An Investment Case for Malaria Elimination in Papua New Guinea

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APLMA ASIA PACIFIC LEADERS MALARIA ALLIANCE

PAPUA NEW GUINEA DEPARTMENT OF HEALTH

UCSF Global Health Sciences Global Health Group

REPORT

An Investment Case for Malaria Elimination in Papua New Guinea

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Cover photo: Gerehu Markets Port Moresby, Papua New Guinea. Photographing market life at Gerehu. Children (pikinini's) and women make up the majority of the market.

Photo by Ness Kerton for AusAID. (The photo shown is a cropped version of the original.)

The **Malaria Elimination Initiative (MEI)** at the University of California San Francisco (UCSF) Global Health Group believes a malaria-free world is possible within a generation. As a forward-thinking partner to malaria-eliminating countries and regions, the MEI generates evidence, develops new tools and approaches, documents and disseminates elimination experiences, and builds consensus to shrink the malaria map. With support from the MEI's highly-skilled team, countries around the world are actively working to eliminate malaria – a goal that nearly 30 countries will achieve by 2020.

shrinkingthemalariamap.org

Contents

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Key Terms and Acronyms

ACT	Artemisinin-based combination therapy
ADB	Asian Development Bank
AIP	Activity implementation plan
APLMA	Asia Pacific Leaders Malaria Alliance
AUD	Australian dollar
BCC	Behavior change communication
CSR	Corporate social responsibility
DALY	Disability-adjusted life year
DDT	Dichlorodiphenyltrichloroethane
DOT	Department of Treasury
EMMIE	Elimination of Malaria in Mesoamerica and Hispaniola
ESP	Elimination Scenario Planning
G6PDd	Glucose 6-phosphate dehydrogenase deficiency
GDP	Gross domestic product
Global Fund	Global Fund to Fight AIDS, Tuberculosis and Malaria
GoPNG	Government of Papua New Guinea
HFG	Health function grant
HMM	Home management of malaria
HSIP	Health System Improvement Program
IMR	Papua New Guinea Institute for Medical Research
IP	Inpatient
IRS	Indoor residual spraying
ITN	Insecticide-treated net
LLIN	Long-lasting insecticidal net
LNG	Liquefied Natural Gas
MDA	Mass drug administration
MEI	Malaria Elimination Initiative
NCD	National Capital District
NDoH	National Department of Health
NEFC	National Economic & Fiscal Commission
NHIS	National Health Information System
NMCP	National Malaria Control Program
NMSP	National malaria strategic plan
OOP	Out-of-pocket
OP	Outpatient
OSF	Oil Search Foundation
PAR	Population at risk
PNG	Papua New Guinea
PSI	Population Services International
RAM	Rotarians Against Malaria
RDT	Rapid diagnostic test
RIGFA	Reform of Intergovernmental Financing Arrangements
RMTF	Regional Malaria and Other Communicable Diseases Trust Fund
RPHSDP	Rural Primary Health Services Delivery Project
ROI	Return on investment
SP	Sulfadoxine-pyrimethamine
USD	United States dollar
VLY	Value of additional life year
WHO	World Health Organization

Executive Summary

Through the collective action of national and local governments, malaria program implementers, and research partners, Papua New Guinea (PNG) has witnessed significant reductions in its malaria burden. To sustain its momentum, PNG in 2015 aligned itself with the regional goal of making Asia Pacific malaria-free by 2030. Once achieved, malaria elimination would be a historical achievement for PNG and the world.

PNG's gains, however, are fragile and threatened by declining domestic and donor support, budget deficits, and persistent health system challenges. Without adequate resources, malaria interventions would be scaled down, creating an opportunity for malaria to resurge. To turn this tide, the National Department of Health and the UCSF Global Health Group's Malaria Elimination Initiative developed an investment case to generate economic evidence that highlights the benefits of malaria elimination.

This study found that malaria elimination will cost a median USD 425 million (range USD 373-481 million) between 2016 and 2030. Targeting of interventions and efficiency improvements can modestly reduce this cost. Compared to a business as usual scenario, interrupting local transmission can save over 7,000 lives (range 4,798-12,133) and avert over 3.86 million cases (range 2.6-6.7 million). Malaria elimination has an incremental return on investment of 9:1 with over USD 1.92 billion (range 1.3-3.3 billion) in economic benefits over 15 years.. Malaria elimination has an incremental return on investment of 9:1 with over USD 1.92 billion in economic benefits over 15 years.

By preventing resurgence, malaria elimination results in major cost savings to the health system and generates broader economic benefits by saving lives and increasing productivity. With enough political and financial commitment, PNG can look forward to a prosperous and malaria-free future.

REPORT

ECONOMIC BURDEN

Productivity losses due to malaria morbidity and mortality (82%)

Direct health system costs (17%)

- Prevention
- Treatment
- Monitoring and surveillance
- Program management

Direct household cost (1%)

THE TOTAL ECONOMIC BURDEN OF MALARIA IN 2015

USD 90 million

PRESUMED AND CONFIRMED

MALARIA CASES(2015): 553,103

This is second highest in the Asia Pacific region after India.

Source: WHO's World Malaria Report 2016

MALARIA DEATHS(2015): 163

Malaria was responsible for 2% of all deaths and 3% of all disability-adjusted life years (DALYs) lost in 2015.

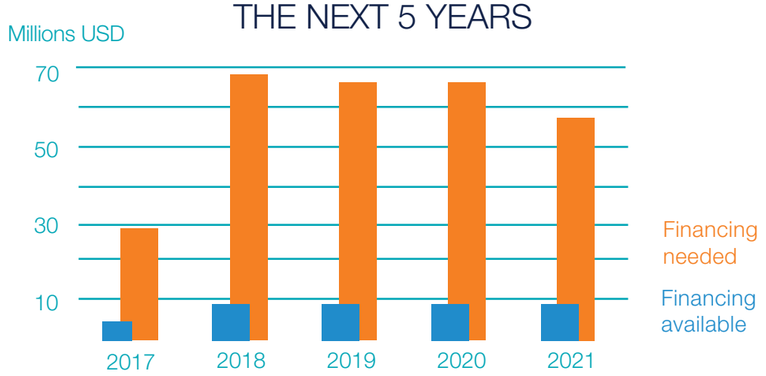
Source: Institute of Health Metrics and Evaluation

COST OF ELIMINATION

USD 425 million (2016-2030)

Range USD 373-481 million

FUNDING GAP FOR THE NEXT 5 YEARS



OPPORTUNITIES FOR RESOURCE MOBILIZATION

NEW REVENUE

- Domestic funding
- Continued external support
- Innovative financing mechanisms

EFFICIENCY IMPROVEMENTS

- Technical
- Allocative
- Financial
- Procurement reform

BENEFITS & RETURN ON INVESTMENT (ROI)

Malaria elimination not only saves lives, it contributes to the social and economic wellbeing of individuals and communities.

MALARIA CASES AVERTED:
3.86 MILLION

MALARIA DEATHS AVERTED:
7,067

Savings from healthcare costs and wage and productivity losses averted	Incremental cost
USD 1.92 BILLION	**USD 197 MILLION**

ROI

9:1

This is same as investment in community healthworker (9:1), and higher than investing in cardiovascular disease research (5:1)

Source: Jamison D, et al. Investing in health: the economic case. Report of the WISH Investing in Health Forum 2016.

Introduction

Papua New Guinea (PNG) has achieved significant gains against the malaria over the last fifteen years. Malaria cases have been reduced by 68%, and deaths due to malaria have been cut by almost three-fourths (Figure 1).[1] This progress is attributed to increased coverage and access to effective diagnosis, treatment, and vector control interventions, particularly long-lasting insecticidal nets (LLINs) through the support of the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund).[2–4]

Building on the country's momentum, the government of PNG (GoPNG), through its Minister of Health and HIV/AIDS, aligned itself with the Asia Pacific Leaders Malaria Alliance (APLMA) in 2015 and its goal of making the Asia Pacific region malaria-free by 2030.[5,6] Also in 2015, PNG became the latest country to join the Asia Pacific Malaria Elimination Network, a community of Asia Pacific nations and stakeholders committed to regional malaria elimination.[7] However, malaria remains a major public health threat in the country, and PNG's progress is imperiled by declines in funding for malaria and competing domestic health priorities. To reverse the trend of decreasing financial and political commitment and to prevent resurgence, policymakers responsible for resource allocation must be convinced of the economic returns of maintaining PNG's gains against malaria.

This report presents an investment case for malaria elimination in PNG. The National Malaria Control Program (NMCP) of the National Department of Health (NDoH) In collaboration with the Malaria Elimination Initiative (MEI) of the University of California, San Francisco Global Health Group assessed the current and future costs of malaria control and elimination in PNG and estimated the economic returns associated with interrupting local malaria transmission by 2030. This report also provides a landscape of malaria financing in the country with estimates of financial need and potential sources of sustainable funding.

The burden of malaria

PNG is one of the most ecologically, linguistically, and culturally diverse countries in the world. PNG's land area measures 452,000 km^2 and includes offshore islands and coral atolls, coastal swamps, rainforests, river and upland valleys, and mountains that reach an excess of 4,000 m.[8–10] The climate, though tropical, varies by altitude. PNG experiences northeast monsoon (dry season) from December to March and southwest monsoon (wet season) from May to November.[9,10]

Figure 1. Presumed and confirmed malaria cases and reported deaths in PNG, 2000-2015[1]

Malaria remains a leading cause of morbidity and mortality in PNG. According to the World Malaria Report of the World Health Organization (WHO), the number of presumed and confirmed cases of malaria in 2015 was 553,103, the second highest in the Asia Pacific region after India; malaria deaths were at 163.[1] According to the Global Burden of Disease Study, malaria in PNG was responsible for 2.36% of all deaths and 3.08% of all disability-adjusted life years (DALYs) lost in 2015.[11] Malaria, along with other neglected tropical diseases, was in the top 10 causes of DALYs lost in 2000 and 2015 (Figure 2). Malaria in PNG affects primarily children under 15 years (57% of cases), as in most endemic countries.[4,8] Among the provinces, Milne Bay, West Sepik, New Ireland, West New Britain, and East Sepik had the highest incidence of clinical malaria in 2015.[12]

Altitude, which is indirectly associated with temperature, determines malaria transmission intensity in PNG (Figure 3).[4,13–16] In the islands and lowlands where over 60% of the population live, transmission is year-round with limited seasonality.[4,8,13] In the highlands, malaria is seasonal, with a peak during the late dry and early wet seasons (i.e., March to August).[17–19] Localized outbreaks resulting in severe morbidity have been recorded in areas between 1,200-1,700 m above sea level usually after the rainy season.[13,17,18]

Of malaria mono-infections, 40% are due to *Plasmodium falciparum* and 21% are due to *P. vivax*.[1] The remaining 39% of malaria infections are mixed or caused by *P. malariae* and *P. ovale*, which are found in PNG but remain rare.[1,4,8,19] Prior to nationwide LLIN distribution, parasite prevalence in a national sample was comparable to rates reported in Africa (range of 0-49.7%, 12.1% weighted average).[13,20] At the end of 2010, parasite prevalence in the general population was estimated to be 4.8%, and by 2014 it was at 1.8% in the general population and 3.0% among children less than five years.[2,21,22] Despite this progress, the entire population remains at risk for malaria, with 94% considered to be at high risk.[1]

Figure 2. Leading causes of disability-adjusted life years lost in PNG, 2000 and 2015[11]

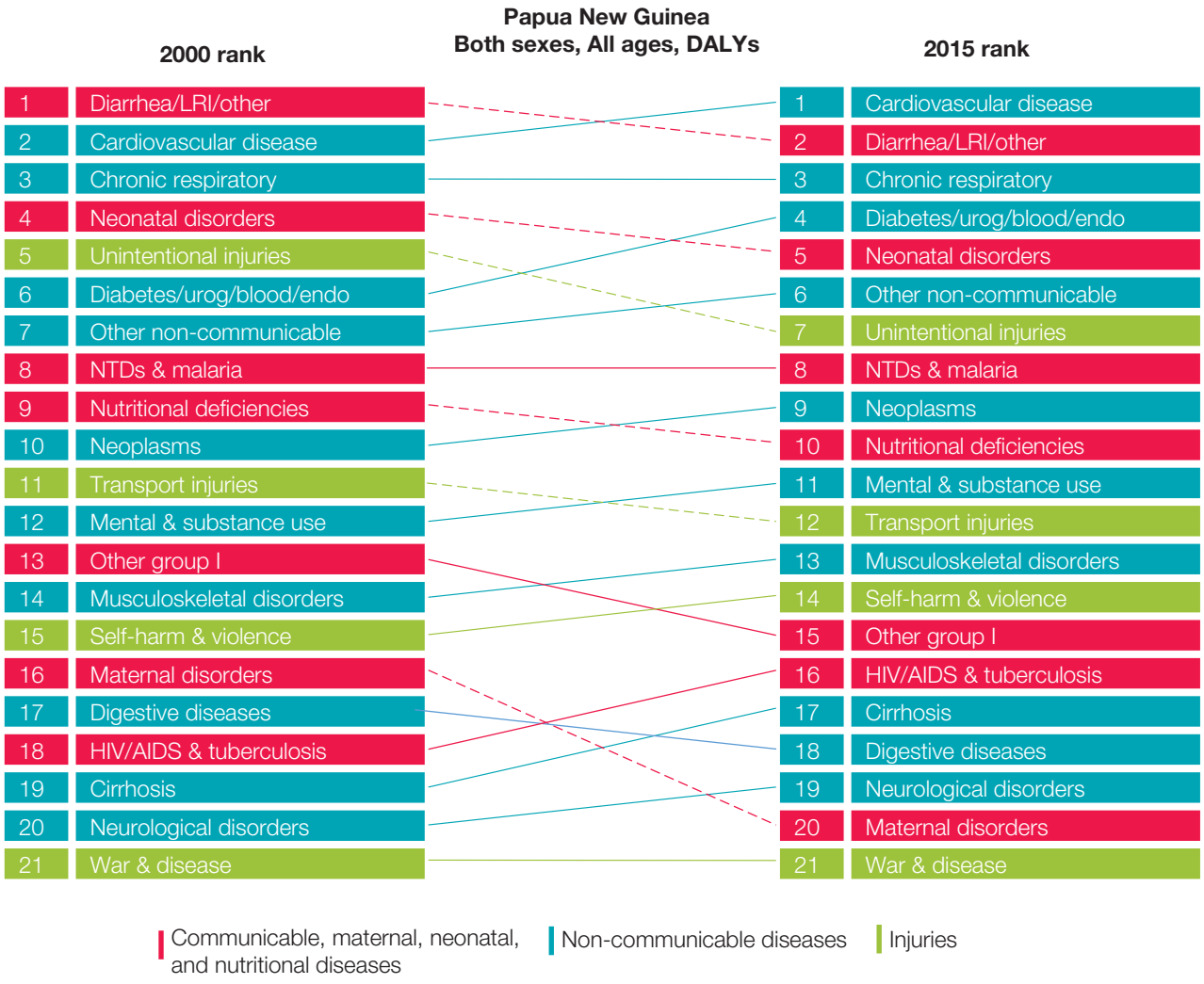
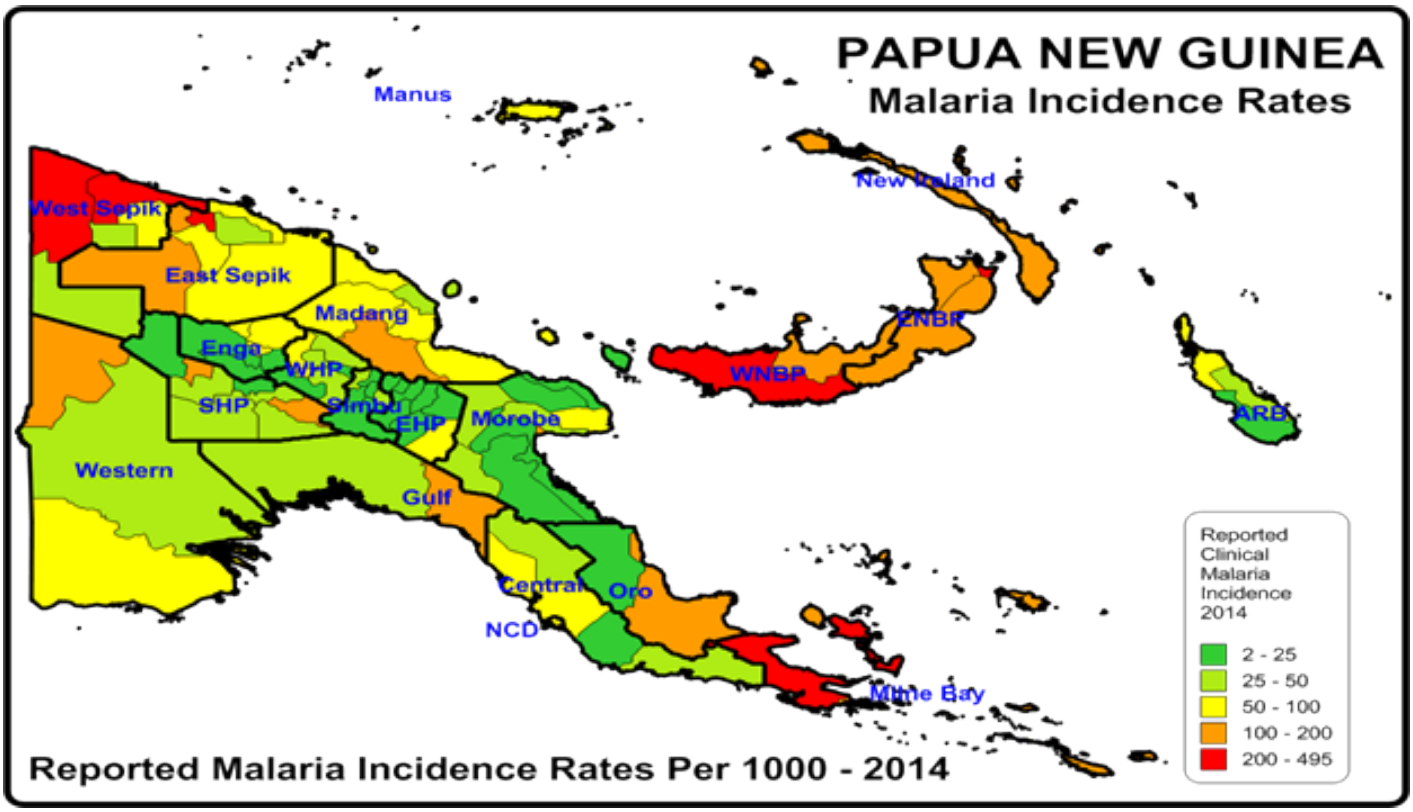


