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Building Sustainable Connectivity

Free and Open Source Software adoption for community-based internet providers

Final Report

Prepared by **Connect Humanity**

Building Sustainable Connectivity: Free and Open Source Software Adoption for Community-based Internet Providers

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Table of contents

Introduction

By 2025, internet access had expanded to 86% of Brazilian households. Yet, despite this ostensibly high level of penetration, only 20% of the population could be said to possess *meaningful connectivity*, defined as access with adequate data allowances, sufficient speed, and appropriate devices (ICT Households 2025, Núcleo de Informação e Coordenação do Ponto BR, 2026).[1] The evident gap in internet access and quality of access is strongly marked by economic class, urban-rural divides, and race, and is also unequal across the five major Brazilian regions (north, northeast, midwest, southeast, and south).

Small ISPs, of which there are 11,853 in Brazil (Núcleo de Informação e Coordenação do Ponto BR, 2025), play an important role in filling this connectivity gap. A considerable portion of them use free and open source software (FOSS) to reduce network deployment and maintenance costs, but they face significant challenges, including differences in technical knowledge, limited technical support, and issues with interface usability. This study gathers empirical data on the adoption of FOSS by small providers and assesses these barriers and opportunities, thereby providing insights for policymakers, funders, and community connectivity initiatives.

This research is justified by the extensive body of literature in recent years that consistently links internet access to economic development and the reduction of social inequalities (Van Dijk, 2012; Wessels, 2013; Whitacre, Gallardo & Strover, 2014; Senne, 2022). Further, internet access is included as a goal of the UN Sustainable Development Goals (SDGs), with Goal 9(c) explicitly including universal access at affordable prices as one of its objectives: "significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020" (United Nations General Assembly, 2015). Moreover, the research is also justified by the fact that, to the best of our knowledge, there is limited systematized empirical data on the use of FOSS by small ISPs and/or community networks in Brazil, nor are there any academic articles on other countries addressing the issue.

Lastly, although this research focuses specifically on the adoption of Free and Open Source Software (FOSS) by small internet service providers (ISPs), it has been written with a broader audience in mind. The text does not presuppose prior familiarity with the

[1] The concept of “meaningful connectivity” originated from advocacy work led in 2020 by the Alliance for Affordable Internet (A4AI), an initiative of the World Wide Web Foundation, a team that included the author, Nathalia Foditsch. The concept moves beyond a binary understanding of connectivity as merely the presence or absence of internet access. Instead, it emphasizes the quality and usability of connectivity, taking into account factors such as the amount of data available, whether users have access to unlimited data, connection speed, and the type of device used to connect.

internal operations of ISPs or with the nuances of the FOSS debate. The intended audience includes individuals engaged in digital inclusion initiatives who recognize the centrality of ISPs to this discussion, members of the FOSS community interested in its application within ISP environments, and professionals from other fields with a general interest in the topic. Consequently, the report adopts a more expansive format to provide necessary contextual explanations regarding ISP processes and deliberately employs language that minimizes technical jargon wherever possible.

Research objectives

This research pursues two primary objectives. First, it seeks to identify and analyze patterns of Free and Open Source Software (FOSS) adoption among small internet service providers (ISPs) and community-networks in Brazil. Second, it aims to assess the extent to which greater reliance on FOSS can strengthen both the sustainability of these providers and the accessibility of the services they deliver.

To achieve these objectives, the study maps the current landscape of FOSS use among small ISPs, examining not only levels of adoption but also the underlying drivers and constraints shaping these decisions. Particular attention is given to providers' perceptions regarding costs, usability, availability of technical training, and access to specialized support, factors that consistently emerge as critical barriers to wider adoption.

Building on these findings, the research develops a set of recommendations to inform strategies for advancing digital inclusion and promoting meaningful connectivity in Brazil through more effective use of FOSS. In addition, the study proposes a practical, modular "suggested stack" tailored to the operational realities of community-focused and small ISPs, illustrating how open-source solutions can be integrated across core network, systems, and business layers to reduce costs, increase autonomy, and improve operational resilience.

What is free and open source software (FOSS)?

The acronym FOSS stands for "free and open source software", which is software whose code is open and anyone can download and use it, as well as study and modify it for their needs. The difference between Free Software and Open Source Software is a difference in philosophy and permissiveness of their licenses. For free software advocates, the focus is on promoting and maintaining user freedom, as defined by the Free Software Foundation (FSF):

> *“Free software” means software that respects users' freedom and community. Roughly, it means that the users have the freedom to run, copy, distribute, study, change and improve the software. Thus, “free software” is a matter of liberty, not price. To understand the concept, you should think of “free” as in “free speech,” not as in “free beer.” We sometimes call it “libre software,” borrowing the French or Spanish word for “free” as in freedom, to show we do not mean the software is gratis.*
>
> — Free Software Foundation, n.d.

FOSS is thus based on maintaining the openness of the software code and the freedom to access the source code of software derived from it, so that the community can benefit from it. For everyday users or operators, the concepts of free software and open source software are practically identical.

In general, open source licenses are more flexible and permissive for users of the software, including permission for users to close the code of the derivative product, something that a free license does not allow. It is important to note that open source does not mean that the software usable by the user will be free. Part of the paid uses of FOSS software come from the sale or permission to use it via API or web of functional packages installed on a company server. Even so, much of the FOSS software is available free of charge, and a user with some technical knowledge can compile, install, and use it wherever they want at no additional cost.

Internet access and service providers in Brazil

In 2025, internet penetration in Brazil reached 86% of households. However, only 20% of the population enjoys what can be considered "meaningful connectivity",[2] underscoring the gap between nominal access and usable, high-quality access. (ICT Households 2025, Núcleo de Informação e Coordenação do Ponto BR, 2026).

The composition of these connected households, however, reveals a more nuanced picture of digital inclusion. Of the approximately 78.9 million Brazilian households, 43.4 million have internet access but no computer, while only 24.7 million have both a computer and an internet connection. A further 296,000 households have a computer but no internet, and 10.5 million remain without either (ICT Households 2025, Núcleo de Informação e Coordenação do Ponto BR, 2026). In other words, although roughly 86% of households are now connected, nearly two-thirds of those connections (around 64%) occur in homes that lack a computer altogether.

