The Cost of Reaching Zero-Dose Children in Ethiopia

Study report

THINK WELL

FENOT ASSOCIATES

Acknowledgments:
We would like to thank everyone who supported and contributed to this work. We express our sincere appreciation to the Ministry of Health for their guidance throughout the project, with particular thanks to Mr. Melkamu Ayalew and Mr. Yohannes Lakew for their continued engagement and technical support.

We are also grateful to UNICEF and other development partners for their valuable support and for providing essential information that contributed to this work.

Our heartfelt thanks go to the Afar and Somali Regional Health Bureaus for their active involvement and assistance in facilitating field activities. We particularly acknowledge the EPI coordinators in Elidar, Mille, Ewa, Babili, Erer, and Yahob districts, whose local knowledge and cooperation were vital to the successful implementation of this project.

We also wish to acknowledge Mr. Muluneh Getachew for his assistance during the pilot assessment phase and Dr. Abebayehu Tora for his contributions to the qualitative work. Our gratitude extends to Ms. Frehiwot Getachew for her dedicated administrative support, which ensured the smooth coordination of project activities.

Study team:
- Abdi Gari
- Dr. Firew Bobo
- Flavia Moi
- Dr. Girmaye Dinsa
- Laura Boonstoppel
- Prof. Mirkuzie Woldie

Recommended Citation:
Fenot Associates and ThinkWell. The Cost of Reaching Zero-Dose Children in Ethiopia: Study Report. September 2025.

This report was produced by Fenot Associates in September 2025.

ACRONYMS

DTP	Diphtheria, tetanus, and Pertussis-Containing Vaccine
EPI	Expanded Program on Immunization
ETB	Ethiopian Birr
MCH	Maternal and Child Health
MHNTs	Mobile Health and Nutrition Teams
MoH	Ministry of Health
PIRI	Periodic Intensification of Routine Immunization
RI/RO	Routine Immunization and Regular Outreach
USD	United States Dollar
VPDs	Vaccine Preventable Diseases
WHO	World Health Organization
ZD	Zero Dose

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Rationale

Despite global progress in vaccination, many children in low-income countries remain unvaccinated. Ethiopia is among the top five countries with the highest number of zero-dose (ZD) children, particularly in rural and pastoralist areas such as Afar and Somali regions. Efficiently reaching these children requires evidence-based planning. However, data on vaccination program costs are limited, and existing studies are often outdated or insufficient for informed policy decisions. This study estimates the costs of immunization delivery strategies targeting zero-dose children in Afar and Somali, providing critical insights to optimize immunization efforts and improve access to vaccines for Ethiopia's most vulnerable children.

Methods

An activity-based, bottom-up micro-costing approach was employed to estimate vaccine delivery costs for three main strategies: Routine Immunization and Regular Outreach (RI/RO), Periodic Intensification of Routine Immunization (PIRI), and Mobile Health and Nutrition Teams (MHNTs). Both financial and opportunity costs, including costs shared with other health programs, were considered.

Data were collected retrospectively from December 2023 to November 2024 across 49 health facilities (17 health centers and 32 health posts), six MHNT teams, and six PIRI campaigns. Key informant interviews across all administrative levels provided context on operational and financial enablers and bottlenecks. Costs were converted from Ethiopian birr to 2024 US dollars, and results are reported as cost per vaccine dose delivered and cost per zero-dose child reached.

Results

Health posts delivered the majority of vaccine doses, while PIRI sessions were most effective in reaching previously unvaccinated children. On average, per district per year:

- Health posts delivered 34,368 doses; health centers, 11,664 doses.
- MHNTs delivered 5,568 doses; PIRI delivered 9,449 doses.
- PIRI reached 646 zero-dose children; health centers, 324; health posts, 144; MHNTs, 75.
- Regular outreach accounted for 15.34% of doses in Afar and 25.37% in Somali, but reached 60.82% and 44.32% of zero-dose children through RI/RO.

The economic cost of delivering services varied by strategy. RI/RO at health posts was the least expensive, with an average monthly cost of $113.96, while RI/RO at health centers was higher at $348.75 per month. MHNTs had much greater costs of $841.89 per month. PIRI was the most costly overall, at $1,606.72 per session. Cost per dose was lowest for PIRI ($0.46) and highest for MHNTs ($2.31). Cost per zero-dose child reached was $6.65 for PIRI, compared to $52.47–$129.26 for other strategies. MHNTs' high overall cost reflects shared program expenses; immunization-specific costs were nearly as low as PIRI. Routine immunization had lower costs per dose but was less effective in reaching zero-dose children compared to outreach services. The main cost drivers for RI and outreach at both health centres and health posts were paid staff and cold chain equipment. For MHNTs, the largest costs came from staff, vehicles, and transport or fuel. For PIRI, per diems and travel allowances were the main contributors to costs. Key barriers to delivering immunization included poor transport and cold chain systems, limited numbers of health facilities, lack of resources, security concerns, frequent movement of pastoralist communities, and challenges faced by health workers.

Conclusion

Of the examined strategies, PIRI is the most cost-efficient delivery strategy for reaching zero-dose children but requires stronger integration with routine immunization to prevent children from falling

behind schedule. MHNTs, while costly overall, are nearly as cost-efficient when only considering immunization-specific costs and benefit from integrating vaccination with high-demand services like nutrition.

A complementary mix of strategies is recommended: leveraging PIRI and MHNTs for targeted, cost-efficient outreach while maintaining the broad reach, service continuity, and sustainability of RI/RO at health posts. Integrating immunization with other health services, staff training, community engagement, and stakeholder collaboration enhances coverage, particularly for zero-dose children. Careful planning to avoid duplication, continuous capacity building, and ongoing monitoring are essential for sustainable vaccination outcomes in remote areas.

1. INTRODUCTION

Despite substantial advancements in improving access to vaccination in low-income nations, an estimated 12.4 million children miss routine vaccinations annually (1). Globally, recent years have seen a stagnation and, in some cases, a deterioration in immunization coverage (2). In 2022, Ethiopia was among the ten nations where 60% of unvaccinated children reside, alongside countries such as Angola, Brazil, the Democratic Republic of the Congo, India, Indonesia, Mozambique, Nigeria, Pakistan, and the Philippines (3).

Vaccination coverage in Ethiopia reveals striking disparities, particularly between urban and rural populations (4). Rural areas, especially pastoralist and nomadic communities in regions such as Afar and Somali, often face limited healthcare infrastructure, transportation barriers, and ongoing security challenges due to conflict and instability (4). These factors significantly hinder vaccine delivery and access, as displaced families and damaged health facilities impede routine immunization efforts.

Recognizing these challenges, the Ethiopian Ministry of Health (MoH), through the National Immunization Program Desk at the Maternal and Child Health Executive Office, has prioritized reaching zero-dose children by implementing targeted strategies. The MoH developed a comprehensive, multi-year accelerated action plan to reach zero-dose and under-vaccinated children from 2021 to 2025, with the overall goal of reducing morbidity and mortality from vaccine preventable diseases (VPDs), increasing universal and equitable access to existing and new vaccines, and strengthening primary health care services (5). Additionally, MoH initiated a measles vaccination campaign in December 2022 and endorsed catch-up immunization guidelines designed to identify and vaccinate under-immunized and zero-dose children, especially in marginalized and hard-to-reach areas (5).

In Ethiopia, there is limited evidence on the cost of delivering routine vaccination programs. The existing evidence is either outdated or lacks the necessary breadth and depth to inform decision-making and resource allocation. Furthermore, there is a need for economic evidence to inform decision-making about reaching under-vaccinated and zero-dose children in Ethiopia. However, the cost of delivering routine vaccination to under-vaccinated and zero-dose children is scarce, and there is no evidence on the cost of vaccinating zero-dose children through the zero-dose specific strategies implemented in the country.

Understanding the financial implications of delivering vaccines to zero-dose children is critical for designing sustainable and scalable immunization programs. Evidence on vaccine delivery costs can inform policymakers about the economic resources required, allowing for more effective allocation of funds and strategic planning (6). Specifically, assessing the costs associated with various immunization delivery strategies can highlight cost-efficient approaches tailored for pastoralist and conflict-affected settings.

This study aimed to estimate the costs of vaccine delivery across various strategies, including routine immunization and regular outreach, mobile health and nutrition teams (MHNTs), and periodic intensification of routine immunization (PIRI), in the Afar and Somali regions of Ethiopia. This analysis provides a detailed breakdown of economic and financial costs per dose delivered and per zero-dose (ZD) child reached, offering valuable insights for optimizing immunization programs in Ethiopia's most vulnerable populations.

2. OBJECTIVES

General Objective

To estimate the costs of two major zero-dose focused immunization delivery strategies (MHNTs and PIRI) in comparison with the standard facility-based approach (routine immunization and regular outreach) and to identify challenges and opportunities in reaching zero-dose children in the Afar and Somali regions of Ethiopia.

Specific Objectives

- To estimate the cost of reaching zero-dose children through routine delivery, including facility-based delivery and regular outreach.
- To estimate the cost of reaching zero-dose children through PIRI.
- To estimate the cost of reaching zero-dose children through MHNTs.
- To explore the challenges and opportunities associated with reaching zero-dose children.

3. METHODS

3.1 STUDY SETTING

There are 12 regions in Ethiopia. Afar and Somali are among the least developed regions, with limited infrastructure and predominantly pastoralist communities. Each region is further divided into smaller administrative districts called "woredas," each with a population of approximately 100,000 people (7). A high proportion of zero-dose children live in pastoralist regions, conflict-affected areas, and hard-to-reach areas (8). These areas face significant challenges with access to healthcare services and immunization, including limited outreach due to insecurity and a lack of awareness among families about the importance of vaccination. Afar and Somali regions were selected for this study because they are rural regions with nomadic pastoralist populations. Both regions are among the most marginalized and conflict-affected, and have the lowest immunization coverage and the highest rates of zero-dose children (8).

The Ethiopian government is employing several key strategies to reach these zero-dose children, in addition to routine immunization efforts. Among these strategies, PIRI and MHNTs are the most prominent ones. These two programs are conducted only in low-performing regions like Afar and Somali, supplementing routine immunization (9, 10).

Currently, there are 52 and 29 functional MHNTs in the Somali and Afar regions, respectively. MHNTs are teams with a dedicated van with which they travel daily into communities, offering various primary care services, including immunization, nutrition, and others. PIRI are immunization campaigns that are planned to be conducted 4 times per year in all woredas. PIRI is organized by the regional health bureau and its respective woredas.

3.2 STUDY DESIGN

This study estimated vaccine delivery costs, defined as the expenses associated with delivering vaccines to children, excluding the cost of the vaccines themselves. An activity-based, bottom-up micro-costing approach was used to capture costs across various programmatic activities, including service delivery, social mobilization, program management, supervision, training, recordkeeping, vaccine collection, distribution, and storage. The study accounted for both financial and opportunity costs, which together constitute the total economic costs. In addition to immunization-specific costs, shared costs with other

programs were also allocated to immunization, providing a comprehensive view of the total costs requirements to delivery immunization services. To provide contexts to the cost findings, a qualitative study was conducted based on key informant interviews at regional, district, health center, and health post levels, with health workers involved in implementing various immunization strategies, including PIRI and MHNT.

3.3 IMMUNIZATION STRATEGIES

Three prominent immunization delivery strategies were assessed:

a. Routine immunization, including facility-based delivery and regular outreach
b. Periodic intensification of routine immunization (PIRI)
c. Mobile health and nutrition teams (MHNTs)

Details of each immunization delivery strategy are provided in Table 1 below.

Table 1: Immunization delivery strategies included in the study

	Routine immunization and regular outreach (RI/RO)	Periodic intensification of routine immunization (PIRI)	Mobile health and nutrition teams (MHNTs)
Main characteristics	This is a facility-based immunization strategy where children are brought to health facilities to receive their vaccinations. Additionally, health workers regularly conduct outreach sessions in communities (5–15 Km) within their catchment areas. The strategy aims to reach and vaccinate all eligible individuals in the catchment area.	It is a time-limited, intermittent, campaign-style immunization activity designed to administer routine vaccinations in districts with low immunization coverage. PIRI is designed to include community mobilization to ensure high participation and target previously missed or underserved populations. Conducted in selected Kebeles (sub-woreda) with weak performance.	Teams equipped with dedicated vehicles travel to remote communities providing health services such as nutrition, maternal and child health care, and treatment of common illnesses. They also provide immunization services.
Frequency of service	– 5 days per week for routine immunization at health centers and 1 to 2 days at health posts – Once per week for regular outreach from the health post and once per month for regular outreach from health center	– Planned to be conducted 4 times per year (in practice, it is conducted less frequently)	– 5 to 6 days per week with scheduled visits to each selected community within their designated area. – Once a community meets the MHNT's graduation criteria, the team moves to the next community.
Location of service	Facility-based for routine immunization and community for regular outreach within the catchment areas of the respective health centers and health posts	Conducted in selected low-performing Kebeles within the woreda, often in the same locations, depending on the available support	Community

3.4 STUDY PERSPECTIVE AND TIME HORIZON

For all strategies, a health systems perspective was employed in this study, capturing all costs incurred by the healthcare system to deliver immunization services. This perspective allows for accurate allocation of both immunization-specific and shared costs, providing policymakers and health managers with detailed insights into the economic burden and efficiency of different immunization delivery strategies. For routine immunization and regular outreach, a time horizon from December 2023 to November 2024 was used, and for PIRI, the time horizon of the PIRI campaign was used, starting from planning to PIRI report submission, which may vary from district to district.

