Immunization Delivery Costs in Low- and Middle-Income Countries

A methodology note for the systematic review, cost catalogue, and analytics

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BREAKING NEW GROUND

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ABBREVIATIONS

AEFI	Adverse event following immunization
BCG	Bacille Calmette-Guerin vaccine
CI	Confidence interval
cMYP	Comprehensive multi-year plan
CPI	Consumer price index
DT	Diphtheria and tetanus toxoids, pediatric formulation
DTaP	Diphtheria and tetanus toxoids and acellular pertussis vaccine, pediatric formulation
DTP	Diphtheria and tetanus toxoids and whole-cell pertussis vaccine, pediatric formulation
EPI	Expanded Programme on Immunization
EPIC	Expanded Programme on Immunization Costing
GDP	Gross domestic product
HepB	Hepatitis B vaccine
Hib	Haemophilus influenzae type b
HPV	Human papillomavirus
ICAN	Immunization Costing Action Network
IDC	Immunization delivery cost
IDCC	Immunization Delivery Cost Catalogue
IPV	Inactivated poliovirus vaccine
JSI	John Snow, Inc.
LCU	Local currency unit
LMIC	Low- and middle-income country
MMR	Measles-Mumps-Rubella
MR	Measles-rubella vaccine
NITAG	National Immunization Technology Advisory Group
NR	Not reported
NUVI	New and underutilized vaccine introduction

OCV	Oral cholera vaccine
OPV	Oral poliovirus vaccine
PCV	Pneumococcal conjugate vaccine
PPP	Purchasing power parity
SA	Sensitivity analysis
SIA	Supplementary immunization activity
Td	Tetanus & diphtheria vaccine, adult/adolescent formulation
ToR	Terms of reference
USD	U.S. dollar or $
YF	Yellow fever

EXECUTIVE SUMMARY

As low- and middle-income countries drive toward achieving high and equitable coverage of life-saving vaccines and largely transition from donor- to self-funded immunization programs, the availability of sustainable, equitable, and predictable financing for vaccine delivery is essential. Sufficient and sustainable financing is built on solid evidence about the costs of vaccination delivery, and while great strides have been made in expanding the coverage of routine and new vaccines, in part through better understanding of the cost of vaccination delivery, translation of cost evidence into policy, programming, and financing at the national and sub-national levels remains a challenge. Cost data are fragmented, of variable quality, and/or difficult for policymakers, program planners, and other global and country-level stakeholders to understand and use. Additionally, as new delivery strategies – such as school-based delivery – are explored to help countries meet these goals and introduce new vaccines, the need for cost evidence to develop and support these programmatic and budget requests is key. However, it can be time consuming and expensive to conduct country-specific costing studies. It also can be difficult to access and interpret cost evidence from other countries and to translate these data so they are relevant for other settings. Having realistic and reliable immunization delivery cost (IDC) evidence that is available at the right time can help countries better advocate, plan, budget, and make programmatic decisions.

To address these challenges, ThinkWell embarked on a systematic review of vaccine delivery costs across low- and middle-income countries (LMICs) to make the available evidence globally accessible and easy to interpret. The review primarily targets country decision-makers: Expanded Programme on Immunization (EPI) managers, members of the National Immunization Technology Advisory Group (NITAG), and other country policymakers responsible for financing and planning at the national and the subnational levels. These decision-makers need to know what it costs to deliver a particular vaccine or range of vaccines in a particular context (e.g., country income level or region) for budgeting the national immunization program or making a programmatic decision. Other target audiences include global and regional stakeholders, such as donors and development banks, other development partners, civil society organizations, and researchers. These groups may be interested in the systematic review and findings as reference data for making financing and resource allocation decisions or managing or supporting development programs, or for academic or applied research pursuits.

This methodology note presents the methods behind the systematic review, the Immunization Delivery Cost Catalogue (IDCC) where the reviewed data are housed, and the analysis and presentation of the data in companion products. This work was done under the Immunization Costing Action Network (ICAN) grant, led by ThinkWell and John Snow, Inc. (JSI) and supported by the Bill & Melinda Gates Foundation (BMGF). The project's aim is to increase the visibility, availability, understanding, and use of evidence on the cost of delivering vaccines.

The systematic review aimed to answer a question frequently asked by global and country immunization stakeholders: What are the unit costs of vaccine delivery across different LMICs and through a variety of delivery strategies? The systematic review includes peer-reviewed articles/reports (resources) and grey literature that included IDCs published between January 2005 and March 2019. The review was limited to LMIC study settings resulting in 68 articles/reports (resources) that presented immunization delivery unit costs (i.e., delivery cost

per dose, per capita, per full immunization of a vaccine or fully immunized child,[1] and per person in the target population). Information extracted from the resources includes metadata about each resource's attributes, details about the resource's costing methodology, and the reported cost results. All cost findings are also converted to a common year (2016) and currency (U.S. dollars [USD]) to ensure comparability across studies and different settings. The quality of each resource was assessed against a parsimonious set of quality criteria developed by the review team to capture methodological rigor and reporting standards, uncertainty of results, and risk of bias and limitations.

The extracted data are housed in the IDCC, available as an interactive Microsoft Excel workbook and searchable web tool, making easily accessible only the most relevant and important information related to the unit cost results. It allows for comparability across numerous resources and the variety of settings captured by the review, with all cost data presented in 2016 USD. It is designed to allow country policymakers, researchers, advocates, donors, and other development partners with different data needs to search and analyze the data in the ways most useful to them, without any analysis by the review team.

For users interested in analyzed unit cost data, we used data from the IDCC to develop immunization delivery cost ranges (cost ranges). These cost ranges consider four or more comparable unit costs from different articles/reports. These estimates are for delivery of specific vaccines or schedules, by different delivery strategies, and for different country income levels and regions. Comparability across unit costs was checked across a number of different areas, including study methdology, contextual criteria, and characteristics of the vaccines costed (e.g., vaccines included and their delivery). This resulted in nine cost ranges. For all cost ranges, we present the minimum and maximum unit costs that are part of the range as well as the median, mean, and 25th and 75th percentile values.

In a companion analytic report, we present a descriptive and gap analysis of findings on IDCs coming from this review. The findings are presented in terms of the spread/scope of the evidence, methods/reporting, and quality of the extracted resources. The report also presents the nine cost ranges. Additional tools and products, including user guides for the IDCC Microsoft Excel workbook and web tool, are accessible at http://immunizationeconomics.org/ican**.** These materials can help with interpretation of the systematic review findings and allow users to dig deeper into the variation in and drivers of IDCs across a variety of country contexts and delivery strategies.

The major limitation of this work is that our understanding of the data is only as good as the reporting in each resource, which may not reflect the quality of the actual costing study conducted. We have taken a conservative approach to data extraction and interpretation, reporting only the language used by the original resource and preferring to report certain characteristics of the data as "not reported" or "unclear" rather than making inferences, but we recognize that some misinterpretations of the reported data may have inadvertently occurred. Our cost ranges are limited by the heterogeneity in the dataset, reflected in the small number of comparable unit costs that could be used for their development. We also acknowledge that there are additional resources on the costs of immunization delivery that

[1] Full immunization of a vaccine refers to all required doses of a specific vaccine (e.g., three doses of HPV). Fully immunized child refers to the provision of a certain number of doses of a specific vaccine(s) to a specific group by a clear point in time (e.g., infants who received all vaccines in the schedule before reaching one year of age), as opposed to a standard global definition, for example, of DPT3.

are not captured in our review due to our specific inclusion and exclusion criteria, and likely more grey literature from the reviewed time period that is not included.

I. INTRODUCTION

ABOUT ICAN

The Immunization Costing Action Network (ICAN), led by ThinkWell and John Snow, Inc. (JSI) since 2016, is a research and learning community supported by the Bill & Melinda Gates Foundation (BMGF) with the aim of increasing the visibility, availability, understanding, and use of evidence on the cost of delivering vaccines.

Under the ICAN grant, ThinkWell conducted a systematic review to compile and analyze the evidence base on immunization delivery costs (IDCs) in low- and middle-income countries (LMICs). The Immunization Delivery Cost Catalogue (IDCC), available as an interactive Microsoft Excel workbook and searchable web tool, allows for comparability across numerous articles and reports and the variety of settings captured by the review, with cost data converted to 2016 U.S. dollars (USD).

This methodology note details the systematic review and IDCC development process, including the data search, extraction, and analysis. Additional tools and products – including a descriptive and gap analysis of the unit cost data, analytics on the unit cost data, and "how-to" user guides – are accessible at http://immunizationeconomics.org/ican. These resources are intended to help with interpretation of the systematic review and enable the user to dig deeper into the variation in and drivers of IDCs across a variety of country contexts and delivery strategies.

Beyond the global level analytics, ICAN conducted research studies on IDCs in India, Indonesia, Tanzania, and Vietnam, as well as facilitated cross-country learning on the common problems of costing immunization delivery and using evidence to inform advocacy efforts, routine planning and budgeting, and decision-making. Resources from those efforts are also available on the previously mentioned website.

The need for accessible immunization delivery cost evidence

As LMICs drive toward achieving high and equitable coverage of life-saving vaccines and largely transition from donor- to self-funded immunization programs, the availability of sustainable, equitable, and predictable financing for vaccine delivery is essential. Over the last two decades, great strides have been made in expanding the coverage of routine and new vaccines, in part through better understanding of the cost of vaccination delivery. However, gaps in cost evidence remain.

Realistic and reliable IDC evidence that is available at the right time and in the right format would help countries better advocate, plan, budget, and make programmatic and policy decisions. Translation of cost evidence into policy, programming, and financing at national and sub-national levels is challenging. Cost data are fragmented and of variable quality, and can be difficult for policymakers, program planners, and other global and country-level stakeholders to understand and use. In an era of transitioning donor aid, the use of cost evidence in these processes, rather than historical funding levels or cost norms, is essential to ensuring that immunization programs mobilize adequate resources to meet coverage goals, address challenges of health equity, effectively manage the introduction of new vaccines, and achieve efficiencies through health system integration.

Additionally, as new delivery strategies – such as school-based delivery – are explored to help countries meet these goals and the introduction of new vaccines, the need for cost evidence to develop and support these programmatic and budget requests is key. However, it can be

time consuming and expensive to conduct country-specific costing studies. It also can be difficult to access and interpret cost evidence from other countries and to translate these data so they are relevant for other settings.

To address these challenges, ThinkWell embarked on a systematic review to make the available evidence globally accessible and easy to interpret. The systematic review aimed to answer a question frequently asked by global and country immunization stakeholders: What are the unit costs of vaccine delivery across different LMICs and through a variety of delivery strategies?

ICAN Definition of Delivery Costs

We define immunization delivery costs (IDCs) (also referred to as operational costs) as the costs associated with delivering immunizations to target populations, exclusive of vaccine costs. Delivery costs may include any or all of the following recurrent and capital cost items: (1) paid human resources, (2) volunteer human resources, (3) per diem and travel allowances, (4) cold chain equipment and their overheads (e.g. energy, maintenance, repairs), (5) vehicles, transport and fuel, (6) program management, (7) training and capacity building, (8) social mobilization and advocacy, (9) adverse event following immunization (AEFI) and disease surveillance (i.e. follow up of post-vaccination events and active cases of diseases), (10) buildings, utilities, other overheads and shared costs, (11) vaccine supplies (e.g. safety boxes, diluents, reconstitution syringes), (12) waste management, (13) other supplies and recurrent costs, and (14) other non-vaccine costs.

Source: Adapted from Vaughan et al., 2019.

Purpose of this document

Past systematic reviews on this topic have consolidated only part of the costing evidence picture. They have focused on either (1) a subset of vaccines, (2) a subset of economic evaluations (e.g., only cost-effectiveness or cost-benefit studies), or (3) only the incremental costs of new vaccine introduction (NUVI). Given the last published reviews and the large number of resources recently published on the topic of vaccine delivery costs, there was an expressed need to bring the evidence base up to date (De la Hoz-Restrepo et al. 2013; Levin et al. 2015; Mogasale et al. 2016; Ozawa et al. 2012).

Our review builds upon previous efforts, updating the evidence base while including IDC data that are not restricted to a particular vaccine, delivery strategy, type of cost analysis, or setting. This document describes the methodology for the systematic review (including the two updates), cost catalogue, and data analysis. It supercedes the previous methodology note, released in March 2019.

This methodology note is designed for anyone interested in using the data, including national and sub-national planners and policymakers, researchers, and international partners supporting country immunization and health system policy, planning, and financing.

Definitions

A full list of technical terms and definitions used in conjunction with the systematic review is found in Annex 1.

II. SYSTEMATIC REVIEW

METHODS

The systematic review methods are based on standard practices and were subject to external review and revision by immunization costing experts at multiple stages throughout the process. Each step is described in detail below; descriptions include methods for the original search and as well as any methodology changes implemented during the two updates.

Search of the published and grey literature

In January 2017, in April 2018 and again in March 2019, we searched six major electronic databases – EconLit, Embase, Medline (via PubMed), NHS-EED, Web of Science, and WHO Global Index Medicus – for peer-reviewed articles published between January 2005 and January 2017, January 2017 and April 2018, and April 2018 and March 2019 that included IDCs for all countries of any income level. We did not go further back than 2005 in order to reflect current vaccine delivery technologies and established costing methods for the sake of greater comparability, and to limit the size of the search. Search terms included three categories of keywords – "immunization" AND "cost" AND "delivery" – and were translated into the query language of each database. The January 2017 search yielded 13,495 resources, the April 2018 yielded 999 resources, and the March 2019 search yielded 1,852 resources. Annex 2 presents the database queries and resulting yields.

