An Investment Case to Accelerate Malaria Elimination in the Guyana Shield

Malaria Elimination Initiative

UCSF

Institute for Global Health Sciences

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MINISTRY OF HEALTH

MINISTERIE VAN VOLKSGEZONDHEID MALARIA PROGRAMMA

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Cover photo: ©PAHO/WHO. Suriname, Malaria Champions 2018.

Contents

Key Terms and Acronyms

ACT	artemisinin-based combination therapy
AL	artemether-lumefantrine
AR	artemisinin resistance
BAU	business as usual
G6PD	glucose-6-phosphate dehydrogenase
GDP	gross domestic product
Global Fund	Global Fund to Fight AIDS, Tuberculosis and Malaria
GNI	gross national income
IRS	indoor residual spraying
LLIN	long-lasting insecticidal net
NMP	national malaria program
NMSP	national malaria strategic plan
METC	Malaria Elimination Transmission and Costing
MoH	Ministry of Health
P. falciparum	*Plasmodium falciparum* or *Pf*
P. vivax	*Plasmodium vivax* or *Pv*
PAR	population at risk
PQ	primaquine
RDT	rapid diagnostic test
RI	reduced investment
ROI	return on investment
SBCC	social and behavior change communication
SU1	scale-up 1
SU2	scale-up 2
TQ	tafenoquine
WHO	World Health Organization
WMR	World Malaria Report

Summary

Overview

The Guyana Shield* has made substantial progress in reducing the burden of malaria over the past three decades, with significant decreases in malaria morbidity and mortality noted since the 1990s. In recent years, however, progress has plateaued and the trend has reversed, with total malaria cases in the region increasing by 164% overall from 2015 to 2019. The Pan American Health Organization (PAHO) Plan of Action for Malaria Elimination 2016–2020 set targets for all PAHO member states to reach a 40% reduction in malaria morbidity and mortality by 2020, compared to a 2015 baseline. Since the publication of the Plan of Action, a great deal has changed for Latin American countries in their fight against malaria. While the targets and milestones have remained constant, countries' technical and financial challenges in reaching these targets – including the COVID-19 pandemic – have multiplied. Sustaining momentum towards future malaria targets in the Guyana Shield will require a coordinated regional effort accompanied by a plan for sustainable financing.

This report describes potential pathways of progress towards malaria elimination** between 2021 and 2030 in Guyana, Suriname, and French Guiana. The report details the approach to developing various scenarios, including the mix and scale of interventions for each, and model findings from these scenarios, including the projected rate of malaria transmission and costs associated with each. A set of three standard scenarios were developed to understand transmission and cost projections associated with 1) continuing current interventions, 2) scaling up interventions in Suriname and Guyana, and 3) scaling up interventions across the entire region. Two additional, special scenarios were developed in response to specific country interest in understanding alternative future scenarios in which negative factors could cause resurgence or delay achievement of elimination. Where possible, all scenarios were informed by country direction on what is currently underway or possible in the future and were not designed to 'force' elimination by a particular year. Recognizing that progress towards elimination will require coordination amongst countries, the study includes the broader regional context and connectivity. As such, the impact of imported malaria transmission from Brazil and Venezuela on the rest of the region was considered in the study; however, due to limited availability of intervention data and strategic insight, findings for these two countries are not presented. The report incorporates recommendations for strengthened collaboration to address limitations and maximize the utility and validity of the study findings.

The COVID-19 pandemic emerged in 2020 as an additional challenge to the global malaria response. Disruptions to commodity supply chains, service delivery, and treatment-seeking are likely to have had a negative impact on malaria program efforts during the pandemic. The totality of financial and health consequences of the pandemic, while not fully known, is potentially substantial. Given that 2019 data was the most recent available at the time that this study was conducted, findings do not account for the effect of the COVID-19 pandemic on malaria transmission and response. However, the potential impact of COVID-19 on study findings is considered throughout the report.

Objectives

This investment case aims to generate economic evidence to inform resource mobilization efforts and regional coordination for malaria elimination in the Guyana Shield. With the aim of estimating the costs and economic benefits of malaria elimination efforts by country, findings can be used by the national malaria programs and regional partners to improve program budgeting, strategic planning, and advocacy efforts for the purpose of securing sufficient financial

*For the purposes of this study, the Guyana Shield is defined as Suriname, Guyana, French Guiana, Venezuela, and the Brazilian states of Amapá, Pará, and Roraima. However, the level of inclusion in the study varies by country, according to data availability. Full details are included in the methodology section.

**For the purposes of this study, malaria elimination is defined as being achieved when projected indigenous cases are less than 0.1 per 1,000 population at risk. At this low case level, it is assumed that most cases will be imported. The World Health Organization (WHO) defines elimination as zero indigenous cases in a specified geographic area;[1] however, lack of comprehensive subnational case data required use of a different operational definition for this study.

resources and political commitment to accelerate and achieve elimination and prevention of reintroduction. Specifically, the investment case aims to:

1. Estimate the epidemiological impact and economic cost of continuing current malaria interventions in Guyana, Suriname, and French Guiana;
2. Estimate the epidemiological impact and economic cost of scaling up malaria interventions in Guyana, Suriname, and French Guiana;
3. Estimate the epidemiological impact of scaling back malaria interventions in Suriname and French Guiana, and of increased artemisinin resistance in Guyana;
4. Recommend technical measures and coordination to accelerate the path towards malaria elimination in the Guyana Shield.

Methods

Estimation of the cost and benefits of malaria elimination in the Guyana Shield was performed in coordination with the National Malaria Program (NMP) of Suriname, the National Malaria Programme of Guyana, the Ministry of Health (MoH) of Brazil, Agence Régionale de Santé de Guyane, PAHO, The Global Fund to Fight AIDS, Tuberculosis and Malaria (the Global Fund), and other relevant partners. This process consisted of collation of subnational epidemiological and cost data in Guyana and Suriname and national epidemiological data in Brazil, French Guiana, and Venezuela. In consultation with malaria program staff and partners, scenarios were developed to chart potential pathways of progress towards malaria elimination, with interventions tailored to local context in each country. A multi-species, epidemiological-economic transmission model was used to project *Plasmodium falciparum* (*P. falciparum* or *Pf*) and *Plasmodium vivax* (*P. vivax* or *Pv*) malaria transmission rates. Outputs from the model were used to inform estimations of the direct healthcare costs and indirect economic costs associated with each scenario.

Summary of Findings

The study estimates that, with a simultaneous intensification of malaria interventions across the region, Suriname could eliminate both *P. falciparum* and *P. vivax* malaria by 2024; French Guiana could eliminate both parasite species by 2029; and Guyana could eliminate *P. falciparum* malaria by 2025 (Table 1). This coordinated approach to malaria elimination in the Guyana Shield has a compelling economic benefit, with a 230% return on investment. In other words, every 1 U.S. dollar (USD) invested in malaria in the region would generate USD 2.30 in economic benefits, resulting in as much as USD 80 million in economic benefits from 2021 to 2029.

Table 1. Summary of key findings

	Suriname	Guyana	French Guiana
Business as Usual			
Projected Elimination	2028	After 2030	After 2030
Investment Required (2021 to 2029)	USD 21.6 million	USD 49.3 million	USD 8.6 million
Scale-Up 1			
Year of Elimination	2024	After 2030	Not applicable
Investment Required (2021 to 2029)	USD 29.3 million	USD 101.1 million	
Return on Investment	0.1	2.2	
Scale-Up 2			
Projected Elimination	2024	After 2030 (*Pf* elimination by 2025)	2029
Investment Required (2021 to 2029)	USD 28.9 million	USD 93.9 million	USD 16.4 million
Return on Investment	0.2	2.8	1.4

Through the implementation of current interventions, Suriname is predicted to achieve malaria elimination by 2028. However, a decline in external financing that is projected to begin in 2024, indicates that Suriname may be at risk of resurgence unless financing is increased. Intensifying malaria interventions in Suriname could accelerate elimination of both parasite species by 2024 and would require an additional investment of USD 3 million over the next four years but yield economic benefit to the country by 2023.

Elimination in Guyana is estimated to be dependent on the simultaneous reduction in malaria transmission throughout the region. The model estimates that elimination will not be achieved before 2030 if current interventions are continued or interventions are scaled up within Guyana alone. Scaling up malaria interventions regionally is projected to result in elimination of *P. falciparum* malaria by 2025 in Guyana and is estimated to avert 240,000 clinical malaria cases within the country from 2021 to 2024 (compared with continuation of current interventions). This accelerated approach would require approximately USD 7.5 million in additional financing from 2021 to 2024 in Guyana. Such an investment would generate a 285% return on investment in indirect economic benefits. The potential spread of artemisinin resistance in Guyana requires vigilance, as it is projected to result in a rise in cases and could reduce the effectiveness of passive case detection if drug efficacy is not closely monitored and treatment failure addressed.

It is predicted that if current intervention levels are continued, French Guiana will not reach elimination before 2030. A coordinated regional approach to elimination would enable French Guiana to eliminate malaria (both parasite species) by 2029. The economic benefits of accelerating malaria elimination in French Guiana would be substantial, resulting in economic savings of nearly USD 1 million annually by 2028.

This investment case provides compelling evidence for the benefits of regional coordination and increased investment for malaria response in Suriname, Guyana, and French Guiana and can be used to develop an advocacy strategy for increased domestic and external financing for the region to reach its goal to be malaria-free by 2030. Given limitations in the availability of data and strategic insight for malaria activities, the full range of limitations and assumptions that are detailed within this report should be considered when interpreting study findings.

Region at a Glance

Malaria in the Guyana Shield

The Guyana Shield (defined as Suriname, Guyana, French Guiana, Venezuela, and the Brazilian states of Amapá, Pará, and Roraima) (Figure 1) achieved substantial reductions in the burden of malaria over the past three decades, experiencing significant decreases in malaria morbidity and mortality since the 1990s. In recent years, however, the trend has reversed, and total malaria cases in the region have increased by 164% between 2015 and 2019 (Table 2 and Figure 2).

In 2019, the vast majority of cases in the region were reported in Venezuela (83%), followed by the Brazilian border states (13%) and Guyana (4%). Suriname and French Guiana contributed minimally to the regional burden (0.4% each) in 2019. While indication of progress has been noted in certain countries over the past five years, there remain persistent and emerging threats to malaria elimination in the Guyana Shield region. These include migrant populations associated with gold mines, the region's ecological characteristics, and regional transmission dynamics.

Figure 1. Map of the Guyana Shield

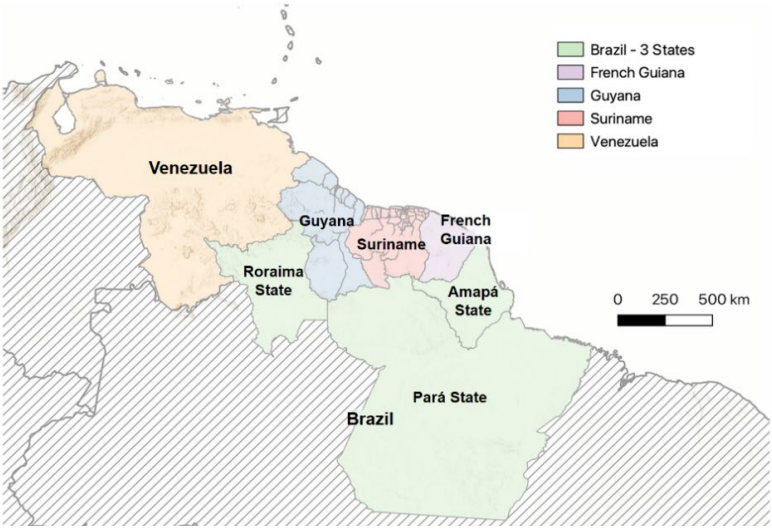
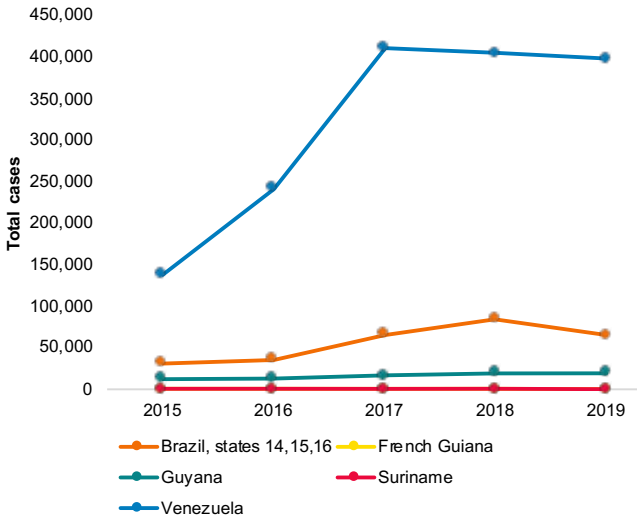


Table 2. Total malaria cases reported in the Guyana Shield, 2015–2019

Location	2015	2016	2017	2018	2019
Brazil, states 14,15,16[a]	31,048	35,737	66,478	84,450	64,567
French Guianaa	433	258	597	546	212
Guyanaa	13,244	12,975	15,732	19,214	19,319
Surinamea	391	327	551	244	212
Venezuela[b]	137,996	242,561	411,586	404,924	398,285
TOTAL	183,112	291,858	494,944	509,378	482,595

a. Data provided by countries' respective MoHs.
b. Data sourced from the 2020 WHO World Malaria Report.

Figure 2. Total malaria cases reported in the Guyana Shield, 2015–2019



Malaria transmission in the region is concentrated in the Amazonian interior, or "hinterland". Expansion of gold mining and logging activities across the region has resulted in significant migration to the hinterland of people seeking work as miners or mining service providers. Increasing migration to these malaria-endemic areas contributes to a corresponding rise in susceptible populations. As such, malaria transmission in the Guyana Shield is closely connected to international gold prices: as gold fetches a higher price on the market, mining activities expand, and a larger population is placed at greater risk of exposure.[2]

Ecological and geographical dynamics in the malaria-endemic areas of the Guyana Shield continue to impact malaria transmission and response as well. Increased human activity in the gold-rich Amazonian region, coupled with a lush rainforest climate, creates favorable conditions for mosquito breeding. The remote and treacherous terrain in the hinterland, the transient nature of migrant populations, and the time and cost burden associated with transporting supplies and delivering services in the interior present significant challenges to local health authorities in providing quality malaria services and interventions.[2,3]

While Venezuela eliminated malaria in 1961, insufficient vector control and surveillance activities in recent years have contributed to a drastic resurgence.[4] Venezuela is reported to have had nearly nine times more cases in 2019 (398,285) than in 2010 (45,155) a 780% increase. The World Health Organization (WHO) reported that in 2019, Venezuela accounted for 55% of total malaria cases and over 70% of total malaria deaths for the entire WHO Region of the Americas.[5] Resurgence of malaria in Venezuela has not only caused an increase in the nation's preventable morbidity, mortality, and related healthcare costs, but has also hindered malaria control and elimination progress in neighboring countries, particularly Guyana and Brazil. A significant increase in Venezuelan migrants, primarily attracted by mining and logging activities in the remote hinterland, has been recorded in Guyana, and an increase in the number of malaria cases among these migrants has also been documented.[2] Recent WHO projections suggest that the current trajectory of malaria cases in the WHO Region of the Americas will rise sharply, driven by increasing malaria incidence in Venezuela (Figure 3).[5]

A large number of imported cases has been reported throughout the Guyana Shield region (Table 3). Notably, over 80% of all malaria cases in Suriname from 2015 to 2019 were classified as imported, while less than 1% of all cases in Venezuela were reported as imported over the same period.

