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Cost-Effectiveness Analysis of Telemedicine in Rural Healthcare Systems

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Abstract:

Telemedicine has emerged as a promising strategy to address geographic, workforce, and infrastructure constraints that limit access to care in rural regions. This paper presents a pragmatic cost-effectiveness analysis (CEA) framework for rural health systems, focusing on primary-care consultations and chronic-disease follow-up. We develop a simple decision-analytic model that compares telemedicine to conventional in-person care from a health-system perspective over a one-year horizon. Cost categories include capital (hardware, connectivity, platform), operational (staff time, training, maintenance), and patient-incurred costs (travel and time). Effects are measured as additional consultations delivered, avoided referrals, and quality-adjusted life-years (QALYs) proxied through improved guideline-concordant care. Scenario analysis shows telemedicine is cost-saving at moderate-to-high utilization due to reduced travel, better provider time allocation, and avoidance of unnecessary facility visits and referrals. At low utilization, fixed costs dominate and telemedicine can be more expensive per consultation. Threshold analysis highlights breakeven volumes and connectivity prices at which telemedicine switches from cost-increasing to cost-saving. We discuss

implementation levers—workforce workflows, hub-and-spoke routing, device sharing, demand generation, and data governance—that improve value for money while safeguarding equity and quality. The results support scaling telemedicine in rural systems when paired with adequate throughput, training, and reimbursement alignment.

Keywords: telemedicine, rural healthcare, cost-effectiveness, QALY, decision analysis, primary care, health economics, implementation.

INTRODUCTION

Rural healthcare delivery is constrained by long travel distances, limited specialist availability, and intermittent facility hours. These barriers increase out-of-pocket expenditure, delay treatment, and exacerbate inequities in chronic-disease outcomes. Telemedicine—synchronous video/voice visits, asynchronous store-and-forward, and remote monitoring—offers a partial solution by decoupling basic clinical decision-making from physical co-location. Yet policy makers and payers require robust economic evidence to prioritize scarce resources. This article develops a transparent CEA structure that a district health authority can adapt with local prices and volumes. We adopt a health-system perspective with sensitivity to patient costs, compare telemedicine with standard care for common rural use-cases (primary-care triage, diabetes/hypertension follow-up, maternal/child health counseling), and summarize the utilization thresholds and cost drivers that determine value for money.

Methods: Perspective, Model Structure, and Outcomes

This section elaborates on the framework and methodology used to evaluate the cost-effectiveness of telemedicine in rural healthcare systems. The key components of the model include the perspective from which the analysis is conducted, the structure of the decision model, cost components, outcomes, and approaches to handling uncertainty.

Perspective & Horizon

Health-System Perspective:

The analysis adopts a **health-system perspective** that focuses on the costs and outcomes experienced by healthcare providers, health authorities, and payers (e.g., governments, insurers). The perspective prioritizes efficiency in resource utilization, considering not only direct costs but also system-level benefits such as reduced patient burden and overall healthcare utilization.

Horizon:

The **time horizon** is set to **12 months**, reflecting a typical annual cycle for healthcare interventions, especially in rural settings where the adoption of telemedicine might be evaluated over multiple operational phases. This allows an assessment of the cost-effectiveness of telemedicine during the initial year, which would include:

Setup costs (e.g., equipment, connectivity infrastructure).

Training costs for healthcare staff.

Operational costs (e.g., platform usage, clinical consultations).

Healthcare outcomes over the one-year period.

Secondary Analysis – Patient Travel/Time Costs:

Additionally, the analysis includes **patient travel and time costs**. In rural areas, patients often need to travel long distances to access in-person care. By including these costs, the model

captures the potential savings in patient time and transportation, an important consideration for both healthcare systems and individuals in remote areas.

Training Costs: Initial and ongoing training of healthcare staff to ensure that they can effectively use telemedicine platforms and manage remote consultations.

Maintenance: Regular upkeep of hardware, software updates, and troubleshooting.

Clinical and Non-clinical Staff Time:

Staff Time: Includes the cost of healthcare providers' time, both for telemedicine consultations and for managing in-person visits, as well as the time of administrative staff.

Patient Travel and Time Costs:

Travel Costs: The costs incurred by patients to visit healthcare facilities, including transportation costs (fuel, public transport, etc.) and the time spent traveling.