To capture unpublished reports, we sent out direct requests to 64 key contacts at organizations involved in global and national immunization-related work. In addition, we posted a call for grey literature in eight immunization-related newsletters, communities of practice and web discussion forums.

We applied advanced search syntax in Google to search for resources on the webpages of key organizations and relevant databases housed within these organizations. We also searched conference proceedings and the ProQuest dissertation database. These searches used terms to capture resources relevant to immunization delivery and costs. Actual strategies used in searches varied by the organizations and forums targeted, and were refined iteratively. Finally, we reviewed reference lists of all resources, plus references used in systematic reviews.

Annex 2 presents the list of organizations directly queried, the organization webpages searched, and the communities of practice and discussion forums contacted.

Inclusion and exclusion criteria

From an initial 16,263 resources, we first removed duplicate resources, clearly irrelevant resources,[2] and resources published before 2005. An additional 88 systematic reviews were also removed, leaving 3,835 resources for screening. Reported search numbers represent the sum of the initial search and the two updates.

We included resources with full text availability in English, French, or Spanish, conducted only in LMIC study settings determined using the World Bank country income classification.[3] We included resources that reported unit delivery costs (i.e., delivery cost per dose, per capita,

[2] Clearly irrelevant resources included veterinary studies, in vitro studies, high-income country studies, qualitative studies, therapeutic studies, and so on.

[3] A variety of approaches have been taken to account for year-to-year fluctuations in countries' World Bank income-level classifications, including either selecting the country's present year classification or choosing a single year at the midpoint of a systematic review's timeframe as the year of classification. Our approach was to keep consistent with the context of each resource included in our review, so we matched the year for which the costing data was reported with the country's World Bank income classification of that same year. If the costing year was not reported, we used the year of the intervention. If that was also not available, we used the publication year. World Bank: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

per full immunization of a vaccine,[4] per fully immunized child,[5] and per person in the target population). Resources reporting costing, cost-effectiveness, cost-benefit, return on investment, cost-utility, and other analyses that included a form of unit cost data were included.

We excluded resources if they used secondary or modeled immunization delivery unit costs alone (not based on actual program costs) and if the costing methodology was unclear or insufficient to allow for extraction and analysis by the review team. In the case of unclear/insufficient methods but where all other inclusion criteria were met, we contacted authors and included the resource if we could obtain the necessary information. We also contacted authors to obtain the full text of some resources.

Title, abstract, and full text review

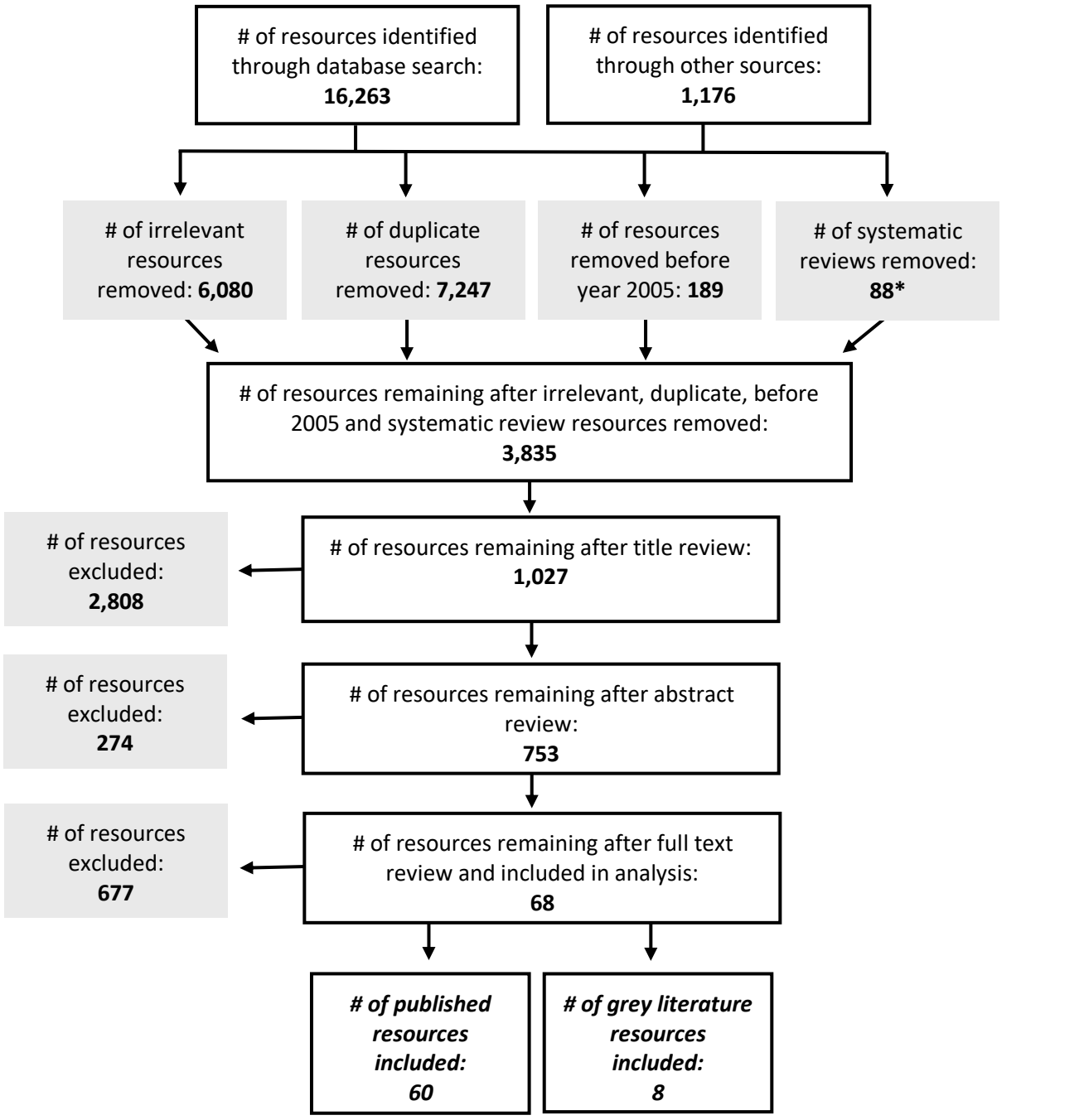
Two investigators completed title and abstract review on the remaining published and grey literature search results using standard methods, with one investigator performing the initial review, the second investigator reviewing for agreement, and any disagreements discussed and jointly resolved (Higgins et al. 2011). Following title and abstract review, a total of 753 resources remained for full text review.

In the original review, a team of four investigators performed full text reviews of the 753 resources that passed title and abstract review; during the 2018 refresh, a team of three investigators worked on this step, while in the 2019 refresh two investigators performed the full text review. Of these, 68 met the inclusion criteria and were extracted, and 677 were excluded.[6] In the original review and in the two subsequent refreshes, there were resources that met inclusion criteria after checking with authors, but their responses came in too late to be extracted; three resources found in the original review were carried over to the 2018 refresh, 14 resources from the 2018 review were carried over to the 2019 refresh, while 8 resources found in the 2019 search were unable to be included. See Annex 3 for a list of resources included in the systematic review.

Figure 2 presents the total number of resources reviewed, excluded, and extracted at each stage of the search process.

[4] Full immunization of a vaccine refers to all required doses of a specific vaccine (e.g., three doses of HPV).
[5] Fully immunized child refers to the provision of a certain number of doses of a specific vaccine(s) to a specific group by a clear point in time (e.g., infants who received all vaccines in the schedule before reaching one year of age), as opposed to a standard global definition, for example, of DPT3.
[6] One resource was a dataset and personal communication with the Expanded Program on Immunization Costing (EPIC) project.

Figure 2. Systematic review search results



* Systematic reviews were removed after reference lists were reviewed to ensure relevant secondary resources were captured.

Data extraction

Resources meeting all inclusion criteria after title, abstract and full text review underwent data extraction. We extracted information on the context of country and costing study, details of the study design and costing methodology, the vaccines costed and their delivery strategies, the cost categories included, and the reported results. See Annex 4 for a list of all variables extracted. We extracted data as reported by the authors without any recoding or analysis, but we noted where the reported methods (e.g., study perspective) appeared to deviate from commonly accepted definitions (Drummond et al. 1997).

We entered extracted data into a Microsoft Excel data extraction tool. We designed the data extraction tool using an iterative approach, piloting it on three resources, and thereafter revising it. We conducted preliminary data analyses over a two-week period to evaluate the tool's design and ensure inter-extractor reliability, with subsequent further revisions. Two investigators reviewed full text extractions, returning incomplete extractions to the original investigator extracting the data for any necessary revisions. Each resource was extracted on one row in the Excel workbook unless the resource reported separate unit costs – for different country contexts, delivery strategies, type of costs reported (e.g., economic costs and financial costs), vaccines, or other criteria – in which case multiple rows were used.

We extracted total, incremental, and unit delivery costs; delivery costs by cost category; and any other additional delivery cost data. In a few resources, cost data included costs incurred at all levels of the health system (including those incurred at the facility level and at different levels of administration above the facility). Due to the small number of resources presenting this information, we did not record unit costs by level. We did not extract immunization delivery unit costs from individual facilities, but rather used aggregated unit costs where unit costs from various facilities were averaged by the authors.

Quality review

Two investigators reviewed each exclusion or extraction for completeness. Both exclusions and extractions were returned to the original investigator extracting the data for any necessary revisions (e.g., errors or inconsistencies with exclusion or extraction methods). Additionally, in both the initial review and the two refreshes, all involved investigators engaged in weekly discussions about extracted resources so as to establish interrater reliability.

We assessed the quality of each resource using a set of quality criteria designed for this review as part of the initial review (Annex 5). Building on other quality assessment systems and checklists (Avenir Health 2015; Constenla et al. 2016; Drummond et al. 1997; Evers et al. 2005; Husereau et al. 2013; Pegurri et al. 2005; Vassall 2017), ours included a parsimonious set of criteria to evaluate the resource in three areas: methodological rigor and reporting standards (8 items), uncertainty of results (3 items), and risk of bias and limitations (3 items). Each item was given an individual score of 1 (lowest), 2, or 3 (highest); for some items there was also a "not applicable" option. Scores for all items were summed and averaged, excluding any "not applicable" answers, to produce a final score for each resource on the same 1 to 3 scale. Investigators applied the quality criteria to their own extractions, and then one investigator reviewed all quality ratings against their respective data extraction and against the others and adjusted scoring to ensure interrater reliability. Annex 5 provides a full description of the quality assessment methodology, while a summary analysis of the quality scores against the 14 criteria is presented in our summary report at http://immunizationeconomics.org/ican.

Data cleaning

Following extraction and quality review, we combined all extractions into a single Microsoft Excel worksheet and cleaned the data to recode text for filtering and ensure consistent formatting and use of text. Cleaning also included:

- Identifying resources that are related to one another to ensure data are not reported twice (e.g., Expanded Program on Immunization Costing [EPIC] Project studies that reported findings in both a peer-reviewed publication and a grey literature report). In instances where there were multiple resources reporting the same data, we used the source that provided more extensive detail.
- Adding contextual information not included in the resources to each record to help with interpretation and analysis (Table 1).
- Adding descriptor columns to help identify records by their attributes (e.g., "This line reports economic costs by activity for measles only").
- Checking for inconsistencies in cost findings, either as a result of an error in the resource or a data entry error incurred during extraction.
- Contacting resource authors to clarify findings, where necessary.

Table 1. Contextual information added by review team during data cleaning

Contextual information added	Source
Country region	World Bank*
Country income level	World Bank*
Country population	World Bank**
Country land area (km^2)	World Bank**
Country population density (persons per km^2)	World Bank**
Vaccine mode of administration for single vaccines only (i.e., oral or injectable)	World Health Organization***

* https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups
** http://databank.worldbank.org/data/reports.aspx?source=population-estimates-and-projections&preview=on#
*** WHO 2013.

At this stage we also removed some additional records that were initially extracted but later found not to meet inclusion criteria.

Conversion of cost findings to 2016 USD

We converted all cost findings to a common year (2016) and currency (US dollar, US$) to ensure comparability across studies and different settings. Our methodology for doing so is based on a review of a variety of resources:

- Eight peer-reviewed literature reviews that reported cost findings in immunization, malaria, and other health areas (De la Hoz-Restrepo et al. 2013; Ghandi and Lydon 2014; Johns and Torres 2005; Levin et al. 2015; Mogasale et al. 2016; Ozawa et al. 2012; Pegurri et al. 2005; White et al. 2011;).
- Similar unit cost repositories (Avenir Health 2015; Global Health Cost Consortium 2017).
- Large international data projects such as G-FINDER (Policy Cures n.d.) and Primary Health Care Performance Initiative (PHCPI n.d.).
- *The Reference Case for Estimating the Costs of Global Health Services and Interventions* (Vassall et al. 2017).