Figure 3. Malaria incidence map of PNG, 2014*



*Provided by Rotarians Against Malaria

Anopheline vectors are distributed heterogeneously across the country. The main vectors are *Anopheles punctulatus, A. koliensis*, and *A. farauti* that bite outdoors between early evening to the early hours of the morning,[1,8,23,24] though many other species have been incriminated for transmitting malaria.[23] Because of differences in preferred breeding sites, vectors can vary among villages.[24]

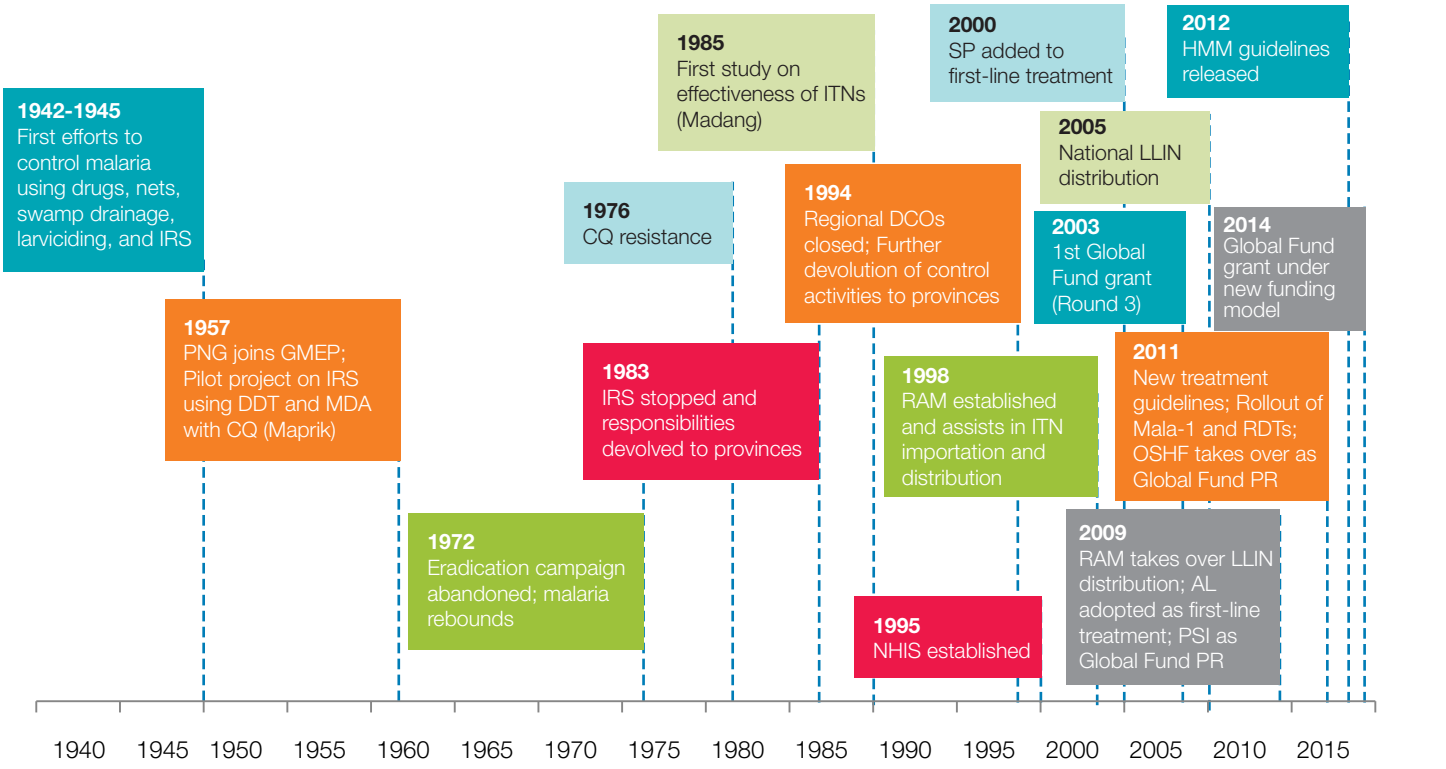
Malaria control: then and now

The early years

The first large-scale attempt to control malaria dates back to the 1930s when larvivorous fish were introduced in all anopheles breeding sites along a 72-mile coastal strip in New Ireland Province.[25] Prior to this, there were smaller scale attempts to control, which included mass treatment of villages with quinine, oiling of swamps, and home screening.[25] The use of mosquito nets was also encouraged at this time, particularly among Australian servicemen who were in Rabaul during World War I. However, it was not until the latter years of World War II that control measures would be systematically carried out in PNG (Figure 4). Between 1942-1945, several malaria outbreaks overwhelmed ill equipped Australian troops fighting to regain Japanese-held territory. This forced Australians to use prophylaxis, personal protection measures (such as suitable clothing and mosquito repellants), and mosquito nets. In 1944, troops used dichlorodiphenyltrichloroethane (DDT) for the first time to effectively control adult mosquito populations, including spraying by aircraft.[25,26] Malaria Control Units and Mobile Entomological Sections were also established, which followed servicemen on their campaigns and advised them on preventing malaria and other vector-borne diseases.[25,27] After the war, the following activities were scaled up: larviciding, outdoor spraying, and swamp drainage.[20,27]

In 1957, PNG joined the WHO's Global Malaria Eradication Programme (1955-1969).[28] In the same year, residual spraying with DDT and mass drug administration (MDA) using chloroquine were piloted in the Maprik district of East Sepik province. These interventions were later extended to larger endemic parts of the country, which made the NMCP the largest vertical program of the NDoH at that time.[8] Recognizing that elimination would not be achieved, PNG abandoned its plans in 1972, though spraying with DDT continued for several years, reaching high coverage in certain areas.[25,27] It was not until 1984 that national operations ceased after malaria control activities were delegated to provincial authorities.[25,27,29] Malaria quickly resurged; in areas such as the highlands,

Figure 4. Key dates and events in malaria control in PNG



the burden of disease reached or exceeded pre-control levels by the 1990s.[14,17,18,30,31]

When spraying stopped in the 1980s, treatment with chloroquine became the mainstay of the national malaria program.[8,29,32] Chloroquine-resistant and amodioquine-resistant *P. falciparum* were first detected in 1976 and 1986 respectively, though these medicines remained as the first-line treatment until 2000 when treatment guidelines were amended to specify sulfadoxine-pyrimethamine (SP) as first-line treatment.[8] Only a few years after, treatment failures (as high as 29% for *P. falciparum* and 12% for *P. vivax*) were being reported for the new SP regimen.[33]

One of the first trials demonstrating the impact of insecticide-treated nets (ITNs) on preventing *P. falciparum* malaria and reducing mosquito populations was conducted in Madang province in 1985 by the Papua New Guinea Institute for Medical Research (IMR).[34,35] By 1989, ITNs were being distributed in PNG, though in very low numbers.[27] Coverage rose when Rotarians Against Malaria (RAM) sold ITNs (donated by the Australian government to the NDoH) at a subsidized, slightly profitable price, primarily in the lowlands; proceeds were used to purchase and sell more ITNs.[8,27] Net retreatment with the insecticide permethrin became logistically and financially challenging, though limited studies did suggest that use of untreated nets had modest benefits.[36,37] Between 2000 and 2004, roughly 1.3 million ITNs were distributed through subsidized sales and community-based campaigns.[8,27,28]

Global Fund era

PNG received its first Global Fund grant (Round 3) in 2004 for USD 20.1 million. Funds were used to purchase and distribute roughly 2.3 million LLINs between 2005 and 2009 through the efforts of the NDoH, provincial governments, and RAM.[27] However, PNG did not achieve its goal of 80% LLIN ownership; by the end of 2009, only 64.6% of households reported owning an LLIN, and only 32.5% of those households reported using a LLIN in the previous night.[38]

In 2009, the country adopted its first national malaria strategic plan (NMSP) for 2009-2013.[28] In the same year, the NMCP amended its malaria treatment policy to include artemisinin-based combination therapy (ACT) as first-line treatment, with a 14-day primaquine regimen added for *P. vivax* infections.[39] The new policy also signaled the shift from presumptive diagnosis to the use of rapid diagnostic tests (RDTs) prior to treatment.[39–43] Despite these changes, however, nationwide rollout of ACTs and RDTs did not take place until 2011.[42] Also in 2009, PNG received its second Global Fund grant (Round 8), which supported RAM in its LLIN distribution campaigns. Population Services International (PSI) also received funding for behavior change communication (BCC) activities and pilot projects

for home-based management of malaria (HMM) in East Sepik and East New Britain provinces.[44] HMM was later expanded to West Sepik in 2014.

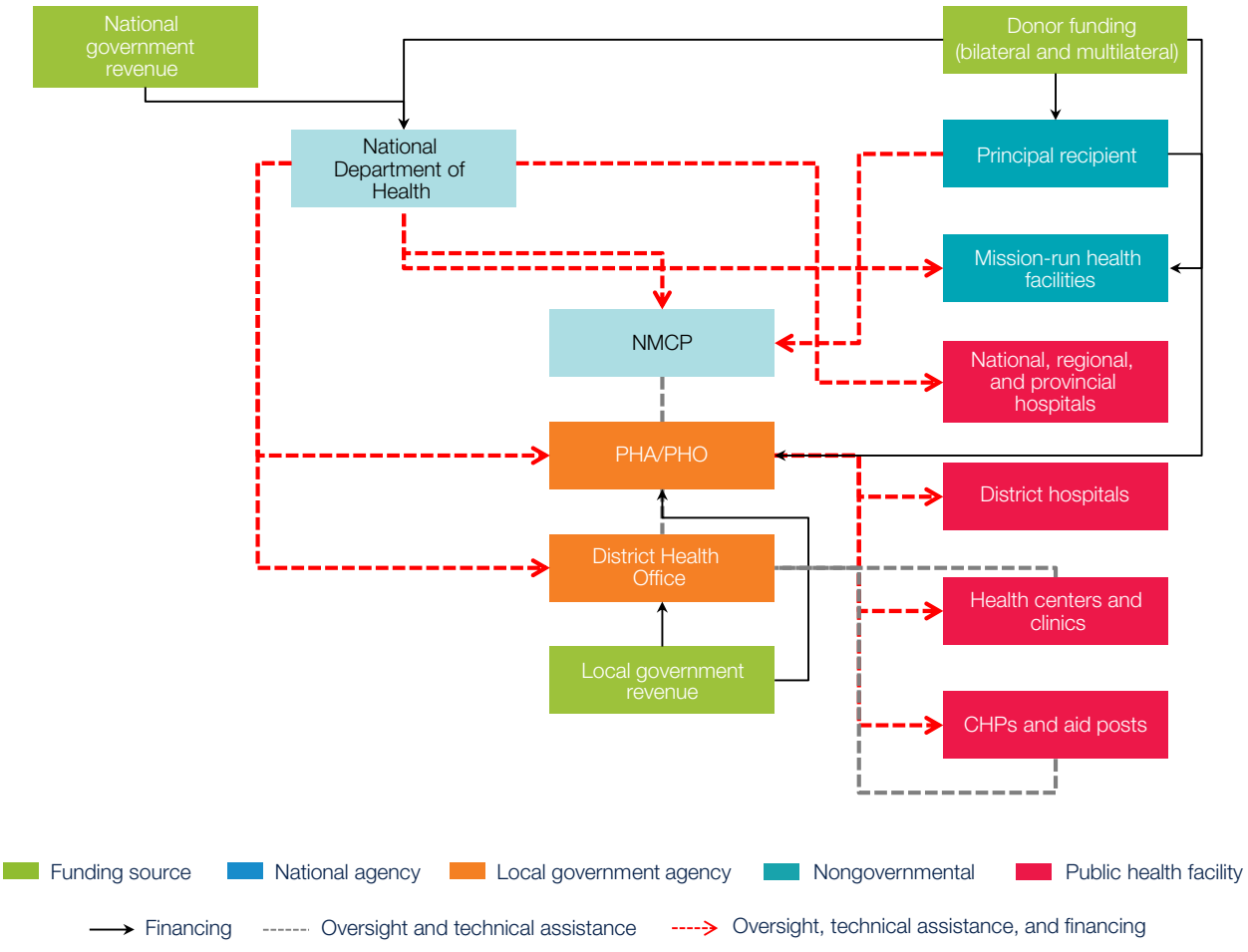
Two years into its new grant, PNG saw major improvements. LLIN ownership in 2011 among households rose to 81.8%, and reported use was at 48.3%.[3] IMR also reported single-digit population parasite prevalence.[2]

In 2011, the NDoH withdrew from its role as Global Fund principal recipient, giving way to Oil Search Health Foundation (now Oil Search Foundation [OSF]) to step in.[44,45] OSF helped in providing access to ACTs and RDTs and strengthening technical and operational capacity at all levels.[45] In just a few years, PNG again saw some notable progress. At the end of 2010, only 15% of health facilities reported having RDTs or functioning microscopy, and none had ACTs in stock.[43] By 2012, studies estimated that over half of surveyed health facilities had access to RDTs and ACTs, though availability was greater in larger health centers than aid posts serving rural and far-flung areas.[41] Case management practices also improved. In 2010, only 20% of fever cases were tested for malaria, though 96.4% of them were prescribed an antimalarial[40]; by 2012, 68.3% of fever cases were tested for malaria, and only 39% of fever cases were prescribed an antimalarial, including 98.2% of RDT-positive patients.[41]

2014 to present

Following a 2013 review of the malaria program[46], PNG adopted a new NMSP for 2014-2018, which builds on the progress from previous years. The NMSP aims to reduce annual parasite incidence from 154 cases per 1,000 in 2014 to 72 cases per 1,000 by 2018 to position the country for subnational elimination.[27] The release of the strategy coincided with the approval of a new Global Fund grant in early 2015. As principal recipients, RAM is using the funds to procure and distribute LLINs, and PSI is continuing its limited BCC program activities and moving the current HMM program toward integrated community case management. PSI is also in charge of hiring and maintaining selected malaria staff at the national, regional, and provincial levels, operational research, and monitoring and evaluation activities. The NDoH manages the procurement and distribution of antimalarials, RDTs, and microscopy supplies. Figure 5 provides an overview of the current malaria program in PNG.