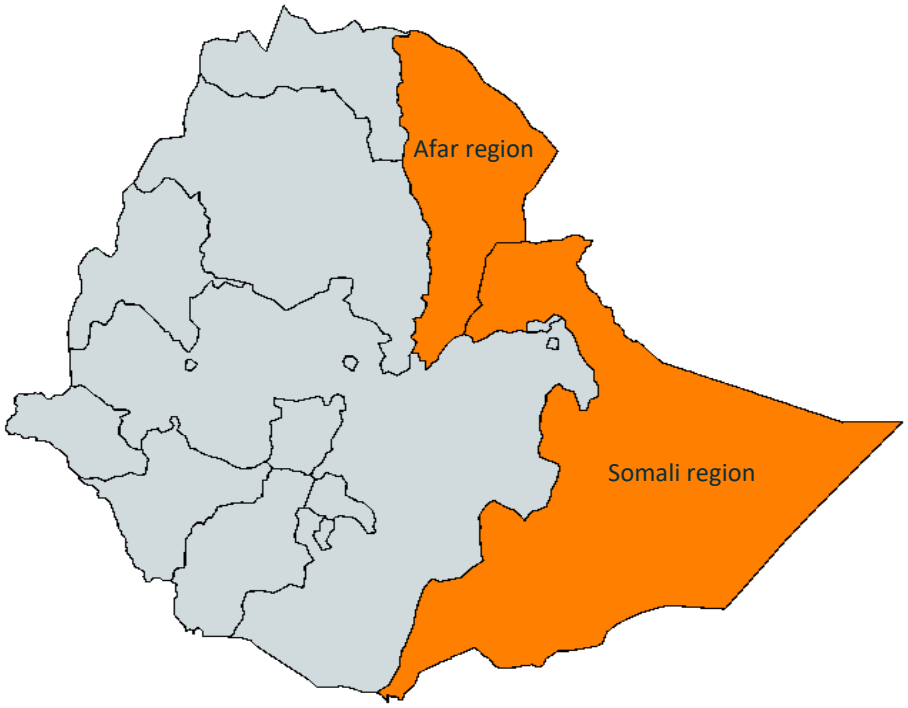
3.5 SAMPLING

In consultation with the MoH EPI team, we selected Afar and Somali regions for this study, as both are among the regions in Ethiopia with the highest proportion of zero-dose children. Within each region, three districts were purposefully chosen based on two main criteria: the presence of functional MHNTs and the recent implementation of PIRI campaigns. From each selected district, we included three health centers and two health posts that were fully functional during the year preceding the data collection period and actively conducting routine immunization and outreach services. Additionally, from each district, we selected one MHNT and the most recent PIRI campaign for inclusion in our assessment. In total, the study included 49 health facilities, of which 17 health centers and 32 health posts, alongside six MHNT teams and six PIRI campaigns, one from each district. For the qualitative assessment, 16 key informants were interviewed from the federal level to the health post level.

Table 2. Study sample at implementation level

Region	Districts	MHNTs	PIRI	Health centers	Health posts
Afar	Elidar	1	1	3	6
	Mille	1	1	3	5
	Ewa	1	1	3	6
Somali	Babili	1	1	3	6
	Erer	1	1	4	7
	Yahob	1	1	1	2
Total		**6**	**6**	**17**	**32**

Figure 1: Map of study area



3.6 DATA COLLECTION PROCESS

In each region, data was collected by a team of six people, including three representatives from each region's health bureau. The team underwent a three-day training session before starting data collection. Cost data collection tools were developed in Microsoft Excel and adapted to the local context to facilitate the collection of cost information related to immunization delivery strategies. A specific data collection tool was prepared for each immunization delivery strategy. These tools included sections on staff time, social mobilization, training and meetings, vaccine delivery, cold chain equipment, travel and transport, as well as recordkeeping and reporting. Vaccine delivery volume and the number of zero-dose children reached was also collected simultaneously from EPI registries, catch-up immunization reports, immunization tally sheets, and PIRI reports.

The data collection tools were piloted in the Goljano district, Somali region, at one health center, two health posts, and one for both PIRI and MHNTs. Following the pilot, necessary adjustments were made to improve the data collection tools.

After data collection, three investigators carefully reviewed all cost data sheets to ensure completeness and to identify and verify any potential outliers. They scrutinized data such as hours worked by health staff, purchase and acquisition costs of cold chain equipment and vehicles, and the quantity of vaccination supplies used. If any issues were found, the relevant data sheets were returned to the data collection team for clarification and correction. When further verification was needed, phone calls were made to respondents at the implementation level. If specific data remained unavailable despite these efforts, assumptions were made to impute missing information using data from the same or similar sites. Capital costs were annualized using the replacement value of capital equipment with a discount

rate of 3% (11). Costs were initially collected in Ethiopian Birr (ETB) and then converted to 2024 US dollars using the average monthly exchange rate for the study period (November 2023 to December 2024). Costs incurred in 2023 were adjusted to 2024 USD. The yearly average exchange rate was 1 USD = 70.69641 ETB (12).

Resources shared across the health system, such as cold chain storage or paid labor, were allocated to the immunization based on the proportion that respondents estimated was used for immunization activities. Similarly, resources shared among different vaccination strategies were allocated to each strategy based on the respondents' estimates. When respondents could not allocate resources across immunization activities, the allocation rules detailed in **Annex 3** were employed.

Semi-structured interview guides were utilized to conduct key informant interviews. The primary questions included in the guide focused on exploring factors that impact vaccination coverage, vaccination financing mechanisms, current strategies for identifying zero-dose children, and elements influencing the implementation of MHNT and PIRI strategies. The full interview guide can be found in **Annex 4**. Experienced qualitative data collectors with public health degrees were recruited and trained before being deployed to the Afar and Somali for data collection.

3.7 DATA ANALYSIS PROCEDURE

3.7.1 Quantitative

We estimated volume-weighted average unit cost for each administrative levels, and then aggregated unit costs across all levels to obtain the overall unit cost. The volume-weighted unit cost for study sites at each level is estimated by dividing the total cost incurred at sites at that level by the total number of vaccine doses administered or zero-dose children reached at sites at the same level, according to the following formula:

$$unit\_cost\_level\_A_{vw} = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} Q_i}$$

Where C_i represents the total cost of vaccine delivery at location *i*, Q_i is the total quantity of doses delivered at location or the total quantity of zero-dose children reached at location *i*, and n is the sample size for that level.

For routine immunization and regular outreach, we analyzed unit costs separately for health posts and health centers at the district, regional, and national levels. Similarly, unit cost calculations for PIRI and MHNTs were performed at the regional and national levels. For routine immunization, regular outreach, and MHNTs, we used average monthly costs, while for PIRI, we used the average cost of the most recent PIRI session. We estimated financial and opportunity costs and then summed them up to estimate total economic costs. To allow for adequate comparison across strategies, we disaggregated results to show immunization-specific costs separately from shared costs. A list of resource types included, as well as whether they are considered shared or immunization-specific costs, is provided in in **Annex 2**

The denominator for unit cost calculations included the number of doses delivered (of any antigen), the number of zero-dose children reached, and the number of any child reached with Penta1. Therefore, unit costs for all delivery strategies were reported as cost per dose, cost per zero-dose child reached, and cost per any child reached with Penta1. Microsoft Excel was used to perform the cost data analysis for this study.

To enable systematic comparison across strategies, costs were extrapolated from the sample data to the district level using the average number of health facilities in a district as a scaling factor. The outcomes

are presented as district-standardized delivery volumes and costs, thereby ensuring consistency and comparability across different immunization strategies.

3.7.2 Qualitative

The qualitative data collected were analyzed using a thematic approach. Transcripts were imported into the NVIVO#11 software program for coding. The coding of themes relied on both deductive and inductive approaches. Deductively, the predefined themes in the study protocol, such as operational challenges, suitability assessment, and lessons learned, were used to guide the inductive identification of sub-themes from the data. The operational definitions for the deductively identified themes are described as follows:

- Operational challenges were perspectives from health workers regarding the practical difficulties faced during the implementation of each strategy (e.g., logistical issues, resource limitations, challenges with community engagement).
- Suitability assessment examined how health care workers view the effectiveness of each strategy in addressing the specific challenges they encounter in reaching zero-dose children within their contexts.
- Lessons learned are key takeaways and insights from program implementation that can inform future efforts to optimize strategies for reaching zero-dose children.

Under each deductively identified theme, a range of recurrent sub-themes was identified. An open coding approach was employed to identify sub-themes through the re-reading of transcripts. Sub-themes that emerged from the data were coded, organized, and interpreted under the deductively identified themes. The validity and reliability of codes were determined by checking the congruence of informants' statements under each code with the operational definitions of deductively identified themes and agreement among four of the research team members on the coding framework.

3.8 OPERATIONAL DEFINITIONS

Zero-dose children: Defined as infants who have not received the first dose of diphtheria, tetanus, and pertussis-containing vaccine (DTP1) or Penta1 by the end of their first year of life (13).

Immunization-specific costs (program-specific costs): Costs of resources that are used exclusively for immunization programs i.e. costs that would not be incurred if the immunization program did not exist. Examples include salaries of health workers whose time is devoted solely to immunization, immunization-only cold chain equipment, and safety and injection supplies.

Shared costs: Costs of resources used by immunization but also used by other health services or programs. They are not generated only because of immunization, but a portion is attributable to immunization. Shared costs are allocated to immunization based on a proportion of usage, time, or other allocation rules. Examples include multi-purpose health personnel (who spend part of their time on immunization and part on other services), facility space and utilities, shared equipment and vehicles, overheads, and general administrative and support resources.

3.9 ETHICAL CONSIDERATION

This study protocol was submitted to the Ethiopian midwife association ethical review board for approval. All data collected during the study, including interview transcripts and any identifying information, were anonymized. We assigned participants unique identifiers to track data internally, but these identifiers will not be linked to their personal information. Data collection was started after

getting an official letter of permission. The study purpose, procedure, duration, risks and benefits of the study was clearly explained to all respondents involved in the study.

4.RESULTS

4.1 VACCINE DELIVERY OUTPUT

In the sampled districts, routine immunization through RI/RO delivered 62,749 doses in Afar and 59,290 doses in Somali region per year. MHNTs administered 7,990 doses in Afar and 20,577 doses in Somali region, while the last PIRI campaign session in the sampled district delivered 21,184 doses across both regions. Table 3 presents district-standardized vaccine volumes and zero-dose children reached. Health posts delivered the majority of vaccines, but PIRI sessions were the most effective at reaching zero-dose children.

Table 3 . Volume delivered, zero-dose children reached, and district standardized volume delivered and zero-dose children reached by each strategy.

Strategies	Average vaccine volume delivered	District Standardized Volume delivered	Average ZD children reached	District Standardized ZD children reached
RI/RO Health Post	179 per month	34,368 per year	2 per month per health post	324 per year
RI/RO Health center	324 per month	11,664 per year	4 per month per health center	144 Per year
MHNTs	350 per month	4,208 per year	6 per month per team	75 Per year
PIRI	3,539 per PIRI session	9,449 per year	242 per PIRI Session	646 Per year

Note: Monthly data and per session data extrapolated over a year. Considering 16 health posts, 3 health centers, and 1 mobile health and nutrition team per woreda, and PIRI sessions conducted 2.67 per year

Figure 2a and Figure 2b show the box-and-whisker plots of vaccine volume and zero-dose children reached for the delivery strategies assessed. These illustrate high variation in the average monthly vaccine volume delivered by MHNTs. Health posts have many outliers. MHNTs deliver a higher median volume of vaccines and reach a higher median number of zero-dose children compared to health centers and health posts.

Figure 2a: Box-Whiskers plots of average monthly vaccine volume delivered and zero-dose children reached for RI/RO and MHNTs

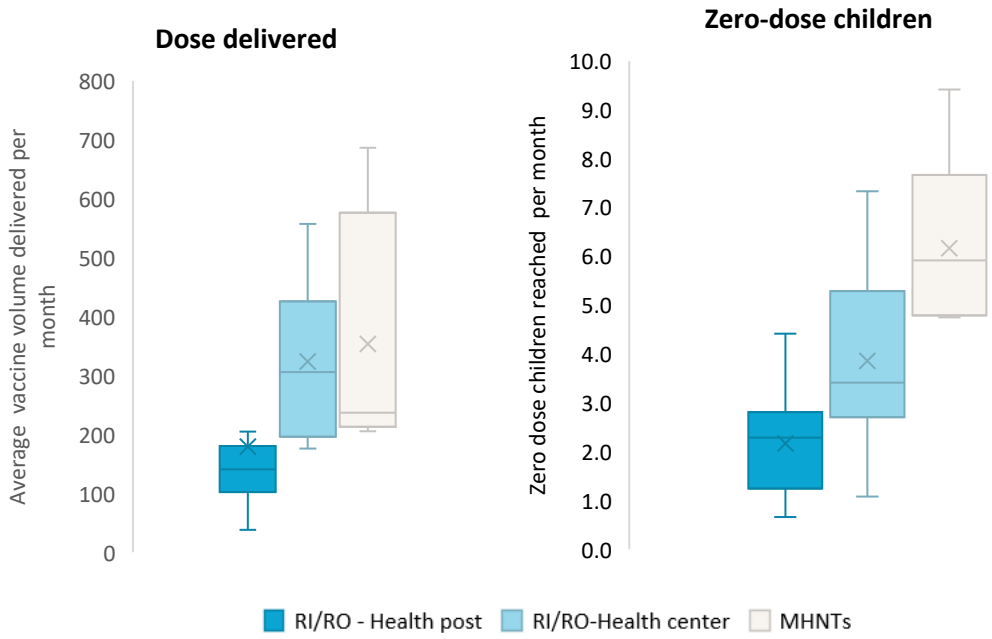


Figure 2b: Box-Whiskers plots of vaccine volume delivered and zero-dose children reached for PIRI, on average per session

