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# A Sustainable Public-Private Partnership Framework for Strengthening Last-Mile Vaccine Delivery in Resource- Constrained Settings

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***Abstract***

*This study presents a Sustainable Public-Private Partnership (PPP) Framework aimed at strengthening last-mile vaccine delivery in resource-constrained settings. Health systems in such settings face numerous challenges, including inadequate infrastructure, governance issues, and heavy reliance on donor funding, which undermine equitable access to vaccines. The proposed framework integrates pooled funding from the public and private sectors, leverages digital technologies such as IoT and GPS for real-time logistics optimization, and incorporates strategies to generate long-term financial sustainability. Using a mixed-methods design, the research combines a stakeholder perception survey (n = 128) and qualitative focus group discussions (FGDs) to assess stakeholder readiness for PPP implementation, identify barriers, and evaluate the framework's potential to improve vaccine access and reduce donor dependency. Results show strong support for PPPs across stakeholders, with technology universally regarded as essential for logistics efficiency. Key enablers for a successful framework include clear governance, robust cold chain infrastructure, and strong inter-sector collaboration. The study concludes that the proposed Sustainable PPP Framework offers a scalable, context-sensitive approach for enhancing last-mile delivery systems in health, promoting equity, operational efficiency, and financial sustainability. Although the framework is based on Nigeria's vaccine delivery system, it is designed to be scalable and applicable to other low-resource settings facing similar logistical and financial sustainability challenges.*

***Keywords:*** *Cold Chain, Low-Resource Settings, Last-mile Delivery, Public-Private Partnerships (PPPs), Sustainable, Supply Chain Strengthening.*

## Introduction

### Context and Relevance

The last-mile delivery of vaccines remains one of the most significant challenges in Nigeria's immunization supply chain. Despite considerable progress in vaccination coverage, the country faces persistent barriers, including inadequate infrastructure, unreliable cold chain systems, and a lack of coordination among stakeholders. These challenges are compounded by governance gaps, insufficient funding, and a heavy reliance on donor support, which often leads to inefficiencies and delays in vaccine distribution [1, 2]. These issues not only affect the timeliness and effectiveness of vaccine delivery but also contribute to vaccine wastage and incomplete immunization coverage, particularly in rural and underserved areas [3, 4].

Nigeria's dependence on external funding for vaccine procurement and delivery exacerbates the fragility of its health system, particularly as donor priorities shift or funding cycles change. The need for sustainable solutions to strengthen last-mile delivery systems has become increasingly urgent. Despite the growing recognition of Public-Private Partnerships (PPPs) as a potential model for addressing these challenges, existing PPP

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models have often overlooked the critical role of logistics infrastructure and technology in ensuring the efficiency and sustainability of vaccine delivery [5, 6].

Drawing from the findings of this study, which assessed stakeholder readiness and identified key barriers to PPP implementation in Nigeria, this manuscript proposes a Sustainable PPP Framework for strengthening last-mile delivery systems in health. The framework integrates pooled funding from public and private sectors, employs digital tools such as IoT and GPS for logistics optimization, and introduces revenue-generating strategies aimed at reducing donor reliance and ensuring long-term sustainability. By aligning stakeholder interests and fostering inter-sector collaboration, this framework aims to provide a scalable, context-sensitive solution for enhancing the equity, efficiency, and financial sustainability of health delivery systems [7, 8].

## Sustainability and PPPs

Sustainability in healthcare logistics is a critical factor for ensuring that health systems can continue to deliver essential services, even in the face of limited resources or shifting external support. In many low- and middle-income countries, healthcare logistics, particularly for immunization programs, often rely on donor funding and external aid to sustain operations. While donor contributions have been vital in the short term, they are inherently unsustainable and subject to fluctuations in international priorities and funding cycles [9]. The lack of sustainable financing mechanisms leaves health systems vulnerable to disruptions, which ultimately undermines their ability to achieve long-term health outcomes [10].

In the context of vaccine delivery, sustainability is not just about securing long-term funding, but also about building robust, efficient, and resilient supply chains that can withstand operational challenges. A sustainable system must be able to absorb shocks, manage demand fluctuations, and continue operations without excessive reliance on external actors. This requires investments in infrastructure, technology, and human capacity, as well as innovative financing models that reduce the burden on national budgets and improve cost efficiency [11].

One promising model for achieving sustainability in healthcare logistics is the Public-Private Partnership (PPP). PPPs have long been recognized as an effective way to combine the strengths of both the public and private sectors. The public sector brings policy guidance, public accountability, and access to public health objectives, while the private sector offers efficiency, innovation, and capital investment. When applied to healthcare logistics, PPPs can drive innovation in last-mile delivery, improving access to vaccines and other essential health services, while ensuring financial sustainability through revenue-generating mechanisms such as shared logistics services or cost-effective infrastructure [12, 13].

The proposed Sustainable PPP Model builds on these strengths by incorporating digital technologies like IoT and Global Positioning Systems (GPS) to enhance logistics efficiency, optimize real-time tracking, and improve cold chain management. By reducing inefficiencies, increasing transparency, and enabling data-driven decision-making, PPPs can help health systems move away from reliance on external funding, creating a more resilient and financially self-sustaining model for health service delivery [14, 15].

## Research Gap

While Public-Private Partnerships (PPPs) have been widely discussed as a potential solution to healthcare delivery challenges in low-resource settings, a significant gap in the literature remains regarding the sustainability of these models, particularly in the context of last-mile delivery. Many existing PPP frameworks focus on short-term collaboration

or financial mechanisms but overlook the long-term operational sustainability required to make these partnerships effective in addressing persistent challenges like logistics, cold chain management, and equitable access [16, 17].

Most of the literature on PPPs in healthcare emphasizes procurement, financing, and policy coordination, yet there is a limited focus on the sustainability of logistics operations and the long-term viability of PPPs in improving last-mile delivery systems. While some PPP models have been successful in securing funding and improving access to vaccines or medicines, they often fail to ensure that the infrastructure, technology, and capacity needed to maintain these gains are in place once external funding is reduced or phased out [18, 19].

Additionally, the integration of technology to optimize logistics—such as IoT, GPS tracking, and real-time data analytics—remains underexplored in PPP models, especially in the context of enhancing last-mile delivery. The potential of these technologies to improve operational efficiency and supply chain transparency has not been fully integrated into many PPP frameworks, leaving a gap in terms of maximizing the efficiency and sustainability of health service delivery [20].

This research aims to fill these gaps by proposing a Sustainable PPP Framework that not only addresses the logistical challenges of last-mile vaccine delivery but also focuses on the sustainability of these partnerships over time. By incorporating long-term financial strategies, digital technologies, and collaborative governance, this framework aims to create a model that is both financially sustainable and operationally efficient, ensuring long-term success in health systems [21, 22].