Time Costs: The time lost by patients in commuting, which could be saved by telemedicine interventions.

Outcomes

The primary **outcomes** are:

Cost per Completed Consultation:

This measures the **cost-effectiveness** of telemedicine by comparing the total cost incurred per completed consultation, including patient and system costs.

Incremental Cost-Effectiveness Ratio (ICER):

ICER is calculated by dividing the difference in costs between telemedicine and in-person care by the difference in outcomes (QALYs). This ratio helps to determine the **cost per QALY gained** for each intervention.

Budget Impact at District Scale:

The model extrapolates the cost-effectiveness results to a larger **district scale**, simulating the cost impacts for rural health systems that aim to scale telemedicine services across multiple sites.

Uncertainty

To address the inherent uncertainty in the model, we perform the following analyses:

One-Way Sensitivity Analysis:

This analysis tests the **sensitivity of results** to changes in key parameters (e.g., cost per consultation, cost of connectivity, salary levels, and training costs). It helps to determine which parameters have the greatest influence on the cost-effectiveness of telemedicine.

Scenario Sensitivity Analysis:

This approach evaluates the impact of **different utilization levels** (low, medium, high) and changes in assumptions about **patient referral rates**, connectivity costs, and staffing models. The results allow us to model a range of possible future scenarios based on variations in real-world settings.

Data & Assumptions for a Rural District

This section presents the underlying assumptions and data used to model the economic and clinical outcomes of telemedicine adoption in rural districts. The assumptions are designed to reflect real-world conditions in low-resource settings and provide a baseline for understanding the expected costs, benefits, and potential barriers to implementation.

Capital & Operational Expenditure (OPEX)

The following assumptions are made regarding the **capital investments** and **ongoing operational costs** (OPEX) for the telemedicine intervention in a rural district:

Capital Costs:

Tablets/Carts Amortized Over 3 Years:

Tablets or **telemedicine carts** are required to support video consultations and provide clinical data inputs such as vital signs (blood pressure, glucose levels, etc.).

These devices are assumed to have an amortization period of **3 years**, with each device being used for at least 1,000 consultations annually. The capital cost is divided evenly over the 3-year period.

Platform Licensing Costs:

Each **telemedicine site** (e.g., a rural health center or community health post) is assumed to require a **platform license** for access to telemedicine software and support services.

Licensing costs are **paid annually per site**, with the cost proportional to the scale and features required (e.g., video consultations, store-and-forward capabilities, data security features).

Data Costs:

Telemedicine consultations require internet access and data usage.

Metered monthly data plans are assumed for each site, with data rates being **variable** depending on the region (e.g., rural districts may have more expensive or slower internet).

Monthly data usage is expected to vary by the number of consultations conducted and the quality of video/audio transmission, but data costs remain a significant operational expense for telemedicine adoption.

Training & Refresher Costs:

Initial training is assumed for all **clinical and non-clinical staff** involved in telemedicine consultations

In addition, **refresher training** is scheduled every **six months** to ensure the workforce remains up-to-date on software updates, new features, and best practices for telehealth.

Training costs include facilitator fees, transportation for trainers, and learning materials, which are spread over the course of the program.

Clinical Workflow:

The **clinical workflow** refers to how telemedicine consultations are integrated into the rural healthcare system. The assumptions are based on the **hub-and-spoke model**, a widely used approach in rural telemedicine implementation:

Hub-and-Spoke Model:

Hub: The **primary hub** consists of **specialist doctors** (general practitioners or consultants) working in the central facility or district hospital, where video consultations are conducted with patients located at remote **spoke sites**.

Spokes: These are **rural health centers** or **community health posts** (CHPs) where **nurses or community health workers (CHWs)** act as facilitators for telemedicine consultations. These healthcare workers are trained to perform basic health checks, provide patient data (e.g., vital signs), and assist with the video consultation process.

Consultation Duration & Referral Protocols:

Consultation Duration: Each **telemedicine consultation** is expected to last between **15 to 20 minutes**, which is slightly shorter than an in-person consultation. This allows for more efficient use of healthcare provider time, especially in busy rural districts.