Table 3. Total imported malaria cases (percentage of total cases) reported in the Guyana Shield, 2015–2019

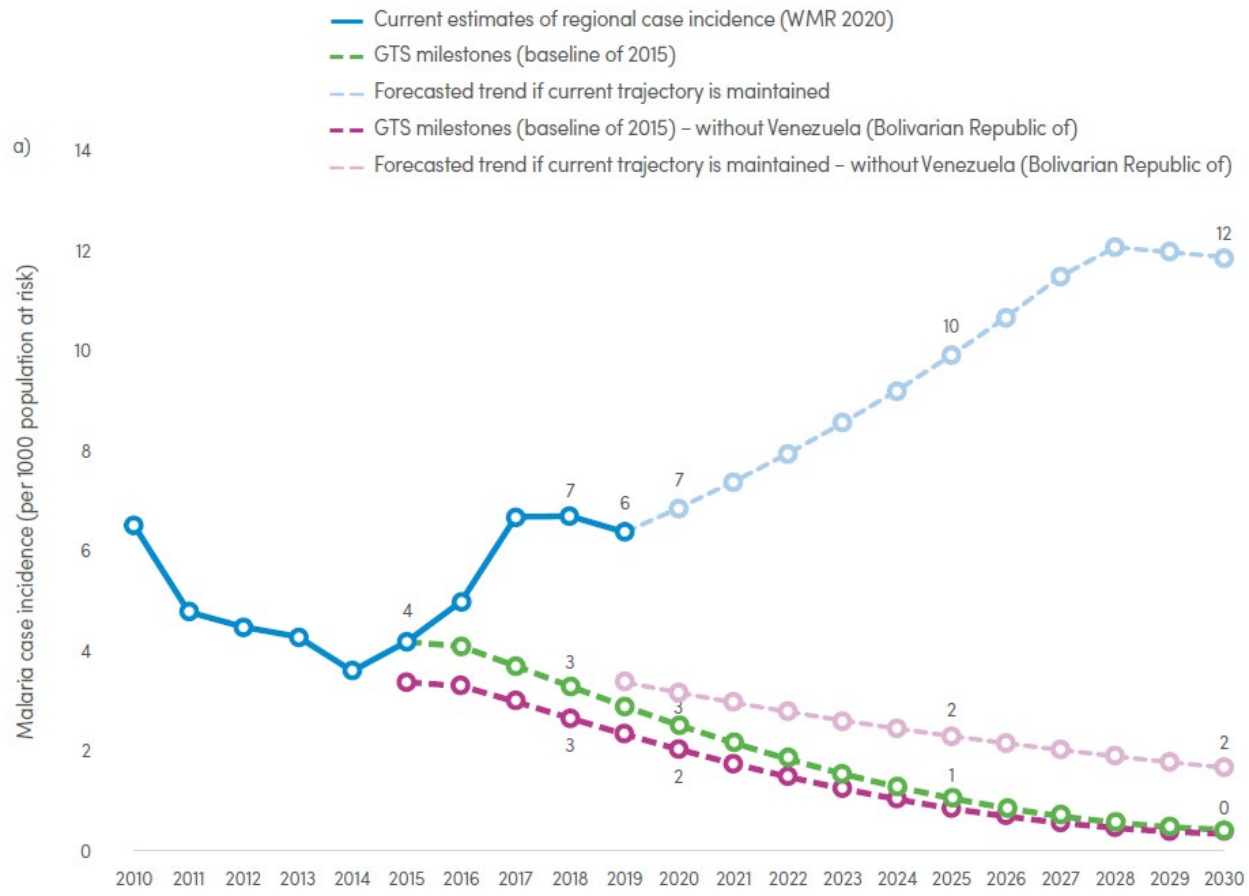
Destination of imported case	2015	2016	2017	2018	2019
Brazil, states 14,15,16[a]	2,241 (7.2%)	3,593 (10.1%)	3,355 (5.0%)	5,458 (6.5%)	2,914 (4.5%)
French Guiana[b]	60 (13.9%)	41 (15.9%)	43 (7.2%)	- (-)	36 (17.0%)
Guyana[a]	206 (1.6%)	411 (3.2%)	793 (5.0%)	874 (4.5%)	- (-)
Suriname[a]	301 (77.0%)	250 (76.5%)	511 (92.7%)	208 (85.2%)	117 (55.2%)
Venezuela[b]	1,594 (1.2%)	1,948 (0.8%)	2,941 (0.7%)	2,125 (0.5%)	1,848 (1.0%)
TOTAL	4,402 (2.4%)	6,243 (2.1%)	7,643 (1.5%)	8,665 (1.7%)	4,915 (1.0%)

" - " refers to data not available.

a. Data provided by countries' respective MoHs.

b. Data sourced from the 2020 WHO World Malaria Report.

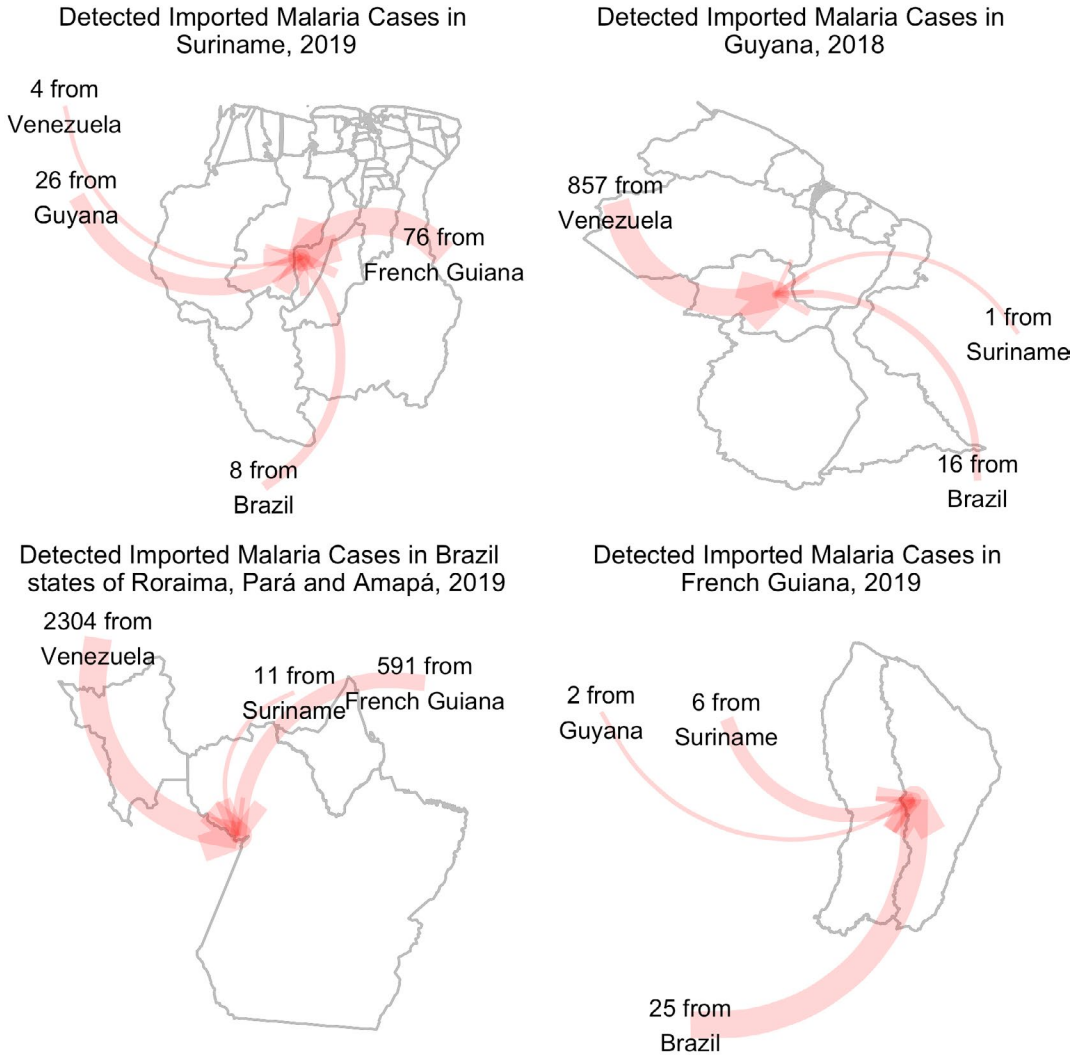
Figure 3. Malaria projections for the WHO Region of the Americas, 2020–2030



GTS: *Global technical strategy for malaria 2016–2030*; WHO: World Health Organization; WMR: world malaria report.

The strong connectivity within the Guyana Shield, predominantly by way of mobile populations in the hinterland, has resulted in high levels of malaria case importation between countries in the region (Figure 4 and Table 4). Malaria transmission in Suriname is heavily influenced by the importation of cases from French Guiana, with over 90% of imported cases in Suriname having a reported origin of French Guiana over the past five years. Venezuela's influence on malaria transmission in the region is significant. A vast majority (79%) of Brazil's imported cases and nearly all (98%) of Guyana's imported cases have a reported origin of Venezuela.[6,7] Despite the interconnectedness of malaria transmission throughout the region, there is currently no mechanism in the Guyana Shield for formal coordination of malaria control and elimination efforts.

Figure 4. Total imported malaria cases by source country within the Guyana Shield*



*No available data on source(s) of imported cases for Venezuela.

Table 4. Total imported malaria cases (percentage of total) by source country within the Guyana Shield*

		Source of imported case				
		Brazil, all states	**French Guiana**	**Guyana**	**Suriname**	**Venezuela**
Destination of imported case	**Brazil, states 14,15, 16 (2019)[a]**	-	115 (3.9%)	476 (16.3%)	11 (0.4%)	2,304 (79.2%)
	French Guiana (2019)[a]	19 (76.0%)	-	2 (8.0%)	4 (16.0%)	0 (0%)
	Guyana (2018)[a]	16 (1.8%)	0 (0%)	-	1 (0%)	857 (98.1%)
	Suriname (2019)[a]	8 (7.0%)	76 (66.7%)	26 (22.8%)	-	4 (3.5%)

" - " refers to does not apply.

a. Data provided by countries' respective MoHs.

*No available data on source(s) of imported cases for Venezuela.

Progress Towards Regional Goals

In 2015, PAHO put forth the Plan of Action for Malaria Elimination 2016–2020 to set a bold vision in order to move the WHO Region of the Americas towards elimination. In this plan, the region committed to a set of targets, including a reduction of malaria morbidity and malaria-related deaths by 40% or more (compared to a 2015 baseline).[8]

According to the 2020 WHO World Malaria Report (WMR), which includes country case data for 2019, French Guiana is the only country in the Guyana Shield (five total countries) that is on track to achieve the 2020 milestone of a minimum 40% indigenous malaria morbidity reduction compared to a 2015 baseline. Brazil and Suriname are each estimated to have reduced indigenous malaria case incidence by less than 25% in 2019 as compared with 2015. Guyana and Venezuela have experienced significant malaria resurgences in the past five years: both are estimated to have seen a greater than 40% increase in indigenous case incidence in 2019 as compared with 2015.[5]

Financing for Malaria in the Guyana Shield

There are two main sources of financing for the malaria response in the Guyana Shield: external donor assistance and domestic government resources.

Donor Financing

Of the total malaria donor assistance received by countries in the Guyana Shield from 2000 to 2019, the majority (79%) was provided by the Global Fund, with additional support reported from the U.S. President's Malaria Initiative (11%) and other bilateral sources (4%).[5,9,10,11,12]

Due to differences in income classification and burden of disease, two factors that affect eligibility for the Global Fund, donor financing for malaria in the region varies by country. Brazil became ineligible for Global Fund support for malaria in 2011, and its last Global Fund grant for malaria ended that same year. As an overseas department of France, French Guiana is ineligible for Global Fund funding.

Guyana and Suriname remain eligible for Global Fund malaria financing, which constitutes the vast majority of donor assistance for malaria response in the region. Both Guyana and Suriname have received Global Fund malaria support since 2005, and, as of 2020, have received cumulative amounts of USD 5,843,662 and USD 13,589,083 respectively.[13] Given its recent reclassification as an upper middle-income country with a low malaria burden, Guyana faces a transition from Global Fund financial support for malaria in 2024. While Suriname is also classified as an upper middle-income country, its categorization as having a high malaria burden means that it does not face an imminent transition in assistance from the Global Fund. It is important to note that malaria burden status is classified according to data from 2000, an approach re-affirmed by technical partners in 2018.

While previously ineligible for Global Fund support, Venezuela has received a malaria allocation totaling USD 19,800,000 for the 2020–2022 period.[14] This decision came at the recommendation of malaria technical partners, given the significant resurgence

of malaria in the country and its overwhelming burden on the region.[15] Despite this promising investment, the malaria situation in Venezuela is assumed to remain challenging, with limited data availability and low visibility into malaria program activities.

Domestic Financing

Over the past five years (2015–2019), Guyana's national malaria response has been 59% domestically financed.[5] Increased domestic financing will be increasingly important as Guyana receives smaller disbursements from external donors in the coming years and eventually transitions from Global Fund support in 2024. This transition is expected to occur as Guyana's gross domestic product (GDP) per capita is anticipated to grow at an annual rate of 26.2% – faster than any other country in the world, despite the economic effects of COVID-19.[16] Over the next four years (2021–2024), Guyana's domestic resource contributions for malaria are expected to grow by nearly 50% (nearly 15 million USD) compared with the previous four years.[17] This projected rapid expansion is informed by recent oil discoveries in Guyana, which are anticipated to lead to a dramatic increase in government revenue. While the above predictions are promising, it is important to note that the availability of increased domestic resources is by no means guaranteed, as the financial boom is only expected and has not yet been fully realized. The COVID-19 pandemic likely only injects added uncertainty into the future state of Guyana's domestic financing for health.

From 2015 to 2019, the Government of Suriname contributed approximately half (49%) of total reported funding for its malaria response.[5] Looking forward, the Government of Suriname is projected to continue this trend, financing approximately half (52%) of the total need (as identified in its National Malaria Strategic Plan (NMSP)) over the next five years (2020–2024) – approximately USD 1.5 million annually.[18] However, Suriname's GDP per capita is expected to contract by 13% in 2020,[16] due in large part to the COVID-19 pandemic. This expected contraction creates greater uncertainty for domestic budgets, including those related to the malaria program.