### Novelty of the Work

The novelty of this research lies in its focus on developing a Sustainable Public-Private Partnership (PPP) Framework specifically designed to address the often-overlooked challenge of last-mile delivery in health systems. While many existing PPP models in healthcare focus primarily on financing and policy coordination, this work introduces an innovative approach by prioritizing the long-term operational sustainability of logistics and supply chain systems. The proposed framework is visually presented in Figure 1, which illustrates the key components and strategic linkages essential for achieving this sustainability.

Unlike traditional models, which often rely on donor funding and external aid, this framework emphasizes self-sufficiency by integrating pooled funding from both the public and private sectors, revenue-generating strategies, and the use of digital technologies such as IoT and GPS tracking for real-time logistics optimization. By focusing on both financial sustainability and operational efficiency, the proposed framework fills a critical gap in the literature, offering a scalable, context-sensitive solution for last-mile health service delivery [23, 24].

This research also contributes to the field by addressing the limited literature on the sustainability of PPP models, particularly in terms of logistics and technology integration. The emphasis on trust-building and collaborative governance between stakeholders further distinguishes this framework from traditional models, ensuring that it not only addresses immediate challenges but also fosters long-term resilience in health systems [25, 26].

## Objectives

1. To Identify the Key Factors Contributing to Sustainable Equity in Last-Mile Delivery.
2. To Explore the Barriers to Sustainability in Public-Private Partnerships (PPPs) for Last-Mile Delivery.
3. To Develop a Framework for Strengthening Stakeholder Collaboration and Building Trust in PPP Models.

4. To Propose a Sustainable Financial Model for Last-Mile Vaccine Delivery Through PPPs.

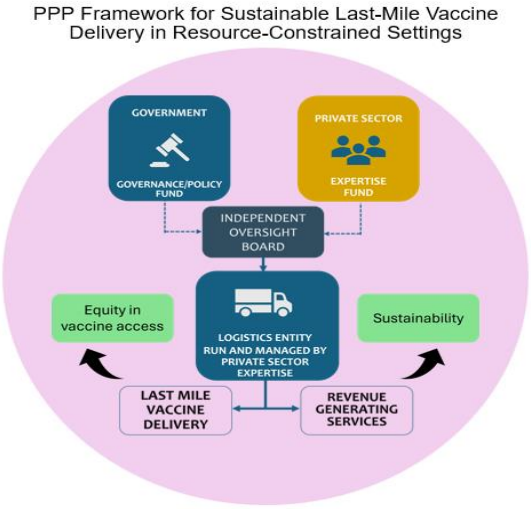


**Figure 1.** Schematic Representation of the Sustainable PPP Model for Last-Mile Vaccine Delivery [28]

## Literature Review

### Overview of Last-Mile Delivery

The last-mile delivery of vaccines and essential health commodities is a critical component of healthcare systems, especially in low-resource settings like Nigeria. However, the country's vaccine distribution system faces significant challenges, including inadequate infrastructure, cold chain issues, poor governance, and donor dependency [1-3]. These challenges hinder the timely availability of life-saving interventions and disproportionately affect rural and underserved communities [4]. The need for innovative solutions to overcome these persistent barriers is evident, particularly as public-private partnerships (PPPs) have gained traction as a means of strengthening health supply chains and delivery systems [5, 6].

While PPPs have been widely applied in sectors like infrastructure and education, their potential to transform health logistics has garnered increasing attention in recent years [7, 8]. PPPs offer the private sector's expertise, capital, and operational efficiency in complementing the public sector's health objectives [9, 10]. In vaccine logistics, they can address issues such as warehousing, distribution, and cold chain management, and facilitate last-mile delivery, which is crucial for expanding immunization coverage [11, 12].

The COVID-19 pandemic underscored the importance of resilient healthcare supply chains, with PPPs emerging as a potential solution to the logistical challenges brought about by global disruptions [5, 13]. Despite the growing recognition of PPPs in health supply chains, there remains a gap in addressing their sustainability and their ability to ensure equitable access to vaccines, particularly when donor funding is reduced or phased out [8, 14]. The sustainability of PPPs in last-mile delivery, specifically their ability to remain financially viable and operationally effective over the long term, is an area that warrants further exploration [15, 16].

This research presents a Sustainable Public-Private Partnership (PPP) Framework designed to enhance last-mile vaccine delivery in Nigeria. The proposed framework incorporates digital technologies such as IoT and GPS to optimize logistics, improve cold chain management, and facilitate real-time tracking of vaccines [17, 18]. By integrating pooled funding from public and private sectors, the

model aims to reduce donor dependency and foster long-term financial sustainability for vaccine delivery [19, 20].

## Public-Private Partnerships in Health

Public-Private Partnerships (PPPs) have long been recognized as an effective strategy for addressing gaps in healthcare systems, particularly in the delivery of essential medicines and vaccines [9, 10]. A PPP is a collaborative agreement between the public and private sectors, combining the strengths of both in the development and delivery of services that are traditionally managed by governments [7, 6]. These partnerships are particularly useful in resource-constrained settings, where the public sector may lack the capacity to effectively manage or finance essential services, such as vaccine distribution and medicine procurement [8, 21].

PPPs play a critical role in vaccine and medicine distribution, especially in low- and middle-income countries where logistical challenges, such as inadequate infrastructure and unreliable cold chains, can impede the timely delivery of life-saving interventions [1, 2]. The private sector's expertise in logistics, infrastructure management, and technology integration complements the public sector's policy guidance and focus on equitable access [21, 22]. This synergy is particularly crucial for vaccine delivery, which often requires precise cold chain management and real-time monitoring systems [23, 17].

Several successful PPP models have been implemented in vaccine and medicine distribution across the globe. For instance, in Rwanda, a PPP between the government and the private company Zipline has revolutionized the delivery of vaccines and blood products using drone technology [11, 24]. This partnership has dramatically improved the speed and efficiency of last-mile delivery, ensuring timely access to essential supplies even in remote and hard-to-reach areas [3, 20]. Similarly, in India, the GAVI Alliance has partnered with both the private and public sectors to strengthen immunization supply chains by introducing innovative financing mechanisms and technology solutions [19, 25].

In addition to vaccines, PPPs have also been effective in expanding access to essential medicines. In Kenya, the government partnered with private logistics providers to improve the distribution of antiretroviral drugs (ARVs), ensuring timely delivery to healthcare facilities across the country [21]. By leveraging the private sector's expertise in warehouse management and distribution logistics, the government was able to enhance the availability and accessibility of ARVs, reducing stockouts and improving patient outcomes [1].