The dependence on a single class of device, the mobile phone, is pronounced. According to ICT Households 2025, roughly two-thirds of users connected to the network using a mobile phone exclusively (65%). This pattern is concentrated among users in less favorable socioeconomic conditions: it reaches 87% among those in classes D and E and 84% among those with only lower primary education, as well as 73% among users who self-identify as Black and 83% among those living in rural areas. The survey also recorded a 5% increase relative to 2024 in exclusive mobile-phone access to the internet (from 60% to 65%), with the sharpest growth among men (from 54% to 64%), users self-identifying as Black (from 56% to 73%), and those with secondary education (from 63% to 73%) (ICT Households 2025, Núcleo de Informação e Coordenação do Ponto BR, 2026).

Prepaid plans accounted for 52% of all mobile plans (ICT Households 2025, Núcleo de Informação e Coordenação do Ponto BR, 2026). Prepaid plans generally entail a lower quality of experience, both in voice service and in mobile internet, than a postpaid one: once the prepaid balance runs out, the user must "recharge" the phone, that is, pay again, to restore service. Prepaid plans also tend to come with more limited packages, offering less data for browsing. In fact, 39% of users saw their data package run out in the three months prior to data collection a situation more frequent among those living in the North and Northeast regions (ICT Households 2025, Núcleo de Informação e Coordenação do Ponto BR, 2026).

[2] See footnote 1.

In 2025, 29% of households with Internet paid more than BRL 100 (about USD 20) for their main connection, a proportion that rose to 59% among class A households. In classes DE, 77% of households paid up to BRL 100 (Núcleo de Informação e Coordenação do Ponto BR, 2026). The United Nations' affordability benchmark for broadband, set for 2025, is 2% of gross national income per capita (Broadband Commission for Sustainable Development, n.d.). Not a single Brazilian state meets this target across its entire population. While the international benchmark is GNI per capita, BRL 100 equals roughly 6% of Brazil's 2026 minimum wage (BRL 1,621). So for class D and E households paying that amount, connectivity can swallow up to three times the UN's affordability threshold, a reminder that "having access" and "being able to afford it" are not the same thing.

Data on internet providers in Brazil

The most consistent data we have on ISPs in Brazil is also produced by Cetic.br, which has been publishing a historical series of surveys since 2011, the "ICT Providers 2024" interviewed 1719 internet service providers and found that 11,853 were operating in Brazil in 2024 (Núcleo de Informação e Coordenação do Ponto BR, 2025). Of these, 5% served up to 100 clients, 19% served between 101 and 500 clients, 17% served between 501 and 1,000 clients, 26% served between 1,001 and 3,000 clients, 9% served between 3,001 and 5,000 clients, and 16% served more than 5,000 clients. An additional 9% of respondents did not know or did not report the number of clients (Núcleo de Informação e Coordenação do Ponto BR, 2026).

Read together, these numbers describe a market concentrated at the small end: roughly three-fourths of providers serve fewer than 5,000 clients. This is precisely the population for which commercial software priced per seat or per subscriber becomes structurally misfit, operations large enough to depend on management, billing, and provisioning systems, yet too small to absorb licensing models designed for national-scale carriers.

While the number of ISPs in Brazil was already high in 2024, it has grown even further since then. For many years, the main entry point for small ISPs was a regulatory waiver. Under ANATEL's rules, providers offering fixed internet access[3] with up to 5,000 broadband connections were exempt from obtaining a formal authorization. In practice, this exemption allowed thousands of small ISPs to operate without facing the full regulatory burden. In 2025, however, ANATEL reversed this policy through a series of decisions that eliminated the waiver, making authorization mandatory for all SCM

[3] Providers offering the Multimedia Communication Service (SCM), the regulatory category under which fixed internet access is licensed in Brazil.

providers regardless of size.[4] The impact was immediate: in less than a year, the number of authorized providers increased from approximately 12,000 to 19,500 (Julião, 2026).

Connectivity in places of lesser economic interest to large companies is provided by micro, small and medium-sized ISPs. As of April 2026, large operators accounted for less than 42% of fixed broadband connections in Brazil, while the others, the so-called "competitive operators", which are mid-sized regional players, small and micro local providers combined, represented 58.2% of the total (Teleco, 2026, with data from Anatel).

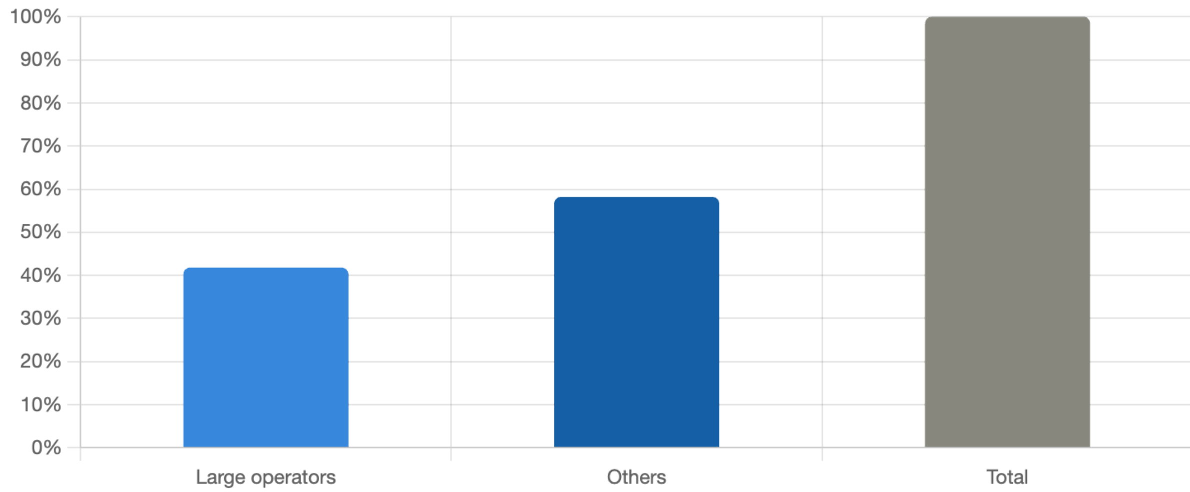

Figure 1 - Fixed broadband market share

Source: Teleco, 2026, based on ANATEL, 2026 data.