Figure 5. Structure of the malaria program in PNG



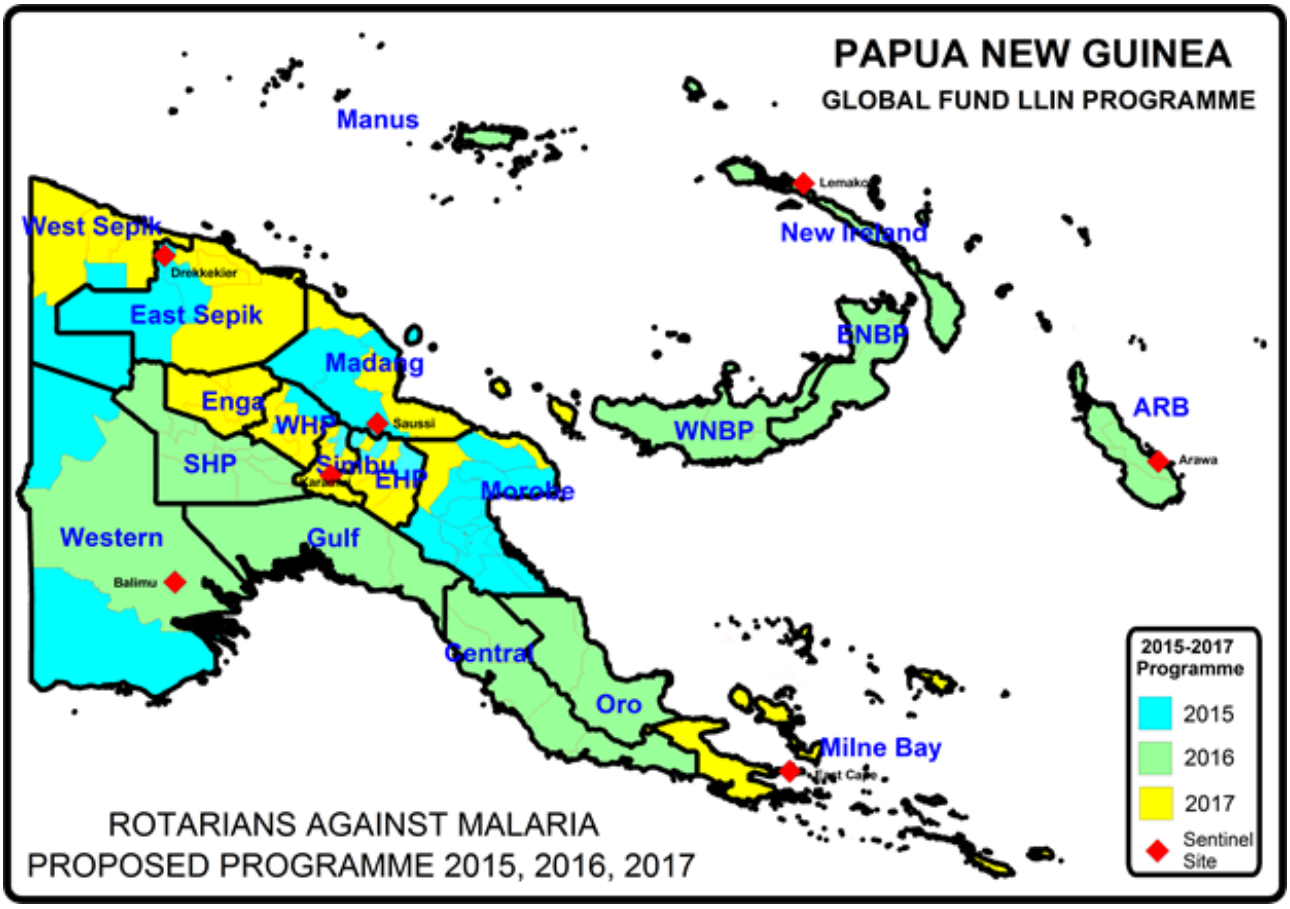
In 2015, PNG received additional support for its malaria program through the Australia-China-Papua New Guinea Pilot Cooperation on Malaria Control, commonly referred to as the "trilateral aid project".[47–49] This effort is a result of a 2013 agreement between Australia and China to jointly support development programs in PNG, including in the health sector.[47,48] The trilateral aid project aims to improve the diagnostic and laboratory services of the Central Public Health Laboratory, as well as to strengthen malaria operational research capacity through the IMR.[47] Australia has pledged AUD 4 million to the project over three years (2016-2018) while China provides technical experts to work closely with the Central Public Health Laboratory and IMR.[47–49]

Impetus for the investment case

The funding PNG received from the Global Fund for 2009-2014 was the largest any country received for malaria control outside of Sub-Saharan Africa.[44] However, Global Fund support for 2015-2017 was about 52% less per year than what PNG received during for its Round 8 grants (USD 13.08 million vs. USD 6.26 million per year).[50] This has led to significant changes to the malaria program, including a shift in LLIN distribution strategy. Instead of household distribution throughout the country as was previously done, RAM targeted LLINs to children under five in urban centers (Figure 6).[44] Similarly, PSI no longer expanded HMM to other provinces and instead continued operations in the three pilot provinces. PNG is expecting further cuts to its malaria program. Based on recently released Global Fund allocations for 2018-2020, PNG's allocation is 47% less compared to 2015-2018.[51]

Evidence suggests that ill-timed downsizing of malaria control programs due to withdrawal of financial and political support can lead to malaria resurgences, which PNG experienced in the past.[52] When indoor residual spraying (IRS) operations were halted in the 1980s, malaria prevalence, particularly in the highlands, rapidly rose to very high levels that left populations worse-off than before the initiation of control measures.[17,18,30–32]

Figure 6. Proposed LLIN distribution in PNG*



*Provided by Rotarians Against Malaria

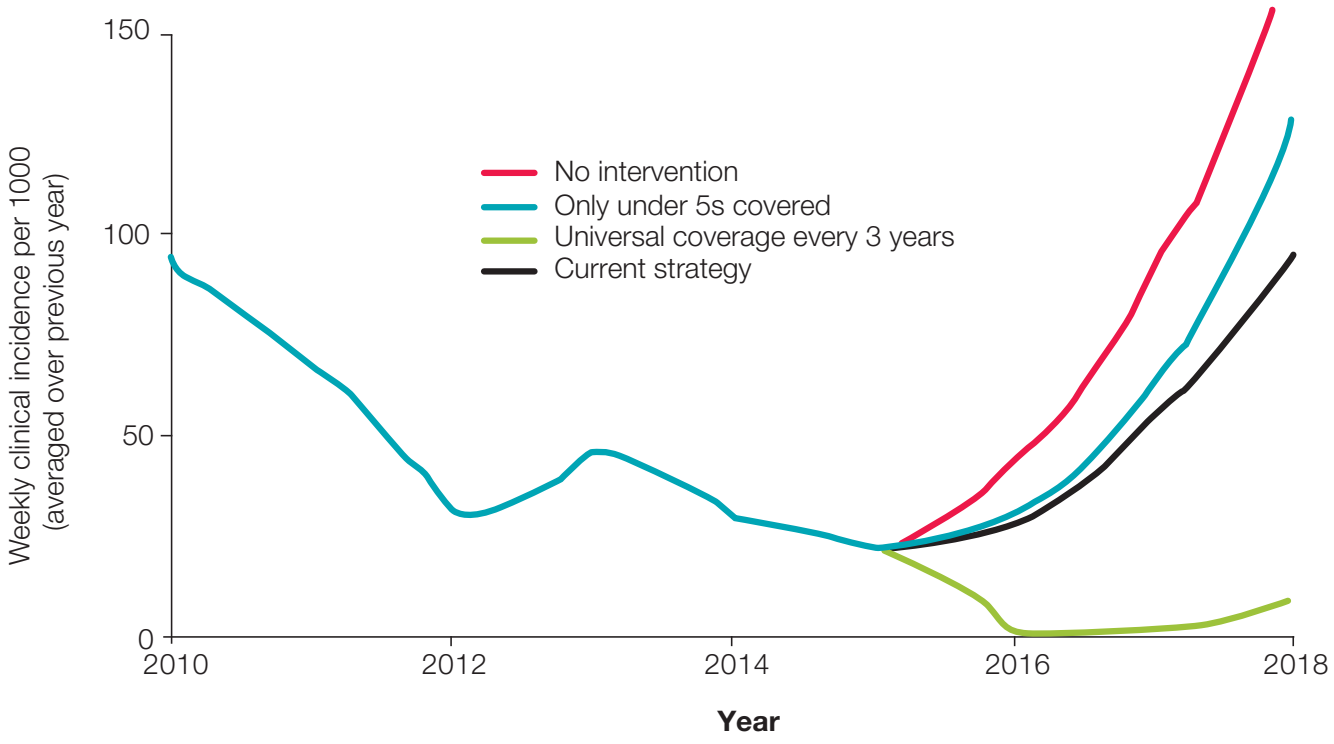
Multiple studies indicate that the threat of malaria rebounding is real. Figure 7[a] shows projections from the Elimination Scenario Planning (ESP) exercise conducted by Imperial College London, Clinton Health Access Initiative, and WHO. The figure suggests malaria incidence will increase under the current targeted LLIN distribution strategy.[53] If further cuts to the malaria program occur, PNG faces worse prospects. Another study found that though biting rates have decreased due to the high LLIN coverage, parasite prevalence in anopheles mosquitoes has increased between 2010 and 2011, suggesting a serious risk of resurgence if vector control measures are not maintained at the same levels.[24] Plateauing malaria incidence rates from sentinel sites throughout PNG also indicate that the impact of LLINs has likely reached a peak, and new interventions will be needed to make further gains against the disease.[56]

PNG is clearly at a critical point. Sustained or increased investment can help PNG maximize its gains and allow it to set sights on national elimination. On the other hand, a withdrawal of support can cause costly and deadly malaria resurgences that squander any previous investments in malaria control. The options facing the country could not be starker. PNG's gains are fragile, and renewed commitment is critical to further reducing the burden of malaria in the country.

To support PNG's efforts, this investment case was commissioned to investigate the economic rationale for investing in malaria control and elimination in PNG. The country-specific evidence generated by this investment case can inform malaria program budgeting and strategic planning, domestic and donor resource mobilization, and advocacy.

a A mathematical transmission model for malaria developed by researchers from Imperial College London and parameterized using epidemiological and intervention coverage data from PNG was used to generate the epidemiological projections in the ESP.[53] The malaria transmission model has been described in detail in the literature[54,55] and applied to other malaria-eliminating contexts.

Figure 7. Projections of clinical incidence from 2015 to 2018 under different scenarios for LLIN distribution[53]



Methods

This investment case for malaria elimination estimates the economic burden of malaria in 2015; projects the financial requirements of malaria elimination through 2030; values the economic and financial returns of malaria elimination compared to alternative scenarios; and explores feasible and sustainable financing options for PNG. To accomplish this, the investment case leverages multiple methodologies and data sources, which are described in full in Annex 2. All monetary figures are expressed in 2015 constant US dollars (USD).

Economic burden of malaria

Using a societal perspective and cost of illness approach, we evaluated the economic burden of malaria in 2015.[57,58] We specifically estimated (1) direct health system costs, (2) direct household costs, and (3) indirect costs (Table 1).

Table 1. Framework for estimating the economic burden of malaria in PNG

Direct health system costs	Direct household costs	Indirect costs
National and subnational expenditures on malaria interventions	Out-of-pocket expenditures for treatment seeking	Productivity losses among malaria patients and caregivers Value of life years lost due to premature death

Direct health system costs

We estimated the cost of malaria interventions at the national and subnational levels by analyzing data on domestic and external spending on four inputs and seven activity categories (Table 2). After estimating separately, national and subnational costs were added together to generate a total direct health system cost for 2015.

To estimate national health system costs, we analyzed expenditure data from the agencies shown in Figure 5. When expenditures were unavailable, we relied on budget figures and secondary sources such as peer-reviewed or grey literature (Table 3). For example, in estimating testing and treatment costs, we used findings from a previous health facility costing study and outpatient (OP) and inpatient (IP) malaria case numbers reported in the National Health Information System (NHIS).[59] Input costs were apportioned by activity using self-reported hours collected during key informant interviews.

Table 2. Categories for direct health system costs

Cost by source	Cost by input	Cost by activity
Domestic	Capital	Prevention and vector control
External	Personnel	Diagnosis
	Consumables	Treatment and prophylaxis
	Services	Surveillance and epidemic management
		Monitoring and evaluation
		Information, education, and communication
		Program management

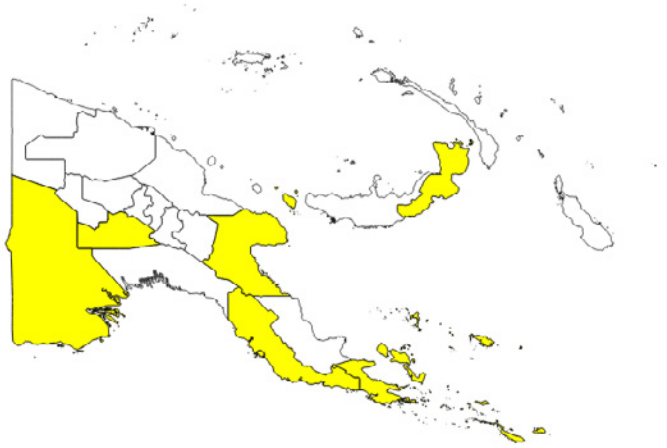
Table 3. Inputs and assumptions used in various analyses

Name	Value	Source
Cost (USD)		
Cost of OP malaria treatment	3.25	59
Cost of IP malaria treatment per day	53.36	59
Cost of RDT per case	0.67	NMCP[a]
Cost of P. *falciparum* medicines per OP case	0.76	NMCP[a]
Cost of P. *vivax* medicines per OP case	0.78	NMCP[a]
Cost of antimalarials per IP case	6.52	NMCP[a]
Cost per LLIN distributed	6.17	RAM[a]
Cost per person treated through MDA	0.54	60
Annual cost of training per capita	0.36	27[a]
Annual cost of surveillance per capita	0.02	27[a]
Annual cost of IEC per capita	0.06	27[a]
OOP per OP malaria case	7.78	61
OOP per IP malaria case	1.39	61
Economics		
GDP per capita (USD)	2,336.52	62[a]
GDP per capita per day (USD)	7.49	62[a]
Coefficient for VLY calculation	2.2	63
Discount rate (%)	3.0	[b]
Mortality		
Life expectancy at 40 (years)	29.36	64
Epidemiology and length of disease		
Proportion of malaria cases that are treated OP	0.84	Model
Proportion of malaria cases that are treated IP	0.16	Model
Length of OP malaria case (days)	4.82	65
Length of IP malaria case (days)	8.75	65
Length of IP malaria hospitalization	5.00	[b]

[a] Calculated by authors using data from the references cited. [b] Assumption made by authors. IEC – Information, education, and communication.

We used budget data in activity implementation plans (AIPs) from seven sample provinces (i.e., Central, East New Britain, Milne Bay, Morobe, National Capital District [NCD], Southern Highlands, and Western; (highlighted provinces in Figure 8) to calculate malaria spending at the subnational level.[b] These provinces were sampled in consultation with the NMCP based on their representativeness of PNG's 22 provinces on selected criteria including malaria burden and population density. To get a total subnational cost, we added the cost from the sampled provinces and the product of mean cost per capita and total population in the unsampled provinces. We adjusted the budget figures from the AIPs using two indicators in order to estimate actual expenditure for malaria in 2015 (see Annex 2 for more details).

Figure 8. Sampled provinces for investment case micro-costing*



Direct household costs

Malaria exacts a significant financial burden on households. Malaria patients often pay for transportation to access health facilities, diagnostic services, and medicines. In PNG, though testing for malaria and antimalarials are free according to government policy, malaria patients still pay out-of-pocket (OOP).[61,66]

To estimate direct household costs on malaria, we multiplied the number of reported OP and IP malaria cases in 2015 by the mean OOP spending (separately for OP and IP cases) from a 2012 study (Table 3).[61]

b Data collected at the provincial level includes costs for districts and lower-level governments.

Indirect costs

The economic impact of malaria extends beyond the health system. Patients forego income while recovering from malaria, and caregivers looking after ill children and the elderly also lose out on potential earnings. Premature deaths also cost society through losses in lifetime productivity and in the value people place in living longer, healthier lives.

To evaluate the economic impact of malaria-related morbidity, we calculated the income foregone of malaria patients and caregivers. We first estimated the gross domestic product (GDP) per capita per day using 2015 GDP estimates from Department of Treasury (DOT). The resulting figure was used as a proxy for daily income and multiplied by the duration of OP and IP illness from published literature and the number of reported OP and IP cases (Table 3).[62,65]

We used full income accounting to quantify the economic impact of premature death.[63,67] Assuming 40 as the average age of death among malaria-related deaths, we multiplied the life expectancy at age 40 among males and females with the value of an additional life year (VLY). Life expectancy was retrieved from the United Nations Population Division.[64] One VLY was assumed was 2.2 times the 2015 GDP per capita of PNG.[62,63]

Transmission model predictions

We used outputs from a dynamic epidemiological transmission model, Malaria Elimination Transmission in the Asia Pacific (METCAP), to estimate the costs and benefits of malaria elimination.[68] Several scenarios were simulated, and outputs from three scenarios were used in this investment case. The business as usual and reverse scenarios represent the counterfactual to malaria elimination. Details on the model and its limitations are found in Annex 2.

- **Business as usual**
  This scenario projects the malaria burden in 2016-2030 based on continuing the mix and scale of malaria interventions implemented in 2014.
- **Reverse scenario**
  This scenario projects the malaria burden in 2016-2030 assuming that LLIN distribution ceases and treatment rates fall by 50%.
- **Elimination scenario**
  This scenario projects the malaria burden in 2016-2030 based on the collective impact of (1) 30% protective effectiveness of LLINs, (2) Enhanced use thus increased surveillance using community health workers (CHWs), and (3) five rounds of MDA starting in 2018 with 50% coverage, from 2018 starting four months before the peak transmission season.

For each scenario above, we assumed a 5% chance of treatment failure due to artemisinin resistance as a baseline. In a separate set of simulations, we increased the treatment failure rate to 30% from 2018 onward to account for the possibility of artemisinin resistance spreading in PNG; this is referred to as the "resistance assumption". The results of both simulations are presented in this report.

In addition, we simulated the effect of improved targeting of malaria interventions on both costs and epidemiological outputs. We did this by reducing intervention coverage by 30% among the PAR for all three scenarios, with and without the resistance assumption.

Cost projections

The costs of various scenarios were estimated using a cost estimation model developed with the malaria transmission model (Annex 2). We used unit costs from our costing exercise and from published literature (Table 3). To calculate the incremental or additional costs of elimination (which is used to calculate the return on investment [ROI]), we subtracted the estimated costs of the business as usual and reverse scenarios from the elimination scenario. Costs were discounted at 3%.

Benefits estimation

We calculated the benefits of malaria elimination by first subtracting the estimated cases and deaths of the elimination scenario from the corresponding outputs of the business as usual and reverse scenarios. The resulting figures—referred to as the morbidity and mortality averted by malaria elimination—were valued using the same methods described previously in estimating the economic burden of malaria (Table 1). In addition, we also estimated the benefits of continuing current interventions by comparing the business as usual and reverse scenarios. Benefits were discounted at 3%.