Referral Protocols for Red-Flags: In cases where telemedicine consultations reveal red-flag symptoms (e.g., signs of severe conditions like stroke or myocardial infarction), immediate **referral protocols** are activated to guide patients to the nearest district hospital or specialist center.

Utilization Scenarios:

The model assumes three **utilization scenarios** based on how widely the telemedicine program is adopted and used in the rural district:

Low Utilization (Under-Used Pilots):

This scenario reflects the **early stages** of telemedicine implementation where **initial uptake** is low. Factors contributing to low utilization could include **limited awareness**, **technological barriers**, or insufficient training.

In this phase, telemedicine consultations are underused and may be restricted to a small number of **pilot clinics** or **outreach initiatives**.

Medium Utilization (Steady Weekly Clinics):

In the **medium utilization scenario**, telemedicine is more integrated into routine clinic operations. **Weekly telemedicine clinics** are scheduled, and the uptake improves as patients become more familiar with the service.

Follow-up consultations for chronic diseases (e.g., diabetes, hypertension) and basic primary care are commonly handled through telemedicine.

High Utilization (Routine Operations):

The **high utilization scenario** represents a fully **integrated telemedicine system** where telemedicine consultations are a **regular part** of healthcare delivery.

At this stage, telemedicine is used **daily** at multiple clinics, and **routine care** (including follow-up, triage, and chronic disease management) is conducted remotely, supported by **community health workers** (CHWs) at the spoke sites.

Effectiveness Proxies:

The **effectiveness proxies** are used to measure the clinical impact of telemedicine, especially in rural healthcare settings where access to in-person care is limited:

Increased Follow-Up Adherence:

Telemedicine has been shown to **increase patient adherence** to follow-up visits, especially for chronic conditions such as diabetes and hypertension, due to the convenience of not requiring travel.

This improves **disease management**, reduces complications, and **minimizes hospitalizations** or emergency visits, leading to better health outcomes.

Earlier Therapy Adjustment:

Remote monitoring and virtual consultations allow healthcare providers to **adjust therapies earlier** in response to changes in patient condition. For example, blood pressure medications can be adjusted more promptly through telemedicine, preventing the escalation of conditions.

Reduced Non-Urgent Transfers:

Telemedicine allows for the **reduction of non-urgent referrals** to higher-level facilities, as conditions can be addressed remotely by primary care doctors, thus **avoiding unnecessary travel** and associated costs for patients.

The **referral protocols** built into telemedicine systems ensure that only those requiring specialist care are transferred, improving efficiency in the referral process.

Equity Guardrails

To ensure equitable access to telemedicine services, the following **equity guardrails** are implemented:

Language Access:

In rural areas, language diversity can be a significant barrier to effective communication. **Multilingual support** is provided through telemedicine platforms and CHWs who are trained to address linguistic needs in **local dialects**.

Disability Accommodations:

Telemedicine systems are designed with **accessibility features** such as **screen readers** and **sign language support** to accommodate **patients with disabilities**, ensuring they can access services without facing technological barriers.

Privacy Safeguards:

To maintain confidentiality and trust in telemedicine services, strong **data security measures** are implemented, including **encrypted communication channels**, **secure patient portals**, and **compliance with local privacy regulations**.

Results: Base-Case and Scenario Analysis

This section explores the **cost-effectiveness** of telemedicine in rural healthcare systems, focusing on three utilization scenarios: **low**, **medium**, and **high** utilization. The results highlight how the **cost per consultation** and the **Incremental Cost-Effectiveness Ratio (ICER)** evolve as telemedicine scales. Additionally, we analyze the **breakeven point**, which reflects the threshold at which telemedicine becomes more cost-effective than traditional in-person care.

Low Utilization (Under-Used Pilots)

In the **low utilization** scenario, telemedicine adoption is still in its early stages. Factors such as **limited awareness**, **technology barriers**, and **lack of demand** may lead to underutilization. As a result, the **fixed costs** associated with implementing telemedicine (e.g., equipment, platform licensing, and training) dominate the overall costs, leading to higher **cost per consultation**.

Key findings:

Higher cost per consult: Due to fixed capital and operational costs, the cost per telemedicine consultation is **significantly higher** than in-person consultations. For example, in rural districts where telemedicine devices are underused, each consultation is less likely to achieve economies of scale.