- Methods of large institutions such as the Organisation for Economic Co-Operation and Development (OECD 2018) and the World Bank (World Bank n.d.).

After consultation with an external group of five immunization costing experts, we agreed on the following methodology:

- **For costs reported in USD:** We first converted from USD to local currency units (LCUs) of the same year using the exchange rate at the year of costing (or year of data gathering if year of costing was not reported; if neither of these two were available, we used the resource publication year). Exchange rates were taken from the World Bank (USD per LCU, period average) (World Bank 2017).
- **With all costs in LCU:** We inflated to 2016 LCU using LCU inflation rates based on average consumer prices reported by the International Monetary Fund. Annual percentages of average consumer prices are year-on-year changes and are expressed in averages for the year, not end-of-period data (IMF 2017).
- **With all costs in 2016 LCU:** We converted to 2016 USD using the 2016 LCU to USD exchange rate. Exchange rates were taken from the World Bank (LCU per USD, period average) (World Bank 2017).

For some countries and/or years, exchange and/or inflation data were not available from the referenced sources, in which case we used alternate sources.

We performed a detailed comparison of other options for conversion of costs to a common currency and year, including using the consumer price index (CPI) deflator and the gross domestic product (GDP) deflator methods to account for inflation. These methods adjust the reported findings to 2016 values using the reported currency's CPI or GDP deflator. For any findings not reported in USD, the 2016 values can then be converted to USD. However, we found that while most of the extracted data came from countries that do not use the USD, findings were reported in USD, which meant we used the USD CPI to adjust for inflation. As such, we felt this method did not take into account inflation and LCU-USD currency exchange fluctuations which would affect unit costs. For this reason we chose to first convert all findings to the resource country's LCU if not reported in LCUs, then adjust for inflation, then convert to USD, as described above.

Further, current costing guidance (Vassall et al. 2017) recommends distinguishing between local and international price sources, and between tradeable and non-tradeable inputs, using different methods for each. However, the data we had available from the resources did not allow for this level of analysis.

Finally, we have chosen not to present findings adjusted for purchasing power parity (PPP) since we understand this metric may be less useful for our primary users: country-level policymakers and program planners. Users are encouraged to do their own PPP conversions as necessary.

Update

We repeated the search, extraction, data cleaning, quality review, and currency conversion process in 2018 and in 2019 to access the published and grey literature published since the initial search conducted in 2017. With each update, additional extracted data was added to the tools and products resulting from the systematic review (see "Tools and Products" section below).

LIMITATIONS

This systematic review has a number of limitations, including:

- The search terms and inclusion and exclusion criteria have pulled a very specific set of resources and associated IDCs; we acknowledge that there are more resources about IDCs that are not included in our review due to not meeting inclusion criteria.
- We did not perform double data extraction due to time and cost considerations, although all extractions were reviewed by one team member to ensure completeness and quality.
- Many resources were not specific or clear enough about methodological details or the unit costs reported, leading in some cases to the resource being excluded, or some data extracted as "not reported" or "unclear." We made every effort to obtain and clarify essential data with authors but in some cases could not resolve all questions.
- Some unit costs may include cost categories marked as not being included due to use of different terminology by authors to describe cost items.
- Vaccine presentation characteristics such as liquid vs. reconstituted (in terms of number of syringes required), wastage, storage volume, and doses/vial have an impact on some cost categories, notably human resources (related to actual service delivery time), cold chain, and transport costs. Most resources did not report enough information on vaccine presentation for us to be able to account for these characteristics and their impact on delivery cost.
- The quality assessment is based on author reporting in the article or grey literature resource, and we recognize that it may not reflect the true quality of the research completed due to limitations in reporting (e.g., journal restrictions on write-ups, peer reviewer comments that impact the material included, and so on).

III. TOOLS AND PRODUCTS

From the data extracted as part of the systematic review, ThinkWell developed a standardized and richly annotated data cost catalogue, along with a set of cost ranges, and companion interpretive products that are housed at http://immunizationeconomics.org/ican.

All tools and products were designed with three different categories of end users in mind. Our primary audience is country decision-makers: EPI managers, NITAG members, and other country policymakers responsible for financing and planning who need to know what it costs to deliver a particular vaccine or range of vaccines in a particular context (e.g., country income level or region) for budgeting the immunization program or making a programmatic decision.

Our secondary audience includes global and regional stakeholders, such as donors and development banks, other development partners, and civil society organizations. They are likely to use the tools and products as references for making financing and resource allocation decisions, managing development programs, providing technical support to enable national governments to use existing resources most effectively and/or advocate for new resources, and holding governments accountable for their performance.

Finally, our tertiary audience is researchers who may want to engage with the data for academic or applied research pursuits. The IDCC and cost ranges may be useful in supporting implementation research on introducing and scaling up vaccines, immunization delivery strategies, or new technologies.

IDCC MICROSOFT EXCEL TOOL

Our Immunization Delivery Cost Catalogue (IDCC) in Microsoft Excel format organizes and makes readily available a subset of the information and standardized cost data from the systematic review. It is intended to support country national and subnational planners, policymakers, researchers and international partners in planning, budgeting, advocacy, research, and other related efforts. The IDCC is not intended to fully replace data used in budgeting processes, eliminate the need for costing studies, or fill gaps in available data (through extrapolation or interpolation).

The workbook catalogues the available extracted data, cleaned, organized, and standardized for usability but without any analysis by the research team. The dataset presents information extracted from the systematic review resources as reported by the authors, along with cost information both as reported and standardized. Cost data are presented in 2016 USD to allow for comparability across studies and country contexts. The dataset also includes additional detail to help with interpretation of those costs, including information on study design, vaccines costed, delivery strategy, type of costs, and so on.

The workbook includes a search/filter tool, and information is presented in two alternate views: basic (designed for government and policy users) and advanced (designed for researchers and academics). The data records show what is included in the total unit cost value, as well as how it was derived, given that immunization costing studies vary substantially with regard to the cost components included and how they are grouped.

A detailed IDCC "how-to" user guide and video are available that describe how to navigate the IDCC Microsoft Excel tool, including how to open the document, filter the data (if desired), and view the data. In addition, a document that describes how the quality assessment scores were calculated is available.

We tested the beta version of the IDCC with 10 individuals representing academic research institutions, civil society organizations, and global development agencies. Feedback from users was incorporated, whenever possible, into the final IDCC Excel tool.

IDCC WEB TOOL

An alternative means of interacting with the same extracted data presented in the Microsoft Excel tool is through a web tool, which allows users to browse the content of the IDCC and search/filter to access information in an interactive data results table. The web tool's design was informed by a survey of potential users.

For greatest advocacy and communication impact, we strived for parsimony in this tool, selecting only the most relevant and important information to present in search return tables for immunization managers and policymakers, while providing enough context to help with interpretation. The web tool is not intended to fully replace other data used in planning processes or eliminate the need for costing studies. As with the Microsoft Excel tool, the presented data do not include data analysis by the review team, nor have we filled gaps in available data (through extrapolation or interpolation). The IDCC web tool is hosted at http://immunizationeconomics.org/ican, along with a detailed IDCC "how-to" user guide and video that describe how to navigate the web tool.

SUMMARY FINDINGS AND COST RANGES

Making data available alone is insufficient without providing guidance on its interpretation and use. We produced a summary report with data visualizations highlighting the contents of the IDCC (with gaps in the evidence base noted) at http://immunizationeconomics.org/ican. We used Excel to run basic counts of the unit cost dataset for different criteria (e.g., unit costs reporting economic costs, unit costs including paid human resources as a cost category, etc.). Based on these counts, we described the evidence in terms of the: (1) spread/scope, (2) methods/reporting, and (3) quality of the data. A short summary of the data gaps follows each descriptive analysis.

We also produced a set of cost ranges based on the 2016 USD data in the IDCC. The cost ranges are for specific vaccines, delivery strategies, country income levels, and geographic settings. These cost ranges may be useful to country policymakers and program planners, advocates, donors, and other development partners for planning and budgeting purposes, cMYP development, and immunization program management. They may also reduce the need for new costing studies or alternative estimation exercises each time immunization program budgetary estimates are needed. See Section IV for a description of the methods for developing the cost ranges.

IV. COST RANGES

METHODS

The methods for the cost ranges developed from the unit cost dataset did not draw on any previous, similar work for methodological inspiration, given that we did not know of any similar "benchmarking" efforts from a heterogenous dataset. Our process was subject to external review and revision by 12 immunization costing experts at several stages.

In both the initial review and the two refreshes, we performed analyses on the unit costs (in 2016 USD) from the IDCC[7] to create cost ranges for delivery of specific vaccines or types of vaccines, by different delivery strategies, and for different country income levels and regions.

[7] For development of the cost ranges, we excluded IDCC data from resources with the lowest 10% of quality ratings. The quality rating of each resource from which unit costs have been drawn was estimated as part of our systematic review data extraction. We considered the following alternative ways to incorporate the quality rating in the selection of comparable (and adequate) unit costs for inclusion in the cost ranges:

- Include all records regardless of assessed resource quality, but include a note in the methodological description for any cost ranges developed with "low" quality data.
- Exclude resources below some quality threshold (for example, the lowest 10%) from cost ranges.
- Consider resources noted as having serious author and/or extractor-perceived limitations on a case-by-case basis for exclusion from cost ranges.
- Weight records according to the assessed quality of the resource from which the unit cost is taken. For example, unit costs coming from higher quality resources would receive greater weighting in development of the cost range (25% and 75th percentile as well as mean and median), and records from resources assessed as lower quality would receive lower weighting.

External immunization economics experts with whom we consulted expressed strong opposition to weighting (option 4). We decided to proceed with option 2 (excluding resources with lowest 10% of quality ratings, amounting to a total of 8 unit costs from 7 articles/reports excluded). Excluding those with serious extractor- and/or author-perceived limitations (option 3) would have affected 7 resources or 25 unit costs in the initial review (13% of the initial dataset), which we considered too many.

The cost ranges combine four or more comparable unit costs and note the minumum and maximum values amongst the four or more underlying unit costs, and other descriptive statistics (i.e., the median, mean, and 25th and 75th percentile values). We determined that fewer than four unit cost findings did not provide enough data for developing a robust cost range.

We opted to emphasize cost ranges, rather than single point estimates (i.e., median or mean), which imply a best practice or standard and are intended for benchmarking purposes. Due to the limited number of comparable unit costs that comprise the cost ranges, it is difficult to objectively say that a single point estimate should be used for comparison or evaluation of country performance, or used as a cost norm to represent "average" performance. Instead, the cost variation across different contexts is important for potential users of the cost ranges to consider in light of the contexts the data will be applied in.

The unit costs for which we aimed to create cost ranges included (1) cost per capita, (2) cost per dose, (3) cost per full immunization of a vaccine or fully immunized child,[8] and (4) cost per person in the target population. We developed the nine cost ranges cost ranges according to the following five steps:

- Identification of unit costs that are methodologically and contextually similar based on a set mandatory comparability criteria, considering type of cost, delivery scale and other factors.
- Checking comparability of unit costs against an additional set of methods, vaccine delivery and contextual criteria.
- Calculation of cost ranges with associated descriptive statistics.
- Validation of cost ranges with a panel of immunization costing experts.
- Preparation of visuals and methodological notes to facilitate interpretation.

Each step is discussed in more detail below.

1. Identification of unit costs that are methodologically and contextually similar.

We systematically explored all possible combinations of unit costs in the dataset matching a set of mandatory comparability criteria, both in terms of methods as well as context, since data from different contexts may not be suitable to consider together in a cost range. The comparability criteria used in the last refresh are noted in Table 2.[9,10]

[8] See page 13 footnote. We used comparable definitions of "fully immunized" as defined by the study authors.

[9] In the initial review, we specified that data needed to match on at least 12 variables to be considered eligible for inclusion in a cost range, which was found to be too restrictive. In the 2019 refresh we relied on 7-8 criteria for development of the cost ranges. This approach reflects the revised classification of the importance of different variables, which the team presented at iHEA in July 2019. In both the initial review and the refreshes, we considered additional variables on a case-by-case basis. We also considered a number of recommendations from our external review committee for the cost range analysis. Additionally, we received recommendations on alternative approaches for the quality assessment scoring we used for each of the resources in the systematic review. We considered the recommendations, but ultimately decided to follow the same methodology used for the initial review.

[10] Methods criteria were developed by the ThinkWell team. Contextual criteria (country region, country income level, population size) were chosen in consultation with policymakers from Indonesia, Tanzania, and Vietnam. The policymakers also recommended number of antigens in the country immunization schedule.

Table 2. Mandatory criteria for identifying comparable records

Level	Purpose and description	Variables
Mandatory comparability criteria	To identify unit costs comparable enough to develop a cost range, we considered these variables important to match on. For example, we searched for unit costs that matched on ALL of the following variables: • Economic costs – Not financial nor fiscal • Full costing – Not incremental • Both introduction/startup and recurrent/ ongoing costs – Not introduction/startup costs only, nor recurrent/ongoing costs only • National level costs included (highest level) • Not supply chain only costs • Routine delivery – Not SIA delivery • Full scale – Not pilot/project • Single vaccine – not multiple antigens part of a schedule of vaccines Where there were four or more unit costs matching ALL these variables, a cost range was attempted.	• Economic, financial, or fiscal costs* • Full or incremental costing • Introduction/startup and/or recurrent/ongoing costs or both • Highest level of costs included • Supply chain only • Delivery platform (routine vs. SIA) • Delivery scale (pilot/project or full) • Number of antigens costed

* Cost ranges were separately attempted for economic, financial or fiscal costs, and also attempted including all the three types of costs.