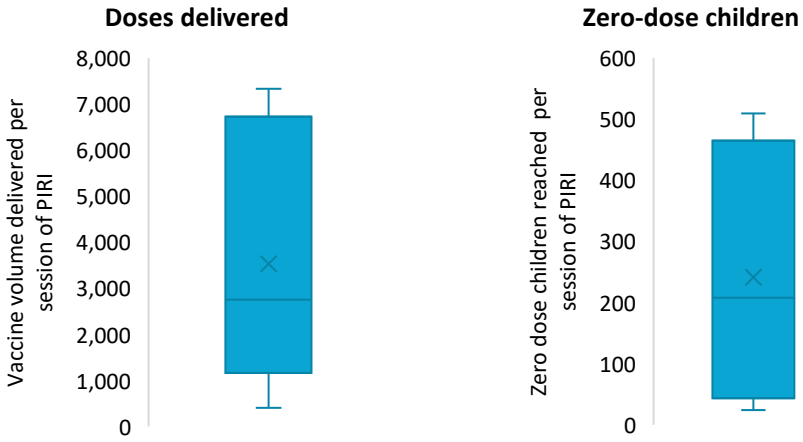
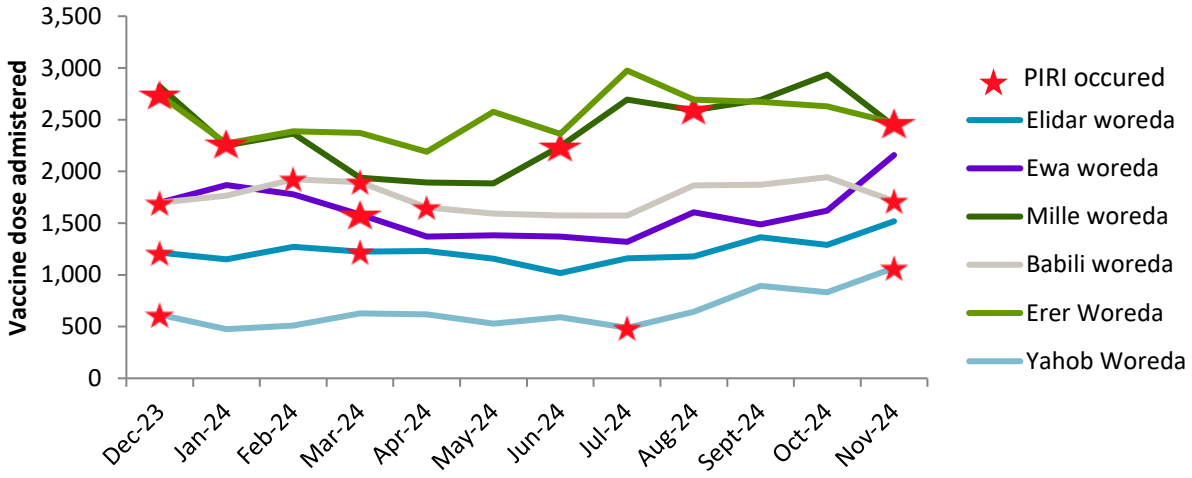


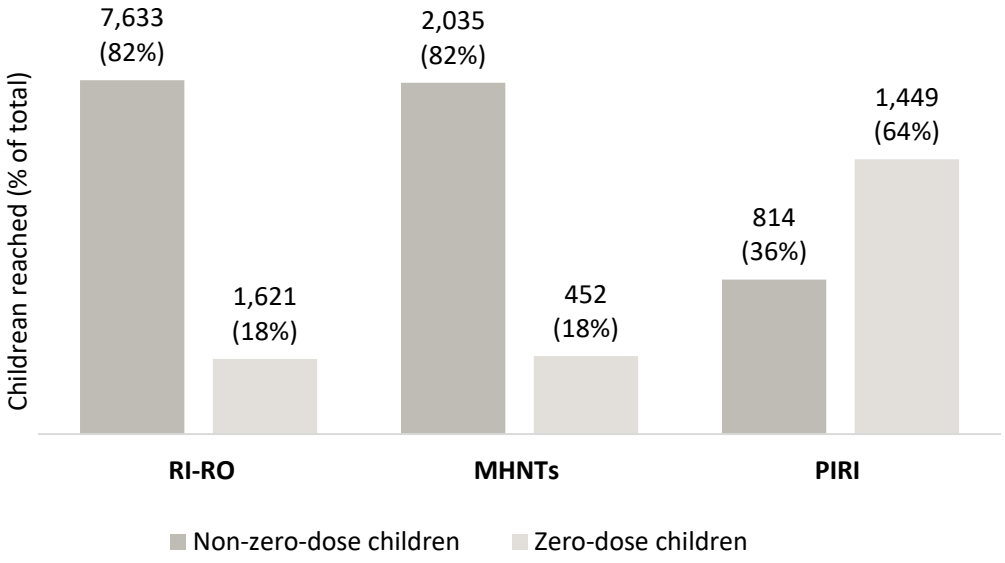
Figure 3 shows monthly vaccine trends at health facilities alongside PIRI sessions that were implemented in the same month of RI/RO. Many children are vaccinated through PIRI; however, no significant changes in the number of vaccines delivered through routine services can be observed following the implementation of a PIRI. This suggests that parents rely on PIRI campaigns and wait for them, rather than taking their children to health facilities where vaccination services are more consistently available. Although children vaccinated through PIRI are expected to be linked to a health center or health post to be vaccinated with other antigens or subsequent doses, this does not happen consistently. Qualitative findings further support this, showing that many parents prefer to wait for the next PIRI round instead of seeking immunization services at health facilities, which contributes to higher dropout rates. In addition, as shown in the graph, PIRI is conducted irregularly, often fewer than three times per year.

Figure 3. Monthly trends in vaccine dose delivered in selected health facilities in Somali and Afar region



The majority of children reached through PIRI were zero-dose children (64%; 1,449/2,263), compared to 17% of all children reached through RI/RO (2,962/9,254) and 18% of children reached by MHNTs (452/2,487) (Figure 4). RI/RO and MHNT primarily served partially vaccinated or children on schedule, whereas PIRI effectively reached unvaccinated children. PIRI and MHNT in Somali reached more children than in Afar.

Figure 4. Number and share of non-zero-dose and zero-dose children out of total children reached for each immunization strategy.



Note: RI/RO and MHNTs figures are annualized, while PIRI volume is for the last session only.

Among 17 health centers and 32 health posts, only 14 centers and 22 posts provided separate routine immunization and outreach data. In these facilities, regular outreach contributed a smaller share of total

doses (15.34% in Afar; 25.37% in Somali) but accounted for a larger share of zero-dose children reached (60.82% in Afar; 44.32% in Somali). Minimal variation was observed by facility type (Figures 5–7).

Figure 5. Vaccine dose delivered at health facilities disaggregated by routine immunization and regular outreach.

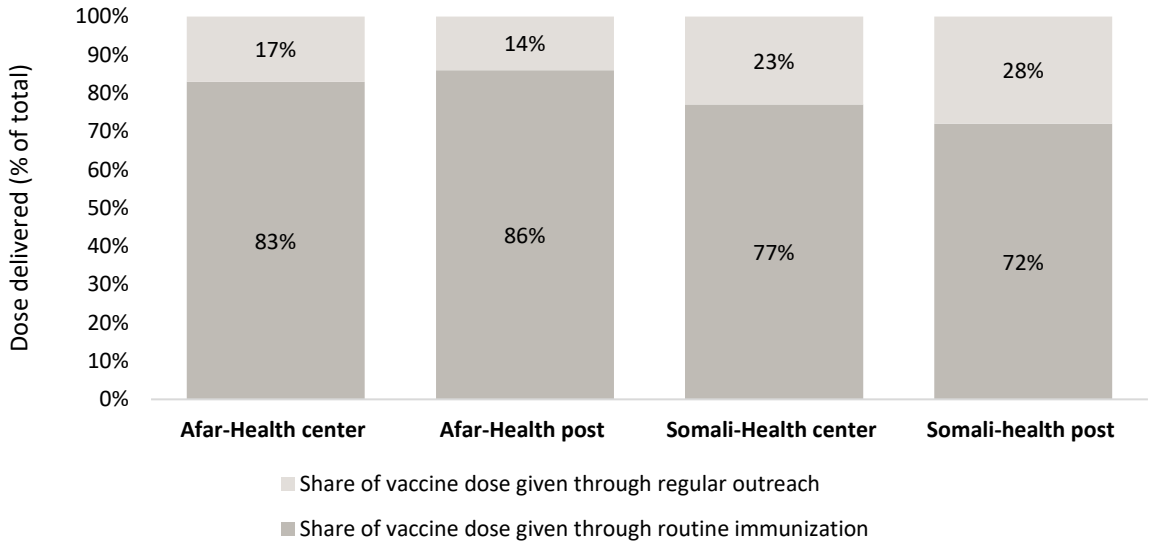


Figure 6. Vaccine dose delivered volume (left) and zero dose children reached (right) by routine immunization and regular outreach, disaggregated by region.

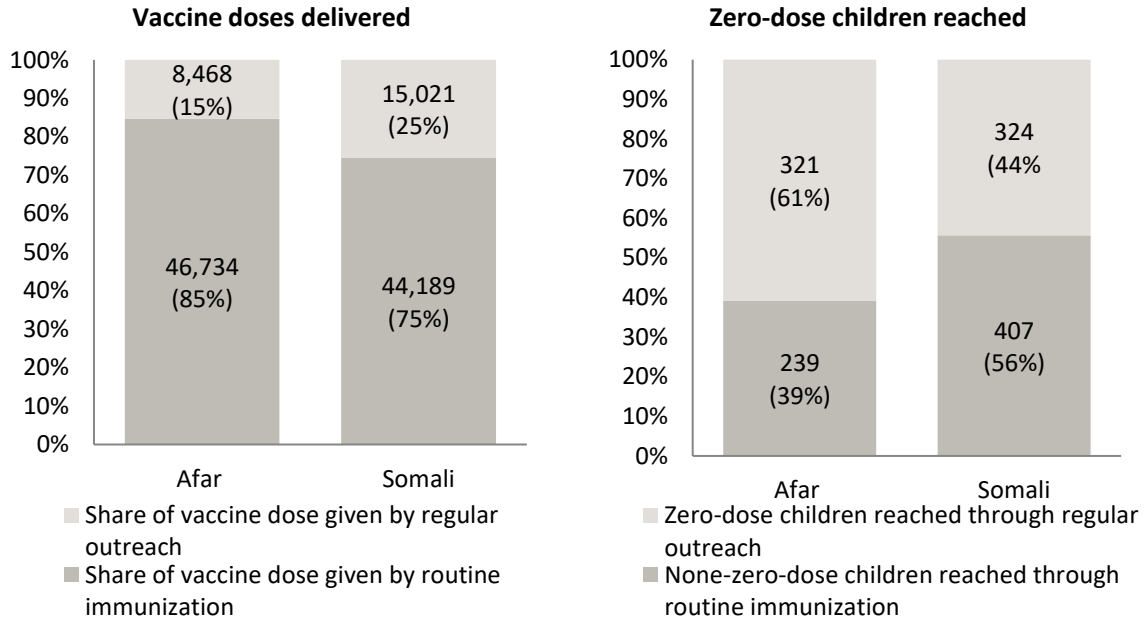
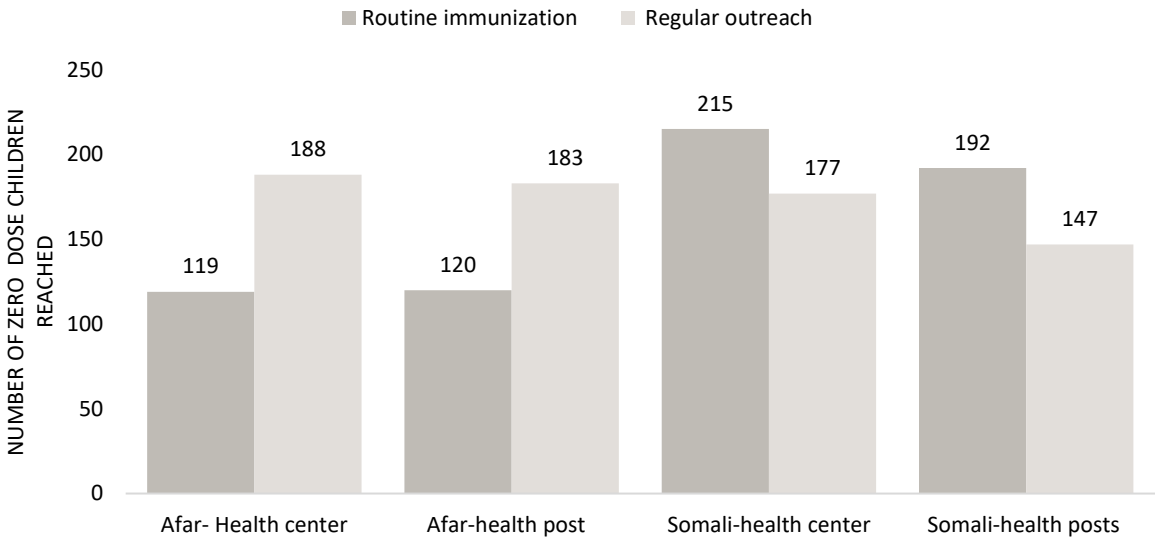
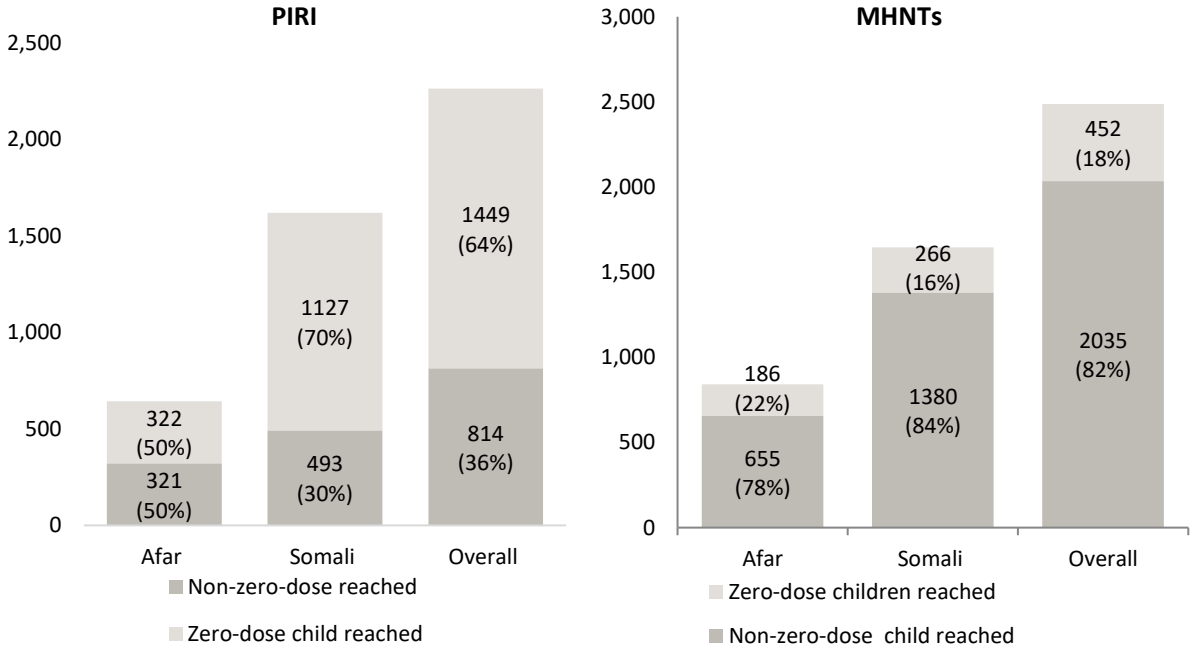


Figure 7: Number of zero dose children reached thought routine immunization and regular outreach disaggregated by facility type and region



Immunization through MHNTs predominantly reached non-zero-dose children (2,035), focusing on schedule completion, whereas PIRI reached more zero-dose children (1,449/2,263), confirming its effectiveness to vaccinate previously unreached children (Figure 6).