According to the 2019 and 2020 WHO WMRs, French Guiana is reported to have allocated no government resources towards malaria response activities from 2015 to 2019, and no other sources of financing were reported during that time. Brazil and Venezuela are reported to have supported nearly 100% of their malaria efforts with government financing during this period[5,9-12]

Potential Impact of COVID-19 on Malaria Programs

In the context of the COVID-19 pandemic, which has precipitated global economic contraction, strained national health systems, and disrupted malaria services, progress against malaria is at risk. COVID-19 pandemic response measures have impacted malaria programs and service delivery at all levels of the system. Local health departments were forced to redirect limited resources, both financial and human, to pandemic response at the expense of other disease programs. Restrictions to large gatherings resulted in the delay or cancellation of malaria campaign activities and events. Messaging advising the public to remain at home if they were experiencing fever, as well as a general fear of public gatherings, may have impacted treatment-seeking for febrile diseases such as malaria.[5] Border closures disrupted supply chains globally, causing delays in the delivery of much needed malaria commodities. As lockdown measures increased and unemployment swelled, migrants returned home through border areas with limited health infrastructure, potentially facilitating transmission of both COVID-19 and malaria.[4]

In the face of these challenges, countries have remained vigilant in the fight against malaria: adapting methods for service delivery, troubleshooting supply chain hurdles, and ensuring the safety of frontline workers and communities. The PAHO Regional Malaria Program has urged countries to sustain malaria efforts and financing in the face of the COVID-19 pandemic in order to protect hard-won gains and reduce strain on overburdened health systems by lowering the burden of malaria.[19] To support countries in addressing COVID-19 and mitigating the impact on other health programs, the Global Fund has provided guidance, tools, and funding. All three countries in the Guyana Shield currently receiving Global Fund financing – Guyana, Suriname, and Venezuela – accessed financial support through two new funding mechanisms: the COVID-19 Response Mechanism to unlock additional funding and the Grant Flexibilities mechanism to reprogram current Global Fund grants. Through these mechanisms, Guyana secured USD 357,894 in additional funding, Suriname secured USD 372,874 in additional funding and reprogrammed USD 192,109 from its current grant, and Venezuela secured USD 1,972,680 in additional funding and reprogrammed USD 7,320 from its current grant.[20]

The economic impact that the COVID-19 pandemic will inflict on the Guyana Shield region is not yet fully known, and may include potential negative consequences for both domestic health financing generally and malaria financing specifically. In light of WHO

predictions for greater-than-expected malaria morbidity and mortality globally,[5] increased commitment to health priorities as well as technical coordination to implement interventions across the Guyana Shield will be key to combating the dual challenges of malaria and COVID-19.

Malaria in Guyana

Guyana has made significant progress in shrinking its malaria burden. Specifically, reported malaria cases have declined from a peak of nearly 60,000 in 1995[10] to a low of 13,244 twenty years later in 2015, while the national population has remained relatively stable (79 malaria cases per 1,000 in 1995, 18 cases per 1,000 in 2015).[7,21] However, in recent years, Guyana has experienced a plateau in progress and a reversal in this downward trend, with a 46% increase in cases from 2015 to 2019.[7] This resurgence can primarily be attributed to increased human activity associated with mining and logging in the malaria-endemic interior, coupled with challenges in deploying and distributing malaria services in the remote, hard-to-reach hinterland.[22]

Malaria in Guyana is concentrated in the sparsely populated interior hinterland regions, specifically Regions 1, 7, 8, and 9 (Figure 5). These four regions accounted for 94% of malaria cases in 2018, despite constituting less than 11% of the national population.[2] In a micro-stratification exercise completed in 2018, Guyana identified 16 foci of malaria transmission across the country, with three foci in Region 1 accounting for approximately one-third of total cases nationwide in the previous three years. Three of the 16 foci with lower relative malaria transmission and vulnerability (foci 8B, 9A, and 9C) have been targeted for elimination by 2025.[2]

The lush rainforest climate of Guyana's malaria-endemic hinterland, together with environmental changes resulting from human activity and increases in susceptible populations, creates a favorable environment for malaria transmission. Guyana's hinterland primarily consists of Amazon rainforest, which provides natural mosquito breeding environments. The abundance of available natural resources, including gems and metals, attracts many migrants to participate in the key economic activities of mining and logging. Nearly 20,000 miners are estimated to have worked in Regions 1, 7, 8, and 9 in 2019.[2] Malaria transmission is closely associated with fluctuations in international gold prices, as increases in gold prices lead to increased mining activity.

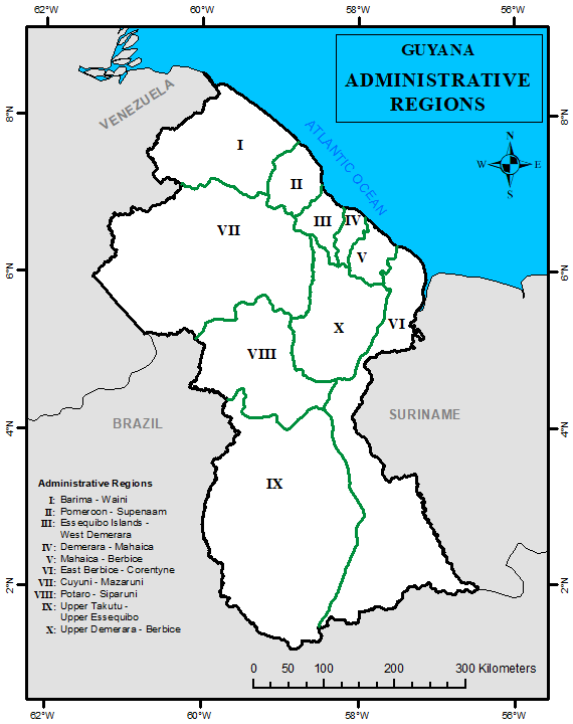
In recent years, Guyana has faced the additional challenge of an increase in migrant populations, particularly from neighboring Venezuela, with many participating in the aforementioned economic activities in the hinterland. The influx of Venezuelan migrants into Guyana has been accompanied by a marked rise in the number of malaria cases among these groups. In Regions 1 and 7 of Guyana, the number of malaria cases among Venezuelans rose from 18 in 2014 to 2,056 in 2018. Although it is not established whether these cases are indigenous or imported, it is likely that at least some are imported.[2] Malaria prevention, diagnosis, and treatment services are provided free of charge to all populations in Guyana, including foreign migrants. This necessitates increased deployment of supplies to the high-burden border areas. Due to the difficult terrain and remote nature of these areas, the distribution of necessary malaria commodities and services requires an increased investment of time and financial resources.

Additionally, the efficacy of artemether-lumefantrine (AL), Guyana's first line treatment for uncomplicated *P. falciparum* malaria, is being assessed and serves as a cause of concern within the context of artemisinin resistance. Guyana has been flagged by the WHO as one of two countries outside of the Greater Mekong Subregion with concerning levels of parasitic mutations, with recent evidence from the WHO indicating the presence of the *Plasmodium falciparum* Kelch 13 (*PfK13*) C580Y mutation, a marker of partial artemisinin resistance, in samples in Guyana in 2010 and 2017.[23] This mutation was not detected in samples from any other country in the Guyana Shield. While the *PfK13* C580Y mutation is a marker of potential artemisinin resistance, its presence does not equate to established artemisinin resistance. A study conducted by the Guyana NMP in 2018/2019 found cases of treatment failure; however, preliminary molecular analysis did not detect the presence of the *PfK13* C580Y mutation in samples analyzed at the time.[24] The differences in the outcomes of the abovementioned studies may have resulted from variations in study population, sample size, and other study parameters. The absence of *PfK13* C580Y mutations in samples from the 2018/2019 study carried out by the Guyana NMP does not rule out artemisinin resistance as a potential threat. Rather, ongoing and future therapeutic efficacy studies are necessary to evaluate the impact of this mutation on delayed parasite clearance and ACT efficacy and its potential spread within and outside Guyana.

Such mutations could potentially result in increased treatment failure, the spread of resistance throughout the country and region, and a general resurgence in *P. falciparum*. As the region moves towards malaria

elimination, the country will need to closely monitor treatment efficacy, identifying treatment failure early and switching to second line treatment when appropriate, in order to halt potentially growing resistance. National guidelines defining treatment failure thresholds and the process for switching to a second line treatment in a timely manner will enable a proactive response. These actions would aid in prolonging the use of currently administered drugs and limiting the impact on the public health system.

Figure 5. Map of Guyana administrative regions by number and name



Sustaining Momentum in Guyana

In line with the WHO Global Technical Strategy for Malaria 2016–2030 (GTS) and the PAHO Plan of Action for Malaria Elimination 2016–2020, Guyana recently renewed its commitment to scaling up its malaria response and moving towards elimination with establishment of the following goals (against a 2015 baseline):

1. Reduce national malaria incidence by 50% by 2022 and 75% by 2025;
2. Reduce national malaria mortality rate by 50% by 2020 and 75% by 2025;
3. Eliminate *P. falciparum* malaria from all regions by 2025;
4. Eliminate malaria in foci 8B, 9A, and 9C by 2025.

Achieving these targets will require both an intensification of efforts and a plan for sustainable financing, particularly given the upward trajectory of malaria cases in Guyana over the past five years. Political and financial commitment from the Government of Guyana, as well as contributions from donors (notably, the Global Fund), have played a significant role in Guyana's progress against malaria to date. However, donor financing is projected to decline in the coming years and disappear entirely after 2024, when Guyana will transition from Global Fund malaria support.[13] While the Government of Guyana is projected to fulfill 88% of total funding needs (as outlined in its NMSP) for the 2021–2024 period, a funding gap of over USD 3 million remains.[17] National financial stressors and health system burdens resulting from the COVID-19 pandemic have the potential to threaten Guyana's ability to intensify its malaria response efforts. Further investment, subnational tailoring, and cross-border technical coordination are needed to ensure that the national malaria program progresses towards its malaria reduction targets and to accelerate the pace of elimination in Guyana.

Malaria in Suriname

Increased financial support, strengthened partnerships, and improved interventions have led to dramatic progress in controlling malaria in Suriname over the past two decades. The number of malaria cases declined from a high of over 16,600 in 1996[10] to just over 200 in 2019.[25] Progress is further indicated by a 46% reduction in malaria cases from 2015 to 2019, and only one recorded death during the same period.[25] Investments in mass net distribution, surveillance and data sharing systems, and expanded service delivery regardless of citizenship status have collectively driven considerable progress against malaria.[3] However, despite substantial advancement towards elimination, emerging challenges threaten gains and jeopardize further progress.

Malaria in Suriname is now concentrated in the border area of the Tapanahony resort, with proximity to the mining areas of French Guiana.[25] Mobile and migrant populations, predominantly from Brazil, are attracted to these areas for work and travel through Suriname en route to the mines in French Guiana. Recent increases in the number of malaria cases in Suriname have been tied to fluctuations in the price of gold.[2] As gold becomes more valuable on the market, gold mining activities generally increase, leading to heightened migration to and from the malaria-endemic mining areas. Historically, gold prices tend to be highly variable and unpredictable, especially during times of economic volatility such as the COVID-19 pandemic. Given that costs related to travel, supply shipment,

and other factors are often directly tied to the price of gold within Suriname's gold mining regions, the unpredictability of gold prices introduces uncertainty into both epidemiological projections and cost estimations associated with operating malaria programs. High costs in the mining areas, remote and transient settlements, and dynamic ecological factors all prove challenging to the provision of stable malaria services in the border regions of Suriname.

From 2015 to 2019, over 80% of all reported cases in Suriname were imported.[3,25] Over 90% of these imported cases had a presumptive origin in neighboring French Guiana, indicative of a major cross-border challenge. Given the highly mobile nature of the population in the mining regions and the concentration of imported cases along border areas, regional coordination is critical if elimination is to be reached in Suriname.[3,25]

Sustaining Momentum in Suriname

Suriname is a regional leader of the fight against malaria in the Guyana Shield, and has set an updated goal to eliminate transmission of malaria by 2025 while avoiding reintroduction from imported cases.[26] In spite of the progress noted above, Suriname was one of only four countries in the world that saw a rise in cases in 2019 compared to 2018, with an increase of 66 cases.[5] Moreover, the country's malaria program could soon face a significant funding gap, as domestic resources are projected to cover only half of the total funding need for Suriname's NMSP from 2021–2024, and donor assistance is predicted to decrease at the end of the same period.[18] National economic stressors and health system burdens, exacerbated by the COVID-19 pandemic, have the potential to further threaten progress. Increased investment and strengthened regional coordination are needed to ensure that the national malaria program will reach malaria elimination and prevent reintroduction.

Malaria in French Guiana

According to data reported to the WHO, French Guiana has made strides in reducing the burden of malaria within its borders. Reported malaria cases have declined from a peak of nearly 6,000 cases in 1990 to a low of 212 nearly three decades later in 2019.[5,10] According to the 2020 WHO WMR, French Guiana is on target for the 2020 malaria morbidity GTS milestone of a reduction of at least 40% in case incidence. The French territory has also curbed malaria mortality, with only 8 reported deaths due to local transmission from 2010 to 2013 and no deaths reported since 2013.[5]

Reported data on malaria spending and interventions is limited, with no publicly available NMSP and minimal reported information in the WHO WMRs. According to the 2020 WHO WMR, French Guiana reported no data on commodities distribution and coverage or case investigation from 2017 to 2019.[5] Similarly, there were no contributions reported by donors or by domestic sources in French Guiana from 2010 to 2019.[5,10-12]

Methodology

A dynamic epidemiological-economic model for malaria transmission from the Malaria Elimination Transmission and Costing (METC) suite of models[27,28] was used to assess the feasibility and cost of potential pathways to progress towards malaria elimination in the Guyana Shield. The multi-species model includes transmission models for both *P. falciparum* and *P. vivax* malaria, and incorporates interactions between the two parasite species (see Appendix A for additional details on the model). Five model scenarios with various combinations and coverage levels of interventions were simulated to chart the possible impact of the interventions and future paths towards elimination. Case, intervention, and cost data were provided directly by MoHs and NMPs or sourced from NMSPs and WMRs. Scenarios for Suriname and Guyana were informed and validated by the respective country NMSPs. Findings are presented only for Suriname, Guyana, and French Guiana. The impact of imported malaria transmission from Brazil and Venezuela on the rest of the region was included in the study; however, due to limited availability of intervention data and strategic insight, findings for these two countries are not presented.

Scenario Descriptions

Informed by countries' NMSPs, and in collaboration with NMPs and regional partners, five scenarios were defined to chart the impact of the interventions and possible future paths for malaria transmission in the Guyana Shield. A summary of scenarios modeled by country can be found below (Table 5), with a more detailed comparison presented in Appendix C. Details on interventions included for each country within each scenario can be found in the respective country findings sections. Three standard scenarios were developed to explore progress towards elimination through implementation of either current interventions or accelerated interventions. Two additional, special scenarios were developed in response to specific country interest in understanding alternative future scenarios in which negative factors could cause resurgence or delay achievement of elimination.

Standard Scenarios

Business as Usual (BAU) - findings reported for: Suriname, Guyana, French Guiana

The business as usual scenario models malaria incidence if a) current interventions are maintained at present levels in Suriname, Guyana, and French Guiana and b) imported cases from Brazil and Venezuela into the rest of the region continue on their current trajectory.

Scale-Up 1 (SU1) - findings reported for: Suriname and Guyana

The scale-up 1 scenario models malaria incidence if scale-up of current interventions and introduction of new, country-focused interventions occur in Suriname and Guyana only, as directed by the most recent NMSP or NMP guidance. In this scenario, business as usual is assumed for the rest of the region (current levels of interventions are maintained in French Guiana, and imported cases from Brazil and Venezuela into the rest of the region continue on their current trajectory).

Scale-Up 2 (SU2) - findings reported for: Suriname, Guyana, French Guiana

The scale-up 2 scenario models malaria incidence if a) scale-up of current interventions and introduction of new, country-focused interventions occur in Suriname, Guyana, and French Guiana and b) there is a decrease in imported cases from Brazil and Venezuela into the rest of the region.

Special Scenarios

Reduced Investment (RI) - findings reported for: Suriname and French Guiana

The reduced investment scenario models malaria incidence if current interventions are scaled back in Suriname and French Guiana simultaneously. In this scenario, business as usual is assumed for the rest of the region (current levels of interventions are maintained in Guyana, and imported cases from Brazil and Venezuela into the rest of the region continue on their current trajectory).

Artemisinin Resistance (AR) - findings reported for: Guyana

The artemisinin resistance scenario models malaria incidence if treatment failure to Guyana's first-line malaria treatment, artemether-lumefantrine (AL), increases in Guyana. In this scenario, business as usual is assumed for the rest of the region (current levels of interventions are maintained in Suriname and French Guiana, and imported cases from Brazil and Venezuela into the rest of the region continue on their current trajectory).