ICER above typical thresholds: The **Incremental Cost-Effectiveness Ratio (ICER)**, which measures the additional cost per **Quality-Adjusted Life Year (QALY)** gained, often exceeds typical **willingness-to-pay (WTP)** thresholds (e.g., \$50,000 per QALY). In this scenario, telemedicine may not be considered cost-effective from the perspective of healthcare policy or funding bodies, unless there are substantial external benefits such as **patient satisfaction** or **improved access**.

Limited impact on outcomes: While telemedicine may improve **follow-up adherence** and **patient convenience**, the limited **clinical effectiveness** from underutilized systems means only modest improvements in health outcomes (e.g., small increases in QALYs).

Conclusion: In the early stages of telemedicine rollout, its costs outweigh the clinical benefits, making it less cost-effective unless utilization increases.

Medium Utilization (Steady Weekly Clinics)

In the **medium utilization** scenario, telemedicine adoption has moved beyond the pilot phase and is being used in a **steady manner**. Weekly telemedicine clinics become a **routine** part of healthcare delivery. As the volume of consultations increases, **per-unit costs decrease**, and the system begins to approach **cost-neutrality**.

Key findings:

Cost per consult drops: With steady utilization, the fixed costs (e.g., equipment, training) are distributed over a larger number of consultations, leading to a decrease in **cost per consult**. This brings the cost closer to that of in-person consultations.

Approaching cost-neutrality: In this phase, telemedicine starts to **break even** or **approach cost-neutrality**, meaning that the cost savings from **avoided travel, reduced hospital admissions, and better resource allocation** outweigh the incremental costs of technology and training.

Modest QALY gains: Telemedicine's impact on **health outcomes** becomes more pronounced as **non-communicable diseases (NCDs)** (e.g., diabetes, hypertension) are better managed through **remote consultations** and **improved adherence to treatment plans**. This leads to **modest gains in QALYs**, though the effect is less than that seen in the high-utilization scenario.

Improved control of NCDs: Patients with chronic conditions experience **earlier therapy adjustments** and **better disease control**, reducing the risk of complications and improving overall health outcomes.

High Utilization (Routine Operations)

In the **high utilization** scenario, telemedicine is fully integrated into the rural healthcare system. **Telemedicine consultations** become **routine**, covering a wide range of services from **primary care** to **specialist follow-ups**. As utilization reaches optimal levels, the **cost per consultation** becomes significantly lower, and telemedicine becomes both **cost-saving and more effective**.

Cost-saving: With high utilization, **telemedicine becomes cost-saving**, as the savings from **avoided travel costs, increased provider productivity, and reduced referrals** outweigh the fixed and variable costs of telemedicine implementation.

Optimized provider schedules: Providers can handle more patients in less time, and the flexibility of telemedicine allows for **efficient scheduling**, reducing **provider burnout** and improving the overall delivery of care.

Avoided referrals: Many patients who would otherwise be referred to higher-level facilities for **non-urgent consultations** are now able to receive care remotely, **avoiding unnecessary hospital visits** and freeing up resources for more critical cases.

Increased QALY gains: With increased consultations and better disease management, the **QALY gains** are more significant. For example, patients with chronic conditions like diabetes are more likely to have **better-controlled blood sugar levels**, reducing the risk of complications and improving their long-term health.

Breakeven Analysis

The **breakeven point** represents the **utilization threshold** at which telemedicine shifts from being **cost-ineffective** to **cost-effective**. Several factors influence this breakeven point:

Throughput per Device/Site:

The more **consultations per device** (i.e., per tablet or telemedicine cart) and **per site** (i.e., each rural clinic or health post), the lower the **cost per consult**. High throughput ensures that the capital and fixed operational costs are amortized efficiently over a large number of consultations.

Connectivity Unit Costs:

The **cost of data** and internet connectivity is a critical factor. If **data costs** are high, this can significantly increase the **cost per consultation** and delay the breakeven point. Reducing **data usage** and **finding cheaper data plans** or leveraging **Wi-Fi networks** can accelerate the breakeven timeline.

Task-Shifting to Nurses/CHWs:

Task-shifting—delegating tasks such as patient intake, basic health checks, and follow-up monitoring to **nurses** or **community health workers (CHWs)**—helps reduce the **staffing costs** associated with telemedicine. In rural areas, where medical professionals may be scarce, this model allows telemedicine to scale efficiently, particularly in areas with limited healthcare personnel.