Figure 8. Share of Zero-dose children reached out of total children reached with Penta 1 through PIRI (left) and MHNTs (right).



4.2 VACCINE DELIVERY COSTS

4.2.1 Total costs

Average economic costs for immunization strategies are summarized in Table 4. Average monthly costs were $348.75 at health posts and $113.96 at health centers for RI/RO, $841.89 for MHNTs, and $1,606.72 per PIRI session. There is huge variation in average economic costs of PIRI per session (Figure 8).

Table 4. Average cost of immunization delivery strategies in Afar and Somali region.

Immunization strategies	Unit of measurement	Sub-category	Opportunity costs (min-max)	Financial costs (min-max)	Economic costs (min-max)
RI/RO	Average monthly costs in USD	At Health centers	$274.29 ($179.91-$387.68)	$74.46 ($35.40-$148.93)	$348.75 ($235.92-$496.83)
		At Health posts	$95.30 ($62.82-$173.78)	$18.66 ($2.85-$64.87)	$113.96 ($66.73-$191.36)
MHNTs	Average monthly costs in USD		$614.33 ($543.61-$738.70)	$197.16 (141.99-250.42)	$811.49 ($736.22-$989.11)
PIRI	Average costs per PIRI session in USD		$588.43 ($296.98-$1,033.06)	$1,018.29 ($332.33-$1,038.59)	$1,606.72 ($629.31-$2,508.16)

Figure 9: Box-Whiskers plots of economic costs for each strategy

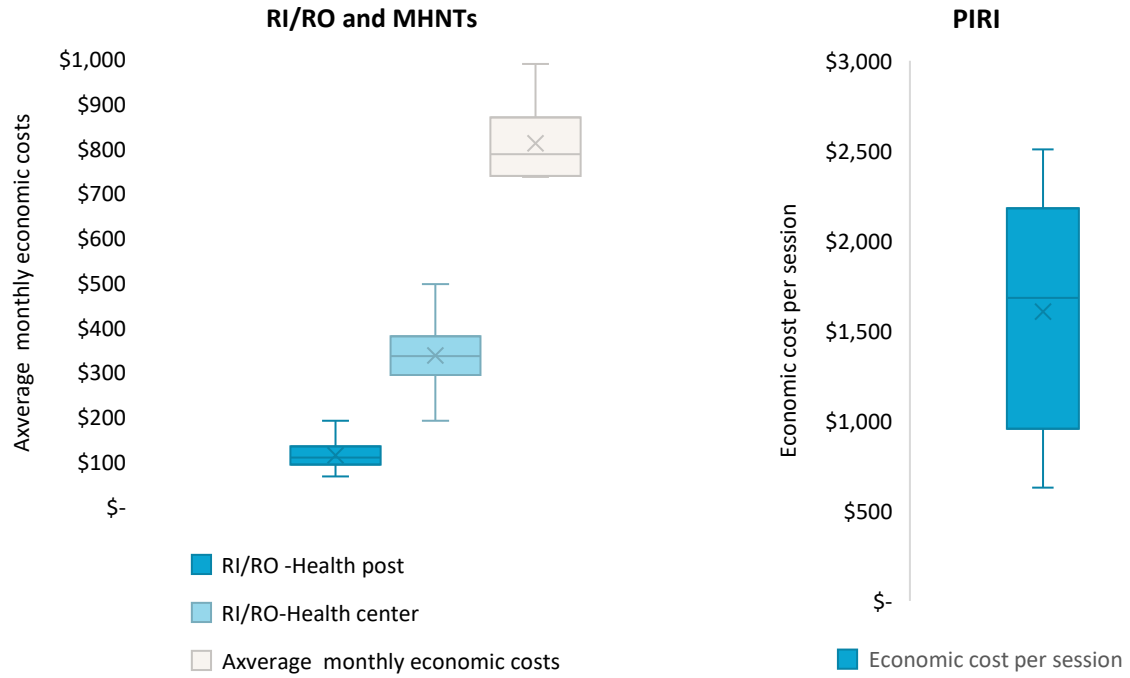


Table 5 shows district-standardized annual costs across delivery strategies.

Table 5. District-standardized estimated economic cost of each strategy, per year.

Immunization strategies		Economic cost
Routine immunization and regular outreach	At Health centers	$12,555
	At Health posts	$21,880
Mobile Health and Nutrition Teams		$9,738
Periodic intensification of routine immunization		$4,290

Note: Monthly data and per-session data extrapolated over a year. Considering 16 health posts, 3 health centers, and 1 mobile health and nutrition team per woreda, and PIRI sessions conducted 2.67 per year on average.

Table 6 and Table 7 show monthly costs or costs per session across the two regions. Regional variation is observed, with lower costs in Afar than in Somali region, for both health centers and posts. The average monthly costs for RI/RO were slightly lower in Afar than in Somali, for both health centers and health posts (see Table 6). MHNT costs were consistent across and within regions, while PIRI costs varied, especially in Afar (Table 7). This variation could be due to differences in woreda population size and the varying intensity of PIRI implementation across woredas. While some woredas receive support from partners and conduct PIRI in many kebeles (sub-woredas), partner support is not uniform across all woredas.

Table 6. Monthly average economic costs of routine immunization and regular outreach immunization delivery strategy in Afar and Somali region.

Region	Facility type	Monthly average total cost (min-max)
Afar	Health center	$323.18 ($235.92-$379.44)
	Health post	$111.20 ($68.74 -$191.36)
Somali	Health center	$377.52 ($289.72- $496.83)
	Health post	$117.09 ($66.73-191.36)
Total	**Health center**	**$348.75** ($235.92-$496.83)
	Health post	**$113.96** ($66.73- $191.36)

Table 7. Average economic costs of MHNTs and PIRI in selected health facilities in Afar and Somali region.

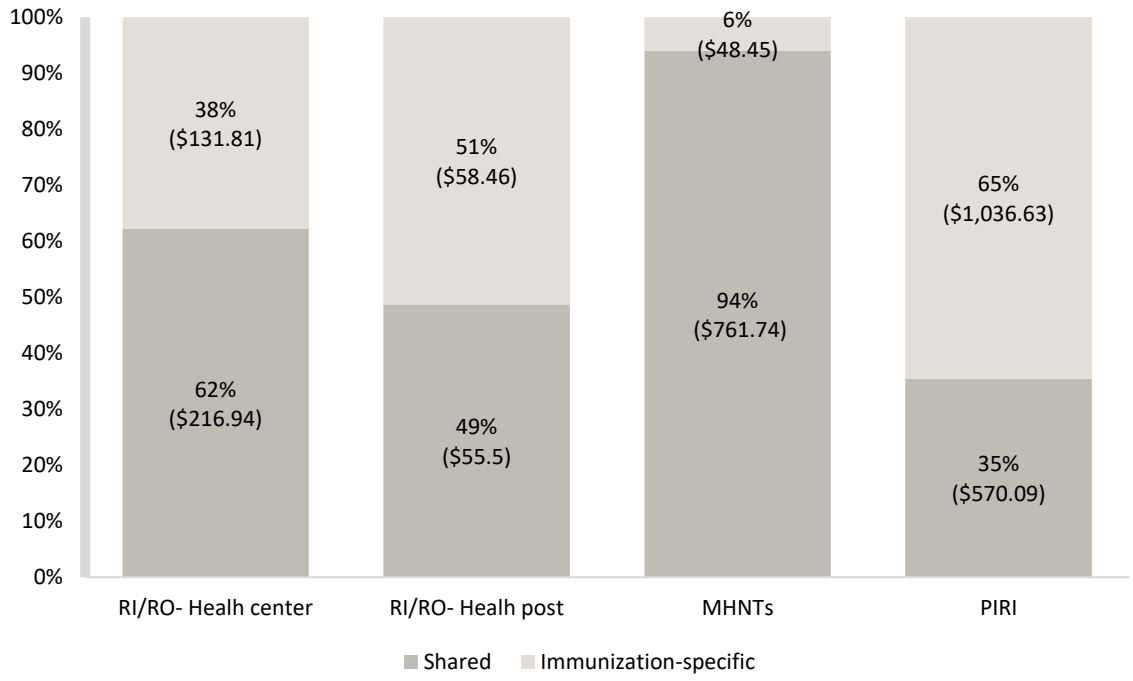
Region	Woreda	Strategy	Unit of measurement in USD	Costs
Afar	Elider	MHNT	Average monthly cost in USD	$806.68
		PIRI	Total cost per session in USD	$1,066.54
	Ewa	MHNT	Average monthly cost in USD	$830.02
		PIRI	Total cost per session in USD	$2,508.16
	Mille	MHNT	Average monthly cost in USD	$767.56
		PIRI	Total cost per session in USD	$629.31
	Total	**MHNT**	**Average monthly cost in USD**	**$801.42**
		PIRI	**Total cost per session in USD**	**$1401.34**

Somali	Babili	MHNT	Average monthly cost in USD	$989.11
		PIRI	Total cost per session in USD	$2,071.65
	Erer	MHNT	Average monthly cost in USD	$739.34
		PIRI	Total cost per session in USD	$1,404.97
	Yahob	MHNT	Average monthly cost in USD	$736.22
		PIRI	Total cost per session in USD	$1,959.68
	Total	**MHNT**	**Average monthly cost in USD**	**$821.56**
		PIRI	**Total cost per session in USD**	**$1,812.10**

4.2.2 Immunization-specific vs shared costs

Figure 9 shows that 65% of PIRI costs are immunization-specific. MHNTs have lower immunization-specific costs (6%) but higher shared costs due to broader service delivery. Health posts and centers have more balanced cost distributions.

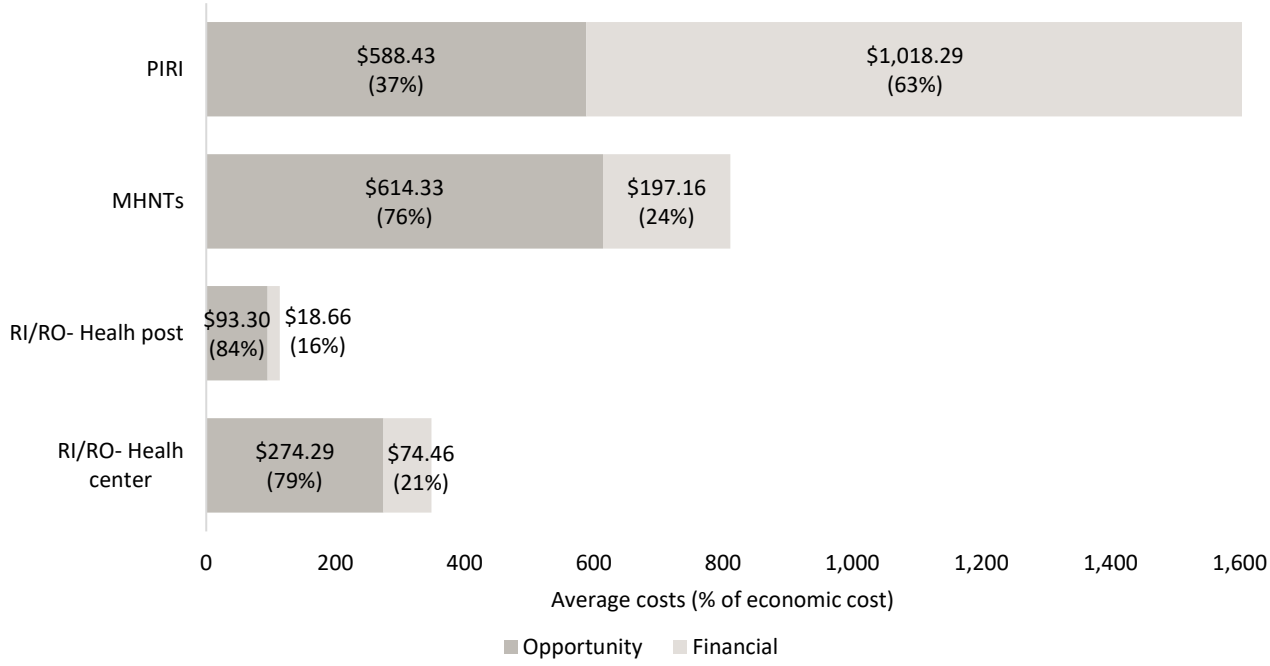
Figure 9. Average economic cost disaggregated by shared vs. immunization specific for each immunization delivery strategy



4.2.3 Financial vs opportunity costs

For RI/RO, opportunity costs dominate with 79% of the economic cost representing opportunity costs at health centers, and 84% at health posts. MHNTs follow a similar trend (76% opportunity cost). PIRI, by contrast, has 63% financial costs, highlighting the requirement for substantial direct expenditures to implement short-term, high-intensity campaigns rather than relying predominantly on existing health system resources (Figure 10).