Due to variation in data availability and validation of scenarios, it is important to note the following regarding how the scenarios are represented for each country in the region:

- In Guyana and Suriname, case and intervention data were received at the subnational level, and the unique mix of interventions and strategies were informed and validated by the respective NMPs. The scale-up scenario for each country was developed to capture interventions proposed in the current NMSP or additional interventions the NMP would intend to implement beyond those in the NMSP.
- In French Guiana, case and intervention data were received at the national level. Scenarios were developed to ensure consistency with current interventions, but could not be validated by local health officials.
- In Brazil, case and vector control data were received at the state level for Amapá, Pará, and Roraima. However, lack of intervention data and strategic insight hindered the team's ability to accurately represent distinct scenarios for the three states. Therefore, future intervention in Brazil is modeled only to reflect the impact of imported cases from Brazil into the rest of the region. No costing is provided for Brazil.
- In Venezuela, case data were only available as reported in the WHO WMRs. Lack of intervention data and strategic insight hindered the team's ability to accurately represent distinct scenarios. Therefore, future intervention in Venezuela is modeled only to reflect the impact of imported cases from Venezuela into the rest of the region. No costing is provided for Venezuela.

Table 5. Overview of the five model scenarios by country

	Suriname	Guyana	French Guiana
1: BAU*	Business as usual	Business as usual	Business as usual
2: SU1*	Scale up interventions	Scale up interventions	Business as usual
3: SU2**	Scale up interventions	Scale up interventions	Scale up interventions
4: RI*	Scale back interventions	Business as usual	Scale back interventions
5: AR*	Business as usual	Increased artemisinin resistance	Business as usual

*Assumes a stable trend in imported cases from Brazil and Venezuela. Details provided below.

**Assumes a hypothetical decline in imported cases from Brazil and Venezuela. Details provided below.

Glossary of Interventions of Inclusion

- Artemisinin-based combination therapy (ACT) - A combination of an artemisinin derivative with a longer-acting antimalarial drug that has a different mode of action[29]
- Active case detection - Detection of malaria by health workers at household or community level in response to a confirmed case or cluster of cases[29]
- Long-lasting insecticidal nets (LLIN) - Protective bednets that maintain an effective level of insecticide for at least three years[29]
- Malakit - Free malaria self-diagnosis and self-treatment kits distributed to high-risk gold miner populations in Suriname and Brazil along the border with French Guiana[30]
- Passive case detection - Detection of malaria cases among patients who, on their own initiative, visit a health post for diagnosis and treatment[29]
- Proactive case detection - Detection of malaria by health workers at household or community level, not prompted by detection of cases[29]
- Primaquine (PQ) - A medication used in prevention and as eradication treatment of *P. vivax* malaria[31]
- Rapid diagnostic test (RDT) - Point of care method of detection of malaria parasite antigens[29]
- Social and behavior change communication (SBCC) - Activities undertaken to increase the uptake of malaria interventions
- Tafenoquine (TQ) - A medication used in combination with other antimalarials for the prevention of

relapse of *P. vivax* malaria (eradication treatment) and by itself as prophylaxis against all species of malaria[32]

Mathematical Modeling Approach

The METC suite of models has previously been used across 22 countries in the Asia-Pacific region (METCAP), Melanesia, Timor-Leste, South Africa (METC-SA) and Ghana, and has been adapted to the Guyana Shield region for this study.[27,28] The METC-Country suite is a set of mathematical models developed by the Mathematical and Economic Modelling Group (MAEMOD, Oxford University) and the Modelling and Simulation Hub, Africa (MASHA, University of Cape Town) to guide national malaria control and elimination efforts. These models combine collection, curation, and analysis of epidemiological and cost data with spatially explicit, multi-species and single-species transmission models of varying complexity. As such, they may be used to predict both the health outcomes and costs associated with various program options for achieving a given malaria elimination strategy. The models are developed to describe the transmission of both *P. falciparum* and *P. vivax* malaria, and are thus suited to the context of the Guyana Shield, where both species occur. Only malaria-related interventions are modeled. Interventions that have an indirect impact on malaria reduction – such as improvements in housing and sanitation, access to education, and economic growth – are not taken into account. The approach that was used to model malaria incidence in the Guyana Shield region for the purposes of this study is described below.

Data Collation

Data was collected from NMPs where available, with any gaps filled by data from WMRs (Table 6). Biological model parameters from relevant literature were referenced (see Appendix A for detailed parameters). Intervention-related information was collected from a variety of sources and validated by NMPs, where possible (see Appendix A for further intervention details).

Table 6. Summary data source table

Data Category	Suriname	Guyana	French Guiana
Case Data	NMP: Annual case data (2015–2019; subnational)	NMP: Annual case data (2015–2019; subnational)	MoH: Annual case data (2015–2019; national)
Death Data	NMP: Annual deaths (2015–2019; national)	WMR: Annual deaths (2019; national)	WMR: Annual deaths (2019; national)
Reporting Rate	NMP: Monthly reporting rate by reporting type (subnational)	NMP: Annual reporting rate by reporting type (2016–2019; subnational)	No data available.
Detection	NMP: Annual total tests (2015–2019; subnational); annual cases by method of detection (2015–2019; subnational)	NMP: Annual total tests (2015–2019; subnational); annual cases by method of detection (2018–2019; subnational)	MoH: Annual cases by method of detection (2015–2019; national)
Imported Case Data	MoH: Annual imported cases by country (2018–2019; national)	MoH: Annual imported cases by species and country (2018–2019; national)	MoH: Annual imported cases by country (2018–2019; national)
LLIN	NMP: Annual bednets distributed (2016–2019; subnational)	NMP: Annual bednets distributed (2011–2019; national)	MoH: Annual bednets distributed (2015–2019; national)
IRS	No data available.	No data available.	MoH: Annual homes treated (2016–2019; national)
Population	NMP: Total population (2017; subnational)	Guyana Bureau of Statistics: Total population (2012; subnational)	WMR: Total population, population at risk (2020; national)

Data collation resulted in a rich dataset for modeling, though data types were not always directly comparable to each other. For countries in the Guyana Shield, it was found that:

- Imported cases could not be uniformly linked to subnational areas in the source country and destination country.
- Imported and actively detected cases were not always differentiated by parasite species.
- Studies on use of bednets, access to care, and adherence to therapy were not always available.
- Data on severe infections, hospital admissions, and deaths occurring within and outside of hospitals were not available for most countries. Data were obtained at a national level from the WHO WMR.

Model Fitting

Data were incorporated and the model was fitted to represent the interconnectivity of the region, in order to ensure that the source and destination of imported cases were captured according to the reported data for each country (where imported case data was provided). The models were then calibrated to represent the number of *P. falciparum* and *P. vivax* infections that were passively and actively detected and that led to severe infection and deaths.

The mathematical epidemiological model was calibrated using subnational data in Guyana and Suriname and national data in French Guiana, Brazil, and Venezuela. The model projected future trends, with interventions commencing in 2021 unless otherwise indicated in the NMSP.

Modeling to Elimination

The WHO defines malaria elimination as the "interruption of local transmission (reduction to zero incidence of indigenous cases) of a specified malaria parasite species in a defined geographic area."[1] The ability to model the achievement of malaria elimination directly and accurately is limited, as the occurrence of a very small number of indigenous cases could result from random events that cannot be predicted. Examples of such events include unexpected rainfall; a delay in the distribution of LLINs; and, of particular relevance to the Guyana Shield, economic events that may lead to an increase in mining activities. Accurately modeling the achievement of malaria elimination is also reliant on subnational data on indigenous and imported cases, which was not always available for the countries of the Guyana Shield. These data limitations further limited the ability to precisely model a reduction to zero incidence of indigenous cases.

Therefore, for the purposes of this study, modeled elimination is defined as being achieved when projected indigenous cases are less than 0.1 per 1,000 population at risk. At this low case level, it is assumed that most remaining cases will be imported.

While it is possible that one parasite species may be eliminated before the other, malaria elimination in a country requires that all species of malaria are eliminated. In the model, three milestones are presented: a) the year in which the sum of *Pf* and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold; b) the year in which the number of *Pv* cases crosses the modeled elimination threshold; and c) the year in which the sum of *Pf*, *Pv*, and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold.

Model Assumptions for Brazil and Venezuela

Under the BAU, SU1, RI, and AR scenarios, the following assumption is made: clinical cases recorded as having been imported into Suriname, Guyana, and French Guiana from Brazil and Venezuela follow a constant trend, based on historical case data.

Under the SU2 scenario, the following assumption is made: clinical cases recorded as having been imported into Suriname, Guyana, and French Guiana from Brazil and Venezuela decrease 10% per annum for both Brazil and Venezuela. This percentage is based on relevant literature regarding economic growth and malaria reduction,[33] as well as country economic projections.[34,35] However, this decrease in cases should be understood as a hypothetical assumption that has not been validated by health officials in either Brazil or Venezuela. It has been included to demonstrate an optimistic scenario in which multiple factors may combine to result in consecutive reductions in cases. This assumption would need to be reviewed and updated as progress in malaria control is monitored in the region.

Economic Costs and Benefits

A cost estimation model was developed to align with the outputs of the epidemiological model in order to estimate the total cost associated with the three standard scenarios: BAU, SU1, and SU2. For each scenario, two different types of costs were estimated: direct healthcare costs, which can further be broken down into intervention-related costs (e.g. bednets, RDTs, healthcare services) and health system costs (monitoring and evaluation, program management); and indirect costs (loss of life due to malaria mortality and the cost of foregone wages due to malaria morbidity and caregiving). In order to estimate direct healthcare costs, both an ingredients approach and a

top-down approach (i.e. disaggregation of historical budgets) were used. This dual approach is advantageous, as it allows the cost estimates to be sensitive to changes in utilization of resources and account for broader, health system-wide spending that may be difficult to measure or separate from broader spending. Intervention-related and health system cost estimates were calibrated using data provided by country NMSPs, historical budgets, data provided by countries to the Global Fund, personal communications with local malaria program managers, and, when necessary, available literature (see Appendix B for greater detail on how these quantities were estimated). In order to estimate indirect costs, estimates of gross national income (GNI) per capita[36,37] were used to account for the loss of wages due to malaria morbidity. A full-income approach established by *The Lancet* Commission on Investing in Health was adopted to estimate loss of life due to malaria mortality. This approach assigns the value of each life year lost at 2.3 times the GNI per capita.[38]

Using both the economic cost and direct healthcare cost, we calculated the return on investment. The return on investment is defined as the subtraction of the direct healthcare cost from the economic benefit divided by the direct healthcare cost. In Suriname and Guyana, the estimated direct cost of each scenario was used to calculate the financing gap, or the difference between expected available financing (both domestic and external) and the expected direct cost of each scenario. All costs and economic benefits are presented in 2020 USD.

It is worth noting that this economic evaluation does not capture the full spectrum of potential incidental benefits associated with national malaria elimination. National malaria elimination can result in many other advantages, such as increased tourism, a strengthened health system, and improved regional health security. Striving for malaria elimination can provide opportunities to strengthen the capacity of local health programs and bolster cross-border disease coordination, with the potential for cascading impact across disease areas. Due to the difficulty in quantifying these externalities, they have not been included in this analysis; however, they are worthy of consideration. Evidence from global analyses indicates that each 10% decrease in a country's malaria burden can result in a 0.3% growth in its GDP.[39] However, it is unknown how generalizable these analyses are to the specific context of the Guyana Shield region.

Findings

A multi-species epidemiological-economic model for malaria transmission from the METC suite of models was applied to intervention and case data to assess the feasibility and cost of malaria elimination in the Guyana Shield region between 2020 and 2029. Findings are presented at the country level for Suriname, Guyana, and French Guiana. The table descriptions of findings contain estimated costs and cases averted from 2021 to 2024 inclusive, while the plots of costs and cases display findings from 2020 to 2029. Evaluating the funding gap until the end of 2024 is aligned with current funding and aligns with national strategic plans for malaria elimination. Additionally, the trajectory of malaria elimination in the region is closely tied to the economic future of the region through oil, gold mining and timber industries. With these uncertainties increasing with the projection window, it is likely that projections and cost estimates beyond 2025 will require revision as the journey towards malaria elimination progresses.

Suriname

Descriptions: Standard Scenarios

The mix and scale of interventions included for each of the three standard scenarios for Suriname (Table 7) were developed in consultation with the NMP, with reference to the NMSP and annual program reports. In 2019, Suriname reported only 212 malaria cases, of which over half were imported. However, the country's ability to reach elimination is significantly affected by the importation of cases from neighboring French Guiana. The Suriname NMP is already engaged in preventative (LLINs), reactive (active case detection), and proactive (proactive case detection) interventions. The distribution to migrant workers of LLINs and Malakits, or self-diagnosis and self-treatment kits provided in border areas, aims to reduce imported infections from French Guiana. These detection and treatment, vector control, and cross border interventions are included under all three standard scenarios, with scale-up of specific interventions distinguishing the SU1 and SU2 scenarios from the BAU scenario.

Table 7. Scenario descriptions with key model predictions in Suriname

Business as Usual (BAU)	Scale-Up 1 (SU1)	Scale-Up 2 (SU2)
Detection and Treatment		
Routine facility-based treatment with ACTs and PQ Active case detection in all resorts (100% of cases followed-up) Proactive case detection in select resorts*	Business as Usual + Switch from 14-day PQ to TQ for all *Pv* cases, starting in 2023**** SU1 in Guyana	Scale-Up 1 (includes SU1 in Guyana) SU2 in French Guiana Decreased imported transmission from Brazil and Venezuela
Vector Control		
LLIN distribution in select resorts (2016–2018 distribution levels scaled for population growth, assuming 70% coverage)**	Business as Usual + LLIN distribution to same resorts increased to 85% coverage SU1 in Guyana	Same as is listed above
Cross-Border Initiatives		
Malakit screening and follow-up in border resorts*** for travellers into French Guiana, with scale-up in distribution planned for 2021	Business as Usual + SU1 in Guyana	Same as is listed above

*SR0101, SR0106, SR0401, SR0905, SR0906

**SR0101, SR0104, SR0106, SR0401, SR0604, SR0902, SR0904, SR0905, SR0906

***Tapanahony, Albina, Blauwgrond resorts

****Tafenoquine (TQ) has been included with the approval of the respective NMPs and technical partners as a hypothetical intervention to demonstrate a potential future treatment that could replace a 14-day PQ regimen. To allow time for required licensing, its inclusion is modeled from 2023 onwards. See Appendix A for further details on the inclusion of TQ.

Findings: Standard Scenarios

Given Suriname's low case numbers, malaria elimination is predicted to be achieved by 2028 under the BAU scenario, or the continuation of current interventions (Table 8). Elimination could be accelerated and achieved by 2024 through the scale-up of interventions within the country (SU1) or through the simultaneous scale-up of interventions across the Guyana Shield (SU2).

Predictions related to the number of projected deaths are not considered to be reliable, as this number is quite low and subject to uncertainty. Deaths and deaths averted should not be used as measures of progress in this context and as such are not reported.

Table 8. Modeled scenario findings in Suriname

	Business as Usual	Scale-Up 1	Scale-Up 2
Projected year of elimination*	*Pf*: 2020 *Pv*: 2027 All: 2028	*Pf*: 2020 *Pv*: 2024 All: 2024	*Pf*: 2020 *Pv*: 2024 All: 2024
Projected clinical cases, accumulated total 2021 to 2024 (averted from BAU)**	3,200 (0)	2,700 (500)	2,400 (800)
Projected reported indigenous cases, accumulated total 2021 to 2024 (averted from BAU)***	300 (0)	220 (80)	190 (110)

*Modeled elimination is defined as being achieved when projected indigenous cases are less than 0.1 per 1,000 population at risk. Three milestones are presented: '*Pf*', the year in which the sum of *Pf* and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold; '*Pv*', the year in which the number of *Pv* cases crosses the modeled elimination threshold; and 'All', the year in which the sum of *Pf*, *Pv*, and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold.

