virtualized cores reduce physical hardware footprint and sleep scheduling of low-utilization cells lowers site consumption while protecting peak-period service (Masanet et al., 2020; Strover et al., 2021). Practically, rural implementations that combine sleep modes with predictable community schedules (school hours, clinic hours) can maintain necessary service windows while minimizing daily energy draw.

➢ *Infrastructure Sharing and Neutral-Host Models*

Shared middle-mile and neutral-host approaches reduce duplicate energy expenditures by colocating radios, sharing fiber/backhaul, and enabling multiple providers to use a single power envelope. Strover, Riedl, and Dickey (2021) analyzed United States community broadband frameworks and conclude that neutral-host and municipal/cooperative models frequently result in more efficient topologies and lower per-capita OPEX, including energy bills than exclusive incumbent builds. Empirical and modeling studies indicate that when states or funders incentivize co-location and conduit sharing, the realized lifecycle energy and cost per connected household decline. However, legal/regulatory barriers and incumbent resistance can impede sharing; therefore policy design is essential to unlock these energy advantages (Strover et al., 2021).

IV. CONCLUSION

Resilient broadband expansion in post-pandemic America requires a technical design, energy strategy, and equity goals be pursued together rather than sequentially. The evidence synthesized in this work shows that geospatially informed siting, mixed low-power architectures, and duty-cycled, energy-aware network operations materially lower both capital and operating energy needs while improving the likelihood of adoption in rural, tribal, and low-income communities. Coupling these approaches with on-site renewable generation and relevant storage converts many off-grid or weak-grid sites into durable nodes of access that support telehealth, remote education, and local economic activity.

Research and pilot priorities remain clear such that demonstrations of renewable-backed, mixed-technology deployments in tribal and frontier communities that publish energy and socio-economic outcomes; policy experiments that test energy-aligned grant scoring; and longitudinal studies of adoption when energy-efficient design is paired with affordability and training. Therefore, these technical, social, and policy actions will enable broadband expansion in underserved United States regions, resilient and sustainable, enabling telehealth, remote education, and local economic growth while minimizing environmental impact and keeping operating costs low for community providers.

REFERENCES

[1]. Adebayo, Y., & Joseph, O. (2025). *Public-Private Partnerships for Rural Broadband Expansion*. ResearchGate.https://www.researchgate.net/publication/392661390_PublicPrivate_Partnerships_for_Rural_Broadband_Expansion

[2]. Agarwal, A., & Canfield, C. (2024). Analysis of rural broadband adoption dynamics: A theory-driven agent-based model. *PLOS ONE*, *19*(6), e0302146. https://doi.org/10.1371/journal.pone.0302146

[3]. Aljohani, T. M., Assolami, Y. O., Alrumayh, O., Mohamed, M. A., & Almutairi, A. (2025). Sustainable Energy Systems in a Post-Pandemic World: A Taxonomy-Based Analysis of Global Energy-Related Markets Responses and Strategies Following COVID-19. *Sustainability*, *17*(5), 2307. https://doi.org/10.3390/su17052307

[4]. Allen S. (2025). Trends and Disparities in Broadband Internet Access in the United States, 2013 to 2023. *Socius : sociological research for a dynamic world*, *11*, 10.1177/23780231251363238. https://doi.org/10.1177/23780231251363238

[5]. Bai, Y., Wang, R. Y., & Jayakar, K. (2022). What $2.5 billion can buy: The effect of the Broadband Initiatives Program on farm productivity. *Telecommunications Policy*, *46*(7), 102404. https://doi.org/10.1016/j.telpol.2022.102404

[6]. Chattopadhyay, A., Sauer, P. W., & Witmer, A.-P. (2024). Can renewable energy work for rural societies? Exploring productive use, institutions, support systems, and trust for solar electricity in the Navajo Nation. *Energy Research & Social Science*, *107*, 103342–103342. https://doi.org/10.1016/j.erss.2023.103342

[7]. Congressional Research Service. (2021). *Tribal broadband: Status of deployment and federal funding programs.* CRS Report R46612. https://crsreports.congress.gov/product/pdf/R/R46612