Return on investment

To calculate the ROI of malaria elimination in 2016-2030, we subtracted the benefits of elimination by the incremental cost of elimination and divided the resulting figure by the incremental cost of elimination. The ROI is interpreted as the economic return from every additional dollar spent on malaria above the business as usual scenario. We calculated ROIs for both the resistance and baseline assumptions.

Financial gap

We consulted various sources to estimate past, present, and future financing for malaria. Historical figures (2000-2014) were retrieved from finance tracking work by the Institute of Health Metrics and Evaluation and MEI (submitted for publication) supplemented by data from the Global Fund and the World Malaria Report of the WHO. Financing in 2015 was taken from the Global Fund and World Malaria Report.

Projected financing for 2016-2021 was estimated using figures from the Global Fund and the ESP report. We assumed that GoPNG contributions would increase by the average projected GDP growth rate for 2016-2017.[69] Contributions from other donors reported in these sources were kept constant.

We calculated a financial gap for 2016-2021 by subtracting the projected costs of malaria control from the projected financing available.

Sensitivity analysis

We performed stochastic sensitivity analysis on the epidemiological and cost outputs of the malaria transmission model. The minimum, median, and maximum malaria cases and deaths predicted by the model for each scenario were used to calculate the minimum, median, and maximum economic benefits.

For the costs, we assigned an uncertainty interval of +/-25% on the value of the input costs used. Three hundred random samples were drawn, which generated a range of costs. From the range of costs generated, we determined the minimum, maximum, median, mean, and other measures (e.g., percentiles) which are presented in Annex 3. A similar sensitivity analysis was conducted over a range of baseline estimated incidence values.

Limitations

It should be noted that this transmission model was not designed for accurately modeling individual countries as it uses only 1 patch for each country. Thus it is unable to take account of subnational heterogeneities in transmission and delivery of interventions. Treating the whole country as a single unit in this way is likely to lead to over-estimates in costs of elimination. The project team are planning to develop the METCAP model to incorporate multiple patches for each country to model scenarios for individual countries in detail.

Findings

Direct health system costs

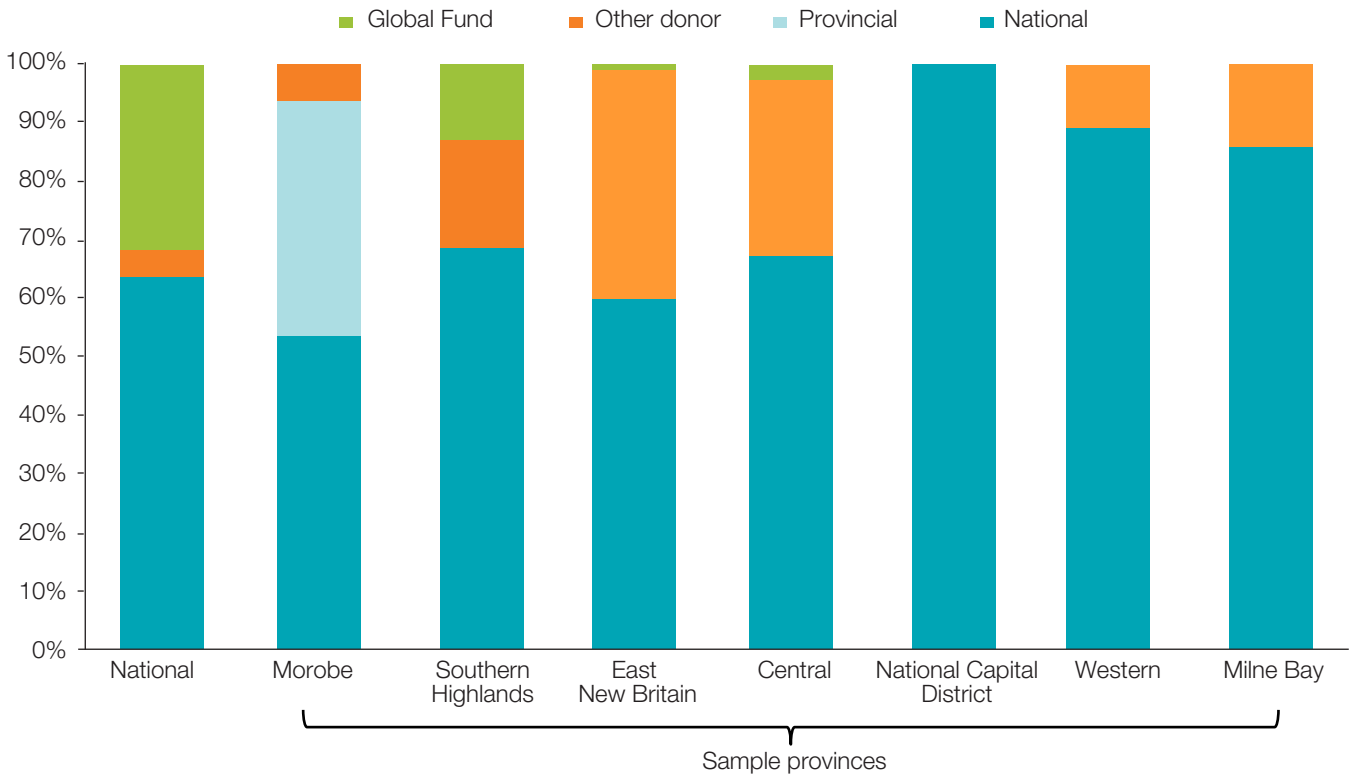
The direct health system costs of malaria at the national level in 2015 was estimated to be USD 13.01 million. Most expenditures were financed through domestic sources (64%). Of the costs funded through external sources, 31% was from the Global Fund and 5% from other mechanisms such as the Health System Improvement Program (HSIP).[c] Another external source of funding is the trilateral aid project (Figure 9).

Due to data limitations, malaria intervention costs could not be fully disaggregated by input or activity. We instead determined the top cost centers at the national level that collectively represent 98% of total costs (Table 4).

Table 4. Top five cost centers at the national level for malaria control, 2015

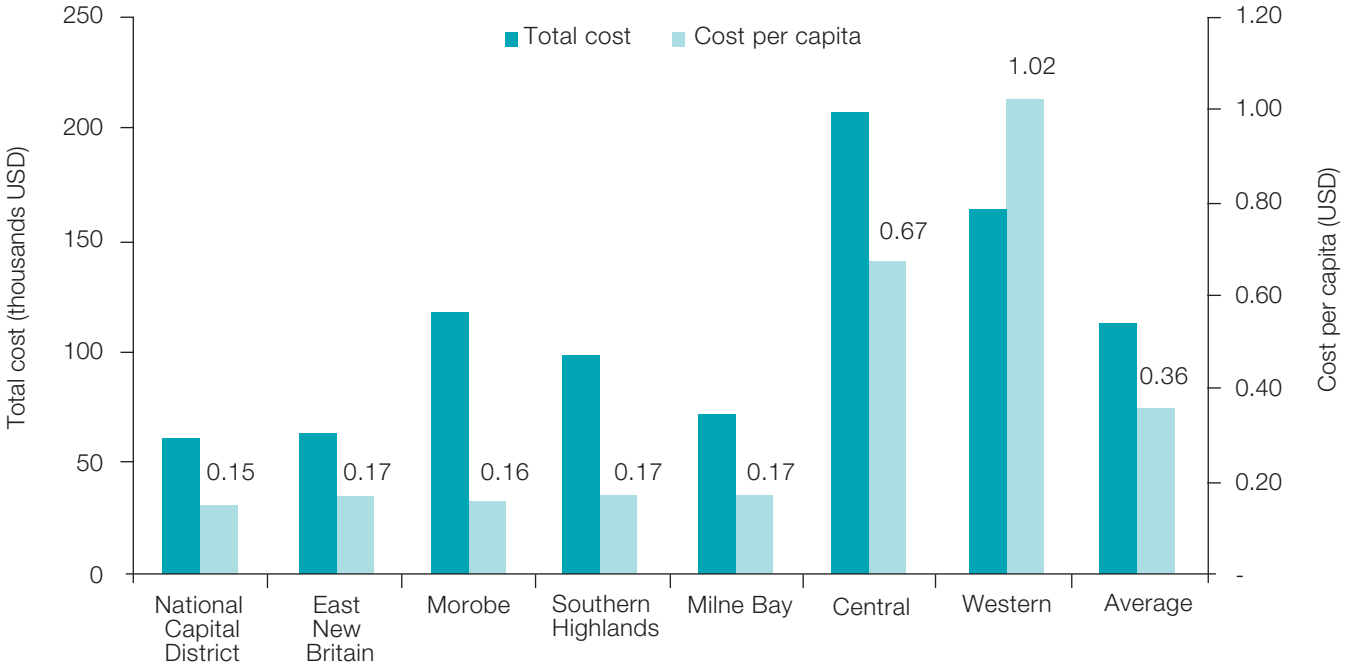
Cost center	Items included	Total cost (USD)
Consumables	RDTs, antimalarials, LLINs, microscopy supplies, office supplies	6,293,671
Testing and treatment	Human resources, health facility costs	3,784,560
LLIN distribution	Vehicle, aircraft, and boat hire, fuel, other operational costs	1,094,583
Personnel	NMCP, RAM, and PSI-supported staff	945,832
Home management of malaria	Cost of testing and treating	610,643

Figure 9. Cost by source of funding



c Established in 1996, HSIP is a sector-wide approach by PNG's development partners including the Australian government who is presently the largest contributor.[70,71]

Figure 10. Unadjusted provincial cost of malaria control, 2015



The total cost of malaria interventions among the sampled provinces ranged from USD 62,488 (NCD) to USD 207,409 (Central Province). The significance of domestic and external sources of funding also varied across provinces (Figure 9). The average unadjusted cost per capita in 2015 was estimated to be USD 0.36 (Figure 10).

Extrapolating the average cost per capita from the sampled provinces to the unsampled provinces generates a total provincial malaria cost of USD 2.68 million (Table 5). When adjusted by possible underspending or lack of funding, provincial malaria cost is estimated to be USD 1.95 million, which is 27% less than the unadjusted figure.

Adding national and provincial costs together, the total direct health system cost of malaria in 2015 comes to USD 15.68 million or USD 1.99 per capita per year. As a share of total health spending (USD 689.32 million), this equates to 2.3%.[d] Using the adjusted provincial costs reduces total costs to USD 14.96 million or USD 1.90 per capita (a 4.7% difference).

Total economic burden of malaria

The total economic burden of malaria in 2015 was estimated to be USD 90.57 million. Indirect costs from productivity losses due to malaria morbidity and mortality had the largest share (82%), followed by direct health system costs (17%; Figure 11). The economic burden of malaria in 2015 was equal to 0.49% of GDP.

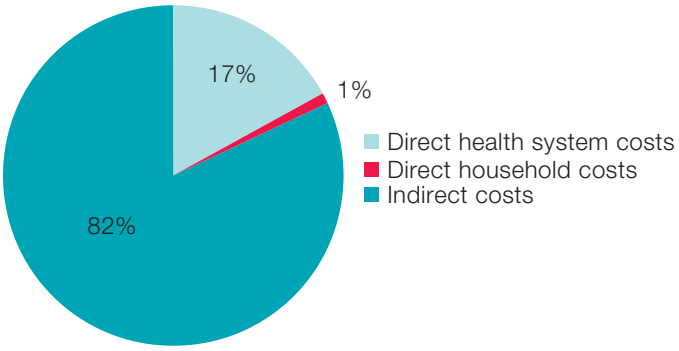
d Health spending in 2014 was used to calculate this figure (latest available).

Table 5. Adjusted and unadjusted provincial cost of malaria control (USD), 2015*

Province	Unadjusted total cost	Adjusted total cost
Morobe	116,542	46,617
Southern Highlands	98,636	63,127
East New Britain	64,485	41,270
Central	207,409	165,927
National Capital District	61,488	39,352
Western	163,474	104,623
Milne Bay	70,694	56,555
West Sepik (Sandaun)	98,818	63,244
West New Britain	107,791	68,986
New Ireland	82,515	52,809
East Sepik	178,572	142,858
Madang	197,189	197,189
Manus	24,410	19,528
Northern (Oro)	75,457	30,183
Gulf	65,211	20,868
Hela	99,591	63,738
Autonomous Region of Bougainville	101,351	64,865
Western Highlands	147,480	117,984
Eastern Highlands	230,655	230,655
Jiwaka	151,712	121,370
Chimbu	154,103	98,626
Enga	177,473	141,978
TOTAL	**2,675,056**	**1,952,353**

*Highlighted cells are the sample provinces

Figure 11. Economic burden of malaria by source, 2015



Malaria transmission model predictions

Figure 12 shows the reported and clinical malaria cases[e] projected by the malaria transmission model for the business as usual, reverse, and elimination scenarios with the resistance assumption. As expected, ceasing LLIN distribution and reducing testing and treatment rates are expected to increase the number of clinical malaria cases, with a peak of over 1.1 million in 2030. Under the business as usual scenario, malaria cases are also projected to increase, though less dramatically.

The spread of artemisinin resistance can exacerbate the burden of disease. If drug resistance spreads, malaria cases are projected to increase by 961,926 and 788,633 in the business and usual and reverse scenarios, respectively. Deaths rise by about 1,566 and 1,720 for the business as usual and reverse scenarios, respectively, under the resistance assumption. However, the model predicts that despite the threat of resistance, elimination can be technically achieved by 2024 through better use of LLINs, increased surveillance, and five rounds of MDA at 50% coverage starting in 2018 (Figure 12).

Cost projections

As shown in Figure 12, the model predicts that PNG can interrupt local malaria transmission by 2025. The estimated costs of the elimination scenario (under the resistance assumption) are shown in Figure 13. Costs are expected to rise as interventions are scaled, and they eventually decrease as the health system treats less numbers of clinical cases and interventions are scaled back due to decreasing numbers of PAR.

The total cost of the modeled elimination scenario is between USD 372.72-481.22 million, or USD 24.85-32.08 million on average per year. The median annual cost of elimination (USD 28.34 million) is roughly USD 13.38 million more than the direct health system cost of malaria in 2015 (USD 14.96 million). With improved targeting, costs are estimated to decrease by USD 1.67 million or 0.4% of total costs for 2016-2030 (Figure 13). The complete results of the sensitivity analysis on the costs of malaria elimination are found in Annex 3.

Benefits estimation

The potential benefits of malaria elimination over 15 years are shown in Table 6. Compared to business as usual, malaria elimination (resistance assumption) can prevent over 3.86 million cases and over 7,000 deaths and generate roughly USD 1.92 billion in total economic benefits. About 2.1% of the total economic benefits of malaria elimination (USD 41.62 million) are potential healthcare savings that the GoPNG can reallocate to other health programs and priorities.

Table 6. Median costs and benefits of malaria elimination compared to counterfactuals, 2016-2030

Scenarios compared	Cases averted	Deaths averted	Economic benefits (USD)	Incremental cost (USD)	ROI
Business as usual vs. elimination (baseline)	2.90 million	5,136	1.43 billion	199.31 million	6
Business as usual vs. elimination (with resistance assumption)	3.86 million	7,067	1.92 billion	196.96 million	9
Reverse vs. elimination (with resistance assumption)	11.12 million	22,846	6.11 billion	207.08 million	29

The benefits of elimination are more dramatic when compared to a reverse scenario: elimination can avert over 11.12 million cases and 22,846 deaths and generate about USD 6.11 billion in total economic benefits (Table 6). If PNG does not pursue malaria elimination and decides to continue its current mix and scale of interventions, the country could still prevent 7.44 million malaria cases and 15,994 deaths by averting a resurgence; the total economic benefits of this business as usual scenario is equal to USD 4.70 billion.

ROI calculation

Without increased risk for artemisinin resistance, the ROI of malaria elimination for 2016-2030 is roughly 6 when compared to business as usual (Table 6). The ROI increases to 9 when the resistance assumption is included. This means that every additional dollar spent on malaria elimination yields about USD 9 in economic returns. The

e A clinical malaria case is an individual who tests positive for malaria while displaying malaria-related symptoms such as fever, headache and vomiting. A reported malaria case refers to a malaria case reported by medical units and medical practitioners to either the health department or the malaria control program, as prescribed by national laws or regulations.