However, despite their potential, the implementation of PPPs in health systems is not without challenges. Many PPPs struggle with issues such as misaligned objectives, weak governance structures, and insufficient regulatory frameworks, which can undermine the partnership's effectiveness and sustainability [6, 26]. Trust between the public and private sectors is often a critical barrier, as private sector partners may prioritize profit over public health objectives, leading to conflicts and inefficiencies [4, 13]. Moreover, long-term sustainability remains a concern, particularly when PPPs are heavily reliant on donor funding or external support, which may not be consistent or guaranteed in the future [8, 25].

To address these challenges, recent literature has emphasized the need for clear governance frameworks and transparent accountability mechanisms to ensure that the objectives of both sectors are aligned and that the partnership remains focused on achieving public health goals [9, 22]. Digital technologies such as real-time data monitoring, blockchain, and GPS tracking can also improve transparency, accountability, and efficiency in PPP-driven health supply chains, making them more sustainable and effective in the long term [17, 18].

In conclusion, PPPs have demonstrated significant potential in improving the efficiency, accessibility, and sustainability of vaccine and medicine distribution systems. When well-designed and implemented, PPPs can leverage the strengths of both the public and private sectors to overcome challenges in last-mile delivery, ultimately improving health outcomes in resource-constrained settings [5, 7]. However, careful consideration must be given to governance, sustainability, and technology integration to ensure that these partnerships deliver on their promise of equitable access and long-term impact [8, 14].

## Sustainability in Health Logistics

Sustainability in health logistics is a critical component of ensuring that healthcare systems, particularly in low- and middle-income countries (LMICs), can continue to function effectively despite limited resources [15, 22]. The concept of sustainability within health supply chains extends beyond financial stability to include operational efficiency, environmental considerations, and the capacity to respond to future needs without excessive reliance on external funding or resources [6, 14].

In the context of health logistics, sustainability involves building resilient systems that can effectively manage vaccine distribution, medicine procurement, and inventory management over the long term [1, 23]. Achieving sustainability requires careful consideration of several key elements, including infrastructure, human capacity, technology integration, and funding mechanisms [8, 18]. Without a strong foundation in these areas, health systems remain vulnerable to supply chain disruptions, particularly in regions where infrastructure is inadequate, or where there is a heavy reliance on donor funding [5, 2].

One of the central challenges to achieving sustainability in health logistics is the fragility of supply chains, particularly in last-mile delivery [4, 11]. In many LMICs, supply chains are heavily reliant on external aid, making them vulnerable to changes in international funding priorities, political instability, or disruptions in global supply chains [13, 21]. The COVID-19 pandemic has underscored these vulnerabilities, exposing how dependent many health systems are on donor funding and external support [5, 3]. These disruptions have underscored the need for self-sustaining systems that can continue to function even in the face of external shocks [14, 26].

Several studies have emphasized the role of Public-Private Partnerships (PPPs) in improving the sustainability of health logistics [6-8]. PPPs are seen as a potential mechanism for integrating private sector efficiency with public sector goals, creating systems that are both financially sustainable and operationally resilient [9, 21]. Private sector partners bring expertise in logistics, infrastructure management, and technology integration, which are essential for improving the efficiency of vaccine and medicine delivery [17, 18]. By leveraging private sector investments in infrastructure and technology, PPPs can reduce the financial burden on governments and help build more sustainable, efficient systems for health supply chains [19, 20].

Moreover, technology integration plays a pivotal role in achieving sustainability in health logistics. Digital tools like IoT, GPS tracking, blockchain, and real-time data analytics are increasingly being employed to optimize logistics efficiency, improve cold chain integrity, and enhance accountability [17, 18]. These technologies enable better visibility and traceability of vaccines and medicines across the supply chain, reducing wastage and ensuring that supplies are delivered on time and in the correct conditions [23, 2]. Additionally, they support data-driven decision-making, which can improve forecasting, inventory management, and overall system efficiency [14].

Another aspect of sustainability is human capacity. Sustainable health logistics systems require skilled workforces capable of managing complex supply chains, particularly in remote areas [25]. The training and capacity building of health workers, supply chain managers, and other relevant personnel are essential to ensure the proper functioning of the logistics system [27]. Building local capacity and ensuring that health systems are not overly dependent on external technical expertise is crucial for long-term sustainability [8].

Finally, the financial sustainability of health logistics systems depends on the development of innovative financing mechanisms. Revenue-generating models, such as cold chain leasing or shared logistics services, can provide a more stable funding base, reducing the reliance on unpredictable donor funding [12, 20]. These models encourage private sector involvement while ensuring that the health system can continue to function effectively without relying solely on external support [21].

In conclusion, sustainability in health logistics requires a comprehensive approach that integrates resilient infrastructure, capacity building, technology, and innovative financing [8, 6]. PPPs offer a promising solution for achieving this sustainability by leveraging the strengths of both the public and private sectors [9, 18]. However, for sustainability to be realized, collaboration, clear governance frameworks, and long-term planning are essential to ensure that these systems remain effective and responsive to future health needs [26, 22].

## Gaps in Current Models

While Public-Private Partnerships (PPPs) have emerged as a promising model for improving healthcare delivery, especially in vaccine and medicine distribution, several gaps persist in the effectiveness of current models, particularly with regard to last-mile delivery [6, 21]. Most existing PPP frameworks have concentrated on addressing short-term challenges such as financing, policy alignment, and service delivery, while overlooking critical long-term challenges related to sustainability, infrastructure, and technology integration [8, 13]. As a result, these models often fail to provide a robust solution for the operational complexities involved in delivering vaccines and medicines to remote and underserved populations [1].

One of the most significant gaps in current PPP models is the inadequate focus on logistics and infrastructure, which are essential for ensuring the efficient and timely delivery of health commodities [2, 23]. While private sector involvement in logistics has helped enhance efficiency in some instances, many models do not address the challenges posed by poor infrastructure in rural and remote areas [4, 3]. For example, a study on vaccine delivery systems in Nigeria highlighted that many PPPs failed to provide the necessary cold chain capacity or ensure that vaccine distribution infrastructure was developed to withstand environmental and logistical barriers [1, 18]. Consequently, many PPPs rely on external donor funding for infrastructure, making them unsustainable in the long term [14].

Another critical gap in the current models is the insufficient integration of technology into the logistics and supply chain systems [17, 11]. Many PPPs have not fully embraced the potential of digital tools like IoT, GPS tracking, and real-time data analytics, which are crucial for enhancing logistics visibility, inventory management, and cold chain monitoring [18, 22]. Without these technologies, PPPs struggle to provide real-time tracking, leading to inefficiencies, stockouts, and delayed deliveries [23, 26]. In particular, the failure to integrate blockchain or other secure tracking mechanisms has been noted as a barrier to improving transparency and accountability in the vaccine delivery process [14].