2. Checking comparability of unit costs against an additional set of methods, vaccine delivery and contextual criteria.

For each combination of four or more comparable unit costs identified by the mandatory criteria above, we then examined their further comparability using an additional set of methods, vaccine delivery and contextual criteria (Table 3).

Table 3. Additional criteria for identifying comparable records

Level	Purpose and description	Variables
Additional comparability criteria – methods	These variables were not used to develop the cost ranges, but were considered in the judgment of the validity of the cost range, which may have resulted in the removal of a unit cost from the range. For example, we did not use "number of included cost categories" to find comparable unit costs (e.g. restricting a cost range to unit costs including only 10 or more cost categories). But if a potentially valid cost range included some unit costs with only six cost categories included, with vehicles and transport entirely excluded, and other unit costs included 14 cost categories, we may have decided to remove the unit costs representing fewer cost categories from the range.	• Number of sampled facilities • Perspective • Number of included cost categories (of 14 total) • Important cost categories included (paid human resources; cold chain equipment and their overheads (installation, energy, maintenance, repairs); vehicles, transport and fuel; and training and capacity building)

Additional comparability criteria – vaccine delivery and context		• Vaccine delivery
		  • Vaccines costed (e.g. HPV, Rotavirus (2 doses), multiple vaccines)
		  • Number of antigens costed
		  • For single vaccines: mode of administration (oral, injectable)

	As another example, we did not use "country income level" to find comparable unit costs (e.g., restricting a cost range to unit costs from only low income countries, or only upper middle income countries). But if a potentially valid cost range included four unit costs from low-income countries and a much higher or lower unit cost from an upper-middle-income country, we may have decided to remove the upper-middle-income unit cost from the range.	• For multiple vaccines: number of contacts required with the health system • Target delivery population • New vaccine introduction status • Vaccine delivery strategy • Delivery sector • Context • Country and number of countries costed • Region • Country income level • Population size • Population density • Geographic setting

In cases of lack of comparability among unit costs, the unit costs in question were removed from consideration in the cost range.

3. Calculation of cost ranges with associated descriptive statistics.

For combinations of four or more comparable unit costs, verified through the two-step process described above, we created a cost range with associated descriptive statistics of the selected unit costs:

- Range (minimum and maximum unit costs)
- Mean unit cost
- Median unit cost
- 25th and 75th percentile unit costs

We chose not to present 95% confidence intervals, given the small number of unit cost estimates composing each cost range and because the unit costs are not a sample of all known data in the universe, making this statistical technique inappropriate.

The cost ranges we attempted include (1) cost per capita, (2) cost per dose, (3) cost per full immunization of a vaccine or fully immunized child, and (4) cost per person in the target population (all excluding vaccine cost).

We decided not to impute missing data when developing the cost ranges. Given the small number of comparable unit costs, we did not have high confidence that we could reliably impute missing values. In some cases, this meant we were unable to develop cost ranges.

We chose not to extrapolate or interpolate data either, again due to the limited number of comparable unit costs and our aim to report the available data, not fill gaps in the available data. For example, we did not use program management costs from one unit cost to fill in the missing program management cost data for another unit cost. That is, we did not feel it was reasonable to use program costs in India to fill in the data gap for Indonesia, even if there was high comparability in the two unit costs otherwise. Similarly, we did not use the percentage of program costs out of total costs in India to estimate the program costs in Indonesia. Finally, we did not use average program costs from similar countries (such as other lower-middle income countries) to fill data gaps.

Additionally, we did not predict costs using cost functions because of data availability challenges and our low confidence in developing reliable cost functions. We also chose not to

weight unit costs based on any factors of the underlying data, for example based on number of doses delivered. We felt weighting would give unit costs from countries like India a much higher weight in a lower-middle-income country cost range than a smaller country like Vietnam. This approach might also give better funded research with larger samples a higher weight in the cost ranges than more poorly funded – but still potentially robust – research with smaller samples.

A sample cost range developed with these analytic techniques is presented below.

4. Validation of cost ranges

A set of cost ranges were presented to a group of eight immunization costing experts in March 2018 who expressed no major concerns with either the methods used to develop the cost ranges or the results themselves. They provided some suggestions regarding advanced methods and techniques to relax some of our stringent comparability requirements, which were incorporated in the 2018 refresh analysis. The 2018 review cost ranges were validated by a group of seven immunization costing experts in February 2019, again with no major concerns with either methods or results. The cost ranges coming out of the 2019 review did not undergo validation as there were no major methods changes from the previous review.

Based on feedback received, we released a total of nine cost ranges in December 2019.

5. Preparation of visuals and methodological notes to facilitate interpretation.

After arriving at a prioritized set of cost ranges, we developed a data visualization format and companion table which includes various methodological notes to help with interpretation. Figures 3 and 4 provide an in-depth look at the components of the visual with more details on how to interpret the immunization cost ranges.

Figure 3. Example cost range

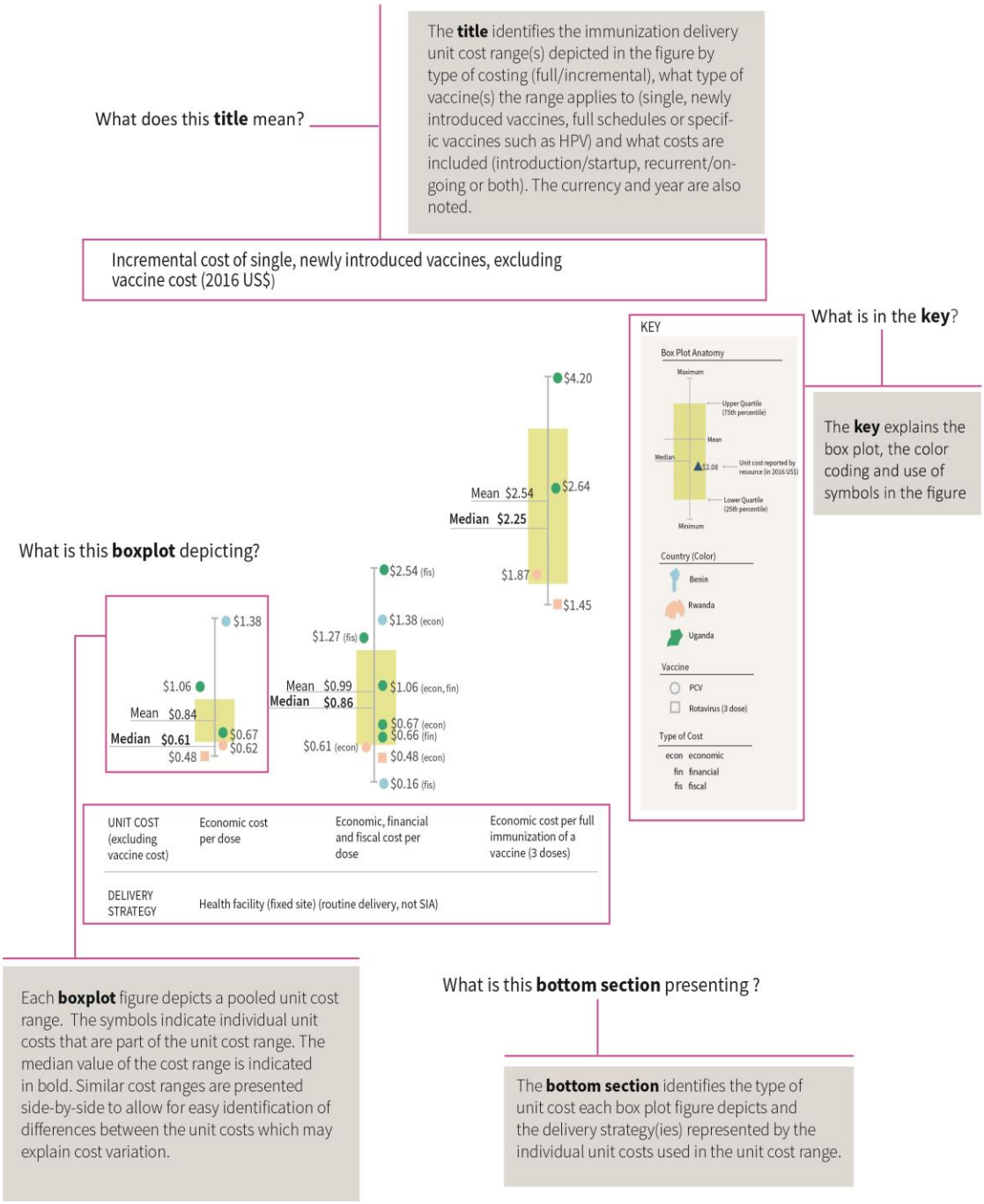
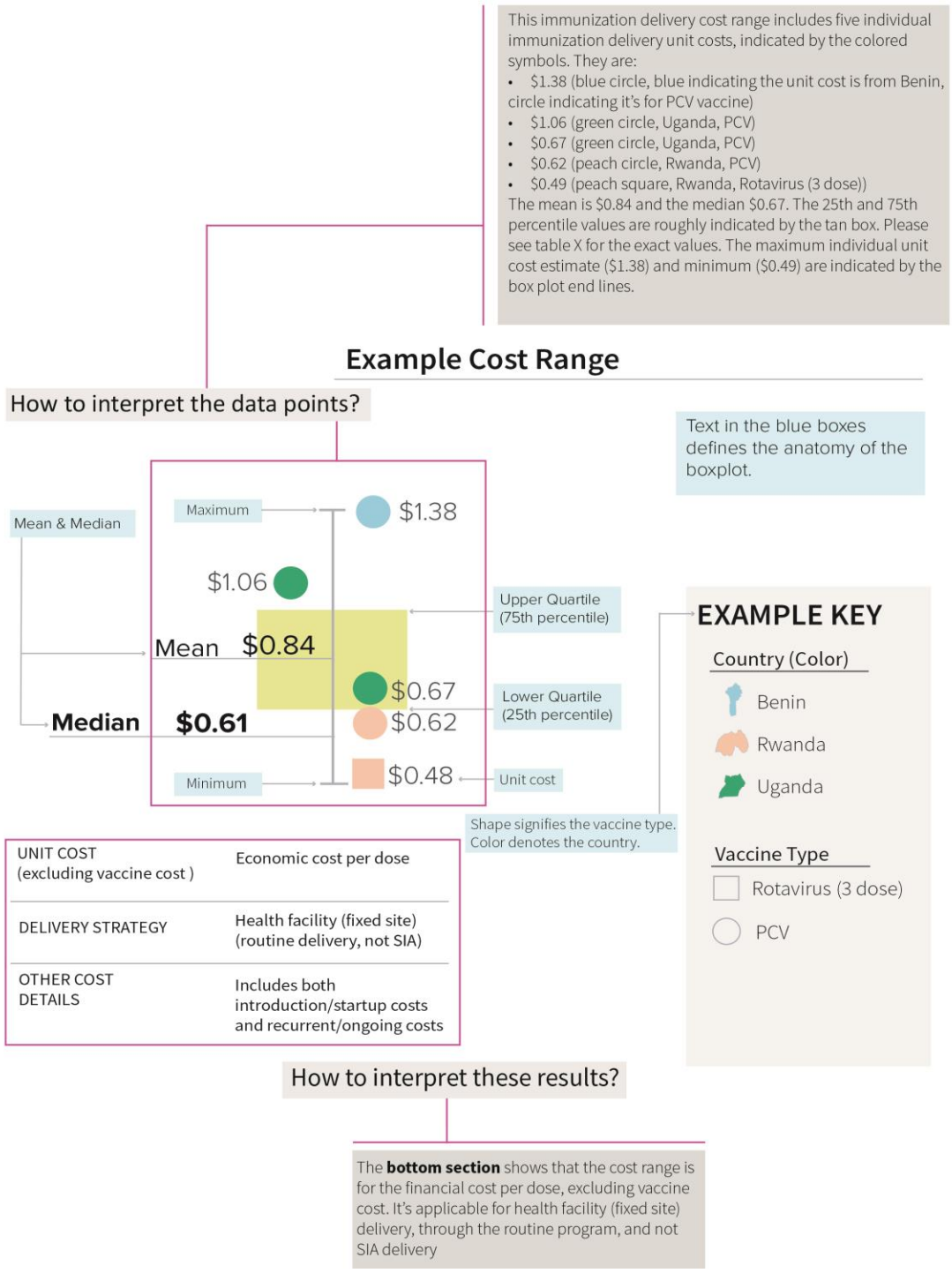


Figure 4. Example cost range II



Finally, we recognize that country policymakers, researchers, advocates, donors, and other development partners have different data needs. Vaccines are delivered using diverse delivery approaches implemented in a range of settings, and in many cases a simple cost range and descriptive statistics may not provide enough detail to prove truly useful for planning and budgeting purposes or resource allocation decisions. Country policymakers may be interested

in only a subset of delivery costs (e.g., the non-labor cost components, or transport only), in which case cost ranges that do not strictly include these cost categories would not be useful for them. Other users may wish to compare unit costs from different groupings of countries than we selected (e.g., West Africa Francophone countries, or countries with similar health spending per capita, or least developed landlocked states). The IDCC Microsoft Excel and web tools make the data available for users to analyze it in the ways most useful to them. Our how-to guide provides suggested guidance on how to do so.