Besides small ISPs, there are also "community networks" that are not ISPs as such. Rather, they are collaborative networks, communities that design, develop, and manage the network infrastructure as a common resource, foster the development of local skills and culture, and administer that infrastructure through shared resources (Labardini Inzunza and Zanolli, 2021; Núcleo de Informação e Coordenação do Ponto BR [NIC.br], 2022; Belli & Hadzic, 2023). There are around 30 of them in Brazil and they play an important role as a complementary model for bringing connectivity to socially vulnerable, geographically isolated communities, such as *quilombolas*[5] and indigenous communities (Núcleo de Informação e Coordenação do Ponto BR [NIC.br], 2022). For the purposes of this research, both small providers and community networks were consulted.

[4] Notably the action plan approved by ANATEL's Internal Resolution No. 449/2025 and Ruling (Acórdão) No. 176/2025.

[5] Communities of Afro-Brazilian descendants of enslaved people, historically associated with resistance to slavery, who maintain their own cultural and territorial traditions.

Data on FOSS use by small ISPs in Brazil

There is no clear data on the use of FOSS by small ISPs in Brazil. The terms "FOSS," "free software," and "open source" do not appear in the "ICT Providers" surveys that Cetic.br has coordinated and conducted since 2011, and the bibliographic and literature review returned no significant matches for any of these terms. Nor are there dedicated materials or guides that compile the types of FOSS used by providers or propose a FOSS stack tailored to them. This absence is itself a finding: it signals that FOSS use among small ISPs, however widespread, remains largely undocumented and unmeasured.

In software terms, a community or small ISP is essentially a small business that requires at least one server, and only a few of its processes call for software specific to this type of enterprise, for example, managing the bandwidth delivered to customers, monitoring the status and operation of routers or cabling (as in a fiber-optic network), or operating the software that runs an OLT (Optical Line Terminal) in a PON (Passive Optical Network). Most of the FOSS an ISP uses is not ISP-specific but common to other kinds of business, and some packages handle several of these processes at once.

Because the technical requirements are this modest, and largely met by software that is freely available, one might expect FOSS adoption to be straightforward. In practice it is not. Many community networks have had the support of persons experienced in FOSS (NIC.br, 2022) and already rely on FOSS, but doing so has meant contending with barriers that are regulatory and economic rather than technical (Labardini Inzunza and Zanolli, 2021), as described below.

Methodology

To the best of our knowledge, this is the first dedicated study of Free and Open Source Software (FOSS) use among small ISPs and community networks in Brazil. This novelty underscores the empirical gap the research seeks to address and shapes its design. Given the absence of prior data, the study adopts an exploratory, mixed-methods approach that combines qualitative and quantitative techniques, with each component informing the next.

Qualitative component

The research began with in-depth, semi-structured interviews with key stakeholders, designed to: (i) assess perceptions of FOSS adoption among small ISPs; (ii) examine the relevance and definitions of terms such as "small ISP" and "community-focused ISP" in the Brazilian context; and (iii) identify the terminology and concepts used in day-to-day ISP operations involving FOSS.

These interviews were conducted with a deliberately broad set of stakeholders, industry representatives, researchers, and practitioners, in order to capture perspectives on ISP operations, FOSS adoption, and international best practices. Their findings directly informed the design of the subsequent survey instruments, ensuring that the questionnaires used terminology and categories grounded in actual practice rather than assumed in advance.

Quantitative component

Two survey instruments were developed and applied in sequence, first in person, then online, both with the support of the Brazilian Association of Internet and Telecommunications Providers (ABRINT), the largest association representing small and medium-sized ISPs in Brazil and the principal voice of this segment.

The in-person survey was administered during the ABRINT Global Congress and yielded 22 responses (see Appendix 3). Beyond its quantitative results, this phase served an important refining function, surfacing regional variations in terminology, divergent interpretations of what counts as FOSS, and the software tools most commonly in use.

The online survey was a refined version of the same instrument, distributed nationwide through partner networks. Before dissemination, it was pilot-tested with small ISPs to confirm clarity and relevance, a step made necessary by the terminological inconsistencies the in-person phase had revealed (see Appendix 2).

Findings were then validated through consultations with key institutional actors, including ABRINT, communities of ISPs that use FOSS, and experts in the field, reinforcing both analytical rigor and practical relevance.

Limitations and scope

Owing to the exploratory nature of this study, it does not incorporate variables related to social markers such as race, class, or gender; examining these would require a different methodological design and is left to future research.

One episode is itself revealing of the field's challenges. The online survey was distributed by ABRINT to more than 2,000 ISPs by email and WhatsApp. Arranging this distribution took considerable time and effort: it required prior approval from ABRINT's board, secured only after sustained coordination, and reflected a notable level of institutional endorsement. Despite this groundwork and backing, the survey received no responses. Incentives had been deliberately avoided due to legal hurdles, but the null result points to a broader obstacle: the difficulty of generating engagement and reliable data on FOSS adoption among small ISPs. Limited time, low perceived relevance of the topic, and competing operational priorities are all plausible contributors, and each, notably, echoes the same constraints the study identifies as barriers to FOSS adoption itself.

Resulting suggested FOSS stack

Drawing on these findings, the study developed a suggested open-source stack for community-focused ISPs, grounded entirely in existing open-source solutions (see Appendix 1). The stack is organized into 16 core categories; the methodology and criteria used to construct it are detailed below.

Findings

Adoption of FOSS

FOSS has contributed to the democratization of internet access in Brazil, though it is by no means the sole driver. Interviewees identified three distinct mechanisms through which FOSS lowered barriers to entry for small ISPs.

The first is direct cost avoidance at the software layer. The availability of FOSS solutions allowed ISPs beginning their operations to build core infrastructure without incurring significant licensing fees, a meaningful advantage for capital-constrained entrants.

The second is the indirect effect of FOSS on hardware costs. The presence of affordable, entry-level equipment is partly attributable to the fact that such hardware runs a FOSS-based operating system and an entire stack of embedded FOSS software. Had small ISPs been required to purchase proprietary licenses, whether bundled into the hardware or acquired separately, the resulting cost passed on to the ISP, and ultimately to end users, would have been substantially higher. In this sense, FOSS shapes affordability not only directly but through the broader equipment market.