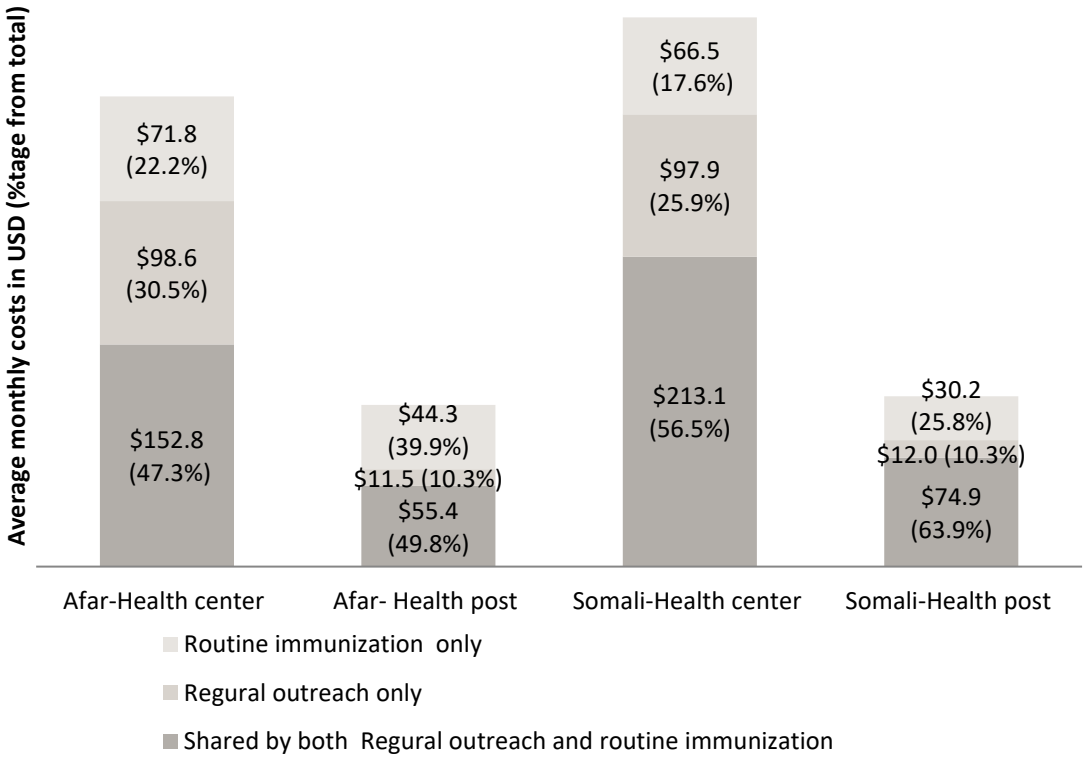
Figure 10. Financial vs. opportunity cost of Immunization strategies



4.2.4 Costs by service type (RI/RO)

From the average monthly cost of immunization delivery through RI/RO, about half of the economic costs are shared between routine immunization and regular outreach in both health centers and health posts. The proportion of costs attributed solely to regular outreach is higher in health centers than in health post, likely due to the fact that health posts are located closer to community they serve and can reach the population with fewer resources, while health centers need additional resource to reach the community for regular outreach.

Figure 11. Share of average monthly total costs by strategy (routine immunization vs. regular outreach)



4.3 UNIT COSTS

The unit costs highlight substantial differences across immunization strategies due to their distinct delivery approaches (Tables 8 and 9). For RI/RO, the economic cost per dose delivered is $1.08 at health centers and $0.64 at health posts, while the cost per zero-dose child reached is $90.40 and $52.47, respectively. MHNTs incur the highest costs, at $2.31 per dose and $129.26 per zero-dose child, reflecting the additional resources required to reach remote populations and to deliver multiple health services. In contrast, PIRI is the most cost-efficient, with a cost of $0.46 per dose and $6.65 per zero-dose child, due to the larger number of children reached, demonstrating its effectiveness in targeting previously unreached children. Overall, PIRI is the most efficient strategy for reaching zero-dose children, followed by RI/RO at health posts (Tables 6–7, Figure 14).

Table 8. Volume-weighted cost per dose delivered, by strategy.

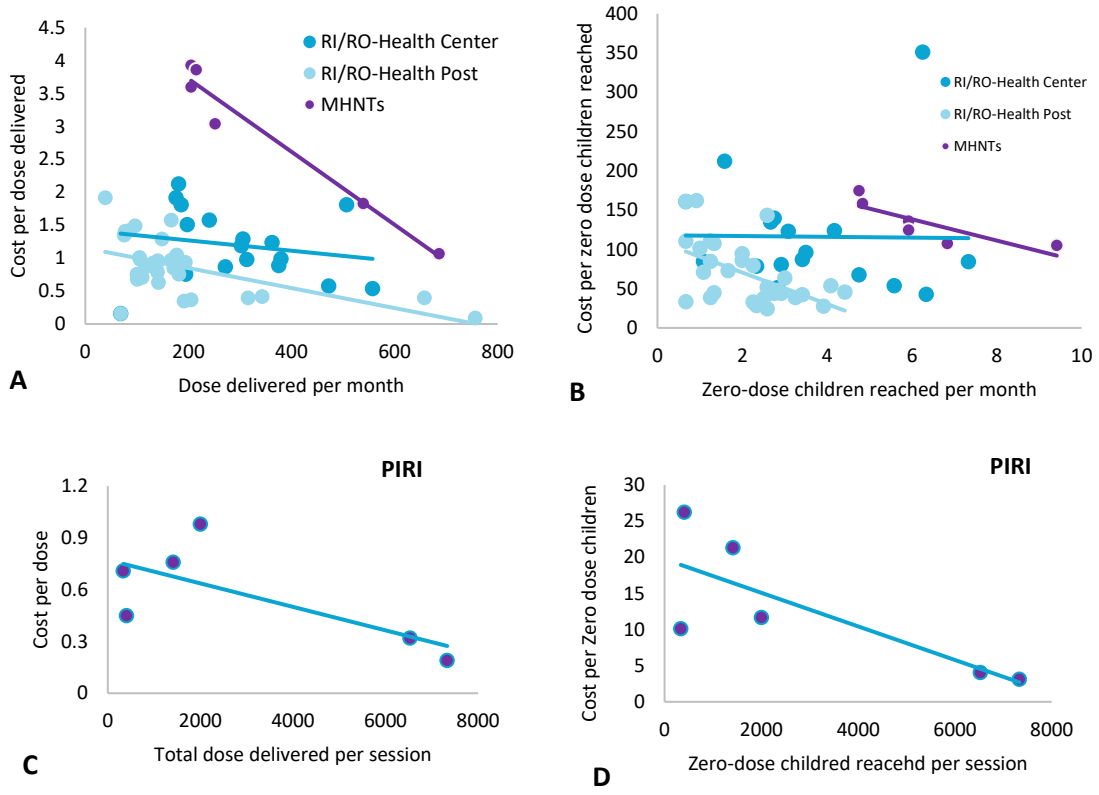
Strategy		Financial cost per dose (min-max)	Economic cost per dose (min-max)
RI/RO	Health center	$0.23 ($0.07 - $0.30)	$1.08 ($0.58 - $2.13)
	Health posts	$0.10 ($0.01-$0.15)	$0.64 ($1.05 - $1.92)
MHNTs		$0.56 (0.21 - $1,05)	$2.31 ($1.07 - $3.93)
PIRI		$0.29 ($0.13- $0.71)	$0.46 ($0.19 - $0.98)

Table 9. Volume-weighted cost per zero-dose child reached, by strategy.

Strategy		Financial cost per ZD child reached (min-max)	Economic cost per ZD child reached (min-max)
RI/RO	Health center	$19.30 ($5.59 - $85.99)	$90.40 ($53.82 - $351.50)
	Health posts	$8.59 ($2.64 - $56.83)	$52.47 ($24.64 - $162.28)
MHNTs		$31.41 ($26.59 - $35.59)	$129.26 ($105.04 - $174)
PIRI		$4.22 ($2.09 - $13.85)	$6.65 ($3.12 - $26.22)

A general decline in unit cost (cost per dose) was observed across all immunization delivery strategies as the volume of vaccine doses delivered increased. A similar trend was noted for the cost per zero-dose child reached; as the number of zero-dose children reached increased, the unit cost decreased. These negative relationship between the unit costs and volume illustrates that economies of scale were present (see Figure 12).

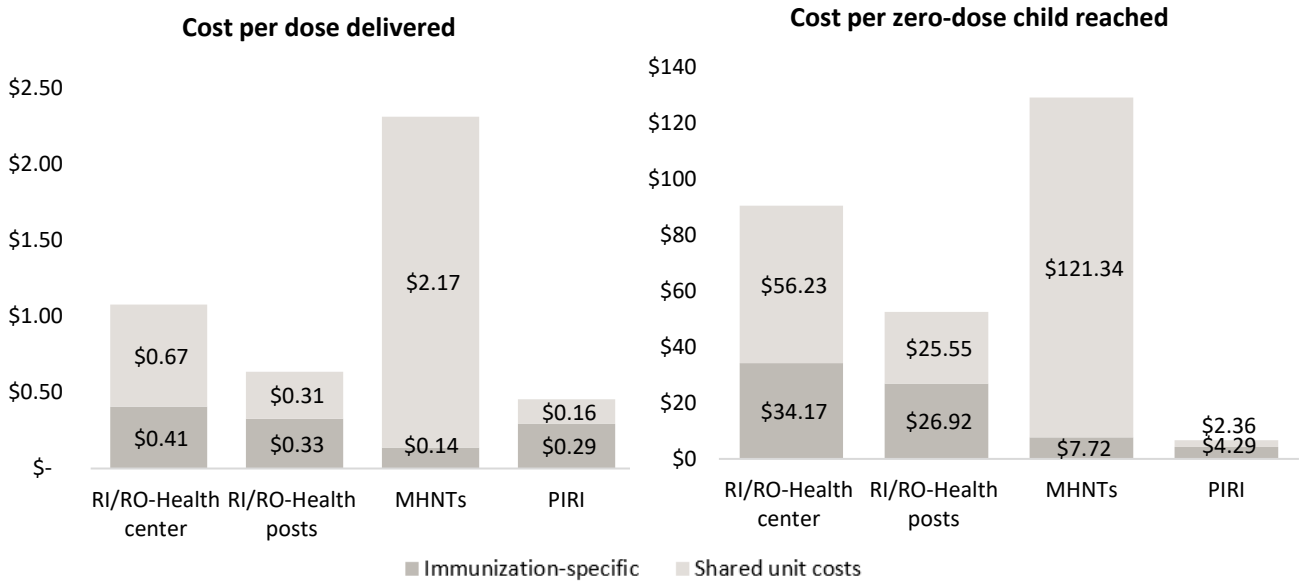
Figure 12: Scatter plots of cost per dose and the volume of vaccine delivered (A and C), and cost per zero-dose child reached and the number of zero-dose children reached (B and D) for all immunization delivery strategies



As MHNTs deliver multiple health services, to allow for adequate comparison across strategies, immunization-specific costs were analyzed separately from shared costs (Figure 13). Immunization-specific costs vary less than overall costs. RI/RO at health centers has an immunization-specific cost of $0.41 per dose, and $0.33 at health posts. MHNTs, despite high overall cost, have the lowest immunization-specific cost ($0.14 per dose), suggesting most expenses ($2.17) are shared with other health services. PIRI's immunization-specific cost is $0.29 per dose, with a shared cost of $0.16.

When looking at the cost per zero-dose child, RI/RO has immunization-specific costs of $34.17 (health centers) and $26.92 (health posts). MHNTs show a low immunization-specific cost of $7.72 per zero-dose child, with shared costs accounting for $121.34 of total $129.26 per zero-dose child reached. PIRI remains highly cost-efficient at $4.29 immunization-specific and $2.36 shared cost per zero-dose child.

Figure 13. Cost per dose delivered (Left) and cost per zero-dose child reached by immunization-specific and shared costs.



4.3.1 RI/RO unit costs

For RI/RO unit costs vary by facility and region. In Afar, health centers cost $1.13 per dose and $91.37 per zero-dose child; health posts cost $0.61 per dose and $50.19 per zero-dose child. In Somali, health centers cost $1.03 per dose and $86.18 per zero-dose child; health posts $0.67 per dose and $55.17 per zero-dose child (Tables 10–11, Figures 13–14).

The volume-weighted cost per any child reached with Penta1 through RI/RO was relatively consistent across regions. At health centers, it was $14.81 in Afar and $13.88 in Somali, with a similar pattern at health posts (Table 10). In contrast, the cost per zero-dose child showed greater variability. In Afar, reaching one zero-dose child cost $91.37 at health centers and $50.19 at health posts. In Somali, the corresponding costs were $86.18 and $55.17, respectively.

Table 10: Volume weighted economic unit cost in Afar and Somali region

Region	Delivery site	Cost per dose delivered (min-max)	Cost per zero-dose children reached (min-max)	Cost per any child reached with Penta1 (min-max)
Afar	Health center	$1.13 ($0.58-$1.92)	$91.37 ($42.91 - $123.06)	$14.81 ($6.91 - $27.15)
	Health post	$0.61 ($0.37 - $1.92)	$50.19 ($28.60 - $110.65)	$9.98 ($4.96 - $43.52)
Somali	Health center	$1.03 ($0.76 - $1.29)	$89.49 ($51.38 - $351.50)	$13.88 ($10.61 - $18.66)
	Health post	$0.67 ($0.40 - $1.00)	$55.17 ($33.34 - $162.28)	$11.44 ($8.98 - $13.72)

Routine immunization shows a lower unit cost per dose delivered at both health centers and health posts—$0.78 and $0.55 per dose, respectively. In comparison, regular outreach incurs higher costs per dose, at $1.85 for health centers and $0.59 for health posts. This pattern is consistent when considering the cost per child reached with Penta1.

However, regular outreach is more cost-efficient for reaching zero-dose children (Figure 13). At health posts, the cost per zero-dose child reached through outreach is $20.88, substantially lower than $77.82 through routine immunization. Similarly, at health centers, the cost is $59.69 per zero-dose child for outreach versus $108.17 for routine immunization. These results indicate that regular outreach is a more economical approach for targeting previously unreached children, whereas routine immunization remains more cost-efficient for general vaccine coverage. This is because regular outreach identifies more zero-dose children in the community compared to a facility-based strategy alone, and reaching more zero-dose children drives the cost per zero-dose child down. Overall, routine immunization provides better value for broad coverage, while regular outreach is more effective for reaching zero-dose children, albeit at a higher cost per child.