LIMITATIONS

- The limited number of unit costs available come from different countries, report about different vaccines and delivery strategies, and were produced using different methods. This finding was also noted by De la Hoz-Restrep et al. (2013) and Ozawa et al. (2012). This heterogeneity in the dataset posed a real challenge for benchmarking, which we opted against, and in developing cost ranges.
- Despite matching the unit costs on numerous comparability criteria, we were limited by the information reported by the authors in each article/report, and we recognize that misinterpretations of the reported cost data may have inadvertently occurred.
- Some cost variation across different contexts likely has not been captured by the comparability criteria chosen. It is important for potential users of the cost ranges to consider appropriateness of the ranges in light of the contexts in which they will be applied.
- Due to the limited number of comparable unit costs that comprise the cost ranges, we cannot be sure they capture all or even the majority of possible delivery unit costs for those scenarios.
- Unit costs for which major methodological information was not available in the resource could not be used in the development of cost ranges. This further limited the number of possible unit costs available for developing cost ranges.

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ANNEXES

ANNEX 1. DEFINITIONS

The definitions in the table below may be useful for understanding the data presented in the IDCC. In addition, a description of each variable in the IDCC can be found in our codebook.

Term	Definition
---	Reviewers could not find the indicated information in the article/report. For example, if a study does not discuss capital costs and their annualization, we have noted that methods for annualizing capital costs are "not reported" or "---".
Annualization	Costing method to spread the costs of items used for more than one year over the lifetime of the item.
Cannot estimate	Value cannot be calculated, due to missing/incomplete data or division by zero.
Cost category	Groupings of costs; also known as cost item, line item, etc. We used the following cost categories: Paid human resources, Volunteer human resources (economic costs only), Per diem and travel allowances, Cold chain equipment and their overheads (installation, energy, maintenance, repairs), Vehicles, transport and fuel, Program management, Training and capacity building, Social mobilization and advocacy, AEFI and disease surveillance, Buildings, utilities, other overheads and/or shared costs, Vaccines, Vaccine supplies, Waste management, Other supplies and recurrent costs, Other category costs.
Delivery cost	Frequently referred to at country level as "operational costs". The costs associated with delivering immunizations to target populations, exclusive of vaccine costs. Delivery costs may include any or all of the following items: paid and volunteer human resources and associated per diem and travel allowances, cold chain equipment and overheads, vehicles, transport and fuel, program management, training and capacity building, social mobilization and advocacy, adverse event following immunization (AEFI) and disease surveillance, buildings, utilities, other overheads and shared costs, vaccine supplies, waste management, other supplies and recurrent costs and other costs. We refer to these inputs as "cost categories"; some articles/reports refer to them as line items and/or activities.
Delivery strategy	How and where vaccines are delivered, such as through health facilities, outreach/mobile clinics (off-site delivery, generally to patients located more than a certain distance from a health facility; this delivery strategy may be called mobile in some countries, or outreach in others), schools, child health days/weeks or national immunization days/weeks, campaigns and multiple strategies (two or more of the aforementioned strategies).
Discount rate	The rate at which future costs are considered compared to those that occur in the present.
Economic cost	Financial outlays plus opportunity costs of health worker time and any donated items such as vaccines.
Financial cost	Financial outlays, usually with straight-line depreciation of capital items.

Fiscal cost	Financial outlays, usually without depreciation of capital items.
Full/total	The sum of all costs associated with vaccination delivery.
Fully immunized child (FIC)	Full immunization of a vaccine or specifically defined by each article/report, but generally refers to provision of a certain number of doses of a specific vaccine(s) to a specific group and at a clear point in time, e.g., infants who received one dose of BCG; three doses each of OPV, DPT, and Hepatitis B vaccines; and one dose of measles vaccine before reaching one year of age.
Incremental	Additional costs associated with introducing a new vaccine or making a change in delivery.
Inferred	Not explicitly stated in the article/report but determined by the reviewers based on other information.
Not reported	Reviewers could not find the indicated information in the article/report. For example, if a study does not discuss capital costs and their annualization, we have noted that methods for annualizing capital costs are “not reported.”
Perspective	The point of view considered for costs (and benefits, if included), in a costing study; to whom the costs were incurred. Common perspectives include provider, government, healthcare, insurer and societal.
Quality assessment score	Indication of the quality of each article/report in the review, as assessed by the review team. Measured on three dimensions: methodological rigor and reporting standards (8 items), uncertainty of results (3 items) and risk of bias and limitations (3 items). Each item was given an individual score of 1 (lowest), 2, or 3 (highest); for some items there was also a “not applicable” option. Scores for all items were summed and averaged, excluding any “not applicable” answers, to produce a final score for each article/report on the same 1 to 3 scale.
Record	A record represents one or more unit costs with unique characteristics. While some articles/reports only report a single unit cost, most present multiple unit costs are calculated using different criteria (e.g., economic/financial/fiscal costs, full/incremental).
Record ID	Identifier for each row in the International Delivery Cost Catalogue (IDCC), representing unique unit cost(s) with a set of attributes, for example, economic, incremental costs of HPV delivery in schools. Many studies report multiple types of unit costs (e.g., financial, economic), so each is presented as a unique record ID. Record IDs including an underscore (_) are all from the same articles/reports.
Routine	Defined by WHO as "sustainable, reliable and timely interaction between the vaccine, those who deliver it and those who receive it to ensure every person is fully immunized against vaccine-preventable diseases" (cite WHO: http://www.who.int/immunization/diseases/poliomyelitis/endgame_objective2/routine_immunization/en/)
Shared costs	Delivery costs that are also used for non-immunization, for example vehicles that are used for outreach but also used for HIV.

Standardized findings	Refers to the data extracted as part of the systematic review, presented in a standard format in the International Delivery Cost Catalogue (IDCC) with all costs brought to 2016 USD.
Supplementary immunization activity (SIA)	Strategy for delivering vaccination to children otherwise missed by routine immunization, or in response to a specific event, such as a disease outbreak.
Type of cost	Either financial, fiscal or economic; see definitions.
Type of costing	Differentiated between full or total costing and incremental costing; see definitions.
Unit cost	The cost of delivery of a single unit of immunization. The review includes four unit costs: per dose, per fully immunized child (FIC), per person in the target population, per capita.

ANNEX 2. SYSTEMATIC REVIEW SEARCH STRATEGY

Published Search Strategies and Yield (Cumulative Total of Initial Search and Refreshes)

Search	Query	Items found
PubMed		
#4	#1 AND #2 AND #3	**5,665**
#3	delivery[tiab] OR campaign*[tiab] OR incremental[tiab] OR strategy[tiab] OR strategies[tiab] OR “cold chain”[tiab] OR logistic*[tiab] OR equipment[tiab] OR personnel[tiab] OR overhead[tiab] OR operational[tiab] OR transport*[tiab] OR distribut*[tiab] OR “non-vaccine”[tiab] OR “per dose”[tiab] OR “per capita”[tiab] OR “per child”[tiab] OR “per person”[tiab] OR “per fully immunized child”[tiab] OR “per fully immunised child”[tiab] OR “per FIC”[tiab] OR universal[tiab] OR “disability-adjusted”[tiab] OR DALY[tiab] OR extrapolat*[tiab]	3,270,790
#2	immuniz*[tiab] OR immunis*[tiab] OR vaccin*[tiab]	370,937
#1	"Costs and Cost Analysis"[mh] OR costs[tiab] OR cost effective*[tiab] OR costing[tiab] OR cost-benefit[tiab] OR cost-utility[tiab] OR "Immunization Programs/economics"[mh] OR "Vaccination/economics"[mh] OR "Mass Vaccination/economics"[mh]	420,050
Embase		**Items found: 8,643**
#6	#3 AND #4 AND #5	
#5	delivery:ti OR campaign*:ti OR incremental:ti OR strategy:ti OR strategies:ti OR 'cold chain':ti OR logistic*:ti OR equipment:ti OR personnel:ti OR overhead:ti OR operational:ti OR transport*:ti OR distribut*:ti OR 'non-vaccine':ti OR 'per dose':ti OR 'per capita':ti OR 'per child':ti OR 'per person':ti OR 'per fully immunized child':ti OR 'per fully immunised child':ti OR 'per fic':ti OR universal:ti OR 'disability-adjusted':ti OR daly:ti OR extrapolat*:ti OR delivery:ab OR campaign*:ab OR incremental:ab OR strategy:ab OR strategies:ab OR 'cold chain':ab OR logistic*:ab OR equipment:ab OR personnel:ab OR overhead:ab OR operational:ab OR transport*:ab OR distribut*:ab OR 'non-vaccine':ab OR 'per dose':ab OR 'per capita':ab OR 'per child':ab OR 'per person':ab OR 'per fully immunized child':ab OR 'per fully immunised child':ab OR 'per fic':ab OR universal:ab OR 'disability-adjusted':ab OR daly:ab OR extrapolat*:ab	
#4	immunis*:ti OR immuniz*:ti OR vaccin*:ti OR immunis*:ab OR immuniz*:ab OR vaccin*:ab	
#3	#1 OR #2	
#2	cost:ti OR costs:ti OR costing:ti OR cost:ab OR costs:ab OR costing:ab	
#1	'cost benefit analysis'/exp OR 'cost utility analysis'/exp OR 'cost effectiveness analysis'/exp	

Search	Query	Items found
Web of Science		
#4	#1 AND #2 AND #3	**6,844**
#3	TOPIC: (delivery OR campaign* OR incremental OR strategy OR strategies OR "cold chain" OR logistic* OR equipment OR personnel OR overhead OR operational OR transport* OR distribut* OR "non-vaccine" OR "per dose" OR "per capita" OR "per child" OR "per person" OR "per fully immunized child" OR "per fully immunised child" OR "per FIC" OR universal OR "disability-adjusted" OR DALY OR extrapolat*)	
#2	TOPIC: (immuniz* OR immunis* OR vaccin*)	
#1	TOPIC: (costs OR cost-effective* OR costing OR cost-benefit OR cost-utility)	
EconLit		**158**
#4	#1 AND #2 AND #3	
#3	costs OR cost-effective* OR costing OR cost-benefit OR cost-utility	
#2	delivery OR campaign* OR incremental OR strategy OR strategies OR "cold chain" OR logistic* OR equipment OR personnel OR overhead OR operational OR transport* OR distribut* OR "non-vaccine" OR "per dose" OR "per capita" OR "per child" OR "per person" OR "per fully immunized child" OR "per fully immunised child" OR "per FIC" OR universal OR "disability-adjusted" OR DALY OR extrapolat*	
#1	immuniz* OR immunis* OR vaccin*	
NHS EED		**169**
#4	#1 AND #2 AND #3	
#3	costs OR cost-effective* OR costing OR cost-benefit OR cost-utility	
#2	delivery OR campaign* OR incremental OR strategy OR strategies OR "cold chain" OR logistic* OR equipment OR personnel OR overhead OR operational OR transport* OR distribut* OR "non-vaccine" OR "per dose" OR "per capita" OR "per child" OR "per person" OR "per fully immunized child" OR "per fully immunised child" OR "per FIC" OR universal OR "disability-adjusted" OR DALY OR extrapolat*	
#1	immuniz* OR immunis* OR vaccin*	
WHO Global Index Medicus		**20**
#4	#1 AND #2 AND #3	
#3	Filter: Health economic evaluations	
#2	(tw:(immuniz* OR immunis* OR vaccin*))	
#1	(tw:(costs OR cost-effective* OR costing OR cost-benefit OR cost-utility))	

Note: WHO's Global Index Medicus contains records from WHO regional indices for Africa, Latin America and the Caribbean, Middle East, Southeast Asia and Western Pacific, as well as WHO documents. Optional search of MEDLINE was not completed. Search string includes only two components due to database limitations. See http://www.globalhealthlibrary.net.