Governance issues also represent a significant gap in the current PPP models. Many existing partnerships suffer from weak

governance frameworks that fail to ensure effective accountability and coordination between the public and private sectors [7, 9]. The lack of clarity in roles and responsibilities, coupled with insufficient stakeholder engagement, often leads to misaligned objectives, undermining the effectiveness of the partnership [4]. For instance, some PPPs have faced challenges in trust-building between the sectors, with the private sector sometimes prioritizing profit-making motives over public health goals, resulting in conflicts that can undermine the long-term sustainability of the model [6, 10].

Additionally, while financial sustainability is a key concern, many PPP models continue to rely on donor funding, which leaves them vulnerable to shifts in funding priorities or economic disruptions [25, 3]. Although some models have explored innovative financing mechanisms such as cost-sharing or revenue generation, these approaches are still in their infancy and often fail to provide sufficient long-term funding [12, 20]. Without developing self-sustaining financial models, many PPPs are unable to create lasting change in the health logistics system [21].

In summary, while PPPs have shown potential in addressing some of the challenges in health logistics and last-mile vaccine delivery, significant gaps remain [1, 8]. The inadequate focus on infrastructure, technology, governance, and sustainability are key limitations that need to be addressed to ensure that these partnerships can deliver long-term, scalable solutions [14, 13]. Future PPP frameworks must prioritize operational resilience, long-term sustainability, and technology integration to overcome these gaps and effectively address the challenges of last-mile delivery [18, 26].

# Methodology

## Description of the Site

This research was conducted in Nigeria, a country facing significant challenges in its healthcare delivery systems, particularly in the last-mile vaccine distribution. The study focused on assessing the feasibility and sustainability of a Public-Private Partnership (PPP) model for strengthening last-mile vaccine delivery systems. Nigeria's healthcare system, characterized by logistical inefficiencies, governance gaps, and a heavy reliance on donor funding, presents an ideal setting for exploring the potential of PPP models to improve the delivery of vaccines and other health commodities. The research was carried out across multiple states in Nigeria, involving key stakeholders from the public sector, private sector, NGOs, and development partners, each playing a role in vaccine logistics.

## Description of the Experiments Done

The research employed a mixed-methods design, combining quantitative and qualitative data collection methods to achieve a comprehensive understanding of stakeholder perceptions, readiness, and the barriers to implementing sustainable PPPs in last-mile vaccine delivery. Two main data collection approaches were used:

**Stakeholder Perception Survey:**

1. A structured survey was distributed to 128 stakeholders from four primary groups: Donors/Development Partners, Government Officials, NGOs/Community-Based Organizations (CBOs), and Private Sector.
2. The survey utilized a Likert scale to assess perceptions regarding the feasibility and sustainability of PPPs, governance quality, technology integration (IoT, GPS), and trust between sectors.

**Focus Group Discussions (FGDs)**

FGDs were held with key stakeholders to explore their experiences, challenges, and recommendations for implementing PPPs in last-mile vaccine delivery. These discussions provided deeper insights into the governance

issues, logistical constraints, and the role of technology in enhancing operational efficiency.

## Description of the Methods

The study utilized both quantitative and qualitative methods to gather a well-rounded set of data:

### Quantitative Methods

1. Descriptive Statistics: The data from the survey were summarized using frequency distributions and percentages to assess the overall perceptions of stakeholders regarding PPP preparedness, governance effectiveness, and technology use.
2. Chi-Square Test: A Chi-square test was used to assess statistical differences in perceptions between stakeholder groups regarding preparedness and governance (e.g., willingness to implement PPPs, trust levels, etc.). This test helped determine if the observed differences were significant (p-values $< 0.05$).
3. Ordinal Logistic Regression: An ordinal logistic regression model was employed to predict the likelihood of a stakeholder reporting higher levels of organizational preparedness based on their group membership (e.g., NGO, Government, etc.). This model helped identify factors that influenced readiness for PPP implementation.

### Qualitative Methods

1. Thematic Analysis: Data from the FGDs were analysed using R software to identify key themes related to infrastructure challenges, governance and accountability, trust, and technology integration. Thematic coding helped categorize responses, enabling an in-depth understanding of stakeholder perceptions and experiences.
2. Integration of Quantitative and Qualitative Insights: The quantitative results were triangulated with qualitative insights to offer a more nuanced understanding of the factors influencing stakeholder readiness and the barriers to PPP implementation.

## Statistical Methods Used

The following statistical methods were used to analyse the data:

### Descriptive Statistics

Frequency distributions, percentages, and measures of central tendency (mean, median) were used to summarize the responses from the survey and present the overall trends and perceptions of the respondents regarding PPP preparedness, governance quality, and technology use.

### Chi-Square Test

The Chi-square test was used to assess the association between stakeholder groups and their perceptions of preparedness and governance. This test helped identify if significant differences existed between the four stakeholder groups (Donors, Government, NGOs, Private Sector) in their perceptions of PPP readiness and governance mechanisms.

### Ordinal Logistic Regression

An ordinal logistic regression was conducted to model the likelihood of stakeholders in different groups reporting higher levels of organizational preparedness. The response variable was the perceived level of preparedness, and the predictor variable was the stakeholder group. This method helped assess the probability of higher preparedness based on sectoral group membership.

### Thematic Analysis

R software was used to perform thematic analysis of the FGD transcripts. The data were coded to identify recurring themes and subthemes, focusing on logistics, governance, technology, and sustainability. This qualitative data was integrated with the quantitative results to enhance the interpretation of findings.

The research adopted a mixed-methods approach, combining quantitative surveys and

qualitative FGDs to assess the feasibility and sustainability of PPPs in last-mile vaccine delivery. The methodology was designed to provide comprehensive insights into stakeholder readiness, governance structures, and the role of technology in enhancing logistics efficiency. Statistical techniques such as descriptive statistics, Chi-square tests, and ordinal logistic regression were employed to analyse the data, while thematic analysis using R software provided deeper insights into the qualitative aspects of the research.

## Results

Data for this study were collected through a stakeholder perception survey and focus group discussions (FGDs). The analysis combines quantitative and qualitative methods to assess stakeholder perceptions on Public-Private Partnerships (PPPs) for last-mile vaccine delivery in Nigeria. Data was gathered from 128 stakeholders proportionately drawn from Donors/Development Partners, Government Officials, NGO/CBOs, and Private Sector actors

### Descriptive Analysis of Stakeholder Perceptions

#### Belief in PPPs to Solve Delivery Challenges

As illustrated in Figure 2, all stakeholder groups generally agree that PPPs offer viable solutions for last-mile vaccine delivery. Donors and NGO/CBOs particularly demonstrated strong belief, with a high concentration of "Strongly Agree" responses.