The third is the informal online learning ecosystem that developed around these tools. ISPs adopting FOSS software and equipment typically did so by drawing on freely available online resources, videos, written guides, and practitioners who worked with and actively promoted these technologies. Online video, particularly on YouTube, plays an especially important role in this process, alongside community portals such as the Brazil Peering Forum,[6] and the "providers" community within the 'Viva o Linux' forum.[7] This ecosystem is significant because it lowers a less visible barrier: the knowledge and skills required to deploy and maintain the technology, which proprietary vendors typically supply through paid support.

These three mechanisms notwithstanding, the picture is not uniformly positive. Some interviewees expressed frustration with small providers themselves, whom they regard as largely indifferent, reluctant even to engage with the subject of free software, let alone consider it seriously as an option.

For these experts, the deeper challenge lies in teaching connectivity entrepreneurs how to build a viable business model around free software. Dwelling only on the philosophical

[6] The forum provides a very good discussion divided into topics, as well as articles and explanations about the various practices and tools for ISPs. It can be viewed at: https://wiki.brasilpeeringforum.org/w/P%C3%A1gina_principal
[7] See https://www.vivaolinux.com.br/comunidade/provedores/

dimension, the rights to read, inspect, copy, and audit the source code, is not enough; what matters is how those rights translate into practice. That translation, they argue, occurs only when a supporting ecosystem takes shape: one in which Brazilian companies provide Portuguese-language support for free-software products, accept commissioned development work on openly licensed code, and finance that development through cost-sharing among multiple players. Equally essential is an intermediary figure, someone with the technical expertise to bridge the gap between the software and the ISP. It is this accountable, commercially grounded relationship that closes the distance between the promise of FOSS and its actual adoption.

Reliance on cracked or unauthorized software

A notable finding from the interviews is that many small ISPs have come to depend on cracked or unauthorized software, including counterfeit license keys and modified systems that circumvent usage restrictions. This practice is driven largely by cost pressures and by limited access to affordable, appropriately scaled solutions. Yet it carries significant risks: security vulnerabilities, absence of updates and patches, operational instability, and legal exposure. It also entrenches a cycle of informality, in which providers lean on unsustainable workarounds rather than transitioning to secure, compliant, and maintainable technology stacks.

This behavior points to a deeper structural gap. Proprietary solutions are frequently out of financial reach, but the available open-source alternatives, though technically viable, are not always sufficiently known, well packaged, or easy for smaller operators to deploy. The result is a kind of double bind: the compliant commercial option is unaffordable, while the affordable compliant option is not visible or accessible enough to be adopted. This is why unauthorized software persists even where free alternatives exist; the barrier is less about the technology itself than about cost, knowledge, and deployment support.

Closing this gap through accessible open-source stacks, training, and implementation support, represents a key opportunity to reduce reliance on unauthorized software while strengthening network resilience, security, and long-term sustainability.

Costs

Drawing on in-depth interviews, survey responses, and group discussions with ISPs, developers, and FOSS communities in Brazil, software costs for small internet service providers follow a relatively consistent hierarchy. The principal cost drivers are, in order: (i) ISP-specific Enterprise Resource Planning (ERP) systems, (ii) operating system licenses for technical and administrative staff, and (iii) Customer Relationship Management (CRM) solutions, where these are not already bundled into the ERP platform. This ordering reflects a key point: operational and billing systems, rather than purely network-related software, tend to dominate the cost structure, especially in the early stages of an ISP's development.

This hierarchy is not fixed, however. It shifts with the provider's stage of growth and its exposure to operational risk. As several practitioners noted, priorities can change abruptly in response to real-world events: a Distributed Denial of Service (DDoS) attack, for instance, can push mitigation tools to the top of the spending list overnight. For early-stage and community-based ISPs, though, ERP systems remain the consistent primary expense, even as the absolute cost varies widely with vendor pricing models and subscriber count.

Business and customer management: ERP Software

ERP systems are the largest and most structurally complex software cost small ISPs face. Pricing is typically opaque, varying with modular configuration, deployment model (SaaS versus self-hosted), subscriber count, and customization. FOSS-based ERP solutions do exist, but none are adapted to the specific needs of an ISP; examples are cataloged on the "Open Source Alternatives to Proprietary Software" website.[8]

The pricing logic itself helps explain why. According to Gilnei Engelmann, CEO of Voalle, a major ISP-focused ERP provider positioned among medium and larger operators, ERP systems average between BRL 0.50 and BRL 1.00 (roughly USD 0.10–0.20) per subscriber per month. He emphasized that Voalle's own solution, priced a little above this average, is only economically viable for providers with at least 5,000 subscribers; below that threshold, operators lack the scale to sustain the model. The result is a structural mismatch: the providers least able to absorb ERP costs are also the ones the dominant vendors are not built to serve.

At scale, this expense is substantial. A small ISP could spend up to BRL 5,000 per month (approximately USD 1,000) and around BRL 60,000 (USD 12,000) annually, on ERP alone, a heavy burden once combined with infrastructure, connectivity, and other software.

The weight of this cost becomes clearer still when measured against revenue. Among interviewed providers with fewer than 5,000 customers, the average retail price is approximately BRL 97.85 (USD 20) per subscriber per month. Against that figure, an ERP cost of up to BRL 1 per user per month can consume more than 1% of total revenue on its own, before any other software is accounted for. Since a substantial share of this amount is absorbed by connectivity, infrastructure, taxes, and labor, an ERP cost equal to roughly 1% of revenue represents a considerably larger share of an ISP's net margin. The burden on the bottom line is therefore greater than the revenue figure alone suggests.

[8] See https://opensourcealternative.to/?searchTerm=ERP

Interviewees noted attempts to build open-source ERP solutions tailored to ISPs, but none has matured into a scalable or widely adopted alternative, largely because no individual or organization has taken ownership of sustaining development. ERP therefore remains one of the clearest sources of vendor dependency and cost concentration in the ISP software stack, and correspondingly one of the clearest opportunities for more accessible, scalable alternatives.

Underlying systems layer: operating systems

Operating systems are a relevant but frequently underestimated component of software spending among small internet service providers (ISPs). Survey data collected for this study show that a clear majority of providers rely on proprietary operating systems, particularly Microsoft Windows, across both technical and administrative functions: approximately 72% of respondents reported using Windows on technical workstations and 75% on customer support systems.

Both surveys and interviews suggest, however, that a portion of these licenses may not be formally paid for, especially among smaller providers. In at least one case, a respondent reported using Windows across multiple functions while simultaneously reporting zero software expenditure overall, a contradiction that is difficult to explain through legitimate licensing alone.