[8]. Cortés-Albornoz, M. C., Ramírez-Guerrero, S., García-Guáqueta, D. P., Vélez-Van-Meerbeke, A., & Talero-Gutiérrez, C. (2023). Effects of remote learning during COVID-19 lockdown on children's learning abilities and school performance: A systematic review. *International journal of educational development*, *101*, 102835. https://doi.org/10.1016/j.ijedudev.2023.102835

[9]. De Weger, E., Van Vooren, N. J. E., Drewes, H. W., Luijkx, K. G., & Baan, C. A. (2020). Searching for new community engagement approaches in the Netherlands: a realist qualitative study. *BMC Public Health*, *20*(1). https://doi.org/10.1186/s12889-020-08616-6

[10]. Deevela, N. R., Kandpal, T. C., & Singh, B. (2023). A review of renewable energy based power supply options for telecom towers. *Environment, development and sustainability*, 1–68. Advance online publication. https://doi.org/10.1007/s10668-023-02917-7

[11]. Emmanuel, M. (2025). *Broadband's Role in Precision Agriculture*. https://www.researchgate.net/publication/392590854_Broadband

[12]. Federal Communications Commission (FCC). (2023). *National broadband map: Broadband serviceable location fabric.* https://broadbandmap.fcc.gov

[13]. *Fourteenth Broadband Deployment Report*. (2021, February 1). Federal Communications Commission. https://www.fcc.gov/reports-research/reports/broadband-progress-reports/fourteenth-broadband-deployment-report

[14]. Government Accountability Office (GAO). (2023). *Broadband affordability: FCC should improve ACP performance goals and measures.* GAO-23-105626. https://www.gao.gov/products/gao-23-105626

[15]. Graves, J. M., Abshire, D. A., Amiri, S., & Mackelprang, J. L. (2021). Disparities in Technology and Broadband Internet Access Across Rurality: Implications for Health and Education. *Family & community health*, *44*(4), 257–265. https://doi.org/10.1097/FCH.0000000000000306

[16]. Hampton, K., Fernandez, L., Robertson, C., & Bauer, J. M. (2020). Repercussions of Poor Broadband Connectivity for Students in Rural and Small Town Michigan. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3749644

[17]. Humphrey, C., Mack, E. A., & Horrigan, J. B. (2025). Moving toward a continuum model of broadband affordability for low-income households. *Telecommunications Policy*, 103027–103027. https://doi.org/10.1016/j.telpol.2025.103027

[18]. Islam, M. M., Hasan, M., Mia, M. S., Masud, A. A., & Abu. (2025). Early Warning Systems in Climate Risk Management: Roles and Implementations in Eradicating Barriers and Overcoming Challenges. *Natural Hazards Research*. https://doi.org/10.1016/j.nhres.2025.01.007

[19]. Kelley, B., & Sisneros, L. (2020). Broadband Access and the Digital Divides. Policy Brief. *Education Commission of the States*.

[20]. Kostelnick, J. C., Thayn, J. B., & Sinha, K. (2024). Mapping and spatial analysis to expand rural broadband access. *Papers in Applied Geography, 10*(2), 1–22. https://doi.org/10.1080/23754931.2024.2332238

[21]. Lai, J., & Widmar, N. O. (2021). Revisiting the Digital Divide in the COVID-19 Era. *Applied economic perspectives and policy*, *43*(1), 458–464. https://doi.org/10.1002/aepp.13104

[22]. LoPiccalo, K. (2022). Impact of broadband penetration on United States Farm productivity: A panel approach. *Telecommunications Policy*, *46*(9), 102396. https://doi.org/10.1016/j.telpol.2022.102396

[23]. Masanet, E., Shehabi, A., Lei, N., Smith, S., & Koomey, J. (2020). Recalibrating global data center energy-use estimates. *Science*, *367*(6481), 984–986. https://doi.org/10.1126/science.aba3758

[24]. Michael, Ilesanmi & Jayathilake, Dulanjala & Idowu, Marvel & Oluwasogo, Joseph. (2025). Identifying Resilient Broadband Paths via GIS.