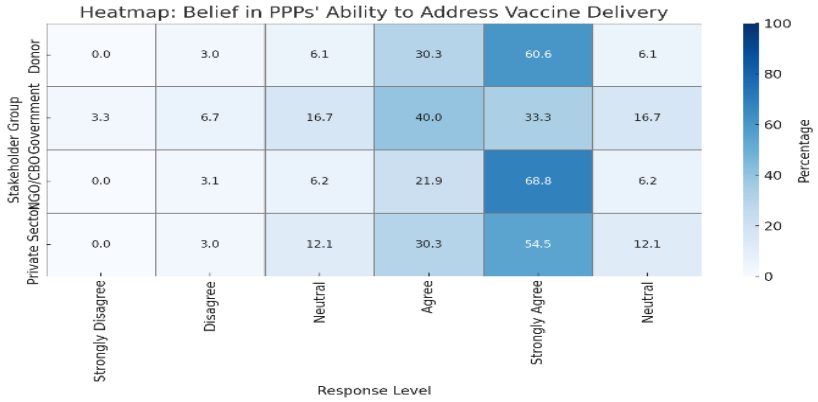


**Figure 2.** Belief in Public-Private Partnerships (PPPs) to Address Vaccine Delivery Challenges [28]

#### Organizational Preparedness for PPPs

Figure 3 presents the distribution of stakeholder responses on how prepared their organizations are for implementing PPPs. NGO/CBOs are the most self-assured, with 23 out of 32 indicating "Somewhat Prepared." Donors displayed a broader distribution, including 9 "Fully Prepared" responses, pointing to varied institutional readiness.

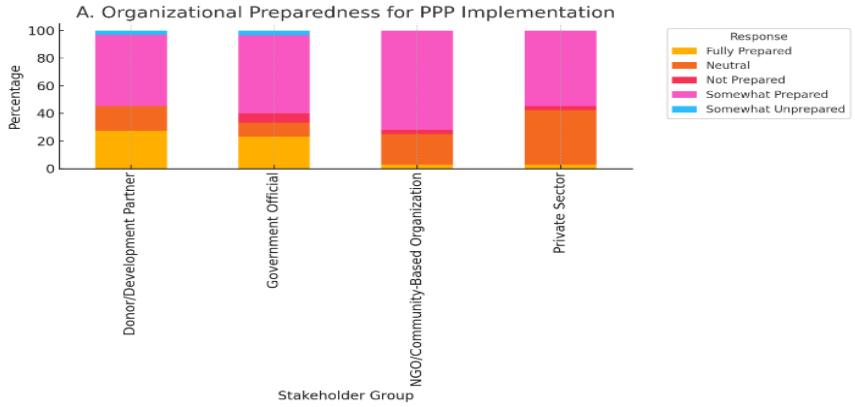


**Figure 3.** Organizational Preparedness for PPP Implementation (Overall Perceptions) [28]

### Preparedness Levels by Stakeholder Group

To further compare preparedness across stakeholder categories, Figure 4 shows grouped bar charts illustrating how each stakeholder type rated their organizational readiness. This highlights contrasts, such as the relatively low readiness reported by Government stakeholders versus the strong self-perception of NGO/CBOs.

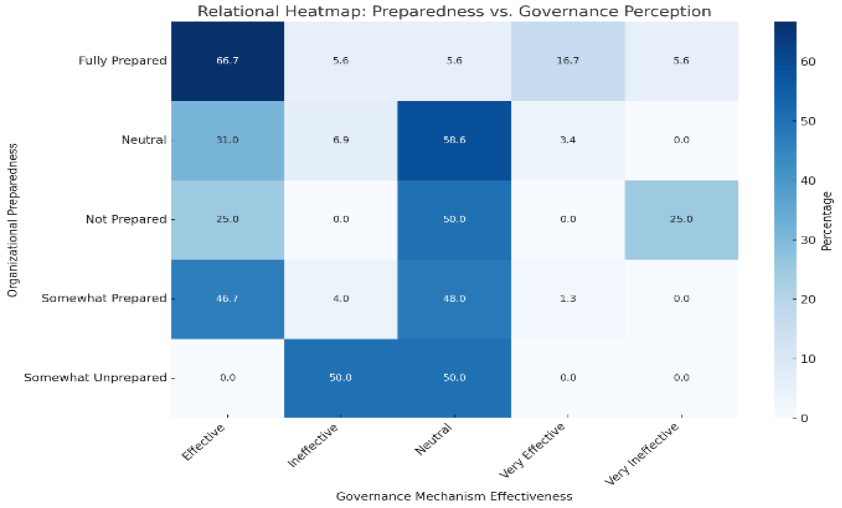


**Figure 4.** Preparedness Levels by Stakeholder Group [28]

### Trust Between Public and Private Sectors

Trust perceptions, captured in Figure 5, were predominantly "Moderate" across all groups. However, government officials showed a wider spread, including both "Low" and "Very High" ratings—signalling inconsistency in cross-sector collaboration experiences.

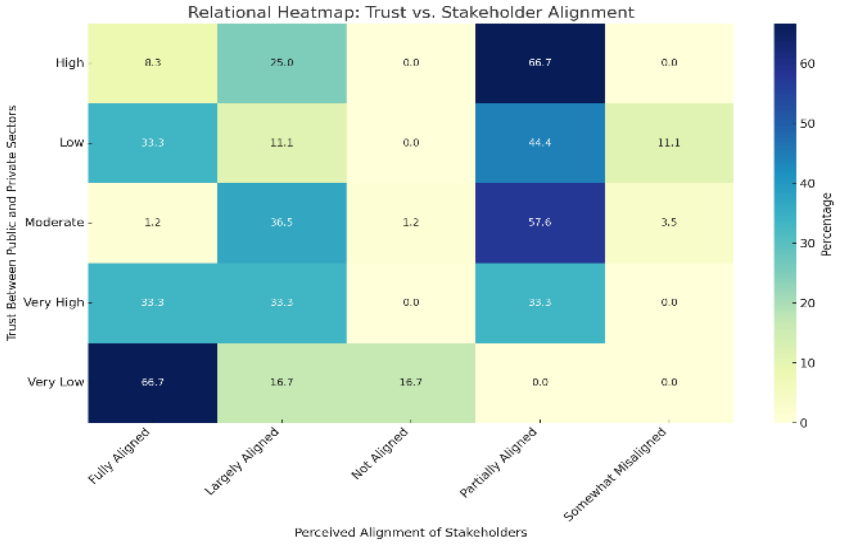


**Figure 5.** Perceived Trust between Public and Private Sector Actors in Vaccine Logistics [28]

### Importance of Technology in Vaccine Logistics

All stakeholder categories overwhelmingly rated technology as “Very Important,” particularly the Private Sector and NGO/CBOs (see Figure 6). This strong consensus establishes digital tools (IoT, GPS, blockchain) as a unifying priority across sectors.