This points to an informal software economy operating within the small-ISP segment. Unpaid or unauthorized licensing may reduce costs in the short term, but it carries real risks and vulnerabilities. More fundamentally, it reflects the structural conditions under which these providers operate, tight margins and limited access to affordable, appropriately scaled software, the same conditions that drive reliance on cracked software elsewhere in the stack.

These conditions also make the true cost of operating systems unusually hard to measure. Licensing costs for proprietary systems vary widely with acquisition channel, bundled hardware, and product version. The prevailing one-time licensing model for desktop systems compounds the difficulty, since costs attach to hardware replacement cycles rather than recurring operational budgets and are therefore easily omitted from year-to-year accounting. Increasingly, moreover, operating systems arrive bundled with cloud-based productivity and collaboration packages that carry recurring subscription fees, an additional layer of expenditure that conventional cost assessments often miss entirely.

The cumulative effect is that the financial burden of operating systems is both heterogeneous and partially hidden, distributed across informal usage, variable licensing practices and cost allocation. The practical implication matters for this study as a whole:

the true cost of software in small ISPs is almost certainly underestimated whenever only reported expenditures are counted.

This same area, however, represents one of the clearer opportunities for cost optimization. Open-source operating systems are a viable alternative for many use cases, particularly in technical environments where compatibility constraints are weaker. Adoption nonetheless remains limited, held back less by technical capability than by familiarity, integration with existing workflows, and the perceived cost and disruption of transition.

Past efforts to reduce structural dependency have not taken hold

Beyond direct licensing costs, there are broader structural dependencies linked to network architecture. A key example is the transition from IPv4 to IPv6, which has created significant operational complexity for ISPs worldwide. Because both protocols must coexist, most providers rely on Carrier-Grade Network Address Translation (CGNAT) to bridge legacy IPv4 systems with newer IPv6 networks.

In practice, CGNAT functions as a technical intermediary, similar to an adapter between incompatible systems, and is essential for sustaining network growth in the context of IPv4 exhaustion. However, this functionality is typically delivered through proprietary hardware appliances, which are often too costly. While such systems may incorporate open-source components, their core functionality remains closed and vendor-controlled, reinforcing dependency on a limited set of suppliers.

Efforts to develop open alternatives have emerged. For example, the Disaggregated Network Operating System (DANOS), originally developed by AT&T and later released through the Linux Foundation,[9] demonstrated the potential to deliver CGNAT through open, software-based solutions running on commodity hardware. DANOS did not achieve long-term sustainability, and community discussions on the project's status on Reddit suggest DANOS was abandoned less through any single decision than through attrition: an unresolved build dependency halted new releases, and with a better-maintained free alternative (VyOS) already available, users had little reason to wait.[10] Nonetheless, this experience highlights a critical and unresolved opportunity: the possibility of reducing dependency on proprietary network infrastructure through open, modular architectures.

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[9] See https://danosproject.org/ and https://www.linuxfoundation.org/press/networking-edge/the-linux-foundation-hosts-danos-project-a-unified-network-operating-system

[10] See this Reddit thread —https://www.reddit.com/r/networking/comments/xaal24/danos_project_status/

Beyond DANOS, several initiatives have sought to deliver carrier-grade network functions through open and disaggregated architectures. As Labardini Inzunza and Zanolli (2021) describe, the effort to popularize the LibreRouter (a device developed by Argentina's AlterMundi from around 2018, running LibreMesh, a FOSS firmware built on OpenWrt) among Brazilian community networks ran into several such obstacles: certification costs set at the same level as those imposed on routers backed by firms with far greater market power; a requirement to recertify with every firmware release or minor hardware change; and the cost of importing the hardware.

ISP and community-networks oriented solutions have enabled partial substitution of proprietary edge infrastructure (see suggested stack in Appendix 1). However, these efforts have generally fallen short of delivering a fully integrated, scalable, and user-friendly open alternative for CGNAT, leaving a persistent gap in the ecosystem.

Conclusions and recommendations

The primary barriers to FOSS adoption are limited awareness, usability challenges, and insufficient implementation capacity, particularly among smaller providers. Addressing these constraints is essential to unlocking the full potential of open-source solutions in the sector. The analysis also points to a broader data gap: software usage patterns and cost structures among small ISPs remain poorly documented, which limits the ability to design evidence-based policies and interventions. This gap, in turn, reinforces the value of producing practical, actionable outputs such as the proposed open-source stack (see Appendix 1).

Key takeaways

Providers have long integrated FOSS extensively into their operations, even when they do not fully recognize or articulate the implications of doing so. The finding is not simply that small and community ISPs can use FOSS, but that they already do—to cut software costs and streamline operations. FOSS is not a future opportunity for this sector; it is the foundation the sector was built on. The expansion of digital inclusion in Brazil, and the remarkable number of small ISPs driving it, would likely have been impossible without it.

That said, **adoption is uneven and often only partially recognized by providers themselves**. Knowledge gaps remain significant, with many ISPs lacking a clear understanding of what FOSS is and how it can be leveraged strategically. A recurring theme in the interviews was the widespread reliance on cracked or unauthorized software, from counterfeit license keys to modified systems that circumvent usage restrictions, a pattern that signals not only cost pressure but the absence of accessible, legitimate alternatives positioned to replace it.

FOSS adoption is fragmented across the technology stack. While the core network and technical layers are increasingly supported by open, modular technologies, the business layer remains concentrated and largely proprietary. ERP systems stand out as the most significant and least flexible cost component: their pricing models, scale requirements, and limited competition raise barriers for smaller ISPs and reinforce vendor dependency. Despite some attempts to develop open-source alternatives, no widely adopted ISP-focused ERP has emerged. Interviewed specialists noted that the idea has circulated among open-source enthusiasts for years, but no effort has succeeded—largely because no single entity has taken ownership of the project, and because sustaining the software would require continuous funding. ERP therefore stands as a key constraint on affordability, scalability, and independence within the ISP ecosystem.