The major drivers of economic cost per zero-dose child reached at the health center were paid labor, cold chain equipment, and vehicles, while at the health post, the major drivers were paid labor and cold chain equipment (Figure 14).

Figure 13. Cost per dose delivered through routine immunization and regular outreach disaggregated by facility type

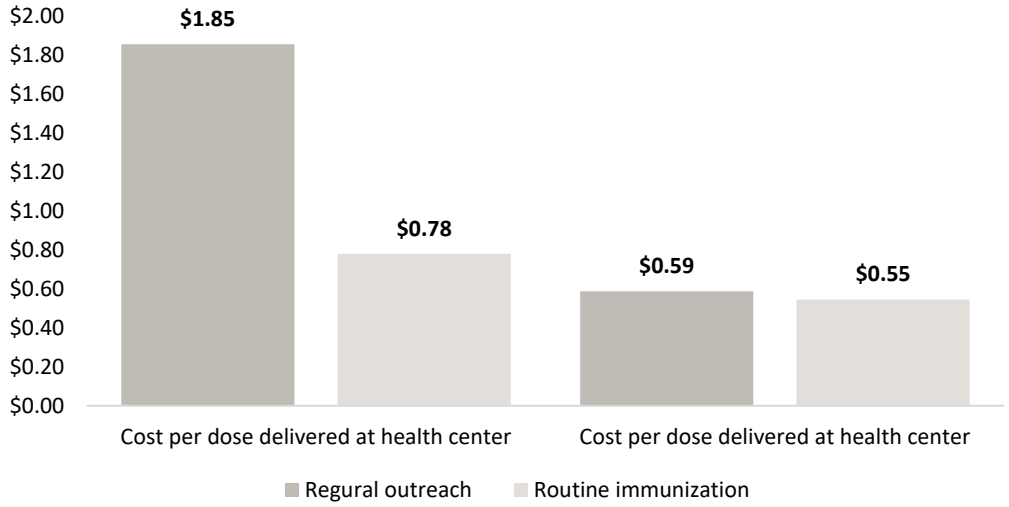


Figure 14. Cost per any child reached with Penta1 and cost per zero-dose child through routine immunization and regular outreach disaggregated by facility type

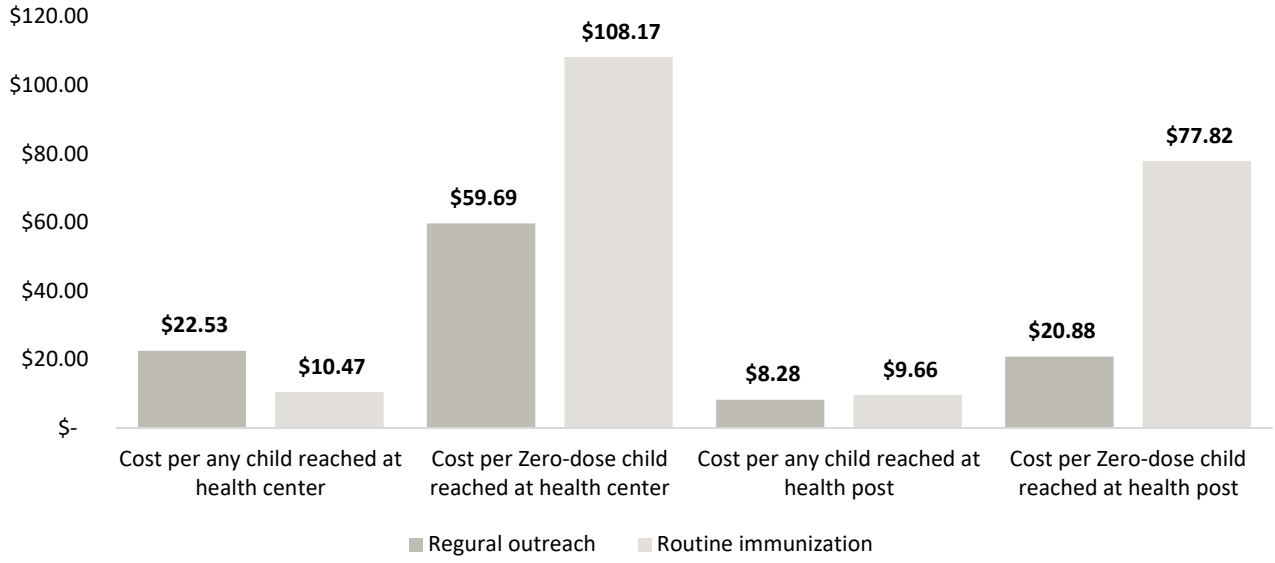
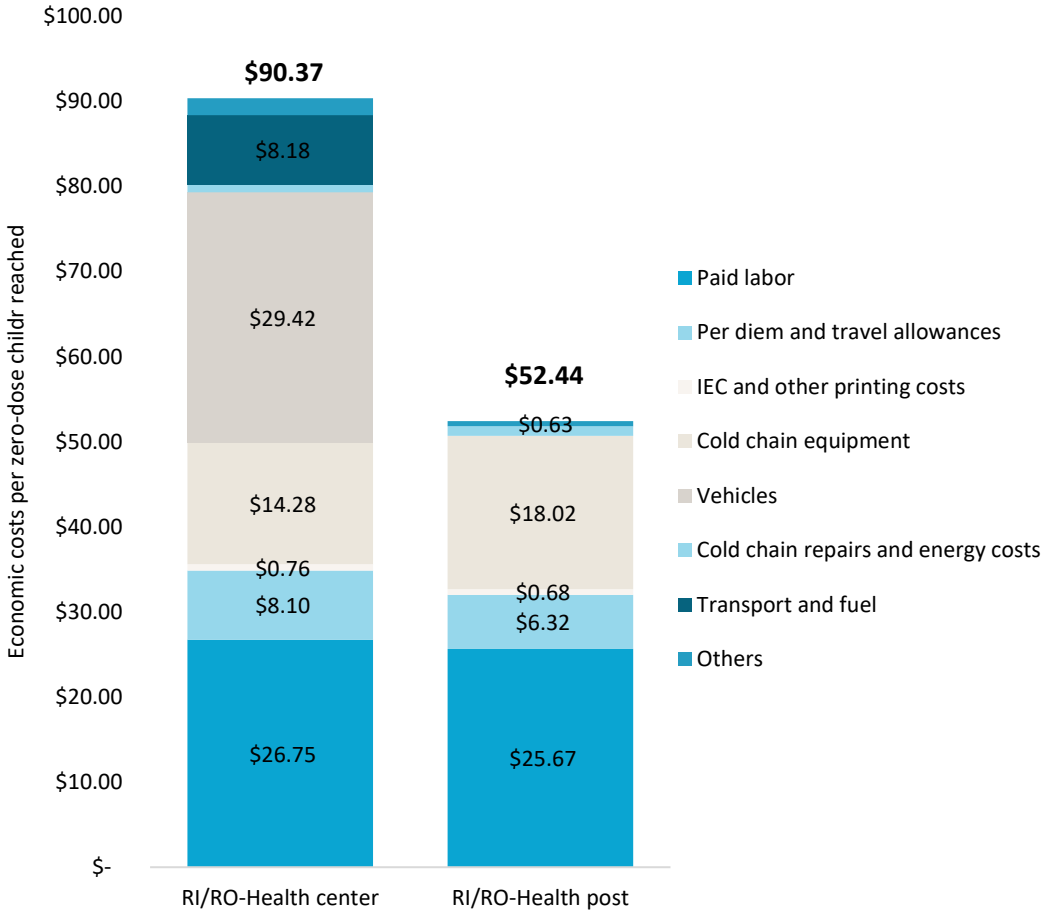


Figure 15. Economic cost per zero-dose child through routine immunization and regular outreach, disaggregated by resource type



Note: Others include communication, vehicle maintenance, workshops and meetings, other equipment, and volunteer labor

4.3.2 MHNT unit costs

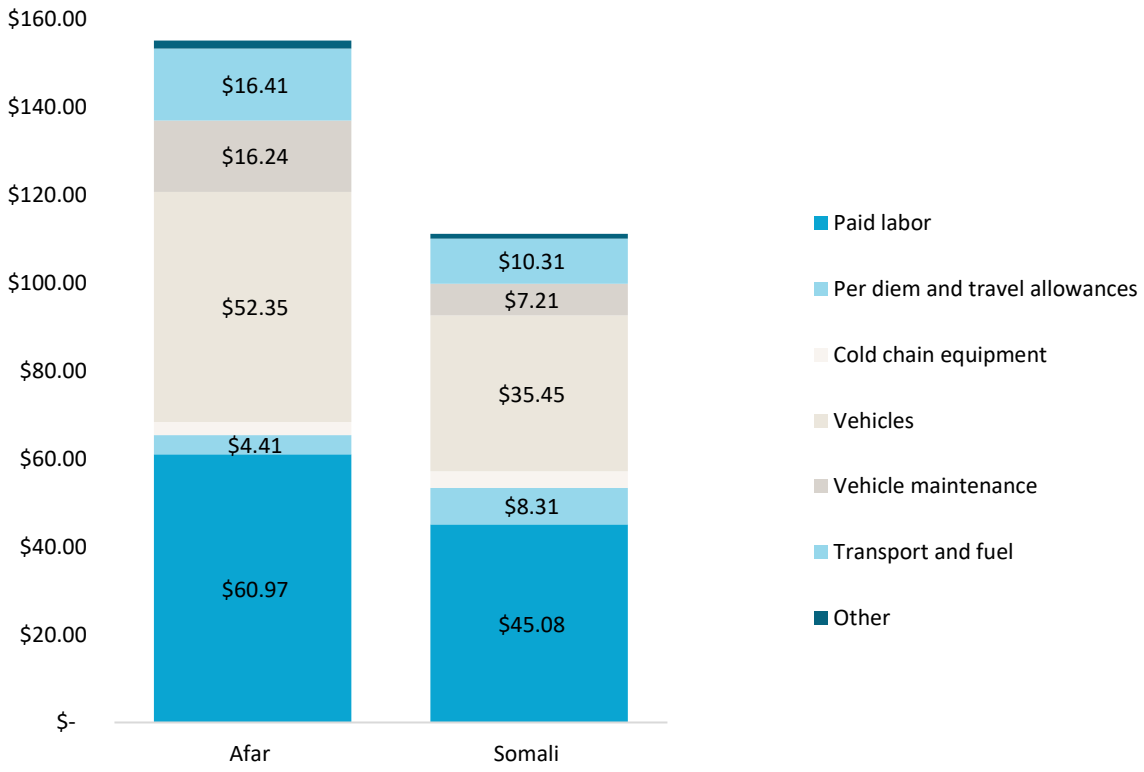
The unit costs for MHNTs are lower in the Somali region than in the Afar region, despite relatively small differences in total costs between the two regions (Table 12). This is primarily due to higher population in Somali region, which enables MHNTs to reach a larger number of children compared to Afar, thereby driving unit costs down. Further disaggregation by resource type shows that paid labor, vehicles, and transport/fuel account for most unit costs in both regions (Figure 16).

Table 12. Volume weighted unit costs (economic) of MHNTs in selected districts

Region	Cost per dose delivered (min-max)	Cost per any child reached with Penta1 (min-max)	Cost per zero-dose child (min-max)

Afar	$3.57 ($3.04 -$3.93)	44.05 ($36.84 - $49.64)	$155.11 ($136.34-$174.74)
Somali	$1.72 ($1.07 - $3.60)	$21.43 ($12.95 - $33.53)	$111.19 ($105.04 - $124.96)
Both	$2.31 ($1.07 - $3.93)	$28.71 ($12.95 - $49.64)	$129.26 ($105.04 -$174)

Figure 16. Cost per zero-dose children reached by MHNTs in Afar and Somali, disaggregated by resource type



Note: Other includes Communication, IEC and other printing costs, other equipment, and Volunteer labor.

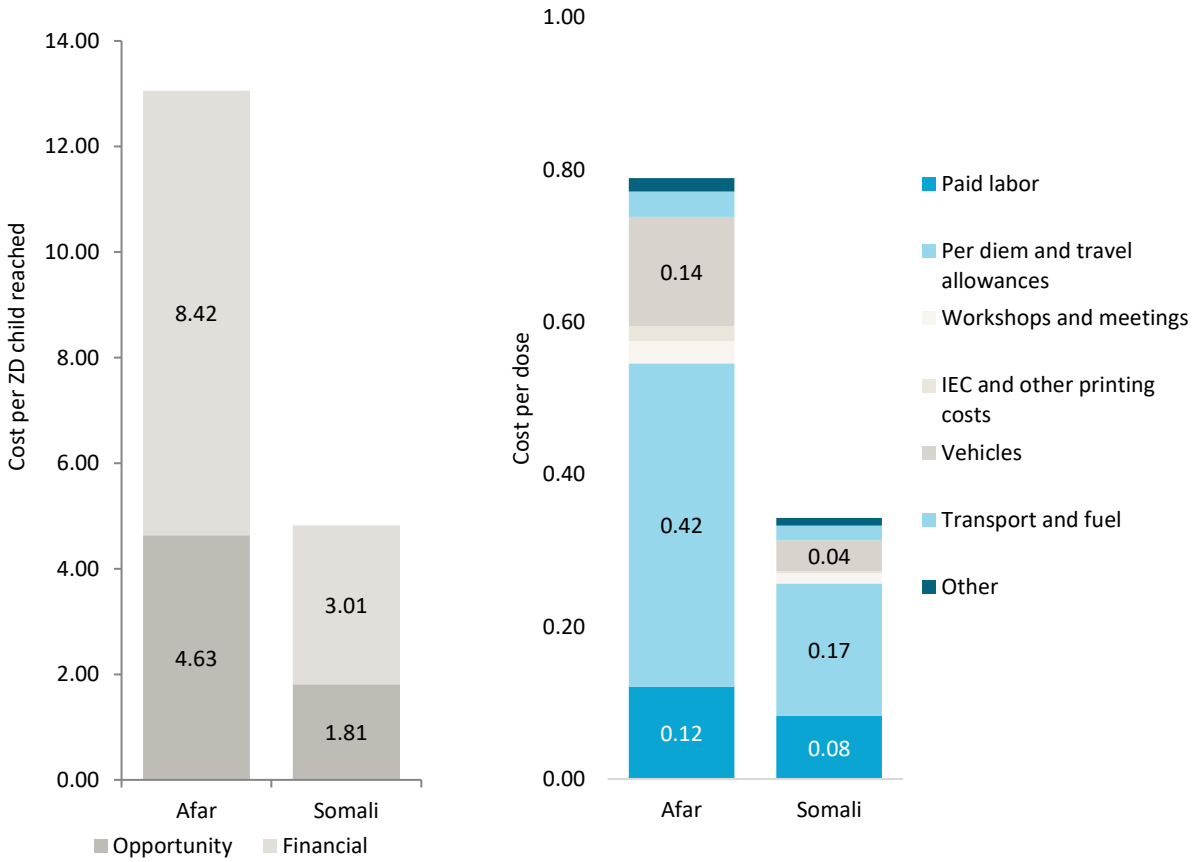
4.3.3 PIRI unit costs

PIRI costs per dose ranged $0.19–$0.98 across districts. Costs per dose in Afar region is $0.79, In Somali region it is $0.34. The cost per zero-dose child is $13.06 (Afar) and $4.82 (Somali). As indicated in Table 13, unit costs were lower in Somali region, likely due to economies of scale, as PIRI session in Somali region reached a higher number of children. As shown in Figure 17, most of the unit cost is financial. Per diems and travel allowances are a cost driver in both regions.