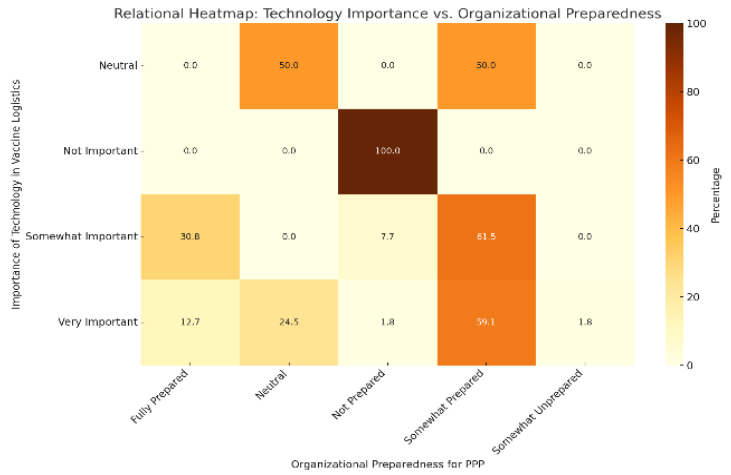


**Figure 6.** Importance of Technology (IoT, GPS, Blockchain) in Vaccine Delivery [28]

## Cross-Variable Relationship: Preparedness vs. Governance Effectiveness

Figure **7** illustrates a cross-tabulated analysis revealing that:

1. Fully Prepared organizations often rated governance as "Effective."
2. Neutral preparedness corresponded with a "Neutral" view of governance (58.6%).
3. Unprepared respondents leaned toward "Neutral" or "Ineffective" ratings.

This pattern suggests that stakeholder perception of governance quality closely aligns with their organizational readiness.

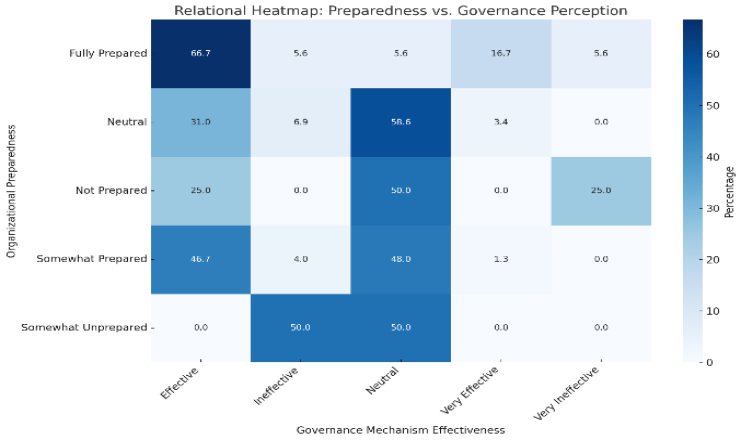


**Figure 7.** Relationship between Organizational Preparedness and Perceived Governance Mechanism Effectiveness [28]

## Chi-Square Test of Group-Level Differences

**Table 1.** Chi-Square Test Results

| Question | $\chi 2$ | p-value | Interpretation |
|---|---|---|---|
| Preparedness | 23.67 | 0.023 | Statistically significant |
| Governance | 22.54 | 0.032 | Statistically significant |
| Donor Dependency | 21.15 | 0.048 | Statistically significant |

These results confirm that stakeholder category significantly influences how PPP readiness, governance, and financial reliance are perceived.

## Ordinal Logistic Regression on Preparedness

In Table 2, NGO/CBOs had a positive coefficient (0.9232) with a p-value of 0.068, suggesting they are more likely to perceive themselves as prepared, though the result does not meet the 0.05 significance threshold. The model's threshold parameters were significant, validating the ordinal structure of the response variable.

**Table 2.** Ordinal Logistic Regression Summary [28]

| Technique | Purpose | Key Variables Analysed | Metrics / Scores | Outcome Summary |
|---|---|---|---|---|
| Descriptive Analysis | Summarize response distributions by stakeholder group | Perceptions on preparedness, trust, governance, importance of tech | Frequency distributions, percentages | Most stakeholders rated tech as "Very Important"; NGO/CBOs reported highest preparedness |
| Chi-Square Test | Assess statistical differences between stakeholder groups | Responses to Likert-scale questions (e.g. preparedness, governance, donor reliance) | p-values: 0.023 (Preparedness), 0.032 (Governance) | Significant group-level differences in responses to preparedness, governance, and donor dependency |
| Ordinal Logistic Regression | Predict perceived preparedness based on stakeholder category | Predictor: Stakeholder Group; Response: Organizational Preparedness (ordinal) | NGO/CBO Coef: 0.9232, p = 0.068 | NGO/CBOs more likely to perceive themselves as prepared, though not statistically significant |
| Visualization (Bar Charts) | Visually compare stakeholder response distributions | Preparedness, Governance Effectiveness, Donor Dependency | Stacked percentage bars | Clearly visualized stakeholder-specific variation in Likert responses |

## Key Insights (Integrated with Visual Evidence)

**Table 3.** Integrated Insights [28]

| Insight | Supporting Data | Visual/Table Reference |
|---|---|---|
| NGO/CBOs are optimistic and operationally ready | Highest preparedness and belief in PPPs | Figures 2, 3 & 4 |
| Governance effectiveness perception varies | Significant Chi² result | Table 1 |
| Tech unites all stakeholders | “Very Important” rated by 90%+ | Figure 6 |
| Trust is moderate and variable | Dominantly “Moderate,” some extremes | Figure 5 |
| Perception links to actual capacity | Preparedness ↔ Governance ratings | Figure 7 |

## Qualitative Insights from FGDs

### Heatmap of Thematic Intensity

Figure 8 presents a heatmap showing the frequency and depth of themes raised across stakeholder groups. "Infrastructure" and "Trust" were universal concerns, while "Technology" and "Sustainability" were more emphasized by Private Sector respondents.