This last point reflects the central obstacle the research identifies, which is institutional rather than technical: **no actor owns or sustains FOSS solutions for the sector.** This ownership vacuum is compounded by a broader ecosystem gap, a cluster of non-technical barriers that prevent small ISPs and community networks from adopting and sustaining FOSS even when the software itself is free and available. These barriers include (i) the lack of centralized, up-to-date documentation, particularly in Portuguese; (ii) the absence of a consolidated "reference stack" for ISPs, which this project begins to address; and (iii) limited technical support and the lack of coordinated development ecosystems to maintain and evolve solutions over time. While communities and institutions such as NIC.br provide important resources, no integrated approach currently supports FOSS adoption across the full ISP lifecycle.

These findings carry a clear implication for policy. Realizing the right to internet access for the share of the Brazilian population that does not yet enjoy "meaningful connectivity" requires drawing on the full range of solutions capable of advancing that goal. Among them, open-source software holds particular promise for small and community ISPs, but unlocking it depends on closing the ecosystem gaps identified here.

Practical tools are one part of the answer. The proposed open-source stack (see Appendix 1) represents a concrete step toward reducing costs, improving operational efficiency, lowering vendor dependency, and advancing digital sovereignty. Yet tools alone are insufficient: as the findings make clear, the binding constraints are as much institutional as technical, spanning knowledge, support, financing, and governance. The recommendations that follow, grounded in these findings, address both dimensions.

Recommendations

Develop an open source ERP

The findings indicate that the most impactful opportunities for intervention lie not in the core network layer, but in the business and ecosystem layers, where cost burdens and vendor dependencies are most concentrated. This reframing matters: it suggests that the binding constraint on FOSS adoption among small ISPs is not the availability of network software, which is already mature and widely used, but the absence of affordable, ISP-specific tools at the operational layer.

The clearest instance is the lack of a viable open-source ERP adapted to the needs of ISPs. As documented above, ERP systems represent the single largest and most structurally complex software cost these providers face, and proprietary vendors are economically geared toward operators large enough to absorb that cost, leaving the smallest providers underserved. An open-source alternative has been discussed within the community for years but has never matured into a scalable solution, largely because no actor has taken ownership of sustaining its development.

Advancing such a system would therefore be a natural and high-impact continuation of this research. A purpose-built open-source ERP could meaningfully reduce operational costs, increase autonomy, and strengthen the long-term sustainability of small and community-based providers. Realizing this goal, however, would require addressing the ownership gap directly: a sustained development effort, a maintenance commitment, and a financing model capable of supporting both over time.

Build capacity and awareness

Strengthening adoption of Free and Open Source Software (FOSS) among small and community ISPs requires a coordinated effort focused on education, mindset shift, and ecosystem development.

First, there is a clear need to increase awareness and technical literacy around FOSS, including its operational, financial, and strategic implications. This includes demystifying FOSS and highlighting its potential to reduce costs, increase flexibility, and mitigate dependency on proprietary vendors.

Second, capacity-building efforts should address the prevailing commercial mindset among many small ISPs. While profitability remains essential, these providers also play a critical public interest role as enablers of connectivity and, by extension, guarantors of citizens' right to access the internet. Framing ISPs as both businesses and infrastructure actors with societal responsibilities can help align incentives with broader digital inclusion goals.

Third, there is a need to foster a more robust FOSS ecosystem, including development, maintenance, and technical support structures tailored to the realities of small providers. A practical starting point would be to build on the FOSS stack identified in this project (see Appendix 1), promoting its adoption and iterative improvement.

Finally, this effort should be consolidated through the creation of a centralized platform and training module, bringing together existing FOSS tools across the full ISP value chain. Over time, governance and maintenance of this platform could be transitioned to a community of practice composed of ISPs already engaged with FOSS, helping address current coordination gaps and enabling peer-driven knowledge sharing and sustainability.

Create institutional support for FOSS

Centers of competency commonly known as Open Source Program Offices (OSPOs) have existed in some parts of the world for over twenty years. Their role is to serve as a hub of competency and excellence that drives organizational readiness around open source. Among other functions, OSPOs provide advice and support on the use of OSS and manage the IT infrastructure required to engage with open-source projects, including tools for compliance tracking and vulnerability scanning (Linåker, Nummelin Carlberg, & O'Riordan, 2026). In doing so, they help bridge the gap between high-level policy commitments to open source and their actual implementation on the ground. They exist across multiple levels and types of organization, national governments, individual public institutions, local governments, member-based associations, and academic bodies, as well as in civil-society organizations that perform OSPO-like functions (Linåker, Nummelin Carlberg, & O'Riordan, 2026).

A similar model could be valuable for fostering the community-connectivity ecosystem in Brazil. Much as an OSPO concentrates scattered expertise and provides the support, risk management, and continuity that individual public bodies cannot sustain alone, an equivalent structure could serve small ISPs and community networks, actors who, individually, lack the time, technical capacity, and resources to evaluate, deploy, and maintain FOSS solutions. Such a body could perform several functions the research has shown to be missing: curating and maintaining a reference FOSS stack adapted to the needs of small providers; offering Portuguese-language documentation, training, and implementation support; channeling shared or public financing toward the development of ISP-specific open-source tools (addressing the ownership gap that has stalled previous efforts, such as open-source ERP); and acting as a neutral intermediary between providers, developers, regulators, and funders.

The association-based and civil-society archetypes identified by Linåker, Nummelin Carlberg, and O'Riordan (2026) are particularly suggestive here. Existing actors in the Brazilian ecosystem[11] could collectively assume this enabling role, or a new structure could be created for the purpose. The question of governance remains open. In either case, the central insight transfers directly: realizing the promise of FOSS depends less on the software itself than on building the institutional capacity to support, sustain, and govern it.

Increase advocacy to support FOSS

Advocacy is needed to advance policy reforms that embed FOSS within federal ICT spending and within the financing mechanisms of Brazil's universal service fund and other telecom-sector funding instruments, positioning FOSS as a cost-efficient and sovereignty-enhancing tool for scaling small and community ISP models.