Table 13: Volume-weighted unit cost (economic) for PIRI strategy

Region	Cost per dose delivered (min-max)	Cost per any child reached with Penta1 (min-max)	Cost per zero dose child (min-max)
Afar	$0.71 ($0.45 - $0.76)	$8.54 ($1.87 - $9.52)	$13.06 ($10.11 - $26.22)
Somali	$0.34 ($0.19- $0.98)	$3.36 ($2.16- 9.80)	$4.82 ($3.12 - $11.66)
Both	$0.46 ($0.19 - $0.98)	$4.56 ($1.87 - $9.80)	$6.65 ($3.12 - $26.22)

Fig 17: Cost per zero-dose reached disaggregated by financial vs. opportunity costs (Left) and cost per dose disaggregated by resource type (Right) for PIRI strategy.



Note. Others include volunteer labor, other equipment, cold chain equipment, and communication.

4.4 KEY TAKEAWAY FROM QUALITATIVE FINDINGS

The qualitative assessment identified several operational challenges and lessons regarding the implementation of zero-dose and other vaccination strategies. This section reports a summary of the findings, while more extensive findings are discussed in a **separate publication** (14).

Operational Challenges

1. Logistical Challenges

- Inadequate transportation delays vaccination sessions and compromises vaccine safety.
- Functional refrigerators are insufficient, primarily due to poor maintenance.

2. Infrastructural Challenges

- Poor road quality limits access to remote populations.
- Newly established districts often lack essential health and logistical infrastructure.

3. Resource Constraints

- While Mobile Health and Nutrition Teams (MHNT) and Periodic Intensified Routine Immunization (PIRI) are adequately funded, routine immunization services are underfunded.
- Lack of transparency in budget allocation, utilization, and disbursement causes delays.
- Health posts face shortages of human resources.
- Insufficient incentives reduce health worker motivation.

4. Security Challenges

- Conflicts have damaged health infrastructure and disrupted vaccination activities and awareness programs.

5. Lifestyle Challenges

- Pastoralist lifestyles make it difficult to track children and ensure completion of vaccination schedules.

6. Attitudinal Challenges

- Misconceptions persist regarding the appropriateness of vaccinating older children.

Suitability of Interventions

- MHNT and PIRI strategies effectively addressed operational challenges by providing transportation, funding, additional staff, and active community outreach, mitigating logistical, financial, and staffing barriers as well as challenges posed by poor roads and long distances.
- Both strategies improved vaccine equity and coverage by reaching previously missed children in remote areas. MHNT was perceived as more effective due to its integrated delivery of essential services and its ability to increase community participation and turnout.

Key Lessons Learned

- Integrating health education and awareness-raising activities into delivery strategies improved community attitudes and increased acceptance of immunization.
- Emphasizing zero-dose children helped shift perceptions among health workers and communities about the importance of proactively catching up older children.
- A combination of complementary delivery strategies—routine immunization, MHNT, and PIRI—significantly improved the capacity to reach zero-dose and defaulting children.
- Strategies that integrate immunization with other services, such as nutrition, were more effective than standalone immunization and increased turnout rates.

- Simultaneous implementation of MHNT and PIRI in the same area may lead to resource duplication and reduced effectiveness, highlighting the need for careful planning and context-based prioritization.
- Infrequent PIRI campaigns may increase dropout rates, as parents delay seeking routine immunization or lack sufficient information about follow-up vaccinations.
- Continuous training, particularly for MHNT staff, is essential to meet the demands of hard-to-reach communities.
- Strong collaboration and information sharing among district coordinators, health facility staff, MHNT teams, development partners (for logistics and funding), and community volunteers were critical to the success of zero-dose vaccination strategies.

5. DISCUSSION

Children in the Afar and Somali regions, predominantly rural areas with nomadic pastoralist populations, often experience low access to health services and vaccination coverage. These regions have also been significantly affected by conflict over the past five years. As a result, they record the highest number of zero-dose children compared to any other region in Ethiopia. Conflict, combined with the common challenges of weak health systems in remote areas, has contributed to this persistent gap.

Ideally, routine immunization systems are expected to deliver vaccines to every child at the appropriate time. However, in practice, limited health system capacity, ongoing insecurity, and the remoteness of these regions mean that many children remain permanently unvaccinated. To address this gap, different strategies have been introduced to reach children missed by routine services. In this study, we estimated the effectiveness and cost of two such approaches: Mobile Health and Nutrition Teams and Periodic Intensification of Routine Immunization. Those who are reached through routine services are usually identified incidentally, for example during health facility visits for treatment of illness or through screening activities. Qualitative findings further suggest that zero-dose children rarely attend health centres unless they are actively tracked in the community or brought in for other medical reasons.

Our results highlight the limitations of facility-based routine immunization as a strategy for reaching zero-dose populations. The significantly higher cost per child reached reflects the very small number of zero-dose children who access vaccination through this channel. In contrast, outreach and PIRI approaches are more effective and cost-efficient because they are designed to actively locate and vaccinate children who would otherwise remain unreached. These indicate the need for tailored delivery strategies in contexts where geographic isolation, conflict, and mobility patterns of pastoralist populations make reliance on facility-based immunization insufficient.

This study found that PIRI was the most cost-efficient strategy for reaching zero-dose children, largely because it directly targets them. In the assessed districts, about 64% of Penta1 doses administered during campaigns were administered to zero-dose children, a much higher proportion than other approaches. The relatively infrequent implementation of PIRI may have contributed to lower unit costs, as more zero-dose children accumulated between rounds. A qualitative study suggested parent wait for the next campaign instead of seeking follow-up doses at health facilities. While this contributes to the lower unit cost, it can also increase dropout rates from the regular immunization schedule. Moreover, the cost efficiency of PIRI is sensitive to its frequency; more frequent campaigns would reduce the number of children reached per session thereby raising delivery costs.

The predominantly pastoralist lifestyle in the study areas further complicates the impact of PIRI. Seasonal mobility makes follow-up difficult, and many children are missed between campaigns, limiting

long-term effectiveness. PIRI may therefore be most beneficial in settled communities, where follow-up is easier and integration with routine services is more feasible. To maximize impact, PIRI should be complemented by stronger links to routine immunization and tailored strategies for mobile populations, ensuring both high initial coverage and continuity of protection.

Another issue is that PIRI largely depends on partner support, and its intensity depends on the availability of allocated government budget and of external support, which may vary. Qualitative findings also support that budget allocation for PIRI is less transparent compared to other strategies. Therefore, its sustainability is questionable. MHNTs incur higher unit costs, largely due to cost shared across all health services provided, but qualitative findings highlight their unique value. MHNTs integrate multiple essential services, such as nutrition and maternal care, which contribute to higher overall costs but also offer a more comprehensive, consistent, and targeted approach to reaching vulnerable populations. Integration with highly demanded services like nutrition increase cost efficiency for immunization delivery compared to standalone immunization delivery. Health worker interviews confirm that this multi-service model is vital for building community trust and increasing demand for vaccination. Despite their higher unit costs, MHNTs provide a more sustainable delivery approach aligned with the lifestyle of most communities in these regions by moving alongside mobile populations to provide services.

There is varying unit cost across the strategies assessed for reaching zero-dose children, with subnational differences between the Afar and Somali regional states. The selected woreda in Afar region has a lower and more dispersed population compared to the Somali region, which likely explains the greater variation in unit costs observed. In contrast, the Somali region's larger population benefits from economies of scale. Additionally, frequent security challenges in Afar probably limit the number of zero-dose children reached there.

Our findings suggest that both MHNT and PIRI help fill gaps in the routine immunization system. MHNTs are useful for reaching children in scattered and mobile communities, while PIRI works well to quickly boost coverage through short, focused campaigns in relatively stable communities. Used together, they complement the routine system by reaching children who would otherwise be missed, especially in remote and hard-to-reach areas. This shows the value of combining approaches that provide regular services with those that give short-term coverage gains.

To achieve lasting and universal immunization coverage, more needs to be done to strengthen the foundation of the routine system itself. Specific efforts should focus on proactively identifying zero-dose children by implementing better community-level surveillance and micro-planning to map and track every child; reducing missed opportunities by improving screening at all health facility contact points (e.g., nutrition clinics, outpatient services, maternity wards) to ensure any eligible child who visits a facility receives all vaccines, regardless of the reason for their visit; and expanding and improving routine outreach by systematically conducting scheduled outreach sessions from fixed facilities to their catchment area to bring services closer to populations on a regular, predictable basis.

6. CONCLUSIONS

In Ethiopia, as in many low-income countries, millions of children remain unvaccinated, highlighting the need for targeted strategies to complement routine immunization. This study, conducted in the pastoralist and underserved regions of Afar and Somali, assessed the costs and efficiency of three key delivery strategies, namely routine immunization and routine outreach, periodic intensification of routine immunization, and mobile health and nutrition teams.

The analysis shows that PIRI is the most cost-efficient strategy for reaching zero-dose children, though its impact is often short-term due to limited integration with routine services. Despite recommendations for quarterly implementation, PIRI campaigns occurred less frequently, contributing to higher dropout rates due to the insufficient linkage of newly vaccinated children to the ongoing system. MHNTs, while the most expensive overall, delivered broader services beyond vaccination. When considering only immunization-specific costs, MHNTs approach the cost-efficiency of PIRI for reaching zero-dose children, suggesting that integrating vaccination with other essential services, such as nutrition, can effectively increase coverage. RI/RO at health posts delivered the highest total volume of doses, underscoring the pivotal role of fixed facilities in sustaining the immunization system.

There is no single solution to reaching zero-dose children. A complementary mix of strategies is essential for long-term sustainability and impact. Strengthening the integration of PIRI and MHNTs with routine immunization and outreach is crucial. Successful programs should combine the targeted, cost-efficient reach of campaigns with the sustainable, broad coverage of RI/RO, supported by careful planning, ongoing staff training, stakeholder collaboration, and strategic health education to ensure continuous service delivery, prevent duplication, and effectively reach the most vulnerable populations.

REFERENCES

1. Lai X, Zhang H, Pouwels KB, Patenaude B, Jit M, Fang H. Estimating global and regional between-country inequality in routine childhood vaccine coverage in 195 countries and territories from 2019 to 2021: a longitudinal study. EClinicalMedicine. 2023;60.
2. Haeuser E, Byrne S, Nguyen J, Raggi C, McLaughlin SA, Bisignano C, et al. Global, regional, and national trends in routine childhood vaccination coverage from 1980 to 2023 with forecasts to 2030: a systematic analysis for the Global Burden of Disease Study 2023. The Lancet. 2025.
3. Asresie MB, Fekadu GA, Dagnew GW. Urban-rural disparities in immunization coverage among children aged 12–23 months in Ethiopia: multivariate decomposition analysis. BMC Health Services Research. 2023;23(1):969.
4. Bobo FT, Hayen A. Decomposition of socioeconomic inequalities in child vaccination in Ethiopia: results from the 2011 and 2016 demographic and health surveys. BMJ Open. 2020;10(10):e039617.
5. MoH Ethiopia Immunization Service Desk. Accelerated Action plan to address zero-dose, and under-vaccinated children in Ethiopia 2023-2025. 2023.
6. Ingle EA, Shrestha P, Seth A, Lalika MS, Azie JI, Patel RC. Interventions to vaccinate zero-dose children: a narrative review and synthesis. Viruses. 2023;15(10):2092.
7. Ethiopian Statistical Service. Population Size by Sex Zone and Wereda July 2023. 2023.
8. Shiferie F, Gebremedhin S, Andargie G, DelPizzo F, Belete K, Fenta TG. Spatial distribution of zero-dose children in Ethiopia: evidence for a targeted intervention from a large-scale cross-sectional evaluation survey. Frontiers in Pediatrics. 2024;12.
9. Health FMo. Ethiopia National Expanded Program on Immunization Comprehensive muti year plan (2021-2025). 2021

July 2021.
10. Desk. MEIS. Accelerated Action plan to address zero-dose, and under-vaccinated children in Ethiopia 2023-2025. 2023.
11. World Health Organization (WHO). Making choices in health: WHO guide to cost-effectiveness analysis. . .2003.
12. World Bank Group. Official exchange rate (LCU per US$, period average) - Ethiopia | Data 2025 [

]. Available from: **https://data.worldbank.org/indicator/PA.NUS.FCRF?locations=ET**
13. Gavi tva. Zero-dose children and missed communities [cited 2025 8/24]. Available from: **https://www.gavi.org/our-alliance/strategy/phase-5-2021-2025/equity-goal/zero-dose-children-missed-communities**.
14. Tora A, Dinsa, G., Woldie, M., Bobo, F., Gari, A., Boonstoppel, L. Exploring Challenges and Lessons Learned in the Implementation of Zero-Dose Vaccination Strategies in Ethiopia: a qualitative analysis of periodic intensification of routine immunization (PIRI) and mobile health and nutrition teams (MHNT) in Afar and Somali Regions.: Addis Ababa: Fenot Associates & Geneva: ThinkWell.; 2025.