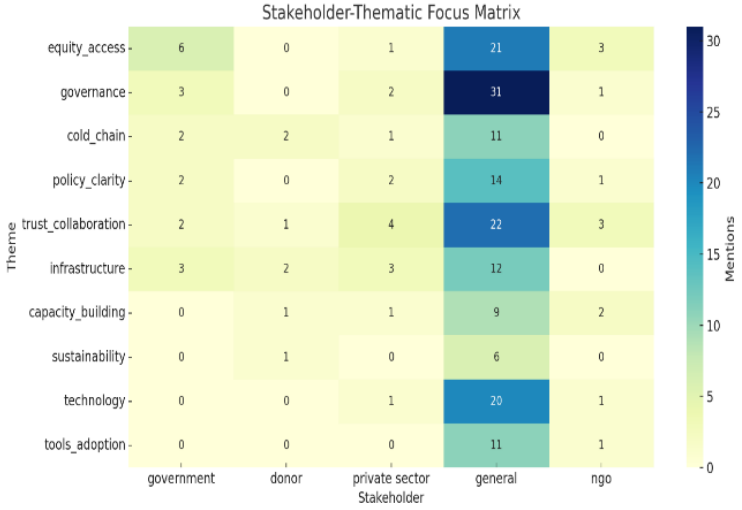


**Figure 8.** Heatmap of Thematic Emphasis in Focus Group Discussions Across Stakeholder Groups [28]

### Illustrative Quotes

Table 4 organizes direct quotes from FGDs around themes such as equity, cold chain, governance, sustainability, and capacity building. For example:

1. **Governance**: "Major barriers include lack of trust, policy bottlenecks, and unclear accountability."
2. **Technology**: "IoT and GPS improve visibility and real-time decision-making."

**Table 4.** Representative Quotes by Theme [28]

| Theme | Quote |
|---|---|
| **equity_access** | As development partners, we primarily provide funding, technical assistance, and policy guidance to support vaccine procurement, cold chain expansion, and delivery strategies. We work closely with the government to strengthen national immunization supply chains and support innovations in last-mile delivery, especially in hard-to-reach areas. |
| **equity_access** | Section 4: Equity and Access |
| **equity_access** | 10. How can a PPP model ensure equitable vaccine access, particularly in underserved and remote areas? |
| **governance** | As development partners, we primarily provide funding, technical assistance, and policy guidance to support vaccine procurement, cold chain expansion, and delivery strategies. We work closely with the government to strengthen national immunization supply chains and support innovations in last-mile delivery, especially in hard-to-reach areas. |
| **governance** | It is quite feasible, especially given Nigeria's growing private sector presence in logistics and warehousing. However, success will depend on a clear policy framework, stakeholder buy-in, and a structured implementation plan. |

| | |
|---|---|
| **governance** | Major barriers include lack of trust between sectors, policy bottlenecks, limited private sector understanding of public health goals, and unclear accountability mechanisms. |
| **cold_chain** | As development partners, we primarily provide funding, technical assistance, and policy guidance to support vaccine procurement, cold chain expansion, and delivery strategies. We work closely with the government to strengthen national immunization supply chains and support innovations in last-mile delivery, especially in hard-to-reach areas. |
| **cold_chain** | Key challenges include weak infrastructure in remote areas, inconsistencies in data reporting, fragmented coordination among implementing actors, and limited local capacity for cold chain maintenance. Additionally, sustainability remains a concern, especially when donor funding tapers off. |
| **cold_chain** | Last-mile distribution, data tracking systems, cold chain equipment maintenance, and transportation logistics are areas where PPPs could add significant value. |
| **policy_clarity** | As development partners, we primarily provide funding, technical assistance, and policy guidance to support vaccine procurement, cold chain expansion, and delivery strategies. We work closely with the government to strengthen national immunization supply chains and support innovations in last-mile delivery, especially in hard-to-reach areas. |
| **policy_clarity** | It is quite feasible, especially given Nigeria's growing private sector presence in logistics and warehousing. However, success will depend on a clear policy framework, stakeholder buy-in, and a structured implementation plan. |
| **policy_clarity** | Major barriers include lack of trust between sectors, policy bottlenecks, limited private sector understanding of public health goals, and unclear accountability mechanisms. |
| **infrastructure** | Key challenges include weak infrastructure in remote areas, inconsistencies in data reporting, fragmented coordination among implementing actors, and limited local capacity for cold chain maintenance. Additionally, sustainability remains a concern, especially when donor funding tapers off. |
| **infrastructure** | Last-mile distribution, data tracking systems, cold chain equipment maintenance, and transportation logistics are areas where PPPs could add significant value. |
| **infrastructure** | These models can diversify funding sources and reduce dependence on donors. For example, cold chain leasing can be a win-win if private partners manage and maintain infrastructure for multiple programs beyond immunization. |
| **trust_collaboration** | Key challenges include weak infrastructure in remote areas, inconsistencies in data reporting, fragmented coordination among implementing actors, and limited local capacity for cold chain maintenance. Additionally, sustainability remains a concern, especially when donor funding tapers off. |

| | |
|---|---|
| **trust_collaboration** | Major barriers include lack of trust between sectors, policy bottlenecks, limited private sector understanding of public health goals, and unclear accountability mechanisms. |
| **trust_collaboration** | There is growing alignment, especially under national strategies like the RI Strategic Plan, but operational coordination still needs improvement. Stakeholders tend to operate in silos without a unified delivery platform. |
| **capacity_building** | Key challenges include weak infrastructure in remote areas, inconsistencies in data reporting, fragmented coordination among implementing actors, and limited local capacity for cold chain maintenance. Additionally, sustainability remains a concern, especially when donor funding tapers off. |
| **capacity_building** | A clear legal and institutional framework, performance-based contracts, local capacity development, and mechanisms for shared investment and risk management would support sustainability. |
| **capacity_building** | Yes, we've supported the deployment of tools like OpenLMIS, VIMS, and eLMIS in several states. While uptake has been promising, challenges include connectivity issues, power supply, and capacity gaps. |
| **sustainability** | 8. What role do you think revenue-generating mechanisms (e.g., shared logistics services, cold chain leasing) can play in ensuring sustainability? |
| **sustainability** | By leveraging private capital, operational efficiencies, and innovative financing, PPPs can gradually transition the burden from donors to sustainable local systems. Over time, this builds resilience within the health system. |
| **sustainability** | 8. What role do you think revenue-generating mechanisms (e.g., shared logistics services, cold chain leasing) can play in ensuring sustainability? |
| **technology** | Section 5: Technology Integration |
| **technology** | 13. What role do you think technology (e.g., IoT, GPS, blockchain) can play in improving vaccine logistics? |
| **technology** | Technology can improve visibility, accountability, and real-time decision-making. GPS tracking, digital inventory systems, and predictive analytics can transform last-mile delivery. |
| **tools_adoption** | 14. Has your organization adopted any technological solutions for vaccine logistics? If so, what has been your experience with these tools? |
| **tools_adoption** | Yes, we've supported the deployment of tools like OpenLMIS, VIMS, and eLMIS in several states. While uptake has been promising, challenges include connectivity issues, power supply, and capacity gaps. |
| **tools_adoption** | We oversee vaccine forecasting, requisition, distribution, and cold chain management at state and LGA levels. We also supervise health facilities, monitor stock levels, and ensure accountability through data reporting tools like NHLMIS and DHIS2. |