**Clinical cases comprise treated and untreated cases, whether indigenous or imported, as all represent a burden to the healthcare system.

***Increases in active case detection activities will result in a higher number of cases being reported, though clinical cases will decline overall.

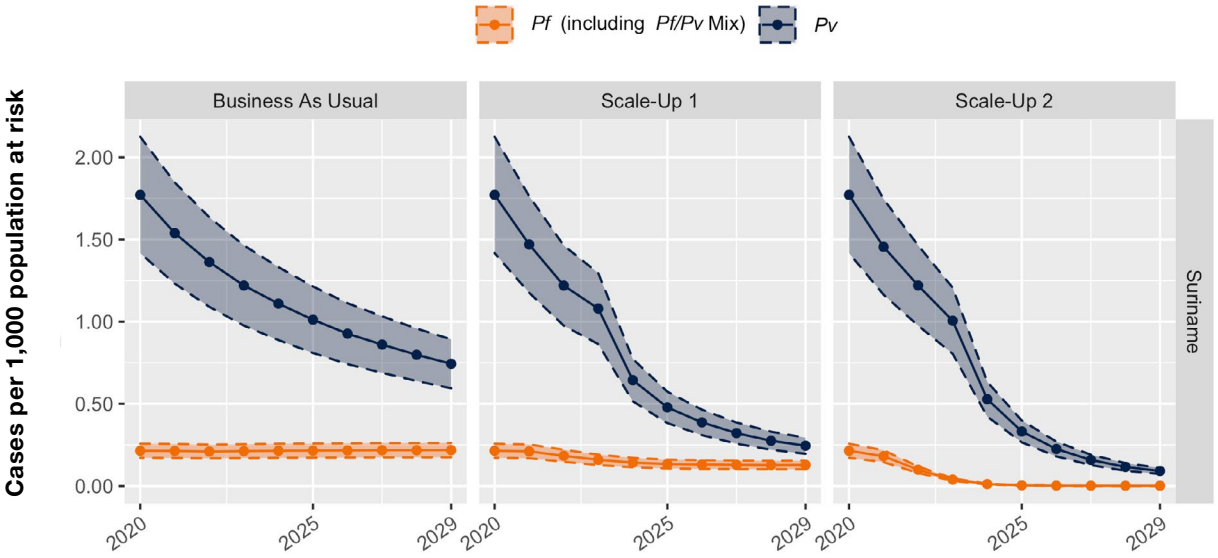
Figure 6 (next page) depicts the projected clinical cases of *P. falciparum* and *P. vivax* malaria for the three standard scenarios in Suriname. Clinical cases represent symptomatic infections, both indigenous and imported (or regardless of origin), that may or may not access treatment from the health system. Clinical cases are depicted in order to demonstrate the full burden of malaria on the health system, but are not used to determine the projected year of elimination. The below figure (Figure 6) demonstrates the accelerated downward trajectory of *P. vivax* malaria projected under both scale-up scenarios (SU1 and SU2), as compared with the BAU scenario, from 2021 to 2029. While accelerated progress towards elimination is projected under both scale-up scenarios, a region wide effort (SU2) would avert more cases over the time period.

It is estimated that Suriname would have the necessary resources to finance malaria interventions, as outlined in the BAU scenario, over the next four years (2021-2024). However, approximately half of the anticipated financing is expected to be provided by external sources, calling into question the financial sustainability of the malaria program. Long-term sustainable financing would be necessary to ensure achievement of elimination by 2028 under the BAU scenario and prevent a potential resurgence as a consequence of reduced investment.

Expansion of malaria interventions, as outlined in the scale-up scenarios (SU1 and SU2) in Suriname, is estimated to cost an average of USD 3.4 million per year between 2021 to 2024 (Table 9) – almost USD 1 million per year more than the BAU scenario. Based on the projected availability of financial resources for malaria response in Suriname, the country would need approximately USD 3.1 million in additional financing over the next four years to adequately fund the SU1 or SU2 scenario through 2024, the year of anticipated elimination under these scenarios (Table 9). The increased investment is projected to help Suriname in achieving *P. vivax* elimination in 2024 – three years ahead of the BAU scenario. The capacity of the country to absorb these funds has not been evaluated.

While total healthcare spending for malaria costs incurred under the BAU scenario are expected to stay fairly constant from 2021 to 2030, total healthcare spending for malaria costs associated with the SU1 and SU2 scenarios are projected to trend downward over time. The only exception involves slight spending increases in 2024 and 2027 due to LLIN distribution campaigns in these years. Regional cooperation (SU2) will likely reduce the probability of malaria importation and reestablishment in Suriname. However, given Suriname's low malaria burden, regional scale-up (SU2) would provide only a modest additional financial benefit to the country compared with the SU1 scenario,

Figure 6. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Suriname, by scenario and species



and would not help Suriname to achieve national elimination any sooner than under the SU1 scenario.

Total healthcare spending for malaria associated with the SU1 and SU2 scenarios never falls below total healthcare spending associated with the BAU scenario within the timeframe of the analysis. The scale-up scenarios (SU1 and SU2) are projected to cost USD 800,000 more than the BAU scenario by 2025 in terms of direct healthcare spending for malaria. However, when considering total economic cost (encompassing both indirect and direct costs), the scale-up scenarios are expected to cost USD 500,000 to 700,000 more than the BAU scenario in 2025 (Figure 7; Panel B). This additional investment in the SU2 scenario is projected to yield a return on investment of 20%. Our projections of cost do not reflect a dramatic drop in spending after elimination is reached in Suriname, because the interconnectedness of the region will likely necessitate continued surveillance, vigilance, and technical capabilities to test, treat, and respond to future malaria outbreaks.

It is important to note that the analysis does not capture the full spectrum of economic benefits of malaria elimination, such as increased health security and tourism. Given that projections show that Suriname will reach malaria elimination four years earlier under the SU1 and SU2 scenarios relative to the BAU scenario, the exclusion of the full spectrum of indirect benefits resulting from malaria elimination likely results in underestimation of the economic benefits of the SU1 and SU2 scenarios.

Figure 7. Projected total healthcare spending on malaria and total economic cost of malaria in Suriname, 2021–2029

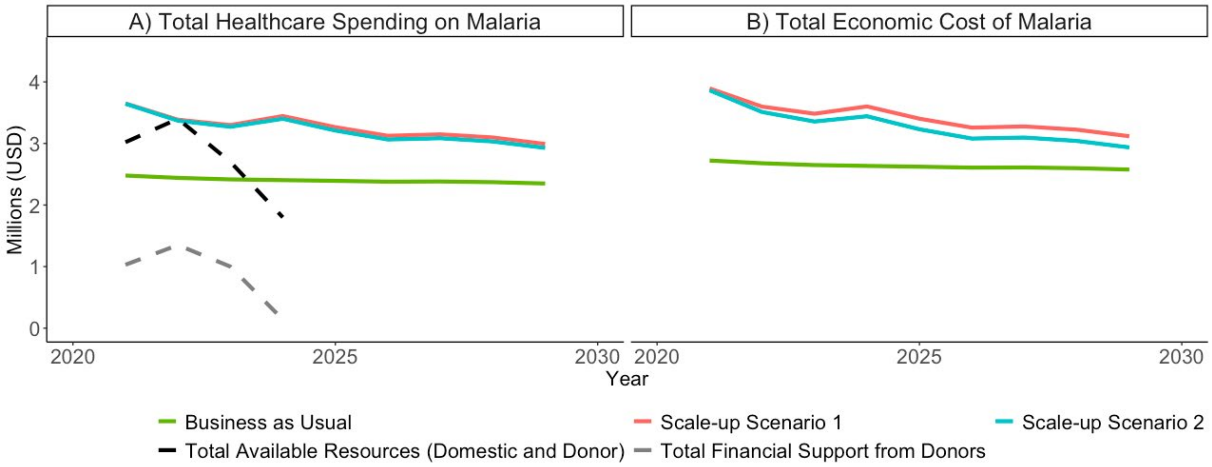


Table 9. Suriname's projected financial resources for malaria, modeled direct healthcare cost related to malaria, and projected financial gap, 2021–2024 (all figures reported in million USD)

	2021	2022	2023	2024	Cumulative 2021–2024
Financing Projections*					
Domestic financing	1.830	1.818	1.594	1.581	6.823
Global Fund financing	1.037	1.312	1.006	0.143	3.498
Non-Global Fund external financing	0.065	0.065	0.065	0.065	0.260
Total projected financing available	2.932	3.195	2.665	1.789	10.581
Modeled Cost Projections					
Modeled cost - Business as Usual	2.478	2.45	2.393	2.417	9.738
Financial gap	-0.454**	-0.745**	-0.272**	0.628	-0.843**
Modeled cost – Scale-Up 1	3.82	3.111	3.114	3.687	13.732
Financial gap	0.888	-0.084**	0.449	1.898	3.151
Modeled cost – Scale-Up 2	3.812	3.11	3.11	3.644	13.676
Financial gap	0.88	-0.085**	0.445	1.855	3.095

*Sourced from the Suriname Funding Landscape Table, as submitted to the Global Fund (2020).
**A surplus of funds was projected.
Financial gap denotes the cost of each scenario less the projected total available financing.

Findings: Special Scenario – Reduced Investment

A Reduced Investment (RI) scenario was developed in response to country interest in modeling the effects of a potential reduction in malaria financing within Suriname from the end of 2024 onwards, in line with the end of current Global Fund support. Interventions for this scenario (Table 10) are scaled back from current malaria activities, reflective of the reduced resources available to the malaria program. This scenario is modeled against the background of simultaneous reduced investment in French Guiana and business as usual circumstances throughout the rest of the region.

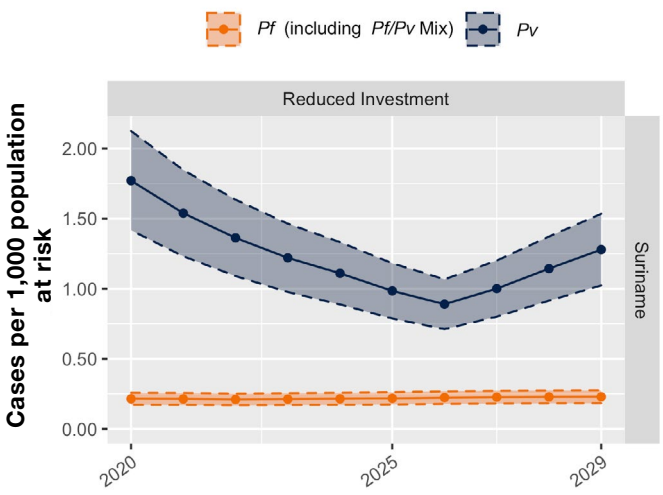
Program management costs often account for a substantial share of total spending for a typical malaria program. It is difficult to project how program management costs would contract under an RI scenario. Therefore, economic costs are not provided for this scenario.

Table 10. Reduced Investment (RI) scenario description with key model predictions, Suriname

Interventions	Reduced Investment (RI)
Detection and Treatment	Routine facility-based treatment with ACTs and PQ
Vector Control	None
Cross-Border Initiatives	None

The RI scenario is predicted to result in an additional 450 to 700 clinical cases (relative to a BAU scenario) between 2025 and 2030 and pushes the projected year of *P. vivax* elimination beyond 2030. An expected reduction in external donor funding in 2024 would come at a time when Suriname is projected to have eliminated *P. falciparum* and to have a steadily decreasing number of indigenous *P. vivax* cases. As such, the estimated case increase above is relatively small in number but may have a substantial impact on reaching elimination. The estimated surge is likely to be predominantly comprised of imported cases, potentially facilitating increased local transmission and threatening overall progress made towards elimination during the 2021 to 2023 period. The below figure (Figure 8) highlights this potential resurgence, with an increasing number of *P. vivax* clinical cases seen from 2025 onwards.

Figure 8. Projected clinical cases per 1,000 population at risk from 2020 to 2029 for Reduced Investment (RI) scenario in Suriname



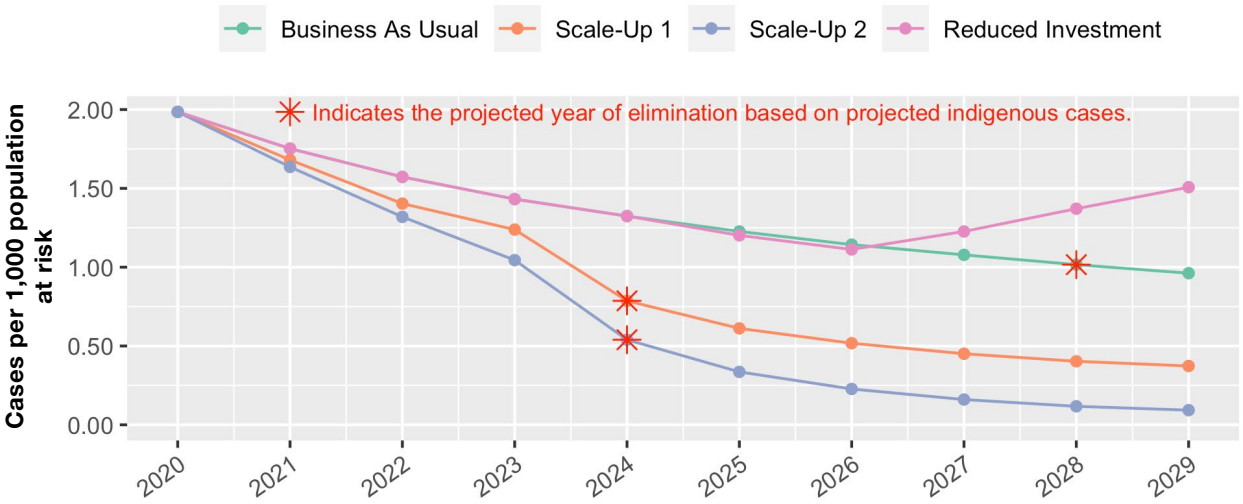
Findings: All Scenarios

Figure 9 (next page) summarizes the estimated trajectory of all clinical cases based on all scenarios in Suriname. The estimated increase in cases and the delay in achieving elimination, under the reduced investment scenario, is also highlighted.

Model Assumptions and Limitations in Suriname

Where possible, all modeled scenarios were informed by data and/or reports received from the NMP. Where data was not available, assumptions were made, and these may affect the robustness of the projections. The subnational model relies on data for all resorts in Suriname, but case data were only available at the national level. A breakdown of cases by species was available at the resort level for indigenous cases. Imported case data was calibrated at the national level. Likewise, data regarding treatment-seeking behavior, the likelihood of testing and treatment at a health facility, and reporting rates were only available nationally and were applied equally to all resorts. Data on LLIN usage were only available nationally for a sample mobile/migrant population and not for the whole population. Therefore, LLIN usage was assumed to be high (70%) among the inland population, but low (34%) among the mobile/migrant population.[40,41] As Suriname approaches elimination, collection and analysis of data at the subnational level will improve the possibility of tailoring and targeting interventions.

Figure 9. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Suriname, by scenario



Projections for Suriname are impacted by the malaria situation in French Guiana, the current source of the majority of cases imported into Suriname. Additional information regarding malaria in French Guiana would be required to ensure the robustness of the model for Suriname.