Implementation & Policy Implications

The successful **implementation of telemedicine** in rural healthcare systems requires thoughtful consideration of several factors, ranging from **financing and reimbursement** mechanisms to **technology choices, human resources, and equity** initiatives. This section outlines the essential steps for scaling telemedicine while ensuring its effectiveness, accessibility, and sustainability in resource-limited settings.

Financing & Reimbursement

Align Tariffs to Encourage Remote Follow-Up:

Reimbursement models should be structured to incentivize **remote follow-up consultations** where clinically appropriate. Currently, many health systems reimburse telemedicine at lower rates than in-person consultations, despite the potential for cost savings and efficiency. By **adjusting reimbursement tariffs**, health authorities can encourage **remote care** for routine check-ups and follow-ups, particularly for **chronic conditions** like diabetes and hypertension.

Bundle connectivity and licensing costs: A bundled reimbursement approach that includes costs for **internet connectivity, platform licensing, and telemedicine consultations** can streamline payments and make telemedicine more financially viable. This could involve creating a **single tariff** that encompasses both healthcare provider time and the associated operational costs of telemedicine delivery.

Suggestions for Policy:

Ensure **telemedicine services** are reimbursed at parity with in-person visits, especially for **chronic disease management**.

Establish **per visit or per consultation** payments for telemedicine services, allowing health systems to track the volume and effectiveness of remote consultations.

Human Resources

Training and Standardization:

Training is crucial to ensure that healthcare workers are equipped to **facilitate telemedicine consultations** efficiently. This includes not only **doctors** but also **nurses, community health workers (CHWs), and administrative staff** who will help with the **technical setup**, patient registration, and remote health monitoring.

Standardize triage scripts for common conditions and consultations, ensuring that **health workers** follow best practices during virtual consultations. This will help reduce diagnostic errors and improve the quality of care provided through telemedicine.

Integrate e-prescribing and Electronic Medical Records (EMR) into the telemedicine system. This will facilitate seamless **record keeping, prescription issuance, and follow-up care**, ensuring that all healthcare data is synchronized and easily accessible for both providers and patients.

Suggestions for Policy:

Implement **comprehensive training programs** for all telemedicine stakeholders, particularly focusing on **standardizing triage processes, patient communication, and data management**.

Include **e-prescribing and EMR systems** in the telemedicine platform to streamline workflow and maintain accurate health records.

Technology Choices

Interoperable Platforms:

Interoperability is a key requirement for telemedicine platforms, particularly in rural healthcare systems where multiple types of technology and data systems (e.g., laboratory systems, hospital records) must work together seamlessly. The platform should be able to **exchange information** with **existing electronic health records (EHRs)**, **laboratory data systems**, and **national health databases**.

Offline-Tolerant Data Capture:

In rural settings with unreliable internet access, it is essential to use telemedicine platforms that support **offline data capture**. Devices such as **BP cuffs**, **glucometers**, and **fetal dopplers** can collect data offline and **sync it** when a stable connection is available. This ensures that patients in remote areas can still receive care without interruptions due to connectivity issues.

Simple Peripherals:

The technology should include **simple, easy-to-use peripherals** for routine check-ups (e.g., **BP cuffs**, **glucometers**, **stethoscopes**, **fetal dopplers**) that can be easily managed by **nurses or CHWs**. These devices should be low-cost, user-friendly, and provide real-time data to enhance telemedicine consultations.

Suggestions for Policy:

Choose **interoperable telemedicine platforms** that can integrate with existing health information systems and national registries.

Select **low-cost, portable devices** that can function in areas with poor internet connectivity while providing accurate, real-time health data.

Ensure that **offline data entry** and **automatic syncing** features are integrated into the platform.

Quality & Safety

Protocolized Red-Flag Escalation:

For telemedicine to be safe and effective, it must include clear **protocols for red-flag escalation**. Healthcare providers must be trained to identify when a patient's condition is beyond the scope of telemedicine and requires **immediate referral** to a higher-level healthcare facility.