Grey Literature Outreach

List of organizations queried for grey literature

AAMP	LSHTM
Abt Associates	PAHO
Aceso Global	PATH
African Development Bank	Pharos Global Health Advisors
Applied Strategies	Public Health Foundation of India
Asian Development Bank	Results for Development Institute
Avenir Health	Sabin Institute
BMGF	Swiss Tropical and Public Health Institute
Center for Global Development	Save the Children
Harvard T.H. Chan School of Public Health	Strategic Development Consultants
CDC	Supply Chain Costing User's Group
CHAI	UCSF
Curatio International Foundation	UNICEF
Gavi Alliance	University of Washington
Global Health Cost Consortium	University of Zambia
Health Alliance International	UNICEF
International Vaccine Institute	University of Cape Town
HITAP	University of Michigan
iDSI	WHO
Johns Hopkins University	World Bank
JSI	Researchers within selected countries

Organizational webpages searched

Organization	Website(s)
Abt Associates	abtassociates.com
Aceso Global	acesoglobal.org
Agence de Médecine Préventive (AMP)	amp-vaccinology.org
Applied Strategies	appliedstrategies.com
Asian Development Bank	adb.org
Avenir Health	avenirhealth.org
Bill & Melinda Gates Foundation	gatesfoundation.org grandchallenges.org
Brandeis University	brandeis.edu
Centers for Disease Control and Prevention (CDC)	cdc.gov
Center for Global Development	cgdev.org
CHAI	clintonhealthaccess.org
Curatio International Foundation	curatiofoundation.org
FHI360	fhi360.org
Faculty of Pharmacy Mahidol University	pharmacy.mahidol.ac.th
GAVI	gavi.org
Global Health Cost Consortium	globalhealth.washington.edu
Harvard School of Public Health	hsph.harvard.edu
Hanoi Medical University	en.hmu.edu.vn
Health Alliance International	healthallianceinternational.org
Health Intervention and Technology Assessment Program (HITAP)	hitap.net
International Decision Support Initiative (iDSI)	idsihealth.org
International Vaccine Institute (IVI)	ivi.int
Johns Hopkins University, Bloomberg School of Public Health	jhsph.edu
JSI	Jsi.com
London School of Hygiene and Tropical Medicine (LSHTM)	lshtm.ac.uk
Médecins Sans Frontières (MSF)	msf.org
National Institute of Clinical Excellent (NICE) International	nice.org.uk

Organization	Website(s)
Pan-American Health Organization (PAHO)	paho.org
PATH	path.org
Pharos	pharosglobalhealth.com
Public Health Foundation of India	phfi.org
Results for Development	resultsfordevelopment.org
Sabin Institute	sabin.org
Save the Children UK	savethechildren.org.uk
Strategic Development Consultants	sdc-africa.co.za
Swiss Tropical and Public Health Institute	swisstph.ch
University of California at San Francisco (UCSF)	ucsf.edu
United Nations Children's Fund (UNICEF)	unicef.org
University of Cape Town	uct.ac.za
University of Michigan	umich.edu
University of Washington	uw.edu
URC	urc-chs.com
USAID	usaid.gov
World Bank	worldbank.org
World Health Organization (WHO)	who.int

Groups, communities of practice, and discussion forums contacted

Contacts
Better Immunization Data Initiative (BID) network
Global Health Cost Consortium (GHCC) November 2016 convening participants
Global Immunization News (GIN) newsletter
HEALTHECON-DISCUSS JiscMail list-serv
Immunization Economics community of practice newsletter
Learning Network for Countries in Transition (LNCT)
ProVac Centers of Excellence

ANNEX 3. REFERENCES OF EXTRACTED RESOURCES

Reference	Records	Countries	Vaccines Costed*
Al-lela, O. Q. B., Bahari, M. B., Al-abbassi, M. G., Salih, M. R. M., & Basher, A. Y. (2012). Estimation of immunization providers' activities cost, medication cost, and immunization dose errors cost in Iraq. Vaccine, 30(26), 3862–3866. https://doi.org/10.1016/j.vaccine.2012.04.014	2	Iraq	BCG, Measles, MMR, HepB, DTP, OPV
AMP. (2014). Costing and financing analyses of routine immunization and new vaccine introduction in Benin Final Report.**	28[X]	Benin	BCG, Measles, DTP-HepB-Hib, OPV, PCV13, YF
Ayieko, P., Griffiths, U. K., Ndiritu, M., Moisi, J., Mugoya, I. K., Kamau, T., … Scott, J. A. G. (2013). Assessment of Health Benefits and Cost-Effectiveness of 10-Valent and 13-Valent Pneumococcal Conjugate Vaccination in Kenyan Children. PLoS ONE, 8(6), 1–10. https://doi.org/10.1371/journal.pone.0067324	4	Kenya	PCV10, PCV13
Bem, J and Stewart, E. "Vaccine Costing Analysis Preliminary Results." Presentation at the Pharmaceutical Fund and Supply Agency, Addis Ababa, Ethiopia, September 2015.	7	Ethiopia	OPV, Rotavirus, (2, doses), TT, PCV10, BCG, Measles, DTP
Bishai, D., Johns, B., Lefevre, A., & Nair, D. (2010). Cost effectiveness of measles eradication Final Report. Retrieved from http://www.who.int/immunization/sage/1_Bishai_Economic_analysis.pdf	2	Uganda	Measles
Brown, S. T., Schreiber, B., Cakouros, B. E., Wateska, A. R., Dicko, H. M., Connor, D. L., … Lee, B. Y. (2014). The benefits of redesigning Benin's vaccine supply chain. Vaccine, 32(32), 4097–4103. https://doi.org/10.1016/j.vaccine.2014.04.090 ***	4	Benin	BCG, Measles, TT, DTP-HepB-Hib, OPV, Rotavirus, (2, doses), PCV13, YF
Cambodia MoH. (2018) Cambodia HPV vaccination demonstration project cost analysis.	16	Cambodia	HPV
Castañeda-Orjuela, C., Romero, M., Arce, P., Resch, S., Janusz, C. B., Toscano, C. M., & De la Hoz-Restrepo, F. (2013). Using standardized tools to improve immunization costing data for program planning: The cost of the Colombian Expanded Program on Immunization. Vaccine, 31(SUPPL.3), 72–79. https://doi.org/10.1016/j.vaccine.2013.05.038 †	4	Colombia	BCG, MR, MMR, HepB, DTP, DT, Td, DTP-HepB-Hib, OPV, Rotavirus (2 doses), PCV7, YF, Influenza
Cavailler, P., Lucas, M., Perroud, V., McChesney, M., Ampuero, S., Guérin, P. J., … Chaignat, C. L. (2006). Feasibility of a mass vaccination campaign using a two-dose oral cholera vaccine in an urban cholera-endemic setting in Mozambique. Vaccine, 24(22), 4890–4895. https://doi.org/10.1016/j.vaccine.2005.10.006	1	Mozambique	OCV

Chatterjee S, Das P, Nigam A, Nandi A, Brenzel L, Ray A, Haldar P, Aggarwal MK, Laxminarayan R. (2018) Variation in cost and performance of routine immunization service delivery in India. DOI: http://dx.doi.org/10.1136/bmjgh-2018-000794	3	India	BCG, Measles, HepB, DTP, DTP-Hib, OPV
Chatterjee, S., Pant, M., Haldar, P., Aggarwal, M. K., & Laxminarayan, R. (2016). Current costs & projected financial needs of India's universal immunization programme. Indian Journal of Medical Research, 143(JUNE), 801–808. https://doi.org/10.4103/0971-5916.192073	2	India	BCG, Measles, HepB, DTP, TT, OPV, JE
Colombini, A., Badolo, O., Gessner, B. D., Jaillard, P., Seini, E., & Da Silva, A. (2011). Costs and impact of meningitis epidemics for the public health system in Burkina Faso. Vaccine, 29(33), 5474–5480. https://doi.org/10.1016/j.vaccine.2011.05.058	2	Burkina Faso	Meningococcal
Dorji, K., Phuntsho, S., Pempa, Kumluang, S., Khuntha, S., Kulpeng, W., … Teerawattananon, Y. (2018). Towards the introduction of pneumococcal conjugate vaccines in Bhutan: A cost-utility analysis to determine the optimal policy option. Vaccine, 36(13), 1757-65. https://doi.org/10.1016/j.vaccine.2018.02.048	2	Bhutan	PCV10, PCV13
Douba, A., Dagnan, S. N., Zengbe-Acray, P., Aka, J., & Lépri-Aka N. (2006). Perception du Programme élargi de vaccination (PEV) dans le district sanitaire de Bouna (Nord-Est de la Côte d ' Ivoire). Sante Publique, 23(2), 113-121.	5	Cote d'Ivoire	BCG, DTP-HepB, OPV
Ebong, C. E., & Levy, P. (2011). Impact of the introduction of new vaccines and vaccine wastage rate on the cost-effectiveness of routine EPI: Lessons from a descriptive study in a Cameroonian health district. Cost Effectiveness and Resource Allocation, 9, 1–8. https://doi.org/10.1186/1478-7547-9-9	3	Cameroon	BCG, Measles, DTP-HepB-Hib, OPV, YF
Goguadze, K., Chikovani, I., Gaberi, C., Maceira, D., Uchaneishvili, M., Chkhaidze, N., & Gotsadze, G. (2015). Costs of routine immunization services in Moldova: Findings of a facility-based costing study. Vaccine, 33(S1), A60–A65. https://doi.org/10.1016/j.vaccine.2014.12.034 **	4	Moldova	BCG, MMR, HepB, DTP-HepB-Hib, OPV
Gotsadze, G., Goguadze, K., Chikovani, I., & Maceira, D. (2014). Analyses of Costs and Financing of the Routine Immunization Program and New Vaccine Introduction in the Republic of Moldova Study Report.**	40	Moldova	BCG, MMR, HepB, DTP, DT, Td, DTwP-Hib, DTP-HepB-Hib, OPV, Rotavirus (2 doses)
Griffiths, U. K., Bozzani, F. M., Chansa, C., Kinghorn, A., Kalesha-Masumbu, P., Rudd, C., … Schutte, C. (2016). Costs of introducing pneumococcal, rotavirus and a second dose of measles vaccine into the Zambian immunisation programme: Are expansions sustainable? Vaccine, 34(35), 4213–4220. https://doi.org/10.1016/j.vaccine.2016.06.050**	21	Zambia	Measles, Rotavirus (2 doses), PCV10

Griffiths, U. K., Hutton, G., & Das Dores Pascoal, E. (2005). The cost-effectiveness of introducing hepatitis B vaccine into infant immunization services in Mozambique. Health Policy and Planning, 20(1), 50–59. https://doi.org/10.1093/heapol/czi006	3	Mozambique	BCG, Measles, TT, OPV, HepB, DTP-HepB
Griffiths, U. K., Korczak, V. S., Ayalew, D., & Yigzaw, A. (2009). Incremental system costs of introducing combined DTwP-hepatitis B-Hib vaccine into national immunization services in Ethiopia. Vaccine, 27(9), 1426–1432. https://doi.org/10.1016/j.vaccine.2008.12.037	2	Ethiopia	DTwP-HepB-Hib
Griffiths, U. K., Santos, A. C., Nundy, N., Jacoby, E., & Matthias, D. (2011). Incremental costs of introducing jet injection technology for delivery of routine childhood vaccinations: Comparative analysis from Brazil, India, and South Africa. Vaccine, 29(5), 969–975. https://doi.org/10.1016/j.vaccine.2010.11.038	15	Brazil, India, South Africa	BCG, MMR, HepB, DTwP-Hib, YF, Measles, DT, TT, DTaP-Hib-IPV, PCV7, DTwP
Guthrie, T., Zikusooka, C., Kwesiga, B., Abewe, C., Lagony, S., Schutte, C., … Kinghorn, A. (2014). Costing and Financing Analyses of Routine Immunization in Uganda. Retrieved from https://static1.squarespace.com/static/556deb8ee4b08a534b8360e7/t/5596fa4ae4b07b7dda4dd04d/1435957834829/UGANDA+Immunization+Costing+Report+1+December+14+submitted+FINAL+update+15+12+14+errors.pdf**	76[X]	Guthrie	BCG, Measles, TT, DTP-HepB-Hib, OPV, PCV10
Haidari, L. A., Brown, S. T., Ferguson, M., Bancroft, E., Spiker, M., Wilcox, A., … Lee, B. Y. (2016). The economic and operational value of using drones to transport vaccines. Vaccine, 34(34), 4062–4067. https://doi.org/10.1016/j.vaccine.2016.06.022***	1	Mozambique	BCG, Measles, TT, DTP-HepB-Hib, OPV, PCV10
Haidari, L. A., Wahl, B., Brown, S. T., Privor-Dumm, L., Wallman-Stokes, C., Gorham, K., … Lee, B. Y. (2015). One size does not fit all: The impact of primary vaccine container size on vaccine distribution and delivery. Vaccine, 33(28), 3242–3247. https://doi.org/10.1016/j.vaccine.2015.04.018***	2	Benin	BCG, Measles, TT, DTP-HepB-Hib, OPV, Rotavirus (2 doses), PCV13, YF
Haque, M., Waheed, M., & et al. (2016). The Pakistan Expanded Program on Immunization and the National Immunization Support Project. Retrieved from http://documents.worldbank.org/curated/en/264971484109785001/pdf/111815-WP-PAKImmunizationEA-PUBLIC.pdf	1	Pakistan	BCG, Measles, DTP, OPV
Hidle A, Gwati G, Abimbola T, Pallas SW, Hyde T, Petu A, McFarland D, and Manangazirab P. (2018) Cost of a human papillomavirus vaccination project, Zimbabwe. Bull World Health Organ. 2018 Dec 1; 96(12): 834–842. Published online 2018 Oct 17. doi: 10.2471/BLT.18.211904	22	Zimbabwe	HPV
Huang, X.X., Guillermet, E., Le Gargasson, J.B., Alfa, D.A., Gboja, R., Sossou, A.J., Jaillard, P. (2017). Costing analysis and anthropological assessment of the vaccine supply chain system redesign in the Comé District (Benin). Vaccine, 35(16), 2183-8. https://doi.org/10.1016/j.vaccine.2016.12.075	2	Benin	BCG, Measles, TT, DTwP-HepB-Hib, PCV13, YF, OCV