At present, no existing instrument earmarks public funds specifically for the development or adoption of FOSS. The financing mechanisms most relevant to this goal are Fundo de Universalização dos Serviços de Telecomunicações (FUST), Brazil's universal service fund and Fundo para o Desenvolvimento Tecnológico das Telecomunicações (FUNTTEL), the telecom technology-development fund. These serve distinct purposes: FUST finances the expansion of access in underserved regions, while FUNTTEL is mandated to stimulate

[11] E.g. Institutions such as Abrint, Nic.br and others.

technological innovation and support Brazil's domestic telecom industry. Given its innovation mandate, FUNTTEL is arguably the more natural vehicle for financing the development of national FOSS and open-hardware solutions. This is a direction already recommended by Labardini Inzunza and Zanolli (2021). FUST, in turn, could support the deployment of FOSS-based small and community ISP infrastructure. The idea of directing FUST toward free software is not new: as early as 2004, then-Anatel president Pedro Jaime Ziller publicly stated that FUST resources would be invested in free rather than proprietary software, in connection with a digital-inclusion project (Exame, 2004). That commitment was never realized, however, and the topic has lost momentum since, illustrating that high-level political intent alone has proven insufficient without sustained advocacy and concrete financing mechanisms.

Suggested technology stack

We developed a suggested technology stack tailored for community-focused internet Service Providers (ISPs), presented below and in Appendix 1. The stack was developed in collaboration with a group of experts who combine deep experience in ISP operations with a long-standing commitment to open-source technologies (See Acknowledgements below for a list of individuals). Their insights reflect both practical deployment realities and a nuanced understanding of the open-source ecosystem's evolution.

The stack is grounded entirely in existing open-source solutions and organized into 16 core categories: Routing / Firewall; AAA (RADIUS); PPPoE / IPoE (BNG); Network Monitoring; Traffic Analysis; DDoS Detection; DNS; CPE Provisioning (ACS); Configuration Backup; Network Automation; IPAM / DCIM; BGP Tools; ERP; Helpdesk / CRM; Operating System; Virtualization.

Within each category, we reviewed the available tools and retained only those that are fully open source, excluding solutions with partial or restricted open-source components to ensure transparency, adaptability, and long-term sustainability. From this curated list, we then selected the tools our experts considered most useful for each category.

To the best of our knowledge, this is the first resource of its kind specifically focused on open-source stacks for small ISPs and/or community networks. It is intended to support both emerging ISPs seeking guidance in their initial setup and established operators aiming to optimize and scale their infrastructure.

While this stack was developed with the Brazilian context in mind, the proposed architecture is built on globally available, mature open-source technologies not tied to specific regulatory environments, vendors, or localized infrastructure constraints. As such, the stack is largely transferable across regions, particularly in emerging and underserved markets where small and community-based ISPs operate under similar structural conditions—such as limited access to capital, reliance on incremental network expansion, and the need for cost-efficient and adaptable solutions.

At the same time, some elements may require contextual adaptation, particularly in areas such as regulatory compliance, taxation, customer management (e.g., ERP and billing requirements), and integration with local payment systems or identity frameworks. These variations primarily affect the business layer rather than the core network architecture.

Overall, the stack should be understood not as a rigid blueprint, but as a modular and adaptable framework that can be tailored to different country contexts while preserving its core principles of openness, cost-efficiency, and technological independence.

Visual representation of FOSS technology stack

Suggested open source stack for community-focused ISPs

Network infrastructure

Routing / Firewall VyOS | FRRouting (FRR) | OPNsense | pfSense CE	**PPPoE / IPoE (BNG)** VyOS (PPPoE AC)
AAA (RADIUS) FreeRADIUS	**DNS** PowerDNS | BIND 9 | Unbound | NSD

Monitoring & security

Network monitoring Zabbix | Grafana + Prometheus	**Traffic analysis** ntopng | Akvorado | Wazuh
DDoS detection FastNetMon CE	**BGP tools** ExaBGP | Routinator (RPKI) | Peering Manager

Management & automation

IPAM / DCIM NetBox | phpIPAM	**CPE provisioning (ACS)** GenieACS | OpenWisp
Network automation Ansible (+ AWX)	**Configuration backup** Oxidized | Borg
ERP / Billing (BSS) ABillS	
Helpdesk / CRM Chatwoot | Zammad | GLPI | ERPNext	
Operating system Debian | Ubuntu Server | OpenWrt	**Virtualization** Proxmox VE | OpenNebula

See full details in Appendix 1

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Appendices

Appendix 1 - Suggested Stack

Suggested Open Source Stack for Community-Focused ISPs				
Function	**Software**	**Country**	**Pricing**	**Website**
Routing / Firewall	VyOS	USA	Free (rolling); Paid (LTS/support)	https://vyos.io
	FRRouting (FRR)	USA	Free (GPLv2)	https://frrouting.org
	OPNsense	Netherlands	Free (BSD)	https://opnsense.org
	pfSense CE	USA	Free (Apache 2.0)	https://www.pfsense.org
AAA (RADIUS)	FreeRADIUS	USA/ Global	Free (GPLv2)	https://freeradius.org
PPPoE / IPoE (BNG)	VyOS (PPPoE AC)	USA	Free rolling	https://vyos.io
Network Monitoring	Zabbix	Latvia	Free (AGPLv3)	https://www.zabbix.com
	Grafana + Prometheus	Global	Free (AGPLv3/Apache)	https://grafana.com
Traffic Analysis	ntopng	Italy	Free (Community); Paid (Enterprise)	https://www.ntop.org
	Akvorado	France	Free (BSD)	https://demo.akvorado.net/
	Wazuh	Global	Free (GPLv2)	https://wazuh.com/
DDoS Detection	FastNetMon CE	UK	Free Community (CE)	https://github.com/pavel-odintsov/fastnetmon
DNS	PowerDNS	Netherlands	Free (GPLv2)	https://www.powerdns.com
	BIND 9	USA	Free (MPL 2.0)	https://www.isc.org/bind/
	Unbound	Netherlands	Free (BSD)	https://nlnetlabs.nl/projects/unbound/
	NSD	Netherlands	Free (BSD)	https://nsd.docs.nlnetlabs.nl/en/latest/
CPE Provisioning (ACS)	GenieACS	Global	Free (AGPLv3)	https://genieacs.com
	OpenWisp	Estonia	Free (BSD)	https://openwisp.org/
Configuration Backup	Oxidized	Global	Free (Apache 2.0)	https://github.com/ytti/oxidized
	Borg	Germany	Free (BSD)	https://www.borgbackup.org/
Network Automation	Ansible (+ AWX)	USA	Free (GPLv3); AAP Not Free	https://www.ansible.com
IPAM / DCIM	NetBox	USA	Free (Apache 2.0)	https://netbox.dev