Recent increases in the number of malaria cases in Suriname have been tied to fluctuations in the price of gold.[2] As gold becomes more valuable on the market, gold mining activities generally increase, leading to heightened migration to and from the malaria-endemic mining areas. Historically, gold prices tend to be highly variable and unpredictable, especially during times of economic volatility such as the COVID-19 pandemic. Given that costs related to travel, supply shipment, and other factors are often directly tied to the price of gold within Suriname's gold mining regions, the unpredictability of gold prices introduces uncertainty into both epidemiological projections and cost estimations associated with operating malaria programs.

Guyana

Descriptions: Standard Scenarios

The mix and scale of interventions included for each of the three standard scenarios for Guyana (Table 11) were developed in consultation with the NMP, with reference to the NMSP and annual program reports.

Table 11. Scenario descriptions with key model predictions in Guyana

Business as Usual (BAU)	Scale-Up 1 (SU1)	Scale-Up 2 (SU2)
Detection and Treatment		
Routine facility-based treatment with ACTs and PQ Active case detection in regions 1,7,8,9	Business as Usual + Treat 100% of positive cases Switch from 14-day PQ to TQ for all *Pv* cases, starting in 2023* Increase treatment-seeking from 34% to 78% (Method: increase passive case detection at RDT posts and kit distribution through SBCC efforts) SU1 in Suriname	Scale-Up 1 (including SU1 in Suriname) + SU2 in French Guiana Decreased imported transmission from Brazil and Venezuela
Vector Control		
LLIN distribution in regions 1,7,8,9 (2017–2018 distribution levels scaled for population growth, assuming 70% coverage)	Business as Usual + LLIN distribution to all regions with active foci (Increase distribution in regions 1,2,3,4, 10 and maintain distribution in regions 7,8,9; scaled for population growth, assuming 85% coverage) Enhance SBCC activities to increase usage of LLINs from 54% to 70% SU1 in Suriname	Same as is listed above

*Tafenoquine (TQ) has been included with the approval of the respective NMPs and technical partners as a hypothetical intervention to demonstrate a potential future treatment that could replace a 14-day PQ regimen. To allow time for required licensing, its inclusion is modeled from 2023 onwards. See Appendix A for further details on the inclusion of TQ.

Findings: Standard Scenarios

With the implementation of currently planned interventions (BAU), Guyana is not expected to achieve malaria elimination before 2030 (Table 12). Increased LLIN coverage and usage, coupled with increased treatment-seeking, is projected to result in a considerable decrease in clinical cases under the SU1 scenario. Specifically, nearly 200,000 clinical cases between

Table 12. Modeled scenario findings in Guyana

	Business as Usual	Scale-Up 1	Scale-Up 2
Projected year of elimination*	>2030	>2030	*Pf*: 2025 *Pv*: >2030 All: >2030
Projected clinical cases, accumulated total 2021 to 2024 (averted from BAU)**	580,500 (0)	386,300 (194,200)	340,300 (240,200)
Projected reported indigenous cases, accumulated total 2021 to 2024 (averted from BAU)***	84,400 (0)	81,800 (2,600)	53,800 (30,600)
Projected deaths, accumulated total 2021 to 2024 (averted from BAU)	115–175 (0)	50–75 (65–100)	45–70 (70–105)

*Modeled elimination is defined as being achieved when projected indigenous cases are less than 0.1 per 1,000 population at risk. Three milestones are presented: '*Pf*', the year in which the sum of *Pf* and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold; '*Pv*', the year in which the number of *Pv* cases crosses the modeled elimination threshold; and 'All', the year in which the sum of *Pf*, *Pv*, and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold.

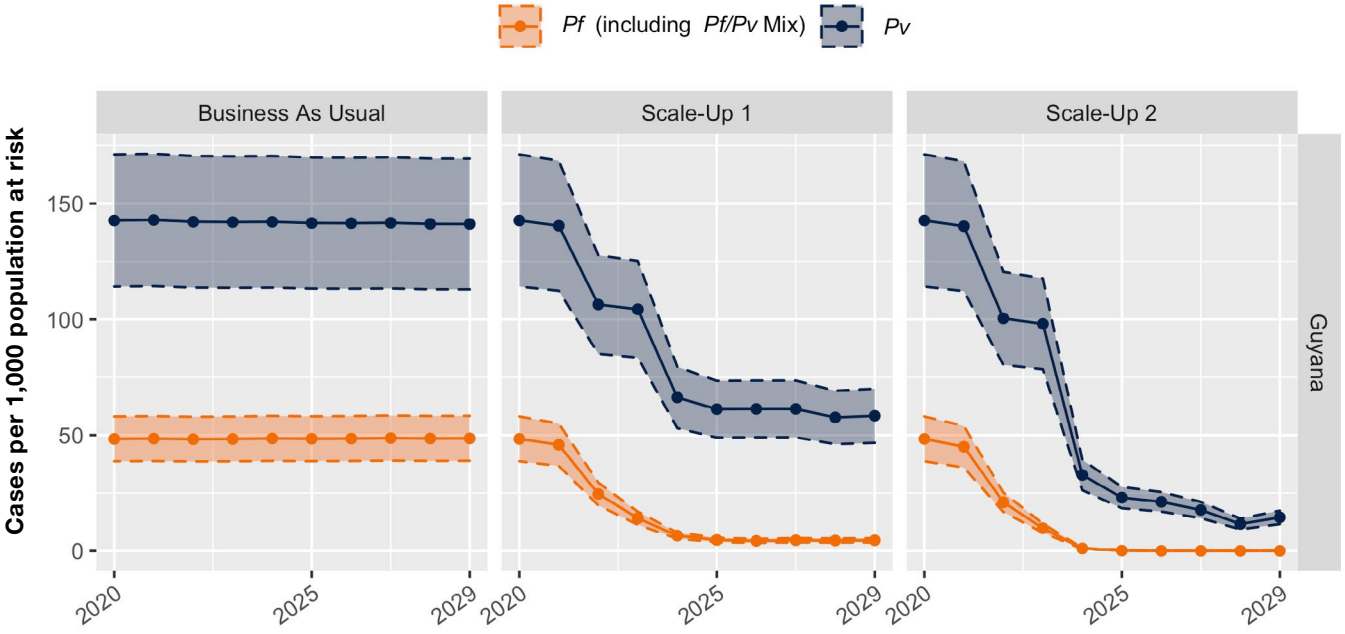
**Clinical cases comprise treated and untreated cases, whether indigenous or imported, as all represent a burden to the healthcare system.

***Increases in active case detection activities will result in a higher number of cases being reported, though clinical cases will decline overall.

2021 and 2024 would be averted, relative to the BAU scenario. The simultaneous scale-up of interventions regionally across the Guyana Shield (SU2) would further accelerate progress in Guyana, with the potential to avert over 240,000 clinical cases and an estimated 45 to 70 deaths between 2021 and 2024 (as compared with the BAU scenario). Under the SU2 scenario, Guyana is projected to eliminate *P. falciparum* in 2025 and reduce *P. vivax* to a lower level. However, elimination of *P. vivax* is not projected to be achieved before 2030, due in part to relapses and asymptomatic infections.

The below figure (Figure 10) demonstrates the accelerated downward trajectory of *P. vivax* malaria projected under both scale-up scenarios (SU1 and SU2) as compared with the BAU scenario from 2021 to 2029. While accelerated progress towards elimination is projected under both scale-up scenarios, a region wide effort (SU2) would avert more cases over the time period.

Figure 10. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Guyana, by scenario and malaria species



Under the BAU scenario, it is expected that Guyana will spend USD 5.5 million in direct healthcare spending on malaria each year (Figure 11; Panel A). In comparison, the SU1 and SU2 scenarios in Guyana would likely cost in excess of USD 10 million annually in direct healthcare spending on malaria.

Guyana is expected to double its commitment to malaria elimination over the next four years by increasing spending from approximately USD 5 million in 2020 to nearly USD 10 million a year by 2024 (Table 13). These resources are predicted to be sufficient to finance the BAU scenario, but insufficient to finance the SU1 and SU2 scenarios. It is projected that Guyana will need approximately USD 2 million annually in additional funding to finance the SU1 and SU2 scenarios.

Considering broader economic costs that include both direct healthcare spending on malaria and indirect costs associated with malaria, it is estimated that the SU1 scenario would save Guyana over USD 8 million annually (relative to the BAU scenario) by the year 2025 (Figure 11; Panel B). The economic savings projected to be achieved under the SU1 scenario are largely attributable to the prevention of around 50,000 cases of malaria annually, compared with the BAU scenario. As additional evidence of the benefits of regional malaria cooperation, the total economic savings resulting from a coordinated regional approach (SU2) would exceed USD 11 million annually relative to a BAU scenario and USD 3 million annually relative to an SU1 scenario. The projections suggest a return on investment of 260% under the SU1 scenario, implying that every dollar Guyana invests in malaria beyond the BAU scenario would yield USD 2.60 in economic benefit. The projected return on investment increases slightly to 285% if the entire region intensifies its malaria response (SU2).

Figure 11. Projected total healthcare spending on malaria and total economic cost of malaria in Guyana, 2021–2029

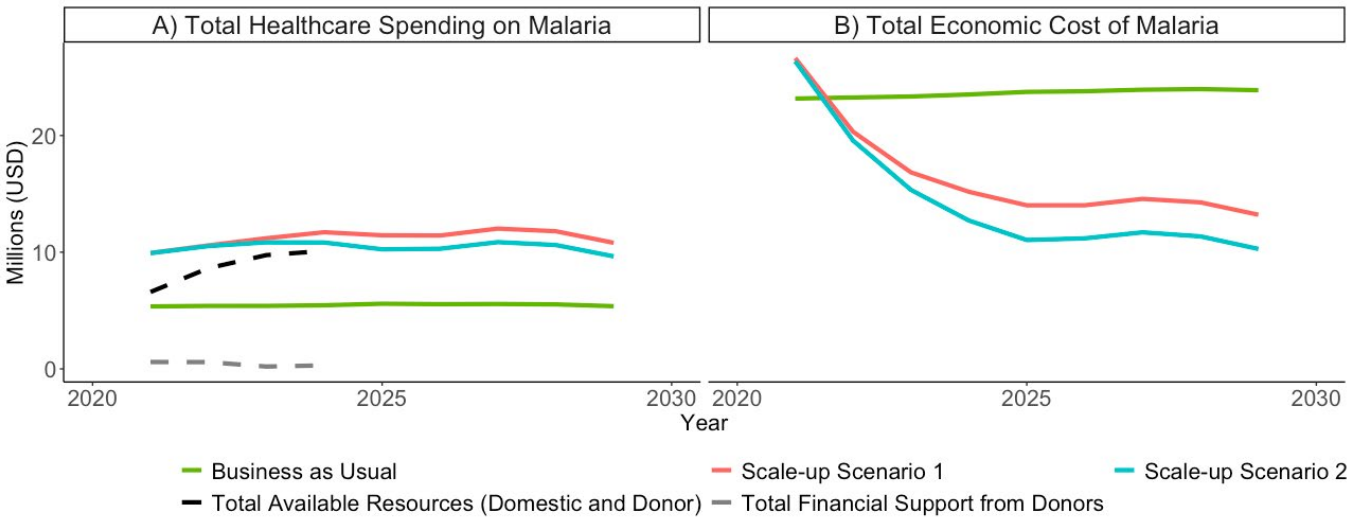


Table 13. Guyana's projected malaria financing, modeled direct healthcare costs related to malaria, and projected financial gap, 2021–2024 (all figures reported in million USD)

	2021	2022	2023	2024	Cumulative 2021–2024
Financing Projections*					
Domestic financing	6.025	8.049	9.547	9.547	33.168
Global Fund financing	0.486	0.475	0.100	0.202	1.263
Non-Global Fund external financing	0.110	0.110	0.110	0.110	0.440
Total projected financing available	6.621	8.6348	9.757	9.859	34.871
Modeled Cost Projections					
Modeled cost - Business as Usual	5.261	5.679	5.214	5.486	21.640
Financial gap	-1.360**	-2.955**	-4.543**	-4.373**	-13.231**
Modeled cost – Scale-Up 1	9.834	10.970	10.540	12.343	43.687
Financial gap	3.213	2.336	0.783	2.484	8.816
Modeled cost - Scale-Up 2	9.830	10.866	10.372	11.262	42.33
Financial gap	3.209	2.232	0.615	1.403	7.459

*Sourced from the Guyana Funding Landscape Table, as submitted to the Global Fund (2020).

**A surplus of funds was projected.

Financial gap denotes the cost of each scenario less the projected total available financing.

Findings: Special Scenario – Artemisinin Resistance

The efficacy and safety of artemether-lumefantrine (AL) for the treatment of uncomplicated *P. falciparum* malaria in Guyana are being assessed and serve as a cause for concern within the context of artemisinin resistance. Recent evidence from the WHO indicates the presence of the *PfK13* C580Y mutation, a marker of artemisinin resistance, in samples in Guyana in 2010 and 2017.[23] While a marker of resistance, the presence of the *PfK13* C580Y mutation does not equate to established artemisinin resistance. A study conducted by the Guyana NMP in 2018/2019 indicated that 17 of the 174 patients enrolled experienced treatment failure. However, preliminary molecular analysis did not detect the presence of the *PfK13* C580Y mutation in samples analyzed at the time.[24] The differences in the outcomes of the abovementioned studies may have resulted from variations in study population, sample size, and other study parameters. The absence of *PfK13* C580Y mutations in samples from the 2018/2019 study carried out by the Guyana NMP does not rule out artemisinin resistance as a threat.

At the request of the NMP, a scenario involving potential artemisinin resistance was included in the current study (Table 14). In order to determine the impact of resistance on *P. falciparum* cases, treatment failure to AL was modeled as increasing from 5% in 2020 to 35% by 2025 in Guyana. Resistance was not modeled to grow beyond 35%, as it was assumed that the drug to which resistance had developed would have been replaced by that point.

Table 14. Artemisinin Resistance (AR) scenario description with key model predictions, Guyana

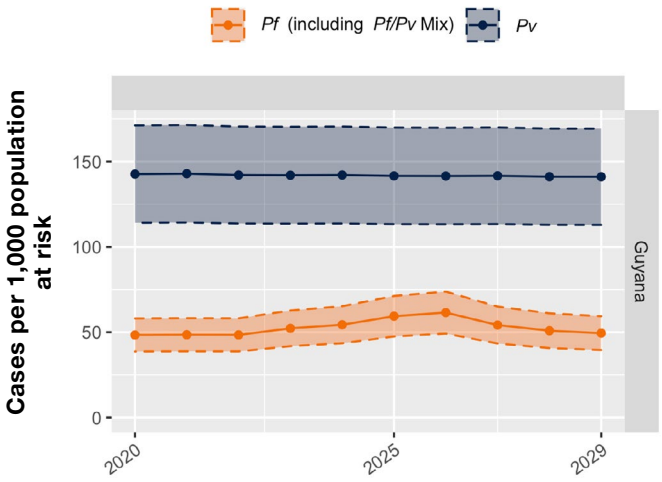
Interventions	Artemisinin Resistance (AR)
Detection and Treatment	Business as Usual + Probability of treatment failure for ACTs increases from 5%* in 2020 to 35% by 2025, after which the drug is replaced with a hypothetical alternative.**
Vector Control	Business as Usual

*Baseline treatment failure (5%) in Guyana was sourced from a systematic review on the efficacy of artemether-lumefantrine (AL) in treating uncomplicated *Pf* malaria.[42]

**Artemisinin resistance has yet to be established in Guyana. Hypothetical increases in treatment failure in the country were based on similar scenarios in the Asia-Pacific[28]

The model projects that increased resistance will result in an additional 33,000 clinical *P. falciparum* cases in Guyana between 2021 and 2030, compared with the BAU scenario. This projection is based upon the assumption that the current trend involving low treatment-seeking behavior (34%) in Guyana will continue during the above period. If there is growing treatment failure with AL, infection will not be properly stopped and resistance will spread further. As Guyana scales up its passive case detection activities in the coming years, increased drug pressure may accelerate the reduction in the useful therapeutic life of AL, thereby potentially decreasing the effectiveness of investment in passive case detection. The hypothetical AR scenario serves to estimate the potential impact of increasing artemisinin resistance, as well as to highlight the importance of monitoring resistance and measuring the efficaciousness of AL. In doing so, the scenario facilitates the process of approximating the timing of a switch to a different ACT, prior to the 35% treatment failure mark.