Figure 12. Projected median reported and clinical malaria cases, 2016-2030

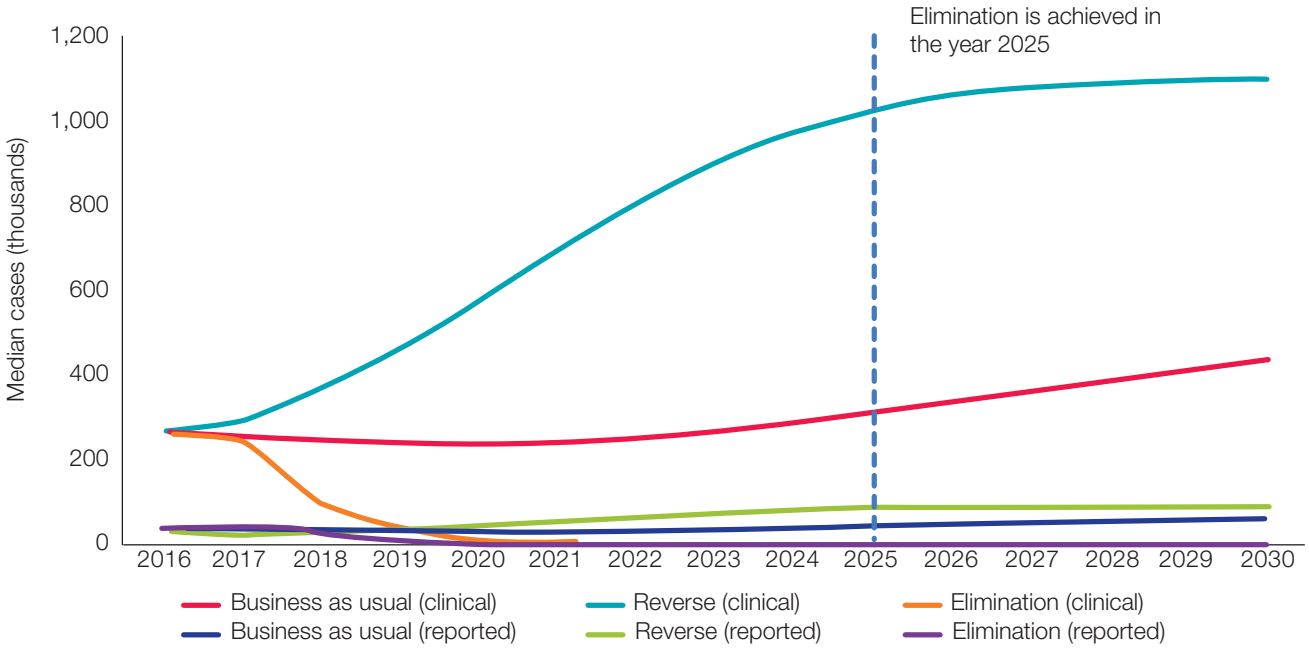
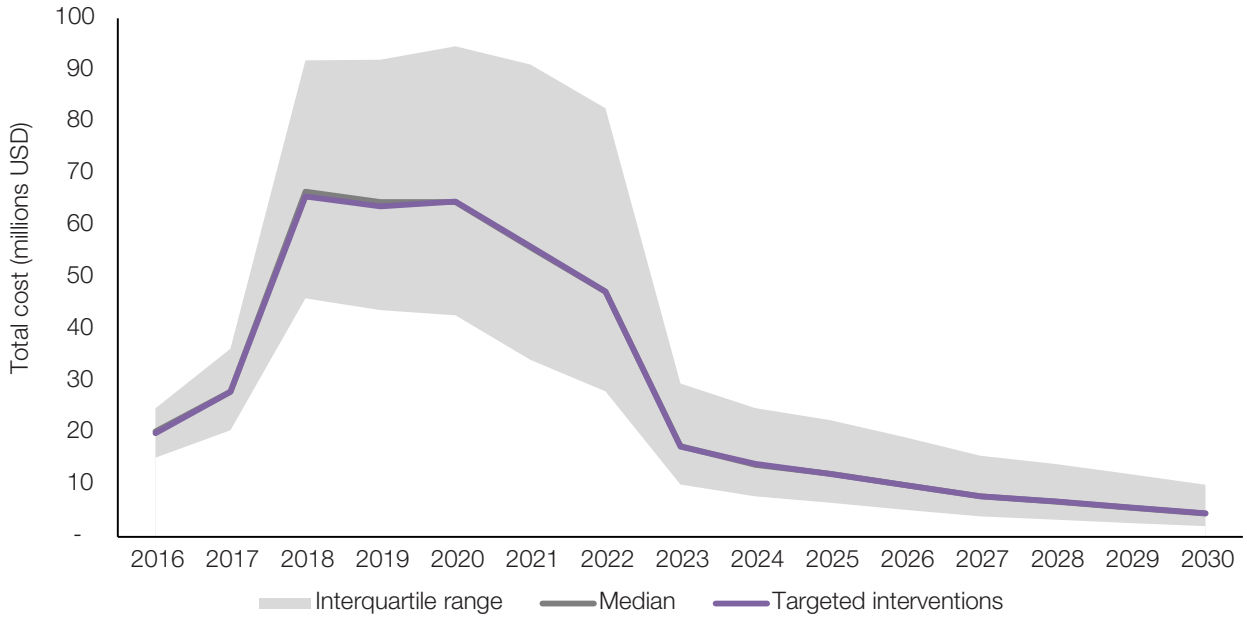


Figure 13. Projected costs of elimination scenario (with resistance assumption), 2016-2030



	Minimum	Median	Maximum
2016	18,926,230	20,302,055	21,734,143
2017	26,227,596	27,995,703	30,941,369
2018	58,595,512	66,565,890	72,710,093
2019	57,116,146	64,566,914	70,701,531
2020	57,308,025	64,535,623	72,010,035
2021	49,054,971	55,781,071	63,369,943
2022	41,172,345	47,237,777	54,989,271
2023	14,872,114	17,478,671	20,155,503
2024	11,775,802	13,859,145	16,319,736

	Minimum	Median	Maximum
2025	10,080,032	12,146,886	14,547,580
2026	8,167,425	9,955,391	12,190,256
2027	6,299,279	7,817,371	9,712,851
2028	5,334,889	6,764,270	8,654,851
2029	4,366,013	5,610,528	7,252,747
2030	3,425,223	4,473,293	5,931,798
Average	24,848,107	28,339,372	32,081,447
Total	372,721,602	425,090,587	481,221,706

ROI of malaria elimination more than triples to 29 when compared to a reverse scenario. Based on the results of our sensitivity analysis, the ROI for malaria elimination remains positive (range: 3-24) even with changes in the estimated benefits and costs (Annex 3).

Financial landscape

Though financing for malaria-specific activities has fluctuated in last 10 years, the trend has mostly been positive due to increases in donor and domestic contributions (Figure 14). Since 2004, the Global Fund has been the largest source of malaria financing, followed by aid from the Bill & Melinda Gates Foundation and the Australian government. PNG received the most funding for malaria in 2009 with over USD 32 million in contributions.

In 2015, financing for malaria was estimated at USD 9.37 million, which is USD 1.98 million less than in 2014.[1] Projected financing for malaria in 2016 was estimated at about USD 8.80 million (Table 7). This includes contributions from the GoPNG and major donors like the Global Fund, Asian Development Bank (ADB), and the Australian government. Subnational funding is excluded from this figure.

Financial gap

If PNG decides to implement the modeled elimination scenario, the country will face significant funding gaps, particularly in the next five years (Figure 15). With only about USD 50.16 million in funding available for malaria in 2016-2021, the funding gap is estimated to be over USD 249.59 million or USD 41.60 million per year.

Opportunities for resource mobilization

To bridge financial gaps, PNG must simultaneously generate new revenue and improve the impact of its existing malaria envelope. Both options present benefits and drawbacks, particularly when viewed through the challenging fiscal situation in PNG today. Below we discuss opportunities for mobilizing resources for malaria elimination; however, we do not assess the feasibility or applicability of implementing any of the mechanisms or instruments, which is beyond the scope of this work.

New revenue

Domestic financing, roughly 17% of financing for malaria in 2015, is one option for increased revenue. Globally, domestic financing is the largest source of financing for malaria elimination, followed by the Global Fund.[72,73] In PNG, domestic financing for malaria has averaged only USD 577,000 per year between 2011-2015 (Figure 14), though this amount is much larger when health system resources used to test and treat malaria are considered. As a share of total government expenditure on health, public spending on NMCP activities in 2015 was only 0.29%.[f,74]

f Total government health spending in 2014 was used as a proxy for 2015.

Figure 14. Financing for malaria in PNG, 2000-2014

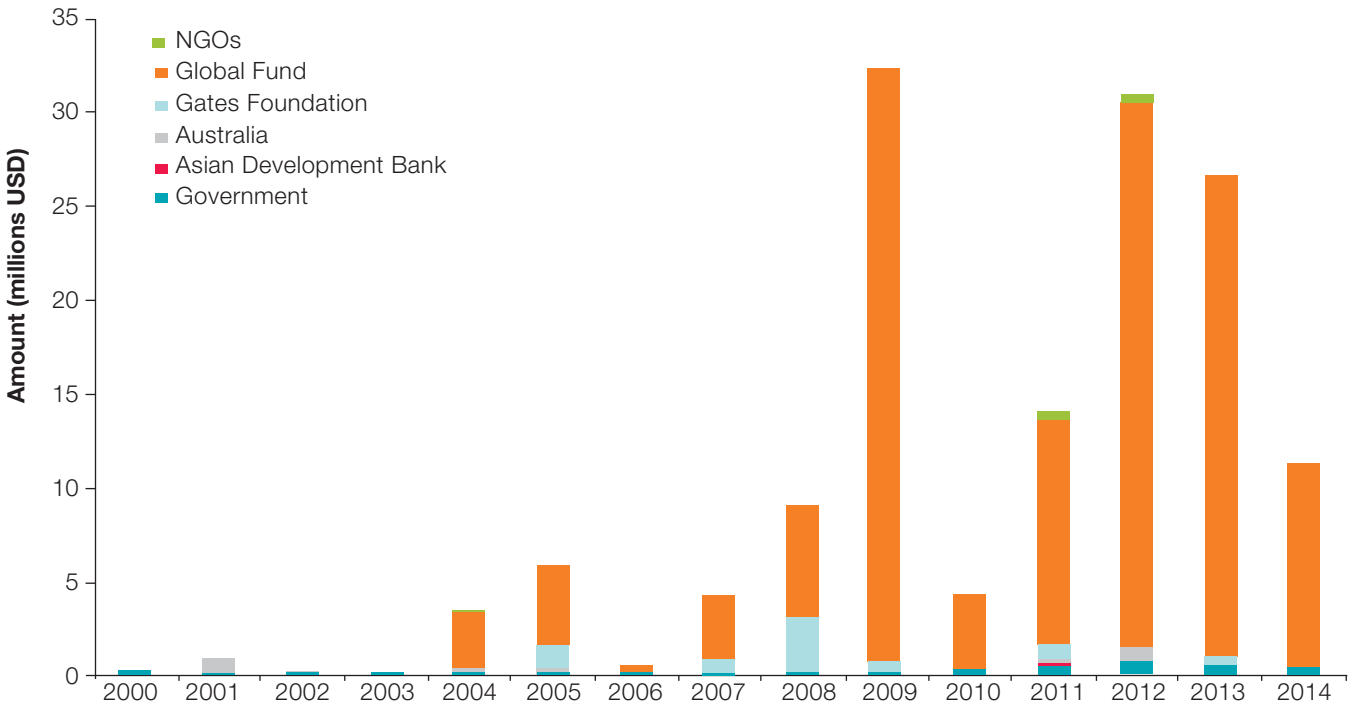
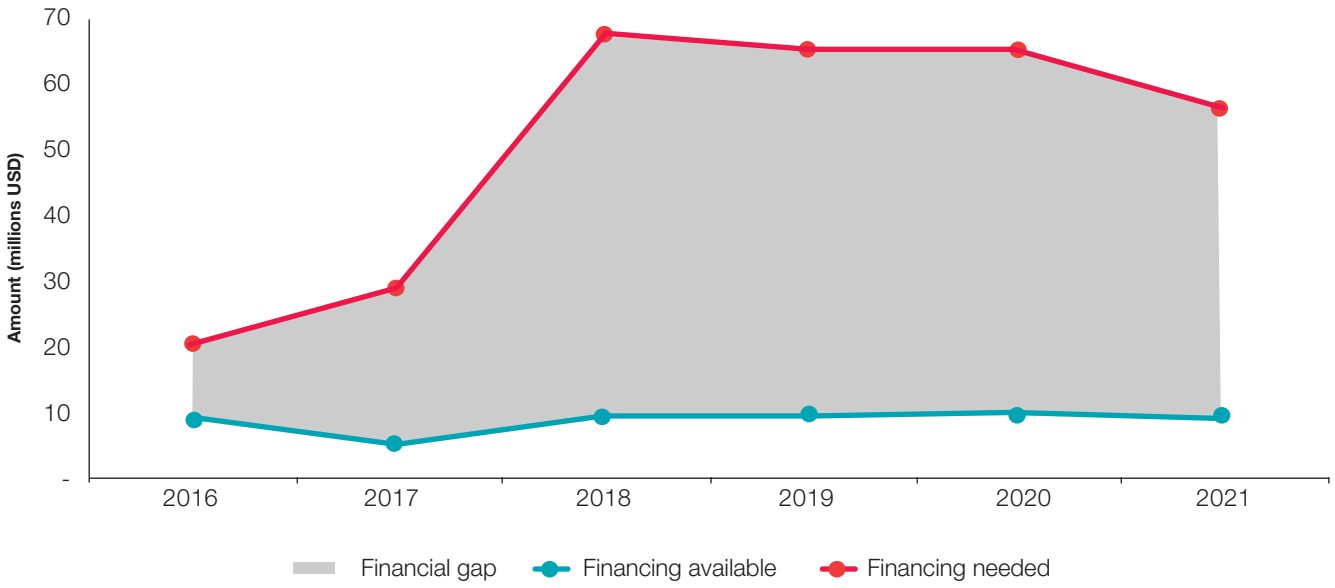


Table 7. Projected financing (USD), 2016-2021

	2016	2017	2018	2019	2020	2021	TOTAL
Global Fund	7,562,557	11,166,666	7,854,366	7,854,366	7,854,366	7,854,366	42,473,921
GoPNG	697,013	715,135	733,258	751,380	769,502	787,625	4,453,913
Other donors	538,184	538,184	538,184	538,184	538,184	538,184	3,229,104
Total	8,797,754	12,419,985	9,125,807	9,143,930	9,162,052	9,180,174	50,156,938

Figure 15. Financial gap analysis, 2016-2021*



*The latest WHO World Malaria Report (2016) provides available financing for malaria up to 2015; therefore, the financing gap for 2016 is included in this table as a projection.

	2016	2017	2018	2019	2020	2021	TOTAL	Average
Financing available	8,797,754	4,747,220	9,125,807	9,143,930	9,162,052	9,180,174	50,156,938	8,359,489.62
Financing needed	20,302,055	27,995,703	66,565,890	64,566,914	64,535,623	55,781,071	299,747,255	49,957,875.82
Gap	11,504,301	23,248,482	57,440,082	55,422,984	55,373,571	46,600,896	249,590,317	41,598,386.20

Given the notable economic growth PNG has experienced in recent years, the GoPNG could allocate more resources towards malaria. PNG's GDP grew at an average of 9.4% in 2011-2015; on a per capita basis, GDP increased by USD 247 between 2011 and 2014.[69,75] Much of the growth during these years is attributed to infrastructure development and other investments associated with the USD 19 billion PNG Liquefied Natural Gas (LNG) Project, which involved building a network of gas production and processing facilities across five provinces.[76–78] LNG production and export, which began in 2014, also contributed to economic growth, particularly in 2014 and 2015.[76,78,79] Broader investments in the domestic service sectors and agricultural exports were also key drivers of GDP growth.[76] PNG hopes to achieve upper-middle-income status by 2050.[80,81]

Several factors may hinder increased government spending on health and malaria. The outlook on the PNG economy for 2016 onwards is less bullish. The GoPNG, who had projected a 4.4% growth in the economy at the start of 2016, reported a more modest growth of 2.2% in its mid-year evaluation.[79,82] For 2017, ADB projects a 3.0% economic growth.[69] Low commodity prices (particularly

oil), the temporary shutdown of a state-owned gold and copper mine, and low agricultural yields due to El Nino and an on-going drought were partly responsible for the sluggish growth.[79] As long as PNG relies on extractive industries for its economic growth, it will be exposed to the volatilities of commodity markets and prone to "Dutch disease", which occurs when large inflow of foreign currency makes a country's other non-tradable products less competitive.[76,83] Because of these issues, the World Bank predicts that general revenue allocations will not increase the fiscal space for health in the short- to medium-term.[71]

Increasing health spending at the provincial level may also be challenging. Most provinces in PNG rely on health function grants (HFG) from the DOT to meet their healthcare costs, including health facility operations.[g,71,84] Implementation of the Reform of Intergovernmental Financing Arrangements (RIGFA) in 2009 led to increases in funding disbursed to provinces.[56] RIGFA stipulated that provinces with less internal revenue were eligible for higher HFGs and other service delivery function grants.[85] However, many provinces still fall short of meeting the full costs of the health sector in their jurisdictions.[84] Without substantial increases in HFGs or internal revenue, provinces lack the fiscal space to spend more on health or malaria given rising health costs due to inflation, population growth, and other pressures.[84]

Another limiting factor is persistent budget deficits. Since 2007, PNG's public spending has exceeded government revenue; to fill funding gaps, DOT has taken on domestic debt through the issuance of short-term bills.[78] In 2012, the budget deficit was 4.3% of GDP, which increased to 7.6% in 2013.[86] Government attention on this issue has helped reduce the deficit to 6.9% of GDP in 2014 and 5.0% in 2015.[62,87] Increases in spending, particularly capital expenditure, and lower than expected tax revenues are jointly implicated for PNG's budget shortfalls.[62,78,86,87] In 2016, the government hoped to limit the budget deficit to 4.5 % of GDP to help meet the maximum debt to GDP threshold (i.e., 30%) set by the Fiscal Responsibility Act.[82]

If PNG's fiscal situation does improve, prioritizing malaria control and elimination may be politically challenging given the equally pressing issues the PNG health system faces. Health infrastructure remains inadequate in many districts, and some primary care clinics still lack health personnel, regular access to water, and essential commodities and equipment.[88–93] Access to and utilization of basic healthcare services is unequal across income groups.[71,94] The National Health Plan 2011-2020 emphasized going "back to basics" precisely to address these challenges.[95] As a consequence, health outcomes in PNG have been stagnating; for example, PNG did not fully meet any of its Millennium Development Goals.[71,93,96–99] Other competing priorities include the current administration's free primary care policy and the increasing burden of non-communicable diseases (Figure 2).[66,100] Without any sustained political support for malaria elimination, this ambitious goal may be pushed aside.