[25]. Mulvaney-Day, N., Dean, D., Jr, Miller, K., & Camacho-Cook, J. (2022). Trends in Use of Telehealth for Behavioral Health Care During the COVID-19 Pandemic: Considerations for Payers and Employers. *American journal of health promotion : AJHP*, *36*(7), 1237–1241. https://doi.org/10.1177/08901171221112488e

[26]. National Digital Inclusion Alliance (NDIA). (2022). *The digital divide persists: An analysis of United States Census data on household Internet adoption.* https://www.digitalinclusion.org

[27]. National Telecommunications and Information Administration (NTIA). (2022). *Internet for All initiative: Broadband Equity, Access, and Deployment (BEAD) program notice of funding opportunity.* United States Department of Commerce. https://www.internetforall.gov/program/broadband-equity-access-and-deployment-bead-program

[28]. Oostdam, R., van Diepen, M., Zijlstra, B., & Fukkink, R. (2023). Effects of the COVID-19 school lockdowns on language and math performance of students in elementary schools: implications for educational practice and reducing inequality. *European journal of psychology of education = Journal europeen de psychologie de l'education*, 1–21. Advance online publication. https://doi.org/10.1007/s10212-023-00679-4

[29]. Rajak, P., Ganguly, A., Adhikary, S., & Bhattacharya, S. (2023). Internet of Things and smart sensors in agriculture: Scopes and challenges. *Journal of Agriculture and Food Research*, *14*(14), 100776. https://doi.org/10.1016/j.jafr.2023.100776

[30]. Reisdorf, B. C., Yankelevich, A., Shapiro, M., & Dutton, W. H. (2019). Wirelessly bridging the homework gap: Technical options and social challenges in getting broadband to disconnected students. *Education and Information Technologies*, *24*(6), 3803–3821. https://doi.org/10.1007/s10639-019-09953-9

[31]. Salmon, C., Bell, K., Reyes, E., Ireland, E., & Danek, R. (2025). An analysis of telehealth in a post-pandemic rural, Midwestern community: increased comfort and a preference for primary care. *BMC health services research*, *25*(1), 270. https://doi.org/10.1186/s12913-025-12413-5.

[32]. Sanders, C. K., & Scanlon, E. (2021). The digital divide is a human rights issue: Advancing social inclusion through social work advocacy. *Journal of Human Rights and Social Work, 6*(2), 130–143. https://doi.org/10.1007/s41134-020-00147-9

[33]. Seneviratne, K., Nadeeshani, M., Senaratne, S., & Perera, S. (2024). Use of Social Media in Disaster Management: Challenges and Strategies. *Sustainability*, *16*(11), 4824. https://doi.org/10.3390/su16114824
[34]. Shaver J. (2022). The State of Telehealth Before and After the COVID-19 Pandemic. *Primary care*, *49*(4), 517–530. https://doi.org/10.1016/j.pop.2022.04.002
[35]. Stocker, V., Lehr, W., & Georgios Smaragdakis. (2023). *COVID-19 and the Internet: Lessons Learned*. 17–69. https://doi.org/10.1108/978-1-80262-049-820231002
[36]. Strover, S., Riedl, M. J., & Dickey, S. (2021). Scoping new policy frameworks for local and community broadband networks. *Telecommunications Policy*, 102171. https://doi.org/10.1016/j.telpol.2021.102171
[37]. US Census Bureau. (2022). *The Number of People Primarily Working From Home Tripled Between 2019 and 2021*. Census.gov. https://www.census.gov/newsroom/press-releases/2022/people-working-from-home.html
[38]. *USDA ReConnect Program Announces $313M in Broadband Funding - Telecompetitor*. (2024). Telecompetitor.com. https://www.telecompetitor.com/usda-reconnect-program-announces-313m-in-broadband-funding/
[39]. Valentín-Sívico, J., Canfield, C., Low, S. A., & Gollnick, C. (2023). Evaluating the impact of broadband access and internet use in a small underserved rural community. *Telecommunications Policy*, *47*(4), 102499. https://doi.org/10.1016/j.telpol.2023.102499
[40]. Zhang, Q., Zhou, L., & Xia, J. (2020). Impact of COVID-19 on Emotional Resilience and Learning Management of Middle School Students. *Medical science monitor : international medical journal of experimental and clinical research*, *26*, e924994. https://doi.org/10.12659/MSM.924994