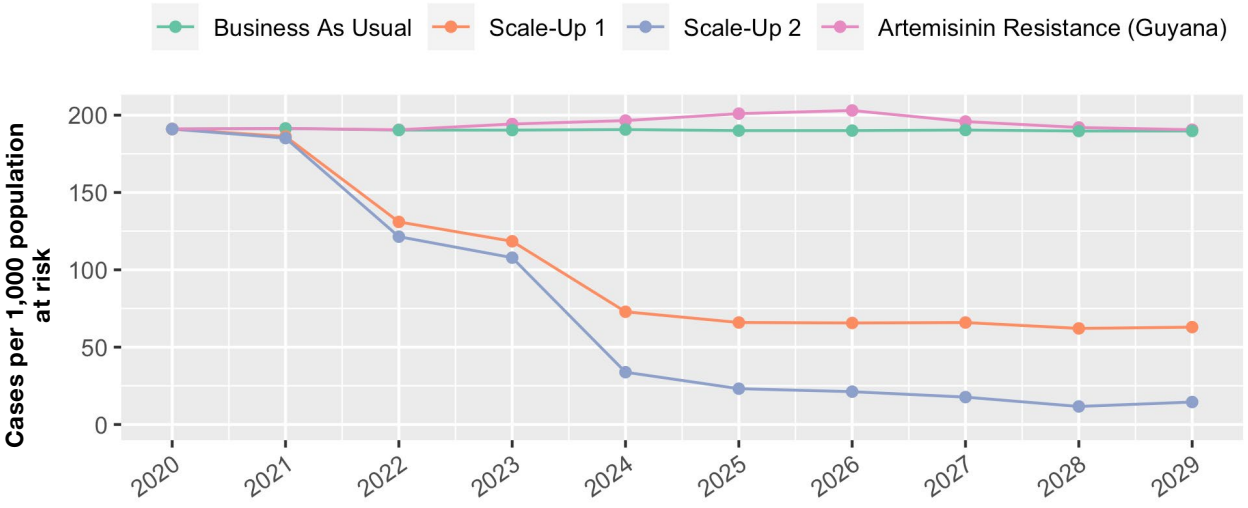
Figure 12. Projected clinical cases per 1,000 population at risk from 2020 to 2029 for Artemisinin Resistance (AR) scenario in Guyana



Findings: All Scenarios

The below figure (Figure 13) demonstrates the projected accelerated downward trajectory of all clinical cases under a scale-up approach in Guyana (as compared with BAU) and highlights the projected increase in cases if artemisinin resistance is not adequately addressed.

Figure 13. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Guyana, by scenario



Modeling Assumptions and Limitations in Guyana

Where possible, all modeled scenarios were informed by data and/or reports received from the Guyana NMP. Where data were not available, assumptions were made. The model considered only *P. falciparum*, *P. vivax*, and *Pf*/*Pv* mixed infections; therefore, the small number of *Plasmodium malariae* cases (275 total cases from 2015 to 2019) were excluded from the analysis.[7] Data regarding treatment-seeking behavior, the likelihood of testing and treatment at a health facility, and reporting rates were only available nationally and were therefore applied equally to all regions. Given that achieving a large decrease in cases depends upon establishing a high rate of treatment-seeking through SBCC, understanding treatment-seeking behavior and barriers in access to care at the subnational level will increase the robustness of the projections. Likewise, data on LLIN retention and usage were also only available nationally from an NMP statistical report and were applied equally to all regions.

The International Monetary Fund (IMF) projects that Guyana's real GDP will grow at an annual rate of 26.2% in 2021, the fastest projected growth rate of any country in the world, though less than an earlier forecasted growth rate of over 40% in 2021.[16] These impressive growth predictions are based upon recent oil discoveries in Guyana. For the immediate future, the fortunes of Guyana's economy will likely be heavily dependent on the oil industry. Strong ties to a nascent and volatile industry will likely result in substantial uncertainty regarding the availability of domestic resources and the economic benefits of malaria elimination in Guyana. For example, the estimates of indirect malaria costs (loss of economic opportunity) are directly tied to future economic growth in the country. A 20% change in expected economic growth could inflate (or deflate) indirect costs and potentially skew associated conclusions. Additionally, the type of rapid economic expansion that Guyana is experiencing often places a strain on immediately available resources and infrastructure. Such a strain could inflate price levels within the country, leading to potential underestimation of the cost of scaling up malaria interventions. Finally, future government revenue — and therefore available domestic resources for malaria — in Guyana will likely be linked to the international price of oil. Due to high volatility in the price of oil, the amount of future domestic resources available for malaria is also unpredictable.

French Guiana

Descriptions: Standard Scenarios

While information on malaria cases and vector control was available at the national level for French Guiana, it was not possible to have the proposed scenarios validated by local health officials. As such, the scenarios for French Guiana were developed based on current intervention data only with all interventions occurring at the national level (Table 15).

Table 15. Scenario descriptions with key model predictions in French Guiana

Business as Usual (BAU)	Scale-Up 2 (SU2)
Detection and Treatment	
Routine facility-based treatment with ACTs	Business as Usual + Switch from 14-day PQ to TQ for all *Pv* cases, starting in 2023* Introduce single low-dose PQ for treatment of *Pf* Gradually introduce active case detection (increase from 50% to 100% over 3 years) SU1 in Suriname and Guyana Decreased imported transmission from Brazil and Venezuela
Vector Control	
LLIN distribution to population at risk (2017–2019 distribution levels continued, scaled for population growth) IRS (2019 levels continued)	Business as Usual + Universal coverage of LLIN distribution (>85% coverage) Enhance SBCC to increase usage of LLINs (from 23% to 70% usage) SU1 in Suriname and Guyana Decreased imported transmission from Brazil and Venezuela

*Tafenoquine (TQ) has been included with the approval of the respective NMPs and technical partners as a hypothetical intervention to demonstrate a potential future treatment that could replace a 14-day PQ regimen. To allow time for required licensing, its inclusion is modeled from 2023 onwards. See Appendix A for further details on the inclusion of TQ.

Findings: Standard Scenarios

The low number of reported cases in French Guiana suggests that the country is on its way to achieving malaria elimination, though it was not possible to access surveillance reports in order to understand the extent of clinical infections among and scope of malaria surveillance efforts related to mobile and migrant populations within the country. With the implementation of current interventions under the BAU scenario, low levels of reported cases are projected to persist without leading to either *P. falciparum* or *P. vivax* elimination by 2030. French Guiana is expected to reach malaria elimination by 2029 under the SU2 scenario and avert 2,000 cases from 2021 to 2024 (as compared with BAU).

Predictions related to the number of projected deaths are not considered to be reliable, as this number is quite low and subject to uncertainty. Deaths and deaths averted should not be used as measures of progress in this context and as such are not reported. Since the SU1 scenario is intended to demonstrate the impact of scaled-up interventions in Suriname and Guyana only, findings for this scenario are not reported for French Guiana.

Table 16. Modeled scenario findings in French Guiana

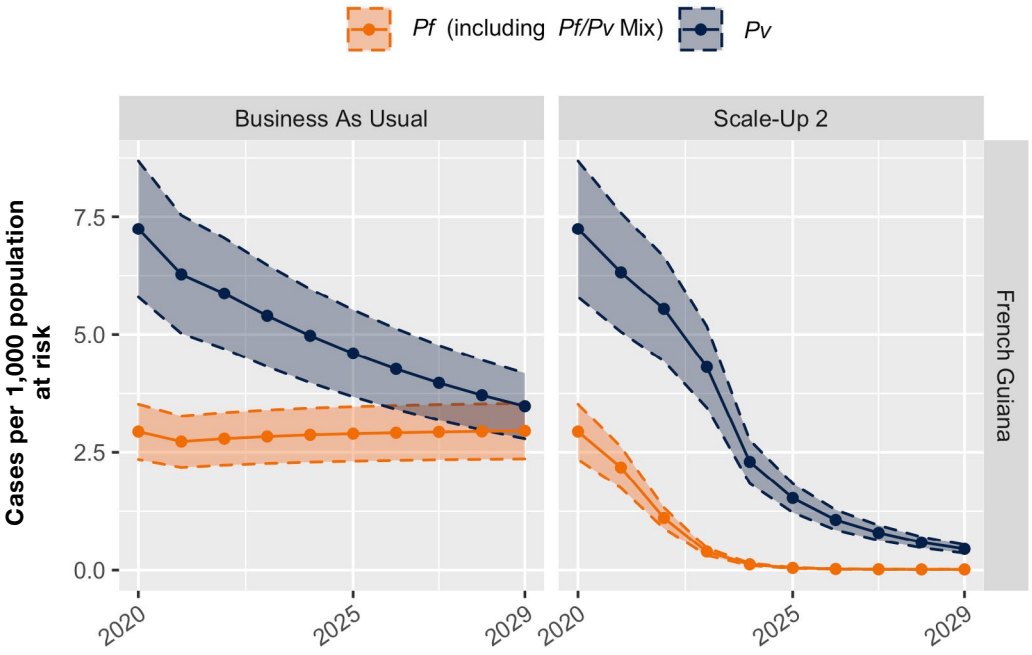
	Business as Usual	Scale-Up 2
Projected year of elimination*	*Pf*: >2030 *Pv*: >2030 All: >2030	*Pf*: 2024 *Pv*: 2029 All: 2029
Projected clinical cases, accumulated 2021 to 2024 (averted from BAU)**	5,800 (0)	3,800 (2,000)
Projected reported indigenous cases, accumulated 2021 to 2024 (averted from BAU)***	1,500 (0)	1,100 (400)

*Modeled elimination is defined as being achieved when projected indigenous cases are less than 0.1 per 1,000 population at risk. Three milestones are presented: '*Pf*', the year in which the sum of *Pf* and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold; '*Pv*', the year in which the number of *Pv* cases crosses the modeled elimination threshold; and 'All', the year in which the sum of *Pf*, *Pv*, and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold.

**Clinical cases comprise treated and untreated cases, whether indigenous or imported, as all represent a burden to the healthcare system.

***Increases in active case detection activities will result in a higher number of cases being reported, though clinical cases will decline overall.

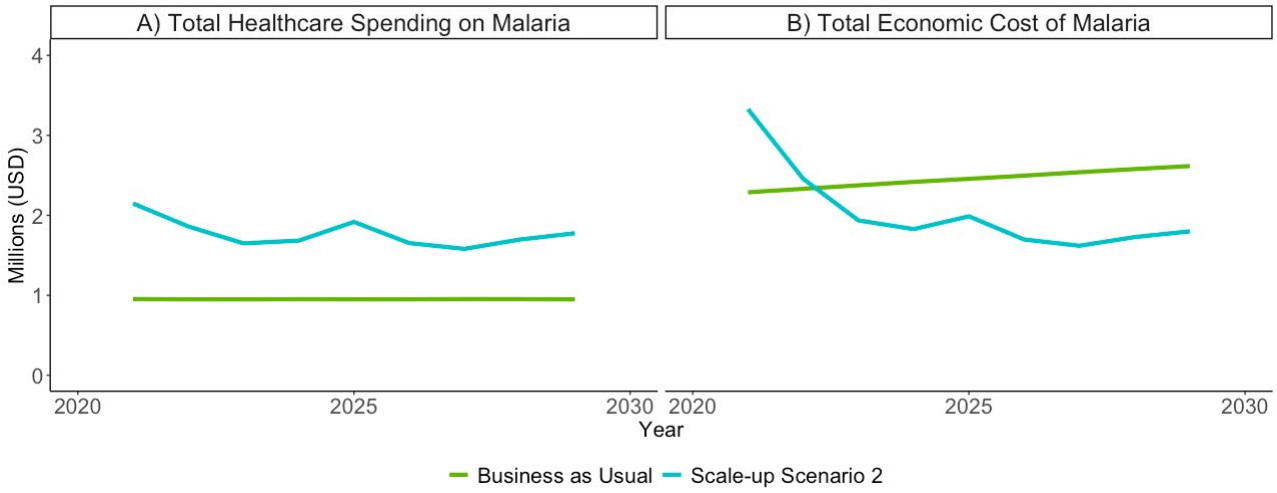
Figure 14. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in French Guiana, by scenario and malaria species



The above figure (Figure 14) depicts the projected downward trajectory of clinical cases of *P. falciparum* and *P. vivax* malaria under both BAU and SU2 scenarios in French Guiana, with an accelerated pace projected with a full regional scale-up (SU2).

Limited financial data related to malaria in French Guiana were available. Information regarding projected financing for malaria was not available. Therefore, there are no financial gap projections provided but only projections related to the scenarios. Based on the assumptions used, the annual direct healthcare spending on malaria associated with the SU2 scenario is estimated to be USD 800,000 more than - or nearly twice as expensive as - the BAU scenario. (Figure 15; Panel A). However, when the total economic cost (both direct healthcare and indirect costs related to malaria) of these scenarios is factored in, the SU2 scenario yields net average economic savings of USD 700,000 annually after the year 2023 (Figure 15; Panel B).

Figure 15. Projected total healthcare spending on malaria and total economic cost of malaria in French Guiana, 2021–2029



Findings: Special Scenario – Reduced Investment

A Reduced Investment (RI) scenario was modeled for French Guiana. Under this scenario, IRS and LLIN distribution were halted in 2025, after which passive case detection remained the only malaria intervention that continued to be implemented (Table 17). Current vector control interventions, as outlined under the BAU scenario for French Guiana, are small in scale, with a reported 250 houses receiving IRS spraying in 2019 and 625 LLINs distributed in 2018. The impact of ceasing these interventions is therefore expected to be negligible, with minimal projected influence on malaria transmission at the population level. As is the case for other scenarios in French Guiana, the validity and robustness of the RI scenario depends on the strength of the country's surveillance data, which have yet to be verified by local health officials.

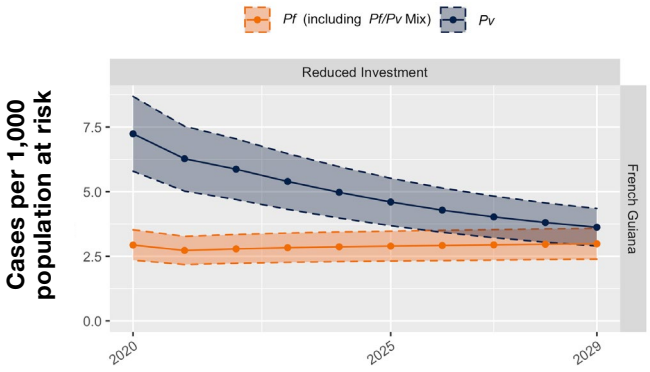
Program management costs often account for a substantial share of total spending for a typical malaria program. It is difficult to project how program management costs would contract under an RI scenario. Therefore, economic costs are not provided for this scenario.