PNG's development partners may step in and usher support for malaria elimination; chief among them is the Global Fund, which provides the largest funding for malaria. The Global Fund has disbursed over USD 126 million to PNG for malaria from 2004-2016, and this support was instrumental in helping the country achieve significant reductions in morbidity and mortality (Figure 1).[50] In December 2016, the Global Fund announced that for 2017-2019, it will allocate USD 25.56 million for malaria, which is 47% less than the allocation for 2015-2017 (USD 44.3 million).[51] Close and steady engagement between the GoPNG, program implementers, and the Global Fund will be required to ensure that financial support for malaria endures and that any reductions in funding are adequately matched by other funding sources.

Support from the Australian government is another potential source of financing for malaria elimination. Since PNG's independence in 1975, Australia has been PNG's primary bilateral partner. In 2016-2017, Australia aimed to provide AUD 558.3 million in official development assistance, of which 20% was allocated to health.[h,104,105] Historically, Australia's health aid has been directed towards improving basic health system functions, infrastructure, and expanding access to essential services (e.g., immunization) and commodities. In terms of disease areas, HIV/AIDS and tuberculosis have been the major focus.[106–108] Australia has also supported malaria activities through the HSIP and its predecessors, which fund provincial and district health offices and the NDoH.[70,106]

In 2014, an assessment of Australia's aid to PNG recommended a shift from direct service delivery towards capacity building, which is now enshrined in aid agreements between the two countries.[101,108–111] The trilateral aid project, which aims to build PNG's laboratory and diagnostic capacity for malaria, is a recent demonstration of this principle.[47–49] Though health remains a priority of Australian aid, PNG must maximize the impact of the funding it receives and engage with other bilateral donors from the region to generate any new resources for malaria.[111]

The ADB is another multilateral partner that PNG can leverage to finance malaria elimination. ADB, the second largest multilateral development partner to PNG, provides grants, concessional loans, and technical assistance to the GoPNG.[102,112] Though ADB does not finance malaria interventions specifically, it does co-fund the Rural Primary Health Services Delivery Project (RPHSDP) along with Australian, Japanese, and Papua New Guinean

g According to a 2012 report on provincial spending by the National Economic & Fiscal Commission (NEFC), only Western Province relies primarily on local revenue for health financing (93%).84

h The proportion of Australia's official development assistance to PNG spent on health has decreased in recent years. In 2013, it was 22% and was reduced to 19% in 2014 and 16% in 2015.101–103

governments, the Organization of Petroleum Exporting Countries Fund for International Development, and WHO. RPHSDP is an eight-year initiative that aims to improve access to and quality of rural health services in 16 target districts across eight provinces.[i,113,114] Over USD 81 million in funding has been committed which will be used to help the NDoH develop and implement national policies and standards; assist provincial and district governments establish partnerships with the private sector; provide training opportunities to health personnel; build community health posts and refurbish existing aid posts and health centers; support health promotion activities, including women's involvement and volunteer health worker programs; and establish a coordinating body in the NDoH for all health system strengthening projects.[113,114] The NMCP can capitalize on RPHSDP programs that can benefit malaria control; for example, adequately stocked community health posts can expand access to prompt testing and treatment which are critical to reducing malaria transmission. Similarly, RPHSDP's health promotion programs can easily incorporate malaria prevention messaging. Any improvements to the current NHIS, including RPHSDP's pilot projects on geospatial mapping, can also benefit malaria control and elimination by improving the accuracy and timeliness of health data. When appropriately used, geo-located data can help government monitor the health system's performance and improve local-level supply of medicines and other consumables.[115]

Though most of its funding to PNG is used for infrastructure development (60%) and energy projects (20%), ADB is committed to supporting health and development in PNG.[83,93,116,117] The country can seek out additional grants and soft-loans from the Bank to help frontload the costs of elimination. ADB is currently in discussion with PNG on a USD 400 million loan package for which builds on the successess of the RPHSDP. However, the DOT may need incentives to take on additional debt, such as debt buy-downs through partnerships with financiers such as the Global Fund, Bill & Melinda Gates Foundation, and Australian government. Another source of ADB financing that PNG can explore is the Regional Malaria and Other Communicable Diseases Trust Fund (RMTF). If successfully replenished after 2017, RMTF could provide supplemental financing for selected high-impact malaria projects, which is one of the fund's priorities.[118,119]

Beyond traditional sources of aid, PNG may explore new and innovative financing mechanisms and instruments to finance malaria elimination. Innovative financing, which includes (a) instruments for resource generation and pooling and (b) fund deployment mechanisms, are favorably viewed as a means to meeting the short- and medium-term needs of health and other development sectors.[72,120] Below is a list of examples, some of which have been implemented in PNG.

- **Taxes**
  Taxes, duties, and other obligatory charges are most countries' primary sources of revenue, and several governments have earmarked tax revenue for health spending. An example is the excise or "sin" taxes on tobacco and alcohol products in the Philippines which generated USD 2.3 billion in new funding in the first two years of implementation. This increased the Philippine Department of Health's budget by 63% in 2015 compared to 2013. Other types of taxes include levies on sugar-sweetened beverages, foreign currency transactions, and transactions in international finance markets. The large revenue base and the long-term nature of taxes make such instruments reliable and sustainable sources of funding. However, imposition of additional taxes may be politically unattractive because of public opposition towards such measures. In 2014, the GoPNG doubled the tax rate cumulatively levied on tobacco products from 5% to 10%.[121] A one-off 15% increase on tobacco excise was announced along with the 2017 budget in late 2016.[122,123] Similarly for alcohol, PNG raised the biannual capped indexation rate from 2.5% to 5% on December 1, 2016.[122,123] Though the tax rate on tobacco products is increasing, it is still below the 70% recommended by the WHO.[124]
- **Voluntary contributions**
  Voluntary contributions refer to donations from private individuals and organizations. Some examples are monetary or in-kind contributions from foundations, state lotteries, and other purchase- or action-triggered donation schemes (e.g., proportion of a product's retail sales are donated to a charity or cause). Corporate social responsibility (CSR) programs also fall in this category. Many of PNG's extractive companies have run CSRs for decades as part of their "social license to operate"; some CSRs have even spun off to form separate charitable organizations, as in the case of OSF and Ok Tedi Development Foundation. With sufficient private sector engagement, the GoPNG (particularly the NDoH) can encourage more corporations to develop CSRs and provide services that will reduce malaria transmission. However, given the slump in commodity prices, many industries in PNG are seeing revenues decline, which hamper greater investments in CSRs. A more robust assessment of private sector contributions to malaria elimination are published in *Business case studies in Bangladesh, Indonesia, and Papua New Guinea*, a companion report by MEI.
- **International and regional funds**
  International and regional funds pool resources from various sources including governments, aid agencies, development institutions, corporations, foundations and individuals to more efficiently finance certain causes or objectives (PNG's HSIP is one example). The pooling of resources reflects a shared commit-

i The eight provinces are Eastern Highlands, East Sepik, Enga, Milne Bay, Western Highlands, Morobe, and the Autonomous Region of Bougainville.

ment to fight specific problems at the local, regional, or global levels. Several malaria funds or initiatives have been established, most of which are supported by the Global Fund; recent examples are the Elimination 8 Initiative in southern Africa, Elimination of Malaria in Mesoamerica and Hispaniola (EMMIE), and the Regional Artemisinin-resistance Initiative in the Greater Mekong Subregion

- **Debt conversion mechanisms**
  Debt conversion mechanisms take several forms but all intend to shift resources away from debt repayments towards development spending. One type is called a debt buy-down where parts or the entire debt of a country is paid by a donor in exchange of achieving predetermined results. In a debt swap, a lender or donor writes off parts of a country's debt; in turn, the government invests an agreed amount on a specific program. Debt swaps have been used by the Global Fund, Germany, and Australia in several countries. Debt conversion is a promising approach for countries like PNG with large public debt to mobilize additional resources for health. However, the partial cancellation of debts typically requires countries to generate counterpart financing immediately, which could be more expensive in the near-term. Debt swap mechanisms are further limited by donors' willingness to cancel debt.
- **Performance-based contracts**
  Also known as results-based financing, performance-based contracts emphasize impact rather than outputs and process, which increases efficiency. In performance-based contracts, countries are incentivized to meet certain benchmarks because disbursements are tied their achievement. On type is cash-on-delivery wherein a recipient country only receives additional funding after pre-agreed indicators of progress are achieved. The Global Fund's first cash-on-delivery grant was for EMMIE initiative. Social impact bonds and development impact bonds are other types of performance-based contracts that have been successfully implemented in selected settings; one example is the Mozambique Malaria Performance Bond which is being used to raise funding from "outcome funders" or investors interested in both financial and social return. As the first "malaria bond", investors are only paid when the malaria program meets its targets.

Efficiency improvements

The current and future costs of malaria control and elimination presented earlier include all the inefficiencies of the malaria program; however, improvements in technical and allocative efficiency[j] can increase the impact of current inputs and potentially lower the costs of implementing malaria interventions. In a 2014 report, the World Bank posited that efficiency gains (coupled with increased general revenue financing) are the most viable option for resource mobilization in PNG, and that addressing inefficiency should be GoPNG's top priority.[71]

The PNG health system has been called a "leaky bucket" where public resources are wasted due to inefficiency.[71] Improving a number of cross-cutting health system functions (e.g., supply chain for medicines) can benefit not only the malaria program but other health areas or priorities. The World Bank report previously cited identified six actions that can help the GoPNG maximize efficiency[71] we discuss four below and explain how each one can impact malaria elimination efforts.

- **Financing**
  Underfunded health facilities can lead to understaffing, crumbling infrastructure, and poor quality services—realities that have been documented in several reports on health service delivery in PNG.[12,66,71,89] Inadequate and inaccessible health services exacerbate illness; for malaria, inappropriate or delayed treatments can quickly lead to complications and death. Thus, not only does inefficiency lead to waste but it can also undermine previous investments in health. If PNG pursues malaria elimination, prompt testing using sensitive diagnostics and treatment with quality-assured ACTs will be required to reduce onward transmission. Aside from the amount of funding, poorly timed disbursements can lead to inefficient spending. For instance, funding that is delayed and disbursed in bulk at end of the fiscal year is either left unspent or spent quickly without proper planning.[84] Another area of improvement is the method of disbursement; studies show that in many cases, funding does not reach health facilities, despite HFGs being received by provincial governments.[66,71,89] Direct facility funding and contracting have been proposed as an alternative to inconsistent sub-allotments.[71] To promote efficiency, PNG will need to simultaneously address sufficiency, predictability, and accessibility of funding.
- **Allocation**
  Allocation refers to the mix of services funded through public resources. Previous analyses suggest that PNG has an overreliance on tertiary care provided in hospitals, which are costlier to sustain and diverts resources away from preventive and primary care.[59,66,71] For the malaria program, allocative efficiency can be improved by implementing an optimal mix of interventions at the right scale. PNG's two national malaria strategies have been informed by expert opinion, consultations with stakeholders, global guidelines, and funding and operational constraints. Results from recent modeling exercises (i.e., ESP) that aim to provide data-driven evidence on the impact of various interventions can be incorporated in future malaria

j Allocative efficiency is achieved when "health service resources are put to their best possible use so that no further improvements in the health status of the community are possible." Technical efficiency is the state where "healthcare interventions are each performed with the least amount of inputs."125

programming decisions and strategies. Currently LLINs, which have made a significant impact on the malaria burden, are the mainstay of PNG's prevention strategy; in the future, NMCP can adopt new or more effective interventions (e.g., MDA, IRS) that are appropriate for the country's endemicity level to maximize the impact of its scarce malaria funding. Targeting of interventions by disease burden can also reduce costs; this study found that elimination costs can potentially decrease by USD 1.67 million or 0.4% over 15 years without compromising impact.

- **Technical inputs**
  In PNG, both the mix and productivity of inputs require improvements. For example, the largest share of PNG's health budget is spent on staff emoluments, particularly at the provincial level.[62] Though PNG does require a large number of health workers to meet basic standards of health service delivery, inefficient use of human resource funding has been documented.[71] Another source of health expenditure is rental payments, which increased by 200% between 2000 and 2011 for the NDoH alone.[71] Because of budget limitations, high spending on these inputs means reduced funding for medicines, medical supplies, and equipment. For the malaria program, LLINs are the costliest input currently. A significant cost driver is transportation during distribution campaigns, which is to be expected in a country like PNG where the majority of the population lives in rural, hard-to-reach areas. The impact of LLINs is limited by improper and infrequent use; thus, community education remains a critical input that should receive its own allocation. However, one study suggests that the impact of LLINs may have reached its peak, and that other interventions may need to be considered soon.[56]
- **Procurement reform**
  Several problems afflict PNG's procurement and distribution system for medical supplies and medicines.[71,91] Inadequate financing and long tender processes cause or exacerbate stockouts. To reduce the impact of shortages, emergency and rush deliveries are made frequently, which drastically increase supply chain costs. Poor information systems prevent the NDoH from proper forecasting, quantification, and budgeting. Finally, leakage through waste and corruption deprives the health system of its limited funding. In malaria elimination, prompt treatment with the right medicines is not only needed to reduce malaria-related morbidity and mortality but also to prevent onward transmission of the disease; thus, antimalarial stockouts must be minimized. Administrative, operational, and legal reforms can help streamline the procurement and distribution of medicines and medical supplies. To lower costs, PNG can explore pooled procurement mechanisms, long-term contracting, and private procurement among others.[71] PNG has some recent experience with procurement and distribution reform in its rollout of "100% kits", and it should build on the successes of that effort.[91]

Optimization and efficiency improvements can be achieved through trial and learning-by-doing, and modeling and operations research can help inform future policies and processes. Robust monitoring and evaluation systems are also useful in this regard. To help NMCPs identify inefficiencies in the malaria program and to track progress against selected indicators, MEI has developed a self-help assessment tool called Malaria Program Efficiency Analysis Tool that looks at performance in financing, malaria interventions outputs, and operations.

Discussion

This investment case is the first to systematically assess the economic costs, benefits, and financial feasibility of malaria elimination in PNG. In this study, we found that over 15 years, the median returns of malaria elimination are 9 times higher than its incremental costs. Even with more conservative estimates on the morbidity and mortality averted from malaria elimination, the ROIs remain robust and positive. The ROIs we present are comparable to those estimated for immunization programs, chronic disease interventions, maternal and child health services, and other public health efforts.[126–130] The ROIs could potentially be higher if we included the distal benefits of malaria control and elimination (e.g., improvements in educational performance and cognitive development)[131–135]; however, these externalities are hard to value.

For 2015, we estimated the per capita cost of malaria to be USD 1.90, which is comparable to the costs reported from other control settings.[136] The primary cost driver was consumables in the form of antimalarials, RDTs, and LLINs. As in other high-burden countries, consumables are expected to remain the largest source of malaria control costs in PNG, until in later stages of elimination where human resources typically take precedence following a scale up of surveillance activities.[137–140]

At the provincial level, the costs of malaria control varied widely and were found to be unrelated to the malaria burden (analysis not shown). Though provincial costs represent a small proportion of total direct health system costs, our reliance on budget figures means that our estimates are inherently limited and should be validated against expenditure reports where available.

The malaria transmission model we used predicted increased effectiveness of LLINs, increased surveillance, appropriate testing and treatment, and multiple rounds of MDA can collectively interrupt local malaria transmission in PNG by 2025—five years before the 2030 goal of APLMA. Though malaria elimination may seem technically feasible based on our model, operational constraints may hamper the rollout and implementation of certain interventions. Many of the operational challenges facing PNG and its malaria program have been identified in the ESP report.[53]

Our cost model estimates that malaria elimination in PNG will require significant financial resources; over USD 249 million in additional funding is needed in next six years alone. Domestic financing cannot fill this gap given the bullish outlook on the PNG economy and the competing priorities facing government. Thus, donors, particularly the Global Fund, will continue to play a big role in financing malaria efforts in the country. PNG also needs to explore new and innovative sources of financing to meet the malaria program's needs in the short- and medium-term. PNG should maximize the impact of its scarce resources by finding multiple ways to improve health system efficiency. We identified several actions that the government can take; however, political commitment will be imperative to improve the status quo.

Limitations

The transmission model was designed with a single homogeneous patch for the whole of each country. Thus spatial heterogeneity within each country was not modeled including malaria transmission and interventions. Targeting of interventions within a country may reduce the costs of elimination thus the estimated costs are likely to be an over-estimate. There is much uncertainty in the estimated malaria burden in each country with a resulting impact on the predicted costs of elimination. Population movement was not included in the model and this is is likely to have reduced the predicted costs.

Estimating the magnitude, timing, and probability of malaria resurgence is fraught with difficulties; our predictions are limited by the malaria transmission model and the data used to calibrate it. However, historical evidence and some recent analyses suggest that PNG remains susceptible to malaria outbreaks and a rebounding of the disease. Our sensitivity analyses also show that ROIs for malaria elimination remain positive even if the mortality and morbidity from the business as usual and reverse scenarios were smaller. Other limitations of this study are listed in Annex 2.

Conclusion

Although PNG has made great strides against malaria in the last 15 years, the country's gains are fragile. Waning donor support and domestic fiscal constraints have forced the country to scale down its prevention efforts, which could negatively impact the progress that has been made thus far. History and recent studies suggest that malaria resurgence is a real threat in PNG.