Hutubessy, R., Levin, A., Wang, S., Morgan, W., Ally, M., John, T., & Broutet, N. (2012). A case study using the United Republic of Tanzania: Costing nationwide HPV vaccine delivery using the WHO Cervical Cancer Prevention and Control Costing Tool. BMC Medicine, 10, 1–10. https://doi.org/10.1186/1741-7015-10-136 ††	14	Tanzania	HPV
Ilboudo PG, Le Gargasson JB. (2017) Delivery cost analysis of a reactive mass cholera vaccination campaign: a case study of Shanchol vaccine use in Lake Chilwa, Malawi. BMC Infect Dis. 2017 Dec 19;17(1):779. doi: 10.1186/s12879-017-2885-8.	5	Malawi	OCV
Immunization Costing Action Network (ICAN). 2019. The Cost of Delivering Vaccines Using Different Delivery Strategies in High Coverage Areas in Indonesia. Washington, DC: ThinkWell.	32	Indonesia	BCG, Measles, HepB, DT, Td, DTP-HepB-Hib, OPV
Immunization Costing Action Network (ICAN). 2019. The Cost of Preparation and Delivery of Td Vaccine to 7-Year-Old Children in Vietnam. Washington, DC: ThinkWell.	18	Vietnam	TT, Td
Immunization Costing Action Network (ICAN). 2019. The Costs of Different Vaccine Delivery Strategies to Reach Children Up to 18 Months in Rural and Urban Areas in Tanzania. Washington, DC: ThinkWell.	104	Tanzania	BCG, MR, DTP-HepB-Hib, OPV, Rotavirus (2 doses), PCV13
Janusz, C. B., Castañeda-Orjuela, C., Molina Aguilera, I. B., Felix Garcia, A. G., Mendoza, L., Díaz, I. Y., & Resch, S. C. (2015). Examining the cost of delivering routine immunization in Honduras. Vaccine, 33(S1), A53–A59. https://doi.org/10.1016/j.vaccine.2015.01.016 **	2	Honduras	BCG, MMR, HepB, Td, DTP-HepB-Hib, OPV, IPV, Rotavirus (2 doses), PCV13, YF, Influenza
Kar, S. K., Sah, B., Patnaik, B., Kim, Y. H., Kerketta, A. S., Shin, S., … Wierzba, T. F. (2014). Mass Vaccination with a New, Less Expensive Oral Cholera Vaccine Using Public Health Infrastructure in India: The Odisha Model. PLoS Neglected Tropical Diseases, 8(2). https://doi.org/10.1371/journal.pntd.0002629	3	India	OCV
Kaucley, L., & Levy, P. (2015). Cost-effectiveness analysis of routine immunization and supplementary immunization activity for measles in a health district of Benin. Cost Effectiveness and Resource Allocation, 13(1), 14. https://doi.org/10.1186/s12962-015-0039-7	6	Benin	Measles
Khan AI, Khan IA, Siddique SA, Rahman A, Islam MT, Bhuiya MAI, Saha NC, Biswas PK, Saha A, Chowdhury F, Firdausi F. (2018) Feasibility, coverage and cost of oral cholera vaccination conducted by icddr,b using the existing national immunization service delivery mechanism in rural setting Keraniganj, Bangladesh. Hum Vaccine Immunotherapy. Sep 27:1-8. doi: 10.1080/21645515.2018.1528833.	1	Bangladesh	OCV
Khan, I. A., Saha, A., Chowdhury, F., Khan, A. I., Uddin, M. J., Begum, Y. A., … Qadri, F. (2013). Coverage and cost of a large oral cholera vaccination program in a high-risk cholera endemic urban	3	Bangladesh	OCV

population in Dhaka, Bangladesh. Vaccine, 31(51), 6058–6064. https://doi.org/10.1016/j.vaccine.2013.10.021 †††			
Le Gargasson, J. B., Nyonator, F. K., Adibo, M., Gessner, B. D., & Colombini, A. (2015). Costs of routine immunization and the introduction of new and underutilized vaccines in Ghana. Vaccine, 33(S1), A40–A46. https://doi.org/10.1016/j.vaccine.2014.12.081**	8[x]	Ghana	BCG, Measles, TT, DTP-HepB-Hib, OPV, YF, Rotavirus (2 doses), PCV13
Levin, A., Wang, S. A., Levin, C., Tsu, V., & Hutubessy, R. (2014). Costs of introducing and delivering HPV vaccines in low and lower middle income countries: Inputs for GAVI policy on introduction grant support to countries. PLoS ONE, 9(6). https://doi.org/10.1371/journal.pone.0101114	39	Bhutan, India, Peru, Tanzania, Uganda, Vietnam	HPV
Levin, C. E., Nelson, C. M., Widjaya, A., Moniaga, V., & Anwar, C. (2005). Costs of hepatitis B vaccine in a prefilled syringe in Indonesia. Bulletin of the World Health Organization, 83(3), 456–461. https://doi.org//S0042-96862005000600014	2	Indonesia	HepB
Levin, C. E., Van Minh, H., Odaga, J., Rout, S. S., Ngoc, D. N. T., Menezes, L., … LaMontagne, D. S. (2013). Delivery cost of human papillomavirus vaccination of young adolescent girls in Peru, Uganda and Viet Nam. Bulletin of the World Health Organization, 91(8), 585–592. https://doi.org/10.2471/BLT.12.113837	10	Peru, Uganda, Vietnam	HPV
Lydon, P., Zipursky, S., Tevi-Benissan, C., Djingarey, M.H., Gbedonou, P., Youssouf, B.O., Zaffran, M. (2014). Economic benefits of keeping vaccines at ambient temperature during mass vaccination: the case of meningitis A vaccine in Chad. Bulletin of the World Health Organization, 92, 86-92. http://dx.doi.org/10.2471/BLT.13.123471	2	Chad	Meningococcal
Mascareñas, A., Salinas, J., Tasset-Tisseau, A., Mascareñas, C., & Khan, M. M. (2005). Polio immunization policy in Mexico: Economic assessment of current practice and future alternatives. Public Health, 119(6), 542–549. https://doi.org/10.1016/j.puhe.2004.08.020	2	Mexico	OPV
Minh, H.V., My, N.T.T., & Jit, M. (2017). Cervical cancer treatment costs and cost-effectiveness analysis of human papillomavirus vaccination in Vietnam: a PRIME modeling study. BMC Health Services Research, 17, 353. https://doi.org/10.1186/s12913-017-2297-x	1	Vietnam	HPV
Minh, V. H., Nguyen, T. B. Y., Bao, G. K., Lan, H. D., Thuy, H. N., & Wright, P. (2008). Cost of providing the expanded programme on immunization: Findings from a facility-based study in Viet Nam, 2005. Bulletin of the World Health Organization, 86(6), 429–434. https://doi.org/10.2471/BLT.07.045161	12	Vietnam	BCG, Measles, HepB, DTP, TT, OPV, JE
Moodley, I., Tathiah, N., & Sartorius, B. (2016). The costs of delivering human papillomavirus vaccination to Grade 4 learners in KwaZulu-Natal, South Africa. South African Medical Journal = Suid-	1	South Africa	HPV

Afrikaanse Tydskrif Vir Geneeskunde, 106(5), 60. https://doi.org/https://dx.doi.org/10.7196/SAMJ.2016.v106i5.9988			
Mvundura, M., Kien, V. D., Nga, N. T., Robertson, J., Van Cuong, N., Tung, H. T., … Levin, C. (2014). How much does it cost to get a dose of vaccine to the service delivery locationα Empirical evidence from Vietnam's Expanded Program on Immunization. Vaccine, 32(7), 834–838. https://doi.org/10.1016/j.vaccine.2013.12.029 ‡	4	Vietnam	BCG, Measles, HepB, DTwP, TT, OPV, DTP-HepB-Hib
Mvundura, M., Lorenson, K., Chweya, A., Kigadye, R., Bartholomew, K., Makame, M., … Kristensen, D. (2015). Estimating the costs of the vaccine supply chain and service delivery for selected districts in Kenya and Tanzania. Vaccine, 33(23), 2697–2703. https://doi.org/10.1016/j.vaccine.2015.03.084	2	Kenya, Tanzania	BCG, Measles, Td, DTP-HepB-Hib, OPV, PCV10, YF
Mvundura, M., Lydon, P., Gueye, A., Diaw, I.K., Landoh, D.E., Toi, B., … Kristensen, D. (2017). An economic evaluation of the controlled temperature chain approach for vaccine logistics: evidence from a study conducted during a meningitis A vaccine campaign in Togo. The Pan African Medical Journal, 27(Supp 3), 27. doi:10.11604/pamj.supp.2017.27.3.12087	2	Togo	Meningococcal
Ngabo, F., Levin, A., Wang, S. A., Gatera, M., Rugambwa, C., Kayonga, C., … Hutubessy, R. (2015). A cost comparison of introducing and delivering pneumococcal, rotavirus and human papillomavirus vaccines in Rwanda. Vaccine, 33(51), 7357–7363. https://doi.org/10.1016/j.vaccine.2015.10.022	24	Rwanda	PCV7, Rotavirus (3 doses), HPV
Pan American Health Organization. (2014). Comprehensive costing and financial flows analysis of the national immunization program in Honduras, 2011. **	5[X]	Honduras	BCG, MMR, HepB, DTP, Td, DTP-HepB-Hib, OPV, IPV, Rotavirus (2 doses), PCV13, YF, Influenza
PATH, World Health Organisation, Health Systems Research Institute, & Mahidol University. (2011). An Assessment of Vaccine Supply Chain and Logistics Systems in Thailand. Path, (September), 1–58. ‡	2	Thailand	BCG, Measles, MMR, HepB, DTP, OPV, JE,
PATH. (2013). Optimize: Senegal Report. ‡	1	Senegal	BCG, Measles, TT, DTwP-HepB-Hib, OPV, YF
Quentin, W., Terris-Prestholt, F., Changalucha, J., Soteli, S., Edmunds, W. J., Hutubessy, R., … Watson-Jones, D. (2012). Costs of delivering human papillomavirus vaccination to schoolgirls in Mwanza Region, Tanzania. BMC Medicine, 10(November 2011). https://doi.org/10.1186/1741-7015-10-137	5	Tanzania	HPV
Riewpaiboon A, Pathammavong C, Fox K, Hutubessy R. (2019) Cost analysis of pilot school-based HPV vaccination program in two provinces of Lao PDR. DOI: 10.29090/psa.2019.01.017.0052	36	Lao PDR	HPV

Riewpaiboon, A., Sooksriwong, C., Chaiyakunapruk, N., Tharmaphornpilas, P., Techathawat, S., Rookkapan, K., … Suraratdecha, C. (2015). Optimizing national immunization program supply chain management in Thailand: an economic analysis. Public Health, 129(7), 899-906. 1016/j.puhe.2015.04.016	4	Thailand	BCG, Measles, MMR, HepB, DTP, DT, DTP-Hib, OPV, JE
Routh, J.A., Sreenivasan, N., Adhikari, B.B., Andrecy, L.L., Bernateau, M., Abimbola, T., … Mintz, E.D. (2017). Cost evaluation of a government-conducted oral cholera vaccination campaign - Haiti, 2013. The American Society of Tropical Medicine and Hygiene, 97(4), 37-42. doi:10.4269/ajtmh.16-1023	6	Haiti	OCV
Ruhago, G. M., Ngalesoni, F. N., Robberstad, B., & Norheim, O. F. (2015). Cost-effectiveness of live oral attenuated human rotavirus vaccine in Tanzania. Cost Effectiveness and Resource Allocation, 13(1), 1–12. https://doi.org/10.1186/s12962-015-0033-0	3	Tanzania	Rotavirus (2 doses)
Sarker, A. R., Islam, Z., Khan, I. A., Saha, A., Chowdhury, F., Khan, A. I., … Khan, J. A. M. (2015). Estimating the cost of cholera-vaccine delivery from the societal point of view: A case of introduction of cholera vaccine in Bangladesh. Vaccine, 33(38), 4916–4921. https://doi.org/10.1016/j.vaccine.2015.07.042 †††	3	Bangladesh	OCV
Schaetti, C., Weiss, M. G., Ali, S. M., Chaignat, C. L., Khatib, A. M., Reyburn, R., … Hutubessy, R. (2012). Costs of Illness Due to Cholera, Costs of Immunization and Cost-Effectiveness of an Oral Cholera Mass Vaccination Campaign in Zanzibar. PLoS Neglected Tropical Diseases, 6(10). https://doi.org/10.1371/journal.pntd.0001844	2	Tanzania	OCV
Schütte, C., Chansa, C., Marinda, E., Guthrie, T. A., Banda, S., Nombewu, Z., … Kinghorn, A. (2015). Cost analysis of routine immunisation in Zambia. Vaccine, 33(S1), A47–A52. https://doi.org/10.1016/j.vaccine.2014.12.040**	4[x]	Zambia	BCG, Measles, DTP-HepB-Hib, OPV
Sume, G. E., Fouda, A. A. B., Kobela, M., Nguelé, S., Emah, I., & Atem, P. (2013). A locally initiated and executed measles outbreak response immunization campaign in the nylon health district, Douala Cameroon 2011. BMC Research Notes, 6(1). https://doi.org/10.1186/1756-0500-6-100	1	Cameroon	Measles
Teshome, S., Desai, S., Kim, J.H., Belay, D., & Mogasale, V. (2018). Feasibility and costs of a targeted cholera vaccination campaign in Ethiopia. Human Vaccines & Immunotherapeutics. https://doi.org/10.1080/21645515.2018.1460295	5	Ethiopia	OCV
Usuf, E., Mackenzie, G., Lowe-Jallow, Y., Boye, B., Atherly, D., Suraratdecha, C., & Griffiths, U. K. (2014). Costs of vaccine delivery in the Gambia before and after, pentavalent and pneumococcal conjugate vaccine introductions. Vaccine, 32(17), 1975–1981. https://doi.org/10.1016/j.vaccine.2014.01.045	4	The Gambia	DTP-HepB-Hib, HepB, TT, OPV, YF , PCV7
VillageReach. (2009). Comparison of Costs Incurred in Dedicated and Diffused Vaccine Logistics Systems, (October), 1–42. ‡‡‡	6	Mozambique	BCG, Measles, TT, DTP-HepB, OPV