### Bridging Quantitative and Qualitative Data

Table 5 aligns survey results with qualitative themes:

**Table 5.** Integrated Insights Matrix [28]

| Dimension | Quantitative Finding | Qualitative Insight | Policy Implication |
|---|---|---|---|
| **Preparedness** | NGO/CBOs rated highest | Field familiarity | Prioritize NGOs as pilot partners |
| **Governance** | Group-based variance (p=0.032) | Accountability a major concern | Clear frameworks needed |
| **Trust** | Moderate levels across board | Trust-building crucial | Invest in collaboration platforms |
| **Tech** | High universal importance | Practical digital tools mentioned | Scale tech infrastructure |
| **Cold Chain** | Not directly surveyed | Common FGD theme | Include in PPP scope |

## Discussion

This study aimed to develop and present a sustainable Public-Private Partnership (PPP) model for last-mile vaccine delivery in Nigeria, drawing from stakeholder perceptions and identifying key barriers and enablers of PPP implementation. The findings underscore the importance of stakeholder readiness, governance structures, technology integration, and financial sustainability in ensuring the success of the PPP model. In this discussion, we examine how the results from the survey and focus group discussions (FGDs) inform the design of the sustainable PPP model, addressing the challenges of last-mile delivery while ensuring long-term sustainability.

### Stakeholder Readiness and Organizational Preparedness

A key insight from the study was the heterogeneity of stakeholder readiness for implementing PPP models. While NGOs/CBOs were the most prepared, the Government and Private Sector showed varying levels of readiness, highlighting the capacity gaps that need to be addressed for effective PPP implementation. The NGOs/CBOs demonstrated strong field-level experience and operational flexibility, making them ideal candidates for early adoption and pilot implementation of the PPP model. However, Government Officials reported mixed preparedness, suggesting the need for capacity building within government agencies to facilitate PPP adoption and ensure policy alignment with the private sector.

These findings directly inform the PPP model's design by highlighting the need for targeted capacity-building efforts. The model must provide clear guidance and support for government institutions, especially in areas related to contract management, performance monitoring, and policy clarity. For NGOs/CBOs, the model can focus on empowering them as early adopters, leveraging their local knowledge and operational readiness to build momentum and demonstrate the model's effectiveness at the grassroots level.

### Governance and Trust: Key Drivers of PPP Success

The role of governance emerged as a central theme in the results. Donors, NGOs, and Private Sector stakeholders emphasized the need for a clear governance framework that defines roles, responsibilities, and accountability mechanisms across sectors. The moderate trust between the public and private sectors identified in the study points to the importance of transparent processes and open

communication channels. For the PPP model to succeed, trust-building strategies must be embedded in the model to foster collaboration and shared responsibility.

The PPP model proposes a governance structure that includes shared accountability, with clearly defined roles for public sector entities in policy oversight and private sector players in logistics and infrastructure management. This dual approach aims to reduce governance risks and align both sectors toward achieving common public health goals. Furthermore, the model incorporates mechanisms for stakeholder engagement at all levels to facilitate continuous communication, ensuring that governance frameworks remain flexible and adaptive to emerging challenges.

### Technology Integration: Enhancing Efficiency and Transparency

Technology integration was universally recognized as essential to the success of PPP models in last-mile vaccine delivery. The findings show strong consensus across stakeholder groups on the importance of IoT, GPS tracking, and real-time data analytics to enhance logistics efficiency, cold chain management, and inventory tracking. These technologies provide visibility into the vaccine supply chain, enabling real-time decision-making and improving accountability.

The sustainable PPP model integrates digital tools such as IoT and GPS systems to enhance logistical efficiency and ensure cold chain integrity, which are crucial for the success of vaccine distribution. By embedding technology into the model, the system can optimize real-time tracking, reduce wastage, and improve the timeliness and accuracy of deliveries. The study highlighted that the Private Sector stakeholders, in particular, are well-positioned to drive technology adoption, but capacity building in technology use is essential for Government and NGO/CBO sectors to fully utilize these tools.

### Sustainability and Financial Viability of the PPP Model

A major challenge identified in the study is the sustainability of PPP models, particularly with regard to financial viability. The findings indicate that while donor funding plays a critical role in vaccine delivery, there is a growing need for models that reduce donor dependency. Stakeholders suggested that shared logistics services, cold chain leasing, and other revenue-generating mechanisms could provide a more stable financial foundation for last-mile delivery.

The sustainable PPP model incorporates innovative financing mechanisms that combine public sector funding, private sector investment, and revenue-generation strategies. These mechanisms aim to reduce the financial burden on governments while ensuring the model's long-term self-sufficiency. By introducing revenue-generating strategies such as shared logistics services, the PPP model can facilitate cost-efficiency and ensure that the delivery system remains sustainable even as external donor support declines.

## Implications for Policy and Practice

The study’s findings have important implications for the design and implementation of sustainable PPP models in vaccine delivery. First, it is crucial to strengthen governance structures to ensure transparency and accountability in PPP implementation. Clear roles and responsibilities, coupled with trust-building strategies, are key to fostering effective collaboration between the public and private sectors.

Second, technology integration must be prioritized to enhance the efficiency and transparency of vaccine logistics. The PPP model should facilitate the adoption of digital tools at all levels, with particular focus on addressing infrastructure constraints in rural and remote areas.

Lastly, the financial sustainability of the PPP model must be ensured through innovative

financing mechanisms that reduce reliance on donor funding and encourage private sector investment. These mechanisms should be designed to ensure that the model is financially viable and can sustain its operations in the long term.

## Conclusions

This study provides a scalable, context-sensitive framework for last-mile vaccine delivery through Public-Private Partnerships (PPPs), with a strong emphasis on sustainability, technology integration, and governance. The PPP model developed from this research offers a viable approach to improving the efficiency and equity of vaccine delivery in Nigeria, with potential applications in other low-resource settings. However, the model's success will depend on addressing the identified barriers to stakeholder collaboration, technology adoption, and financial sustainability. By integrating these elements, the sustainable PPP model has the potential to create a more resilient and self-sustaining vaccine delivery system, ensuring long-term success in public health delivery.

## Conflict of Interest

There are no conflicts of interest.

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