This investment case provides the economic rationale for scaling up malaria interventions that can significantly impact the burden of disease. With an estimated ROI of 9:1, investing in malaria elimination generates staggering economic benefits comparable to other life-saving public health interventions.

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Western Provincial Health Office	Alice Honjepari Dr. Stenard Hiasihri
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East New Britain Provincial Health Office	Benedict Mode Claire Pidik Benedict To Kau Warwakai Issac Guere Peter Vu
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†Attended the data validation meeting held in Port Moresby on November 1, 2016

Annex 2. Methods and Data Sources

The investment case leverages several research approaches to determine the costs, benefits, and financial feasibility of malaria elimination in PNG. This section discusses in detail the methods and data sources used.

Data collection and validation

Financial, economic, and epidemiologic data for this study was collected through multiple visits to PNG between March and November 2016. Disease burden was estimated through data collected from the malaria program. To fully understand the malaria landscape in PNG and identify appropriate data sources, we first conducted interviews with a purposive sample of key informants from central government agencies, nongovernmental organizations and civil society organizations, bilateral and multilateral organizations, and private sector organizations who had knowledge of or direct involvement in malaria programming and health financing in PNG. We contacted key informants via phone and e-mail and organized in-depth, semi-structured interviews. During the interview, we asked about data sources that key informants knew about or had access to that would allow us to develop the investment case. Data was shared to us electronically and through hard copies.

We organized and analyzed data in Microsoft® Excel® 2011. Files were stored in encrypted, password protected computers. All monetary figures are expressed in 2015 USD, using a mid-year exchange rate of 2.77 Papua New Guinea Kina per USD.

On November 1, 2016, MEI presented preliminary findings of the investment case to a selected group of NDoH officials and staff, malaria program implementers, development partners, and provincial health staff in Port Moresby (see Annex 1 for partial list of attendees). MEI received feedback and additional data sources from the participants, which were incorporated in the final report.

Economic burden of malaria

We used a societal perspective in estimating the economic burden of malaria. We classified costs as (1) direct health system costs, (2) direct household costs, and (3) indirect costs, which we discuss separately below. A summary of inputs and assumptions are found in Table 3.

Direct health system costs

We used activity-based micro-costing with a combination of ingredients (or consumption-based) and expenditure data collection approaches to estimate direct health system costs in 2015.[141–143] We collected data on domestic (national and provincial) and external spending on four inputs used to implement seven activity categories (Table 2). When possible, we apportioned input costs by activity using data on time allocation gathered during key informant interviews.

Capital goods were annualized and discounted using common useful life and standard annuity factors based on a 3% discount rate (Table A2-1). Maintenance costs for equipment, vehicles, and buildings were based on actual expenditures reported. No replacement costs were used in valuing capital resources whose current value had depreciated to zero, assuming that replacement would not occur in the near future.

Table A2-1. Values used in discounting capital expenditure

Capital Goods	Useful Life Years*	Annuity Factor†
Motorcycles and computers	5	4.58
Vehicles and microscopes	10	8.53
Buildings	20	14.88

* The ULYs used are based on the recommendations in the Bill & Melinda Gates Foundation's "Guidance for Estimating Cost for Malaria Elimination Projects."

† Taken from Drummond, Michael F., et al. *Methods for the Economic Evaluation of Health Care Programmes.* 4th ed. Oxford, UK: Oxford University Press, 2015.

Through key informant interviews and a comprehensive review of reports and policy documents[27,144], we determined malaria interventions implemented in PNG and other essential health system functions and the agencies or organizations responsible for delivering them. We then collected data that would allow us to estimate the costs of those interventions and functions. National and provincial costs were separately valued then added together to generate a total health system cost for 2015.

National costs

For national costs, we analyzed expenditure data from the NDoH and program implementers. For the NDoH, data was collected from the Finance & Management Services unit that oversees domestic funding and the HSIP Trust Account that manages donor funding channeled directly to the NDoH. Among malaria program implementers (i.e., PSI and RAM), data on spending was requested and retrieved in person and via e-mail correspondences. When expenditures were unavailable, we relied on budget

figures and secondary sources such peer-reviewed or grey literature (e.g., donor reports). Input costs were apportioned by activity using self-reported hours collected during key informant interviews.

After estimating total cost, we calculated an annual cost per capita using 2015 population numbers extrapolated linearly from population figures and growth rates from the 2011 census (Table A2-2).[145]

Table A2-2. Population numbers used

Province	Capital	2011 population	Growth rate (2000-2011)	2015 estimated population
Western	Daru	201,351	2.50	221,486
Gulf	Kerema	158,197	3.60	180,977
Central	Port Moresby	269,756	3.50	307,522
National Capital District	Port Moresby	364,125	3.30	412,190
Milne Bay	Alotau	276,512	2.50	304,163
Northern (Oro)	Popondetta	186,309	3.10	209,411
Southern Highlands	Mendi	510,245	3.20	575,556
Enga	Wabag	432,045	3.50	492,531
Western Highlands	Mount Hagen	362,850	3.20	409,295
Chimbu	Kundiawa	376,473	3.40	427,673
Eastern Highlands	Goroka	579,825	2.60	640,127
Hela	Tari	249,449	2.70	276,389
Jiwaka	Banz	343,987	5.60	421,040
Morobe	Lae	674,810	2.00	728,795
Madang	Madang	493,906	2.70	547,248
East Sepik	Wewak	450,530	2.50	495,583
West Sepik (Sandaun)	Vanimo	248,411	2.60	274,246
Manus	Lorengau	60,485	3.00	67,743
New Ireland	Kavieng	194,067	4.50	228,999
East New Britain	Kokopo	328,369	3.60	375,654
West New Britain	Kimbe	264,264	3.30	299,147
Autonomous Region of Bougainville	Arawa	249,358	3.20	281,276
			TOTAL	**8,177,052**

Though malaria testing and treatment happens in health facilities, we classified the costs associated these activities as "national" because most funding (over 99%) for health facilities comes from the central government.[71] To estimate total malaria testing and treatment costs, we multiplied the number of cases predicted by the malaria transmission model with the health service delivery costs from a 2011 study (costs were converted to 2015 USD).[59] Costs were calculated separately by type of health facility and then added to get a total.

For antimalarials and diagnostic supplies, we used the costs provided by the NMCP. The unit costs for these consumables include the cost of demurrage and transport from ports to the area medical stores. We applied a 25% markup on the unit costs to account for distribution and transport from area medical stores to health facilities.[146]

Provincial costs

To estimate subnational costs for malaria, we used data from seven sample provinces (i.e., Central, East New Britain, Milne Bay, Morobe, NCD, Southern Highlands, and Western). These provinces were sampled in consultation with the NMCP based on their representativeness among PNG's 22 provinces on selected criteria believed to determine malaria spending (Table A2-3).

Because of the difficulty collecting expenditure data at the subnational level, we relied on budget figures from AIPs to estimate spending on malaria. AIPs are budget documents that serve as the basis for DOT funding disbursements for health. They are prepared annually by provincial health offices and provincial health authorities on behalf of their respective jurisdictions, including districts and health facilities. Once completed, AIPs are submitted to the health policy unit of NDoH for review and collation. The final health budget NDoH submits to Parliament during its budget process reflects the AIPs submitted by provinces.

AIPs are organized around key result areas from the National Health Plan 2011-2020. Key result area six, which aims to reduce the burden of communicable diseases, includes specific objectives for malaria, tuberculosis, and STI/HIV control and prevention. To estimate the costs of provincial and district spending on malaria, we totaled budget allocations toward key result area six that were intended for malaria. We noted the source of funding for each allocation whenever possible.

Multiple challenges afflict PNG's budget formulation and disbursement processes, which impact subnational spending for health.[66,89,147] For instance, it is unclear how much health funding is made available to provinces, districts, local-level governments, and health facilities. Anecdotal evidence from our interviews suggest that provinces do not receive all of its health function grant, despite DOT reports showing that the national government meets most health budget requests from provinces.[62] Additionally, without credible data on expenditures, it remains

Table A2-3. Criteria for provincial sampling*

Province	Malaria cases (per 1,000)	Population density (population by sq. km)	Geographic size (sq. km)	Sources of funding	Absorption capacity (% of function grant unspent at year end)
Western	142	2.3	98,189	High internal revenue, low grant dependency	63
Central	50	10.3	29,998	Mixed dependency	7
National Capital District	56	1,717.5	240	No data	No data
Milne Bay	314	21.2	14,345	Mixed dependency	0
Southern Highlands	53	38.1	15,089	Mixed dependency	4
Morobe	154	21.6	33,705	High internal revenue, low grant dependency	0
East New Britain	142	24.6	15,274	Mixed dependency	32
Gulf	118	5.2	34,472	High grant dependency, low internal revenue	13
Northern (Oro)	119	9.2	22,735	High grant dependency, low internal revenue	1
Enga	15	42.1	11,704	High internal revenue, low grant dependency	3
Western Highlands	34	95.2	4,299	Mixed dependency	7
Chimbu	15	70.0	6,112	High grant dependency, low internal revenue	29
Eastern Highlands	18	57.4	11,157	Mixed dependency	2
Hela	60	26.3	10,498	No data	No data
Jiwaka	17	87.8	4,798	No data	No data
Madang	142	18.9	28,886	High grant dependency, low internal revenue	8
East Sepik	173	11.4	43,426	High grant dependency, low internal revenue	33
West Sepik (Sandaun)	275	7.7	35,820	High grant dependency, low internal revenue	25
Manus	130	33.9	2,000	High grant dependency, low internal revenue	30
New Ireland	186	24.0	9,557	High internal revenue, low grant dependency	32
West New Britain	235	14.7	20,387	High internal revenue, low grant dependency	7
Autonomous Region of Bougainville	57	30.0	9,384	No data	No data

*Highlighted rows are the sample provinces.

unknown whether the funds subnational units receive are actually spent on their intended purposes as reflected in the AIPs. Our interviews with provincial health staff suggest that health funds are often diverted by provincial administrations toward other functions when faced with fiscal constraints.

To account for these issues, we weighted the AIP budget figures we extracted based on two indicators developed by the NEFC. The first adjustment is based on an indicator called "spending level performance", which is the fraction of provincial spending on a specific sector (such as health) over the NEFC's cost estimate for providing basic services in that sector (Table A2-4).[84] This indicator takes into account fiscal capacity, which describes a province's ability to meet service costs. The NEFC assigns "High" (above 80%), "Medium" (40-80%), and "Low" (below 40%) ratings, and we used the upper limit of each range as weights. For example, East New Britain was given a "Medium" rating by the NEFC on its spending level performance, so we multiplied its malaria budget by 0.80.

Table A2-4. Adjustments for subnational spending on malaria[84]

Indicator	Definition	Rating and score	Weight
Spending level performance	Indicates how much a province is spending on the sector relative to NEFC cost estimates	High (above 80%)	1.00
		Medium (40-80%)	0.80
		Low (below 40%)	0.40
Nature test	General high-level assessment of whether expenditure looks in keeping with the intended purpose	Good: appears largely in keeping with intention of grant	1.00
		Average: appears in keeping with intention of grant with some areas that are questionable or uncertain	0.80
		Not Good: significant areas that are questionable	0.50

The second adjustment uses the "nature test" indicator, which is a high-level assessment on whether provincial spending aligns with the funds' intended purpose (Table A2-4).[84] NEFC rates provinces as "Good", "Average", and "Not Good"; however, the NEFC does not provide any quantitative score for these ratings. We thus assigned the following weights for each rating: 100% for "Good", 80% for "Average", 50% for "Not Good". In example above, we further weighted East New Britain's malaria budget by 0.80 based on its "Average" rating in NEFC's nature test. Taking both indicators together, we estimate that only 64% of East New Britain's reported budget for malaria was spent for that purpose.

To estimate personnel costs at the provincial and district levels, we created a basic package of public health staff involved in subnational malaria programming. Data on salaries, allowances, and benefits were taken from the Milne Bay Provincial Health Authority establishment positions register. We adopted the 0.10 weight reported in the Global Fund 2014 concept note[44] and applied it on staff remuneration to approximate time spent on malaria.

As with the national costs, we calculated total annual cost and annual cost per capita using 2015 population numbers (Table A2-2). To estimate subnational spending among the unsampled provinces, we multiplied the mean cost per capita among the sample provinces by the number of people living in the unsampled provinces. The resulting figure was added to the total annual cost among the sampled provinces to generate a total subnational cost for malaria.

Direct non-health system costs

To estimate the household costs of malaria, we multiplied the number of reported malaria cases in 2015 by the mean direct household costs reported in a 2012 study by Sicuri et al. (figures inflated to 2015 USD).[61] We calculated direct household spending for OP and IP cases separately.

Indirect costs

The cost malaria exacts on society extends beyond the health system. Malaria has been shown to negatively impact school performance and educational attainment among children[131,133–135,148], tourist arrivals[149,150], workers' productivity, and countries' economic growth, among others. However, it is rarely possible to account for or value all these indirect economic and social costs. For this study, the indirect costs we estimated were productivity losses among patients and caregivers and the economic impact of premature morbidity.

For patients' productivity losses, we multiplied the number of malaria cases by the average number of days malaria patients are ill and the 2015 GDP per capita per day which we estimated using GDP figures from the DOT.[62] We assumed that the productivity losses of caregivers were equal to those of patients.

To quantify the economic impact of premature deaths due to malaria, we used full income accounting to estimate VLYs lost. Full income approaches combine growth in national income with the value individuals place on increased life expectancy. By capturing the instrumental and intrinsic value of better health, full income measures provide more accurate and complete picture of the benefits of health investments compared to traditional national income accounting which only looks at GDP growth.[63,67]

Figure A2-1A. Malaria transmission model structure for *P. falciparum*

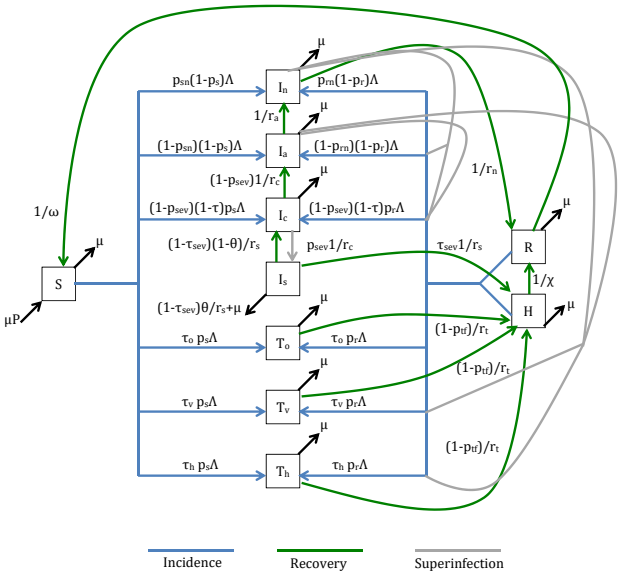
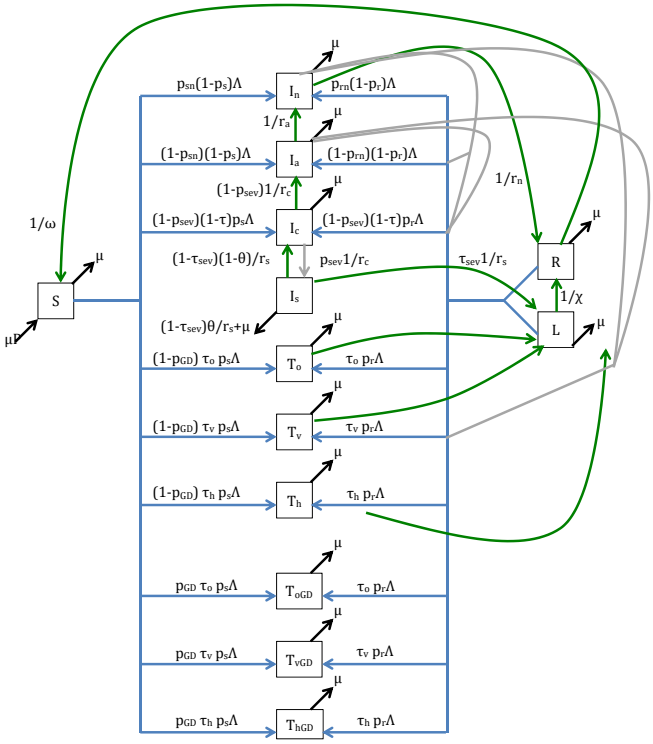


Figure A2-1B. Malaria transmission model structure for *P. vivax*



In full income accounting, one VLY is the value people place in a one-year increase in life expectancy. VLYs vary by region and country, and based on estimates by the Lancet Commission on Investing in Health, one VLY in the East Asia & Pacific region is 2.2 times the GDP per capita at a 3% discount rate.[63] Data on PNG's GDP per capita was taken from the DOT.[62]

We assumed that 40 was the average age of death among malaria-related deaths, and that the life years lost to malaria was equal to the life expectancy at age 40 as reported in the United Nations World Population Prospects (2015 revision).[64] We multiplied this number by the number of deaths and VLY to estimate the total economic impact of premature deaths.