Yin, Z., Beeler Asay, G. R., Zhang, L., Li, Y., Zuo, S., Hutin, Y. J., … Jiang, F. (2012). An economic evaluation of the use of Japanese encephalitis vaccine in the expanded program of immunization of Guizhou province, China. Vaccine, 30(37), 5569–5577. https://doi.org/10.1016/j.vaccine.2012.05.068	2	China	JE
Yu, W., Lu, M., Wang, H., Rodewald, L., Ji, S., Ma, C., … Liu, Y. (2018). Routine immunization services costs and financing in China, 2015. Vaccine, 36(21), 3041-7. 10.1016/j.vaccine.2018.04.008	4	China	BCG, MR, MMR, HepB, DTP, DT, OPV, IPV, JE, Meningococcal
Zengbe-Acray, P., Douba, A., Traore, Y., Dagnan, S., Attoh-Toure, H., & Ekra, D. (2009). Coûts de la riposte vaccinale contre la fièvre jaune à abidjan, 2001. Sante Publique, 21(4), 383–391.	2	Cote d'Ivoire	YF

[x] These resources were extracted with additional information provided by Suharlim, C. and Menzies, N. (2018). Personal communication.

*DT = Diphtheria and tetanus toxoids, pediatric formulation; DTaP = Diphtheria and tetanus toxoids and acellular pertussis vaccine, pediatric formulation; DTP = Diphtheria and tetanus toxoids and whole-cell pertussis vaccine, pediatric formulation; HepB = Hepatitis B Vaccine; Hib = Haemophilus influenzae type b; HPV = Human Papillomavirus; IPV = Inactivated Poliovirus Vaccine; JE = Japanese Encephalitis; MCV = Measles antigen-containing vaccines; MMR = Measles, Mumps & Rubella Vaccine; MR = Measles-rubella Vaccine; OPV = Oral Polio Vaccine; PCV = Pneumococcal Conjugate Vaccine; PCV7 = Pneumococcal Conjugate Vaccine (7-valent); PCV10 = Pneumococcal Conjugate Vaccine (10-valent); PCV13 = Pneumococcal Conjugate Vaccine (13-valent); Tetanus & diphtheria Vaccine, adult/adolescent formulation; TT = Tetanus Toxoid; YF = Yellow Fever

** EPI Costing and Financing Project (EPIC)

*** Highly Extensible Resource for Modeling Event-driven Supply chains (HERMES) Framework

† ProVac Initiative

†† Cervical Cancer Prevention and Control Costing (C4P) tool demonstration for planning and costing nationwide HPV vaccination programs

††† Introduction of Cholera Vaccine in Bangladesh (ICVB)

‡ Project Optimize

‡‡ HPV Vaccines: Evidence for Impact project

‡‡‡ Project to Support PAV (EPI) to strengthen the management, reliability and quality of the health system in Mozambique

ANNEX 4. EXTRACTED VARIABLES

Below is a list of variables initially extracted; additional contextual information, descriptor columns and other information was added to each extracted record during the data cleaning stage. Some variables initially extracted were not used in the public versions of the IDCC and have been omitted below for clarity. See the "Data Cleaning" section for more information.

Background
Record ID
Reference
Region
Country
Endemic status
Geographic setting
Other contextual information
Unit costs
Cost per capita with and without vaccine
Cost per dose with and without vaccine
Cost per person in the target population with and without vaccine
Number of persons in "cost per person in target population" calculation
Cost per FIC with and without vaccine
Definition of FIC
N. of children included in FIC calculation
Other unit cost(s) reported
Disaggregated costs
Vaccines
Entire EPI schedule?
New vaccine introduction?
Vaccines costed
Number of doses included in costing study
Coverage rate of vaccine(s)
Number of doses delivered in study
Delivery site
Routine or SIA
Delivery sector
Target delivery population
Study design and methodology
Study objective/purpose
Study design
Study type
Utilization of Common Approach?
Timeframe

Perspective
Cost data source(s)
Sample unit
Sample size
Number of sampled facilities
Sampling strategy
Economic, financial, or fiscal costs
Full or incremental costing
Introduction/startup and/or recurrent/ongoing costs
Costing methodology
Data analysis strategy (cost aggregation, weighting, averaging)
Methods for annualization of capital items
Discount rate (capital items)
Methodology for allocation of shared costs
Reported currency and conversion
Reported currency year
Reported currency (code)
Original currency (code)
Currency exchange method
Currency exchange rate (original per 1 USD)
Cost categories included
Paid human resources included?
Volunteer human resources included?
Per diem and travel allowances included?
Cold chain equipment and their overheads (installation, energy, maintenance, repairs) included?
Vehicles, transport and fuel included?
Program management included?
Training and capacity building included?
Social mobilization and advocacy included?
AEFI and disease surveillance included?
Buildings, utilities, other overheads and/or shared costs included?
Vaccines included?
Vaccine supplies included?
Waste management included?
Other supplies and recurrent costs included?
Other costs included?
Shared cost items included?
Reported cost exclusions (describe)
Supply chain only?
Scale (pilot/project or national)

Highest level of costs included
Findings
Recurrent costs
Capital costs
Costs by level
Cost categories (totals)
Paid human resources
Volunteer human resources
Per diem and travel allowances
Cold chain equipment and their overheads (installation, energy, maintenance, repairs)
Vehicles, transport and fuel
Program management
Training and capacity building
Social mobilization and advocacy
AEFI and disease surveillance
Buildings, utilities, other overheads and/or shared costs
Vaccines
Vaccine supplies
Waste management
Other supplies and recurrent costs
Other costs
Sensitivity and Uncertainty
Sensitivity analysis (only for delivery cost info)
Sensitivity analysis description
Uncertainty Remarks
References to follow up

ANNEX 5. QUALITY ASSESSMENT

Below we describe the guiding principles, procedure and scoring for the quality assessment of each resource.

Principles

- We aimed for a parsimonious set of meaningful quality criteria to develop a rating for each resource, rather than a laundry list of items. With the intention of striving for inclusion of costing resources that are most relevant, useful, and appropriate for country policymakers to use for planning and budgeting immunization programs, our criteria and scoring are somewhat forgiving. We aimed to identify "technically acceptable" resources for our target audience.
- Our set of quality criteria are based on a number of existing checklists (Evers et al. 2005; Drummond et al. 1997; Husereau et al. 2013; Avenir Health 2015; Global Health Cost Consortium 2017; Constela et al. 2016; Pegurri et al. 2005).

Procedure

- Questions are grouped in three areas: methodological rigor and reporting standards (8 items), uncertainty of results (3 items), and risk of bias and limitations (3 items) (Table 14. Extractors answered each of the questions about the resource at time of extraction based on the information filled out in the data extraction sheet.
- The quality scoring was quality reviewed as part of the data extraction tool, and proposed scoring changes were reviewed and agreed upon by the original extractor.
- One investigator reviewed all quality ratings against their respective data extraction and against that of the other reviewers, and adjusted scoring to ensure interrater reliability.

Scoring

- Each item was given an individual score of 1 (lowest), 2, or 3 (highest); for some items there was also a "not applicable" option.
- Scores for all items were summed and averaged (with equal weighting of all categories and questions), excluding any "not applicable" answers, to produce a final score for each resource on the same 1 to 3 scale (Table 1).

Table 1. Quality assessment scoring

Category		Question	Scoring
Methodology and reporting	Quality of input data/data source	Were primary data used for all cost data? (note: if primary data were not used at all the resource should be excluded) *(see Note A)*	1 Partially 2 Mostly 3 Fully n/a Source not reported (NR)
	Sample strategy in relation to conclusions and generalizability	Were the conclusions and generalizability of findings appropriate given the sampling strategy?	1 No 2 Mostly 3 Fully n/a Conclusions not reported at all or for the costing portion of the study; sampling strategy not reported
	Data analysis strategy	Were statistical tests used and confidence intervals (CIs) reported?	1 No statistical test/CIs reported 2 Either statistical test or CI reported 3 Both reported
	Allocation of shared costs	If shared costs were included, were methods for allocating them described?	1 No/Shared costs excluded with no justification/shared costs not mentioned 2 Partly 3 Fully n/a Shared costs excluded with justification
	Annualization of capital costs including discount rate	Were capital items annualized using appropriate lifetimes and discount rates? *(see Note B)*	1 No/Annualization of capital items excluded with no justification 2 Partly 3 Fully n/a Annualization of capital items excluded with justification
	Replicability	Were methods described well enough that the study could be replicated with the exact same results?	1 No/methodology not reported 2 Partly 3 Fully
		Was the purpose of the study clearly defined?	1 No/purpose not reported 2 Partly 3 Fully
	Reporting of results	Is the type of cost reported clear (economic, financial, fiscal; incremental, full)?	1 No 2 Partly 3 Fully
	Accuracy of reported findings	Does the sum of capital costs + recurrent costs equal reported total costs?	1 No 2 Yes, for some of the findings reported 3 Yes, for all findings reported n/aCapital or recurrent or total costs are NR
	Accuracy of reported findings	Does the sum of all cost categories equal reported total costs?	1 No, for all or most of the findings reported 2 Yes, for most of the findings reported

			3 Yes, for all findings reported n/a Cost categories and/or totals are NR
Uncertainty of results	Sensitivity analysis	If done, did the sensitivity analysis (SA) include all reasonable scenarios affecting costing results? *(see Note C)*	1 No sensitivity analysis done 2 Partly 3 Fully n/a SA was done, but is not applicable to delivery costs.
	Missing cost categories	Were all the important and relevant inputs identified and valued given the stated perspective? Are any relevant cost categories (line items or activities) missing that are not noted and justified as excluded? Is it clear what items are included in the unit costs? *(see Notes D and E)*	1 Yes, more than half are excluded/unclear 2 Yes, less than half are excluded/not completely clear 3 No, all/most of the relevant cost categories included and clear
	Contextual factors	Are there any contextual factors related to the study setting that have not been accounted in the methods and/or results?	1 Yes, some 3 No n/a No contextual factors were reported
Risk of bias/ limitations	Author-stated limitations and/or possible areas of bias	Are limitations and potential sources of bias presented? If yes, do they make you question the findings?	1 Presented and I fully question the findings / no limitations presented 2 Partially question the findings 3 Yes, but they don't make me question the findings
	Extractor-perceived limitations	Are there any extractor-perceived limitations that make you question the findings?	1 Yes, and I fully question the findings 2 Some that make me partially question the findings 3 None, or yes but they don't make me question the findings

Note A – High quality primary data: Primary data are data collected in the study country by the researcher him/herself explicitly for research purposes.

Note B — Appropriate lifetimes for annualization:

- In general, 5-10 years is appropriate for everything except buildings.
- Buildings (health facilities, cold/freezer rooms) may have a useful life of 15-50 years.
- Computers may have a shorter useful life, around 3 years.
- WHO CHOICE guidance also recommends around 10 years for most items, so 5-10 years is good for most items except buildings. For a list of average reported useful lives by WHO CHOICE, see: http://www.who.int/choice/cost-effectiveness/inputs/capital_goods/en/

Note C — Reasonable scenarios for sensitivity analysis: It is appropriate to do a sensitivity analysis on any uncertain components of the costing. The discount rate is always uncertain, but other inputs may also be the price and quantity used to calculate the costs of each cost item (see list of cost categories). Cost items that account for the largest share of the unit cost are usually most important (generally

human resources, cost of vaccine) since changes to items which account for a small percentage of total cost are unlikely to have a large impact on results.

Note D — Key cost categories:[11]

Relevant/key cost categories include:

- Paid human resources (national and sub-national levels; including supervision
- Volunteer human resources
- Per diem and travel allowances
- Cold chain equipment and their overheads (installation, energy, maintenance, repairs)
- Vehicles, transport and fuel
- Program management (M&E, information systems, planning, etc.)
- Training and capacity building
- Social mobilization and advocacy
- Adverse event following immunization (AEFI) and disease surveillance
- Buildings, utilities, other overheads and/or shared costs
- Vaccines
- Vaccine supplies
- Waste management
- Other supplies and recurrent costs
- Other

Note E — Missing cost categories:

Cross reference list of cost items with purpose of the study. For example, if the purpose of the study was to predict cost implications for the cold chain of adding a new vaccine, it would be reasonable for vaccine supplies to be excluded from the study. It would not be reasonable for items related to cold storage (cold boxes, for example) to be excluded.

[11] Cost categories used in this review were developed based on two sources: WHO 2006 and Brenzel 2013.