	phpIPAM	Global	Free (GPLv3)	https://phpipam.net
BGP Tools	ExaBGP	Global	Free (BSD)	https://github.com/Exa-Networks/exabgp
	Routinator (RPKI)	Netherlands	Free (BSD)	https://nlnetlabs.nl/projects/routing/routinator/
	Peering Manager	Global	Free (Apache 2.0)	https://peering-manager.net
ERP / Billing (BSS)	ABillS	Ukraine	Free (GPLv2)	https://abills.net.ua
Helpdesk / CRM	Chatwoot	India	Free (MIT)	https://www.chatwoot.com
	Zammad	Germany	Free (AGPLv3)	https://zammad.org
	GLPI	France	Free (GPLv3)	https://glpi-project.org
	ERPNext	India	Free (GPLv3)	https://erpnext.com
Operating System	Debian	Global	Free (DFSG)	https://www.debian.org
	Ubuntu Server	UK	Free (GPL)	https://ubuntu.com/server
	OpenWrt	Global	Free (GPL)	https://openwrt.org
Virtualization	OpenNebula	Spain	Free (Apache 2.0)	https://opennebula.io/
	Proxmox VE	Austria	Free (AGPLv3)	https://www.proxmox.com

Appendix 2 - Basic interview guide

Online survey distributed to ABRINT member ISPs

Block 1 - Identification

Block 2 - Type of provider

2.1) What is the current number of clients your provider has?

2.2) When was the provider you work for established?

2.3) How many customers did you start with?

2.4) What is the current number of employees at the provider where you work?

2.5) Does your provider serve an area/neighborhood that did not have internet access before?

2.6) What is the general population served by your provider?

2.7) Do you provide any services to customers related to servers and networks other than internet access (such as email, cloud hosting, websites)? If so, which ones:

a) Operating system of the provider's computers:
  a1) Technicians' machines
  a2) Customer Service

b) Server operating system:

c) Monitoring system and routers (NOC):

d) Which DNS resolver do you use?

e) What do you use for IP/IPv6 and VLAN address management?

f) Virtualization of machines (VMs) on the server:

g) Which ERP (Enterprise Resource Planning) system do you use (for ticketing, database, etc.)?

h) Do you use or have you ever used Mikrotik (RouterOS)?

i) Client communications / Sales:

Block 3 - Use of software at the provider

It is important to emphasize here that we know that the same software can be used for several processes (such as Proxmox and MK AUTH), so more than one question may have the same answer. We would like to know which software is used and for which process.

3.1) What software do you use for:

a) Operating system of the provider's computers:

a1) Technicians' machines

a2) Customer Service

b) Server operating system:

c) Monitoring system and routers (NOC):

d) Which DNS resolver do you use?

e) What do you use for IP/IPv6 and VLAN address management?

f) Virtualization of machines (VMs) on the server:

g) Which ERP (Enterprise Resource Planning) system do you use (for ticketing, database, etc.)?

h) Do you use or have you ever used Mikrotik (RouterOS)?

i) Client communications / Sales

3.2) Have you ever modified a device (such as an OLT) to make it compatible with other devices and software? (If so, which one and for what purpose)

3.3) Is there any process or software that you use at your provider that we did not ask about and that you would like to mention?

Block 4 - Funding and resources

4.1) Have you already secured funding to set up or expand your provider? (If so, from whom?)

4.2) Do you know how much you spend on software? What percentage of your total expenses is spent on software?

4.3) Have you ever changed software to reduce costs? (If so, from which to which? In which process?)

4.4) What is the price of the two best-selling bandwidth plans?

4.5) Are you aware of any financing programs for opening ISPs that serve remote or low-income communities?

Block 5 - FOSS and Training

5.1) Do you know what free and open source software (FOSS) is?

5.2) Where did you, or whoever opened the ISP, seek knowledge to start the ISP?

5.3) Have you received specific training to set up the provider? (if so, where, from whom, and when)

5.4) Do you think a booklet with information about all the software needed for an ISP would be useful for opening new ISPs?

5.5) Have you or other employees at your provider taken free courses on software for providers?

5.6) Do you think that an online course module with information about the entire software stack for a provider would be useful for your work? And for opening new providers?

Block 6 - Contact and recommendations:

6.1) Are there any questions you consider important that we have not asked?

6.2) Could you leave your contact information in case we have more questions or clarifications and send you the survey results when they are ready?

- Phone (whatsapp)
- e-mail

6.3) Do you know any small providers or community providers in your city, region, or elsewhere? (If so, could you give us a name or contact information?)

Appendix 3 - In-depth interview guide

Semi-structured interviews conducted with operators and sector experts

Block 1 - Identification

Block 2 - Type of provider

2.1) What is the current number of clients your provider has?

2.2) When was the provider you work for established?

2.3) How many customers did you start with?

2.4) What is the current number of employees at the provider where you work?

2.5) Does your provider serve an area/neighborhood that did not have internet access before?

2.6) What is the general population served by your provider?

2.7) Do you provide any services to customers related to servers and networks other than links (such as email, hosting (cloud), websites)? If so, which ones:

Key questions:

1) How many customers does a provider need to have to be considered "small" or "community-based"? At what size does the operation change?

2) What are the main difficulties faced by small providers?

3) Do small and community providers know what FOSS is? Would it be important for them to know?

4) Are there gaps in the FOSS ecosystem with regard to ISPs? What are they?

5) What could be done to improve the costs of small and community ISPs?
through FOSS?

6) In your opinion, how can the connectivity gap in Brazil be resolved (29 million without internet and 22% with only limited connectivity)?

7) Do you think FOSS can play an important role in this process?

8) Is there any training you took or would have liked to take when you started working with ISPs? What about ISPs and FOSS?

Block 3 - Contact and recommendations:

Are there any questions you consider important that we haven't asked? Anything we should read or know about?

Could you leave your contact information in case we have more questions or clarifications and to send you the survey results when they are ready?

Do you know any small providers and community providers in your city, region, or elsewhere? (If so, please provide us with a name or contact information).

FREE AND INFORMED CONSENT FORM

I, ____, ID/CPF __________________________, hereby declare that I have been informed of the objectives and reasons for conducting the survey "Use of free and open source software as a means of improving processes and reducing costs for small and community internet service providers (ISPs)," conducted in Brazil in 2025 by Connect Humanity.
Consent to mention my name in the research report: ( ) YES   ( ) NO

Date and Place   Signature