METCAP scenarios and detail

The investment case for malaria elimination was generated using the outputs of a mathematical model (METCAP) to project rates of decline to elimination by at least 2030 and determine the associated costs. The dynamic epidemiological models estimated the impact of a variety of interventions against the transmission of *P. falciparum* and *P. vivax* using four infection classes: severe, clinical, asymptomatic and detectable by microscopy, asymptomatic and undetectable by microscopy. *P. vivax* infections were characterized by relapses of malaria arising from persistent liver stages of the parasite (hypnozoites). The relationship between glucose-6-phosphate dehydrogenase deficiency (G6PDd) and *P. vivax* malaria was captured using existing estimated G6PDd proportions in the population (those with G6PDd have a reduced probability of clinical infection compared to the non-G6PDd proportion of the population)[k]. The model was designed to be spatially explicit with interconnected patches representing whole countries.

Data on historical malaria incidence (2000-2014) and intervention coverage used to calibrate and validate the models were sourced from:

1. World Malaria Reports, 2008-2015;
2. Country data collected from the NMEP;
3. Mahidol Oxford Tropical Medicine Research Unit; and
4. Peer reviewed literature.

The models were validated against the estimated burden of disease separately for *P. falciparum* and *P. vivax* malaria and accumulated case fatalities. While reported coverage of interventions (particularly LLINs and IRS distribution) were included in the models to inform changes in incidence, there was little available data on health system advances between 2000 and 2015, such as the introduction of community health workers (CHWs); these were therefore imputed based on observed changes in reported incidence. The fatalities predicted by the models were validated against reported case fatalities. As mentioned above, the METCAP transmission model was only

k Unpublished estimates from the Malaria Atlas Project

able to provide rough estimates of predicted costings. It was not designed to study individual countries in detail as it uses only on patch per country. Future work will adapt METCAP to incorporate multiple subnational units to model individual countries in detail. A full description of the mathematical models and the parameters driving the models is available elsewhere.[49]

The models predicted reductions of malaria incidence required to reach malaria elimination on or before 2030 (based on a set of intervention coverage scenarios described in Table A2-5. Elimination was defined as the first year in which less than one reported clinical case is achieved. Note that the models do not distinguish between indigenous and imported cases. Hence the definition of elimination is strict compared to zero indigenous cases. The scenario that allowed attainment of the elimination threshold using a minimum package of interventions was considered as the "elimination" scenario. The elimination threshold for each country was determined using a regression model of local and imported clinical cases. The outputs of averted mortality and morbidity under the elimination scenarios were used to estimate the cost, benefits, and ROIs.

Table A2-5. Modeled scenarios

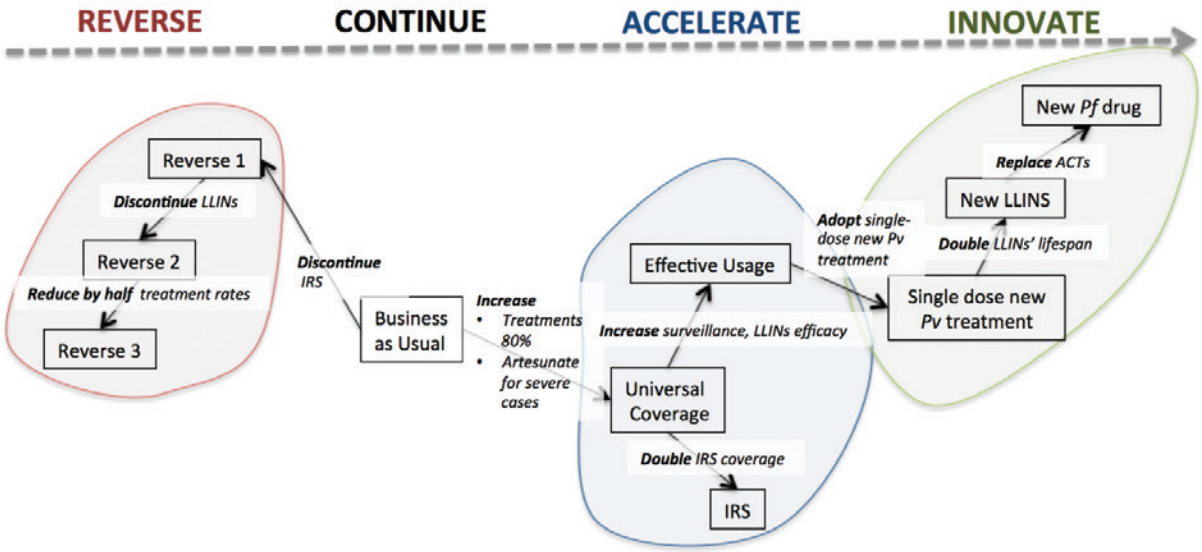
	Scenario	Description
1	Business as usual	• Continue all interventions at 2014 levels from 2016 through 2030
2	Reverse scenario 1	• Business as usual • IRS activities ceased
3	Reverse scenario 2	• Reverse scenario 1 • Distribution of new LLINs ceased
4	Reverse scenario 3	• Reverse scenario 2 • Treatment rates reduced by 50%
5	Universal coverage	• Business as usual • Coverage of test and treat increased from 2017 onwards in a linear fashion over eight years to 80% by 2025 • Quinine is switched to injectable artesunate for management of severe disease in 2017
6	IRS	• Universal coverage • IRS coverage in 2017 doubled in a linear fashion over eight years
7	Effective usage	• Universal coverage • Effectiveness of LLINs increased • Surveillance increased
8	New *P. vivax* treatment	• Effective usage • Replace primaquine with a new *P. vivax* treatment
9	New LLINs	• New *P. vivax* treatment • Life of LLINs doubled
10	New *P. falciparum* treatment	• New LLINs • First-line ACT replaced with new candidate for *P. falciparum* treatment
	Assumption	**Description**
A	Artemisinin resistance	5% probability of treatment failure from ACTs across all countries is constant until 2018 and then increased to 30% through 2025
B	MDA	Five annual rounds of MDA at 50% coverage from 2018 starting four months before the peak of the transmission season
C	LLIN deployment	Scale up of LLIN coverage takes place over a three-year period (i.e., 50% of target achieved in the first year, followed by 25% each in the next two years)

The 10 scenarios were modeled separately using three baselines:

1. Baseline 1: a constant 5% probability of treatment failure to ACTs across all countries and separately for a baseline in which the probability of treatment failure to ACTs increased to 30% by 2025 across all countries
2. Baseline 2: no MDA and separately using five annual rounds of MDA at 50% coverage (of PAR), from 2018, starting four months before the peak of the season
3. Baseline 3: maintaining LLIN coverage at 2015 levels and separately scaling up LLINs to 80% effective coverage deployed in a 3-year cycle (50%, 25% and 25%).

These additional baseline scenarios produced a total of 80 scenarios (with and without resistance, with and without MDA, and with and without LLIN scale up). In addition, we simulated the effect of improved targeting of malaria interventions on both costs and epidemiological outputs. We did this by reducing intervention coverage by 30% among the PAR for all three scenarios, with and without resistance.

Figure A2-1. Visual representation of modeled scenarios



Cost projections

We built a cost estimation model aligned with the outputs of the malaria transmission model to estimate the costs associated with implementing each of the scenarios above. We included the costs of OP and IP treatment, LLIN distribution, IRS (where applicable), supply chains, surveillance, community health workers, information, education, and communication, training, MDA, a new treatment for *P. vivax* (e.g., tafenoquine), and new LLINs in the cost model. Unit costs were obtained from our micro-costing exercise and supplemented by data from published literature and other proxies when data were not available (Table 3). Costs were discounted by 3%.

In projecting costs, we assumed that the PAR on which interventions are administered to decrease over time. Year-to-year rates of decrease are based on analysis done on declining PAR in Sri Lanka, which in 2016 was certified malaria-free by the WHO.

Benefits estimation

We used outputs from the malaria transmission model to estimate the benefits of malaria elimination. We calculated the deaths and cases averted from malaria elimination by getting the difference between the outputs of the elimination and business as usual and reverse scenarios. Using the methods discussed previously, we estimated the direct and indirect costs averted in 2016-2030. The same inputs and assumptions were used in estimating benefits (Table 3). In addition, we also estimated the benefits of continuing current interventions by comparing the business as usual and reverse scenarios. Benefits were discounted at 3%.

Return on investment

To calculate ROI of malaria elimination in 2016-2030, we subtracted the benefits of elimination by the incremental cost of elimination and divided the resulting figure by the incremental cost of elimination. The ROI is interpreted as the economic return from every additional dollar spent on malaria above the counterfactual scenario. We calculated ROIs for both the resistance and baseline assumptions.

Financial landscape

We triangulated data from various sources to estimate past, present, and future financing for malaria. Historical figures (2000-2014) were retrieved from finance tracking work by the Institute of Health Metrics and Evaluation and MEI (unpublished data) supplemented by data from the Global Fund and the World Malaria Report of the WHO. Financing in 2015 was taken from the Global Fund website and the World Malaria Report.

To estimate domestic financing for 2016-2021, we linearly increased the reported GoPNG contribution to malaria in 2015 using the average GDP growth rate for 2016-2017 as estimated by ADB (i.e., 2.6%).[69] For Global Fund financing, we used the actual disbursement reported in the Global Fund website for 2016, and then used the average annual allocation for 2017-2019 for years 2017-2021.[51] Additional donor financing for malaria (from ADB, Australian Department of Foreign Affairs & Trade, and WHO) was taken from the ESP report.

Financial gap

We calculated a financial gap for malaria elimination using the projected costs from the malaria transmission model and the predicted financing available to PNG through 2021.

Sensitivity analysis

We performed stochastic sensitivity analysis on the epidemiological and cost outputs of the malaria transmission model. The minimum, median, and maximum malaria cases and deaths predicted by the model for each scenario were used to calculate the minimum, median, and maximum economic benefits. A similar sensitivity analysis was conducted over a range of baseline estimated incidence values

For the costs, we assigned an uncertainty interval of +/- 25% on the value of the input costs used. Three hundred random samples were drawn, which generated a range of costs. From the range of costs generated, we determined the minimum, maximum, median, mean, and other measures (e.g., percentiles) which are presented in Annex 3.

Limitations

A range of possible incidence estimates was used as input to the model. The model itself was not designed to model individual countries in detai. Due to resource constraints and difficulties in collecting expenditure data, we were unable to cost all malaria program inputs and health system functions. Therefore, our direct health system costs are likely to underestimates. For example, the contributions of NDoH staff outside the NMCP (such as the Deputy Secretary for Health, Public Health Division Manager, and Disease Control & Surveillance) were excluded, though they are involved in high-level planning and oversight of malaria interventions in PNG. We were also unable to cost the time spent by staff at NDoH's Medical Supplies Procurement & Distribution unit on preparing, approving, and executing contracts for centrally procured antimalarials and diagnostic supplies. Technical assistance from the WHO and other development partners were also excluded. Expenditure data from PSI were also incomplete; several functions and sub-grants (e.g., IMR routine surveys and operational research) were excluded.

Most of the expenditure data we received were aggregates; thus we were unable to analyze costs by input and activity. To identify we listed the interventions with the largest reported costs (Table 4). Where possible, costs were apportioned by activity using self-reported hours, potentially introducing reporting bias.

The sample provinces were not chosen randomly, which may be a source of bias. Though the sample provinces were selected based on their representativeness on predetermined criteria (Table A2-3), spending across the sample may not fully capture the diversity of malaria spending at the subnational level.

With no access to subnational expenditure data, we had to rely on budgets reported in AIPs. We made adjustments to the figures we extracted, though it remains unclear how much provinces, districts, and lower-level governments are spending on malaria annually.

Our costing exercise captures all inefficiencies in the current malaria program, and efficiency improvements may significantly decrease the projected cost of elimination. Greater efficiency can be achieved by implementing an optimal mix of malaria interventions that will create the most impact, or by maximizing the impact of current inputs to the malaria program.

As mentioned previously, many benefits of malaria elimination cannot be valued accurately and were excluded from our calculations; thus, our benefits estimations are likely to be underestimates.

The METCAP model has inherent limitations, which may introduce uncertainty to the benefits estimations. The sensitivity analysis we conducted aims to address such issues.

Annex 3. Results of sensitivity analysis

Figure A3-1. Cost of elimination sensitivity analysis

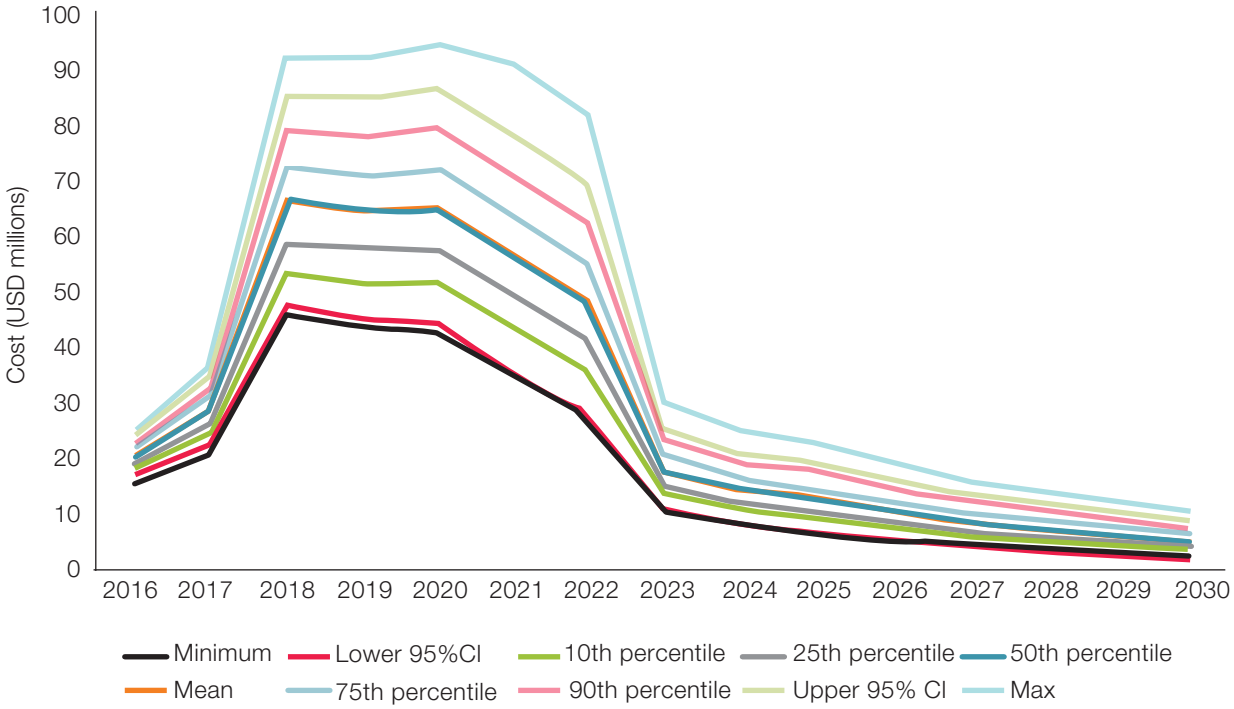
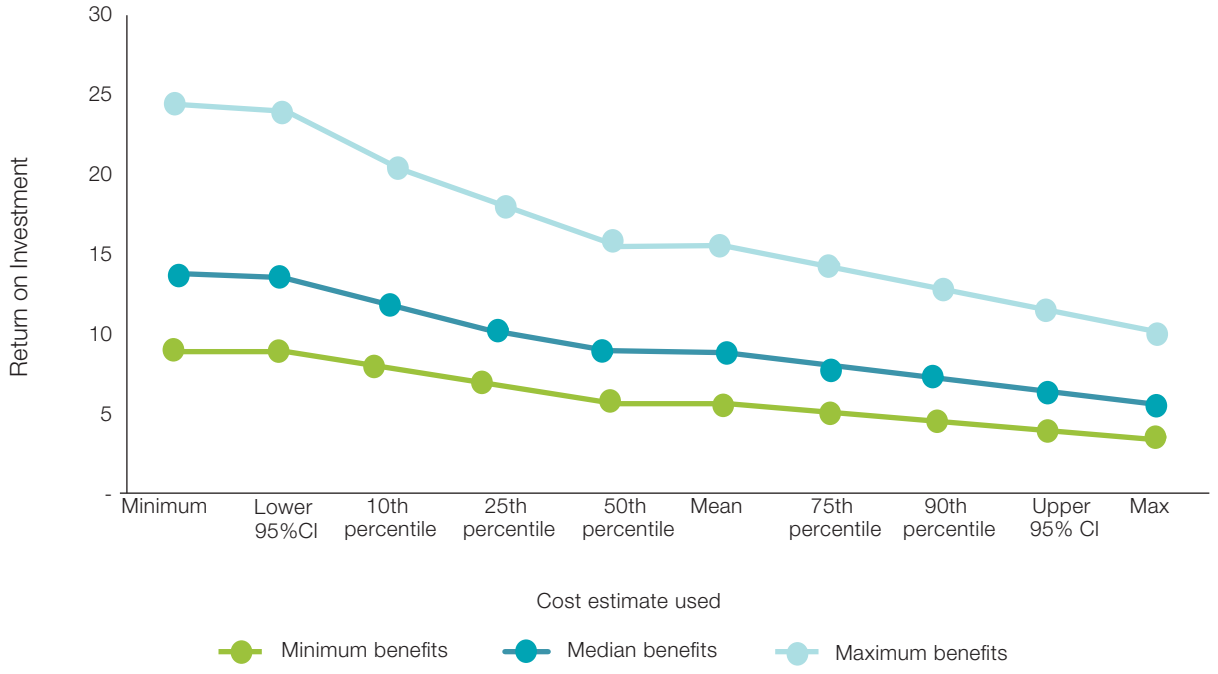


Figure A3-2. ROI estimates for malaria elimination using outputs of sensitivity analysis



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