Establish **clinical pathways** for specific conditions (e.g., stroke, myocardial infarction) that trigger automatic alerts for **emergency referrals**, ensuring timely and appropriate care.

Audit of Missed Diagnoses:

Regular **audit mechanisms** should be established to monitor telemedicine consultations for **missed diagnoses** or **mismanagement**. This can be done through **peer reviews** of telemedicine cases, ensuring that clinical decisions align with **evidence-based guidelines** and **best practices**.

Quality assurance measures, such as **remote monitoring** of patients with chronic conditions, should be in place to ensure that telemedicine is being used to enhance patient outcomes.

Privacy-By-Design and Informed Consent:

Privacy must be a **core principle** of any telemedicine system. The platform should adhere to the **highest standards** of **data security** and **patient confidentiality**.

Implement **informed consent processes** that clearly explain the risks and benefits of telemedicine to patients, particularly in rural areas where **digital literacy** may be low. This can be facilitated through **audio/visual aids** in local languages to ensure understanding.

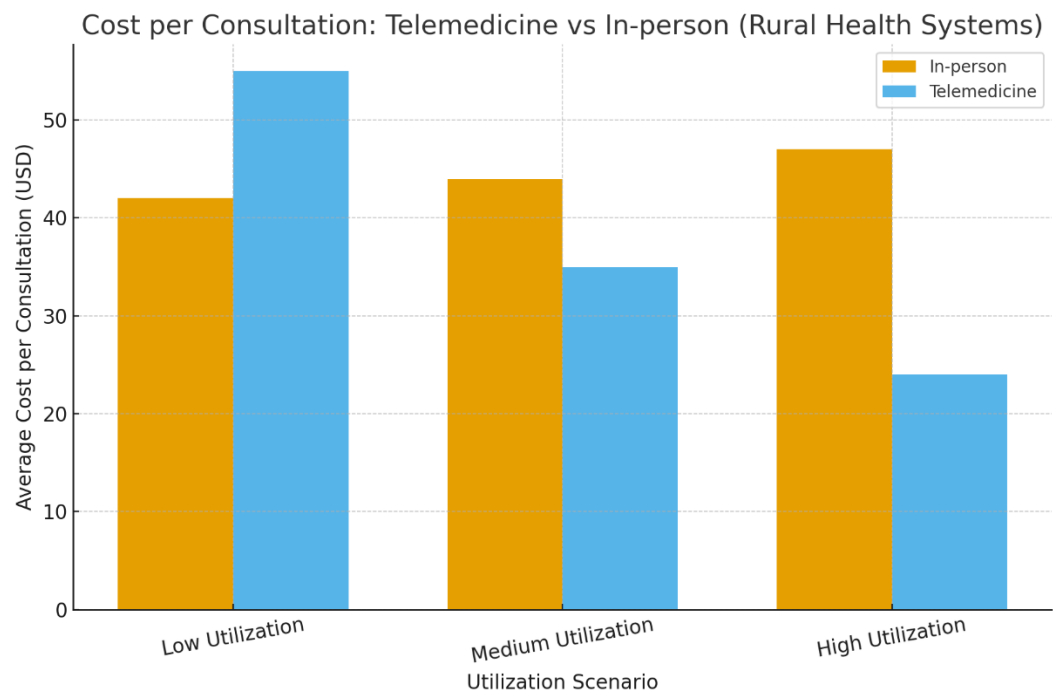
Suggestions for Policy:

Create and standardize **escalation protocols** for critical cases, especially for high-risk patients (e.g., pregnant women, elderly individuals).

Implement an **audit process** for ongoing quality control and to ensure **safe diagnoses** through telemedicine.

Ensure that the **privacy** of patient data is maintained at all stages of telemedicine consultations, with appropriate safeguards in place.

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**Summary**

Telemedicine can be cost-effective—and frequently cost-saving—in rural systems once routine throughput is achieved and workflows are standardized. Low-volume pilots risk overestimating costs due to fixed overheads; therefore, programs should prioritize (i) demand generation, (ii) assisted visits via CHWs, (iii) interoperable platforms, and (iv) reimbursement that recognizes remote follow-up. Sensitivity analysis underscores utilization and data prices as pivotal levers. Policymakers should adopt a phased scale-up with explicit breakeven targets and continuous quality monitoring.

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