ANNEXES

Annex 1.

A. Cost disaggregation by Activity and resource type for all strategies

	Cost for each strategy				Percentage share of total costs			
Cost by activities	RI/RO-Health center	RI/RO-Health post	MHNTs	PIRI	RI/RO-Health center	RI/RO-Health post	MHNTs	PIRI
Service delivery	167.57	49.44	714.08	921.24	48.0%	43.4%	88.0%	57.3%
Social mobilization	10.61	3.41	18.25	175.63	3.0%	3.0%	2.3%	10.9%
Supervision	0.00	0.00	0.00	312.57	0.0%	0.0%	0.0%	19.5%
Refreshment	0.00	0.00	0.00	74.05	0.0%	0.0%	0.0%	4.6%
Training	17.64	9.86	16.55	81.25	5.1%	8.7%	2.0%	5.1%
Program management	12.74	5.18	33.92	11.67	3.7%	4.5%	4.2%	0.7%
Vaccine collection, distribution, and storage	133.71	41.57	21.50	17.77	38.3%	36.5%	2.7%	1.1%
Record-keeping, HMIS, monitoring and evaluation	6.47	4.46	6.91	12.54	1.9%	3.9%	0.9%	0.8%

	Cost for each strategy				Percentage share of total costs			
Resource type	RI/RO-Health center	RI/RO-Health post	MHNTs	PIRI	RI/RO-Health center	RI/RO-Health post	MHNTs	PIRI
Paid labor	103.20	55.75	324.05	327.77	29.6%	48.9%	39.9%	20.4%
Volunteer labor	1.61	0.30	1.65	7.54	0.5%	0.3%	0.2%	0.5%
Other equipment	0.83	0.04	0.91	13.34	0.2%	0.0%	0.1%	0.8%
Per diem and travel allowances	31.23	13.73	42.09	835.47	9.0%	12.1%	5.2%	52.0%
Workshops and meetings	2.51	1.03	0.00	61.18	0.7%	0.9%	0.0%	3.8%
IEC and other printing costs	2.91	1.47	4.66	25.23	0.8%	1.3%	0.6%	1.6%

Cold chain equipment	55.07	39.14	21.50	17.77	15.8%	34.4%	2.6%	1.1%
Vehicles	113.48	0.00	266.21	234.49	32.6%	0.0%	32.8%	14.6%
Vehicle maintenance	0.00	0.00	68.60	0.00	0.0%	0.0%	8.5%	0.0%
Communication	2.79	0.00	1.30	4.24	0.8%	0.0%	0.2%	0.3%
Cold chain repairs and energy costs	3.43	2.43	0.00	0.00	1.0%	2.1%	0.0%	0.0%
Transport and fuel	31.56	0.00	80.50	79.70	9.1%	0.0%	9.9%	5.0%

b. Volume weighted unit cost in each sampled district in Afar and Somali region

Region	District	Facility type	Cost per dose delivered	Cost per zero-dose children reached	Cost per any children reached with Penta1
Afar	Elidar	Health center	1.95	135.02	27.18
		Health post	1.08	47.88	14.01
	Mille	Health center	0.83	73.08	10.76
		Health post	0.27	38.90	4.70
	Ewa	Health center	0.98	81.11	12.81
		Health post	1.09	68.41	13.85
Somali	Babili	Health center	1.13	91.42	27.18
		Health post	0.75	49.37	14.01
	Erer	Health center	1.03	85.51	10.76
		Health post	0.90	52.87	4.70

Yahob	Health center	0.81	107.63	12.81
	Health post	0.33	93.07	13.85

Annex 2. Resource type definitions and categories by financial vs. opportunity cost and immunization specific vs. shared costs

Resource type	Description	Financial vs. opportunity cost	Immunization specific vs. shared costs
Recurrent resource types			
Paid labor	Share of the salary paid to health workers and government employees proportional to the time they spent working on activities related to the intervention	Opportunity cost	Shared
	Salary paid to temporary workers, contractual workers, or new employees hired specifically for the delivery strategy	Financial cost	Immunization-specific
Volunteer labor	Value of volunteer labor (community health volunteers, voluntary social mobilizers) who do not receive a regular salary.	Opportunity cost	Shared
Workshops & meetings	Food, beverages, and meals provided to regular and volunteer staff.	Financial cost	Shared if the meeting have other agenda items in addition to immunization
			Immunization-specific if only about immunization
Per diem and allowances	Daily allowances and/or subsidies and travel allowances paid to regular employees and volunteers for participation in activities related to the intervention	Financial cost	Shared if the meeting/workshops have other agenda's in addition to immunization
			Immunization-specific if the activities were only related immunization

Resource type	Description	Financial vs. opportunity cost	Immunization specific vs. shared costs
Transport and fuel	Fuel costs specifically for activities that required travelling (supervision, trainings, vaccine distribution, etc.)	Financial cost	Shared
Vehicle maintenance	Routine and non-routine vehicle maintenance done during the study period	Financial cost	Shared
Cold chain equipment repairs and energy costs	Routine and non-routine cold chain maintenance/repairs done during the study period	Opportunity cost	Immunization-specific
	Electricity bill for the cold chain	Financial cost	Shared
Communication	Costs incurred for internet and cellular data used by paid or volunteer staff, promotional and advertising costs.	Financial cost	Shared
Capital items			
Cold chain equipment	Depreciation costs of existing cold chain equipment used for the delivery strategy	Opportunity cost	Immunization-specific
Vehicles	Depreciation costs of existing vehicle(s) used for the delivery strategy (trainings, supervision, vaccine collection/distribution) at study sites.	Opportunity cost	Shared
Other equipment	Depreciation costs of existing equipment items used for the delivery strategy	Opportunity cost	Shared if the equipment used for other health services addition to immunization
			Immunization-specific if the equipment is used exclusively for immunization

Annex 3: Imputation methods and allocation rules

If, following communication with the respondent, some data could not be obtained, assumptions were applied to estimate the missing information. These assumptions were derived from details of the same site or other related sites. A summary of these assumptions is provided in the table below.

Assumptions	Description of assumptions and how it was used in costing	Value
Ethiopia's minimum monthly wage	Ethiopia's minimum monthly wage was used to calculate the opportunity cost for community volunteers, particularly for unemployed individuals and volunteers with unknown monthly salaries.	420 Birr per month
Fuel efficiency	When the cost of fuel was not available but the distance traveled for immunization activities was known, we estimated the fuel allocated for distance traveled related to vaccine distribution and outreach by vehicle using the average fuel efficiency estimates provided by ambulance drivers	8 kilometers per liter.
Average Price of a liter of fuel during study time.	When the cost of fuel was not available to estimate the fuel allocated for distance traveled related to vaccine distribution and outreach by vehicle, we used the average price from November 2023 to December 2024 (the study period).	80 birr per liter of fuel.
Useful life of SDD Refrigerators	To annualize capital equipment's	10 Year
Useful life of Cold Box, vaccine carrier, and Icepack	To annualize capital equipment's	5 Year
Useful life of a vehicle in Ethiopia	To annualize capital equipment's	10 Year
useful life of desktop and tablet	To annualize capital equipment's	5 Year
Discount rate	To annualize capital equipment's	3%

Annex 4. Key informant interview guide

Region-level prompts

1. What methods are used in this region to ensure various population groups receive vaccinations?
    a. Can you describe how vaccination approaches differ in urban versus rural areas?
    b. What unique strategies are used to reach populations in hard-to-reach or remote locations?
    c. Are there other factors, such as socioeconomic or cultural considerations, that influence vaccination efforts?
2. How does vaccination coverage vary across woredas in this region, and what are the underlying reasons for these variations?
    a. What are the primary factors affecting woreda vaccination coverage?
    b. How do local health care resources and accessibility impact vaccination efforts?
    c. Are there specific cultural or community beliefs influencing vaccination uptake in different woredas?
3. What are the main sources of support for the vaccination program in this region?
    a. What financing mechanisms support the vaccination program, including government and external funding sources?
    b. How are local communities involved in supporting and promoting vaccination efforts?
    c. What roles do NGOs play in the planning, funding, or implementation of vaccination activities?
4. What strategies do you use to reach zero-dose children in this region?
    a. How do you define zero-dose children, and are there zero-dose children in your region?
    b. Can you describe any logistical or resource-related barriers that impact vaccination efforts?
    c. How do community beliefs and attitudes affect the uptake of immunization services?
    d. What roles do local infrastructure and transportation play in accessing and delivering vaccines?
    e. What challenges or barriers contribute to children remaining zero-dose in your area?
5. How is periodically intensified routine immunization (PIRI) implemented in the region?
    a. How is PIRI used to reach zero-dose children?
    b. How are resources (e.g., staffing, funding, and supplies) allocated and managed for PIRI in the region?
    c. What challenges and facilitators do health care providers encounter in implementing PIRI in underserved communities?
6. Since the introduction of MHNT and PIRI, how has the number of zero-dose children changed?
    a. What factors do you believe have influenced these changes?
    b. How can these programs be improved for future use?
    c. On a positive note, what successes have you experienced in identifying, reaching and preventing zero-dose children?

Region-level MHNT prompts

1. How is the mobile health and nutrition team program implemented to reach zero-dose children in the region?
2. What strategies are used by mobile teams to identify and access zero-dose children in remote or underserved areas?
3. How are resources, such as staff, equipment, and vaccines, allocated and managed within the mobile health and nutrition teams?
4. What challenges and successes have been observed by team members in reaching and vaccinating zero-dose children?

Woreda-level prompts

1. What are the different methods through which children can receive vaccinations in this woreda?
2. How does vaccination coverage vary across kebeles in this woreda, and what are the underlying for these variations?
    a. What are the primary factors affecting kebele vaccination coverage?
    b. How do local health care resources and accessibility impact vaccination efforts?
    c. Are there specific cultural or community beliefs influencing vaccination uptake in different kebeles?
3. In your opinion, what service delivery structure do you think —e.g., health centers, health posts, or mobile health and nutrition teams— contributes the most to vaccinating children in the woreda? Could you provide examples or data to support this?"
    a. Can you describe the specific roles health center, health posts or woreda plays in reaching zero-dose children in remote or underserved areas?
    b. What are the main challenges or limitations associated with each delivery method for vaccination in this region?
    c. Based on your experience, which structure do you think is the most cost-effective, and why?
4. What key obstacles have you encountered while implementing your current strategies (Routine, MHNT, PIRI) to identify, reach and prevent zero-dose children?
    a. Are there any unique factors contributing to this in your catchment?
    b. Can you describe any logistical or resource-related barriers that impact vaccination efforts?
    c. How do community beliefs and attitudes affect the uptake of immunization services?
    d. What roles do local infrastructure and transportation play in accessing and delivering vaccines?
    e. In what part of the implementation process are challenges most often incurred (e.g., finding ZD children, vaccinating them (there might be vaccine hesitancy or stock outs), reporting, follow up with the rest of the vaccination schedule after the initial first dose,
5. How is the mobile health and nutrition team program implemented to reach zero-dose children in the region?
    a. What strategies are used by mobile teams to identify and access zero-dose children in remote or underserved areas?
    b. What challenges and successes have been observed by team members in reaching and vaccinating zero-dose children?
    c. How do you coordinate with woreda health office?
6. How is periodically intensified routine immunization (PIRI) implemented in the region?
    a. How is PIRI used to reach zero-dose children?
    b. How are resources (e.g., staffing, funding, and supplies) allocated and managed for PIRI in the region?
    c. What challenges and facilitators do health care providers encounter in implementing PIRI in underserved communities?
    d. How is PIRI used differently from outreach immunization program?
7. Since the introduction of MHNT and PIRI, how has the number of zero-dose children changed?
    a. What factors do you believe have influenced these changes?
    b. On a positive note, what successes have you experienced in identifying, reaching and preventing zero-dose children?

Health center-level prompts

1. Can you describe the vaccination delivery approaches used at this health center?"
    a. How are vaccinations scheduled and organized for children in this health center?
    b. What strategies are used to ensure timely and equitable access to vaccines for all children, especially those in remote areas?
    c. How does the health center engage with the community to promote vaccination?
    d. How does the health center contribute to identifying and reaching zero-dose children for immunization?
2. How effective do you believe the current strategies (Routine Immunization, Regular Outreach, PIRI, and MHNT) are in addressing the issue of zero-dose children in your community?
    a. In what ways have these strategies impacted the immunization coverage in your area?
    b. What role do health centers play in the implementation of PIRI?
    c. What role do health centers play in the implementation of MHNT program?
    d. What challenges or barriers have you observed in implementing these strategies, especially for reaching zero-dose children?
3. What are the specific challenges encountered in delivering immunization services to zero-dose children in the catchment area on the health center?
    a. Can you describe any logistical or resource-related barriers that impact vaccination efforts?
    b. How do community beliefs and attitudes affect the uptake of immunization services?
    c. What roles do local infrastructure and transportation play in accessing and delivering vaccines?
4. In your opinion, how can we improve vaccination program to reach zero-dose children in your local area?

Health posts level prompts

1. Can you describe the vaccination delivery approaches used at this health post?
    a. How are vaccinations scheduled and organized for children in this health post?
    b. What strategies are used to ensure timely and equitable access to vaccines for all children, especially those in remote areas?
    c. How does the health center engage with the community to promote vaccination?
2. What activities are being implemented to reach zero-dose children at this health post?
    a. Can you describe the specific strategies or outreach efforts used to identify and engage zero-dose children in the community?
    b. How is the success of these activities measured, and what challenges are faced in reaching zero-dose children?
3. What challenges or barriers have you observed in implementing these strategies, especially for reaching zero-dose children?
    a. What challenges are there in addressing zero-dose children using the different strategies e.g., routine, outreach?
    b. What challenges are in mobilizing the community?
    c. What logistic challenges are there in vaccine storage and delivery?
4. In your opinion, how can we improve vaccination program to reach zero-dose children in your local area?