Table 17. Reduced Investment (RI) scenario description with key model predictions, French Guiana

Interventions	Reduced Investment (RI)
Detection and Treatment	Routine facility-based treatment with ACTs
Vector Control	None
Cross-Border Initiatives	None

The below figure (Figure 16) shows the projected decline in *P. vivax* malaria and the relatively stable trend of *P. falciparum* malaria from 2020 to 2029 under a reduced investment scenario.

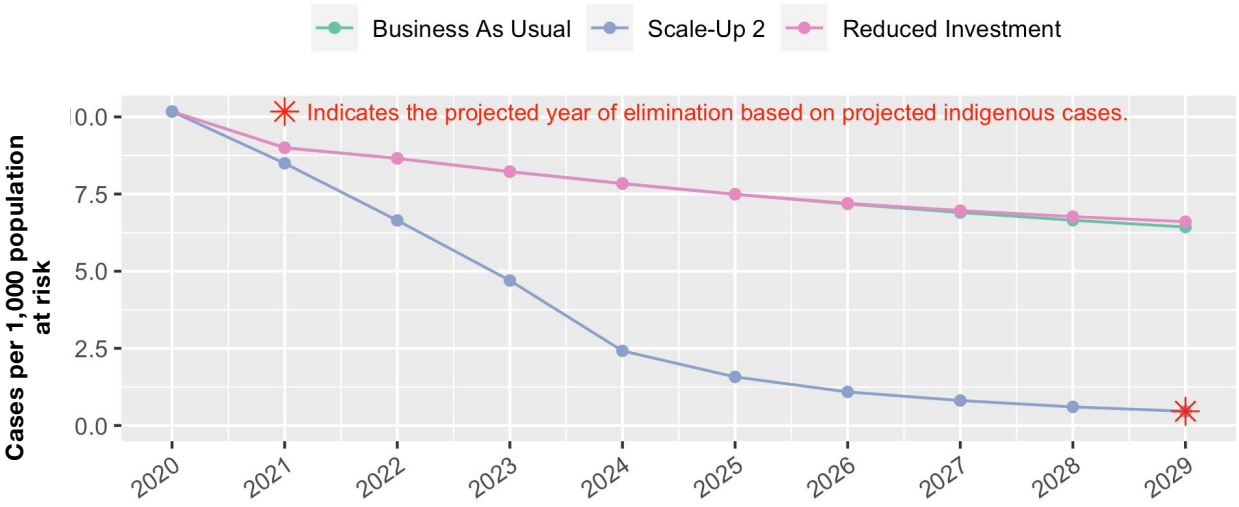
Figure 16. Projected clinical cases per 1,000 population at risk from 2020 to 2029 for Reduced Investment (RI) scenario in French Guiana



Findings: All Scenarios

Figure 17 (next page) demonstrates the dramatic decrease in clinical cases seen in French Guiana with an accelerated regional approach (SU2), with elimination projected to be achieved in 2029 under this approach.

Figure 17. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in French Guiana, by scenario



Modeling Assumptions and Limitations in French Guiana

While information on cases and vector control was available at the national level for French Guiana, it was not possible to access malaria strategic plans. The BAU scenario was based on accessible case and vector control data, while the SU2 scenario was based on a scale-up of the BAU scenario. Inability to have any of the modeled scenarios validated by local health officials limits their validity. The primary interventions under the BAU scenario are passive treatment and rollout of a small number of nets to at-risk populations. Estimates of treatment-seeking behavior were only available for 2013. Since data on LLIN usage were not available, a baseline usage rate of 50% has been assumed for the BAU scenario. Based upon the available data, the extent to which surveillance efforts and treatment access extend to mobile and migrant populations in French Guiana was unclear.

Malaria intervention costs in French Guiana were extrapolated from neighboring countries and the available literature.

Regional

A regional approach to malaria elimination (SU2), wherein each country simultaneously intensifies interventions, is projected to result in sweeping benefits across the region. This hypothetical scenario models not only intensified interventions in Suriname, Guyana, and French Guiana, but also an aspirational decrease in cases imported into these countries from Brazil and Venezuela.

Table 18. Modeled Scale-Up 2 scenario findings for malaria elimination in Suriname, Guyana, and French Guiana, accumulated over the period 2021 to 2024

	Suriname	Guyana	French Guiana
Projected year of elimination (elimination year under BAU)*	*Pf*: 2020 (2020) *Pv*:: 2024 (2027) All: 2024 (2028	*Pf*: 2025 (>2030) *Pv*: >2030 (>2030) All: >2030 (>2030)	*Pf*: 2024 (>2030) *Pv*: 2029 (>2030) All: 2029 (>2030)
Projected clinical cases (averted from BAU)**	2,400 (800)	340,300 (240,200)	3,800 (2,000)
Projected reported indigenous cases (averted from BAU)***	190 (110)	53,800 (30,600)	1,100 (400)

*Modeled elimination is defined as being achieved when projected indigenous cases are less than 0.1 per 1,000 population at risk. Three milestones are presented: '*Pf*', the year in which the sum of *Pf* and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold; '*Pv*', the year in which the number of *Pv* cases crosses the modeled elimination threshold; and 'All', the year in which the sum of *Pf*, *Pv*, and *Pf*/*Pv* mixed cases crosses the modeled elimination threshold.

**Clinical cases comprise treated and untreated cases, whether indigenous or imported, as all represent a burden to the healthcare system.

***Increases in active case detection activities will result in a higher number of cases being reported, though clinical cases will decline overall.

Figure 18 (next page) depicts the three standard scenarios for Suriname, Guyana, and French Guiana. Projections estimate that a regional scale-up approach could result in declines in both *P. falciparum* and *P. vivax* malaria in all three countries.

Figure 19 (next page) allows for a side-by-side comparison of the projected impact of each scenario across the three countries modeled.

Aggregating across the Guyana Shield region, the return on investment in malaria elimination is projected to exceed 130% under the SU2 scenario, compared with a BAU approach. In total, such investment would generate a net economic benefit of USD 80 million between 2021 and 2029.

The economic benefits of a regional approach to malaria elimination (SU2) are most acutely evident in Guyana. By the year 2025, Guyana would accrue an economic benefit of USD 12 million annually relative to the BAU scenario and USD 3 million annually relative to the SU1 scenario. The economic benefits of a regional approach to malaria elimination are less pronounced, but still positive, in Suriname: compared with the SU1 scenario, the SU2 scenario would lead to approximate economic savings of USD 200,000 annually by the year 2025. The modest projected benefit in Suriname is primarily due to the country's current proximity to malaria elimination. The economic benefits of accelerating malaria elimination in French Guiana are projected to result in economic savings for French Guiana by 2023, and grow to nearly USD one million annually by 2028.

The estimated economic benefits of regional malaria elimination are likely understated, as the measurement of indirect costs only includes costs associated with malaria morbidity and mortality. In reality, regional elimination of malaria could yield greater economic benefits by bolstering other industries (e.g. tourism) and strengthening health systems within the region. However, given that these benefits are difficult to quantify and capture accurately, they have been excluded from the analysis.

While the above findings demonstrate the value of coordinated efforts to decrease malaria throughout the region, the SU2 scenario should be considered hypothetical and optimistic. This scenario is dependent upon the simultaneous occurrence throughout the region of multiple interconnected factors. Such factors include financial and programmatic ability to rapidly scale up malaria interventions in Suriname, Guyana, and French Guiana, as well as concurrent continual decreases in malaria transmission in Brazil and Venezuela. The SU2 scenario demonstrates the potential progress that could be achieved if this full regional effort were actualized during the 2021 to 2029 period.

Figure 18. Projected clinical cases per 1,000 population at risk from 2020 to 2029 for Scale-Up 2 scenario in French Guiana, Guyana, and Suriname, by scenario and malaria species

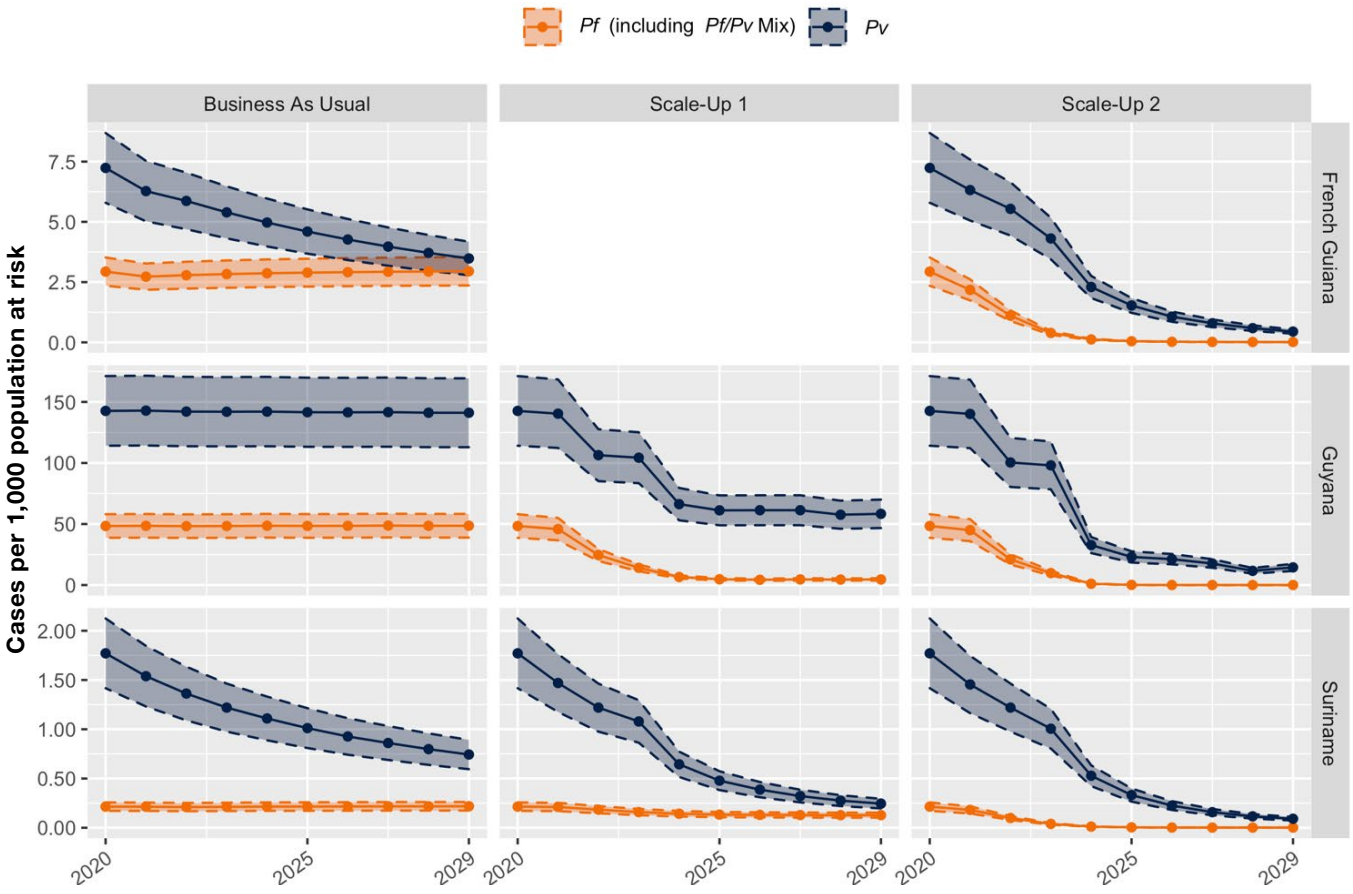
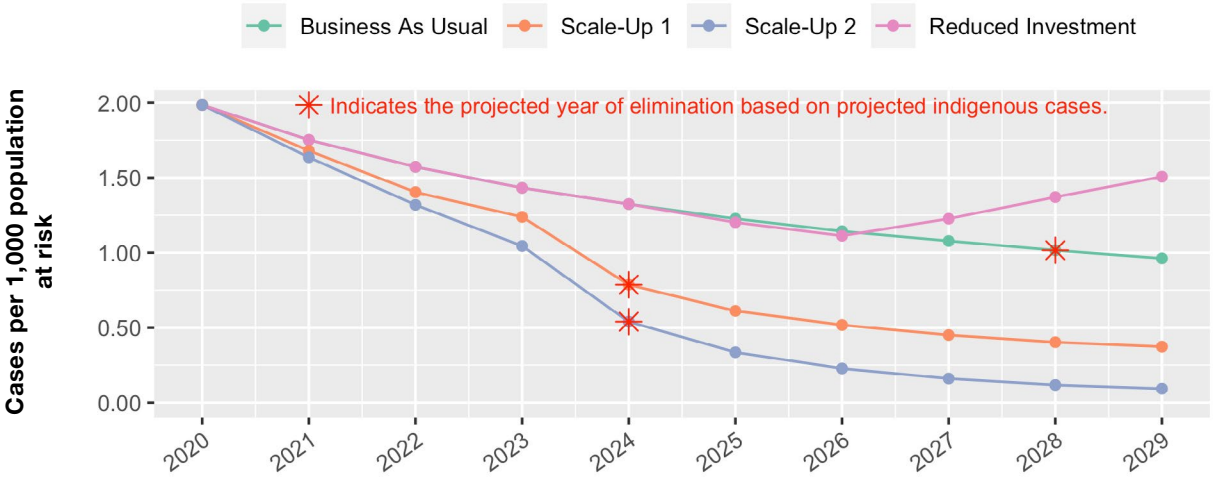
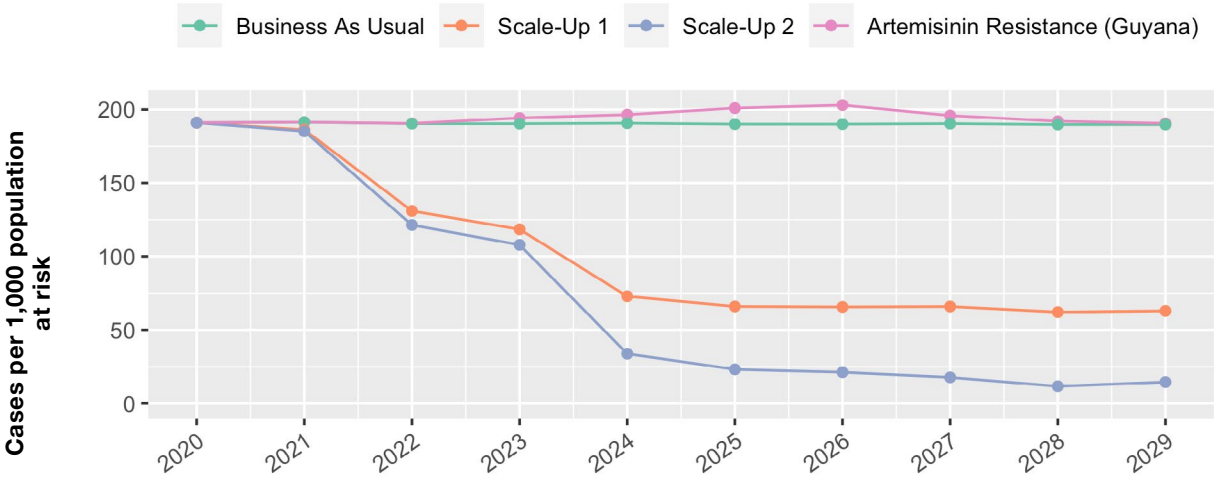


Figure 19. Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Suriname, Guyana, and French Guiana, by scenario

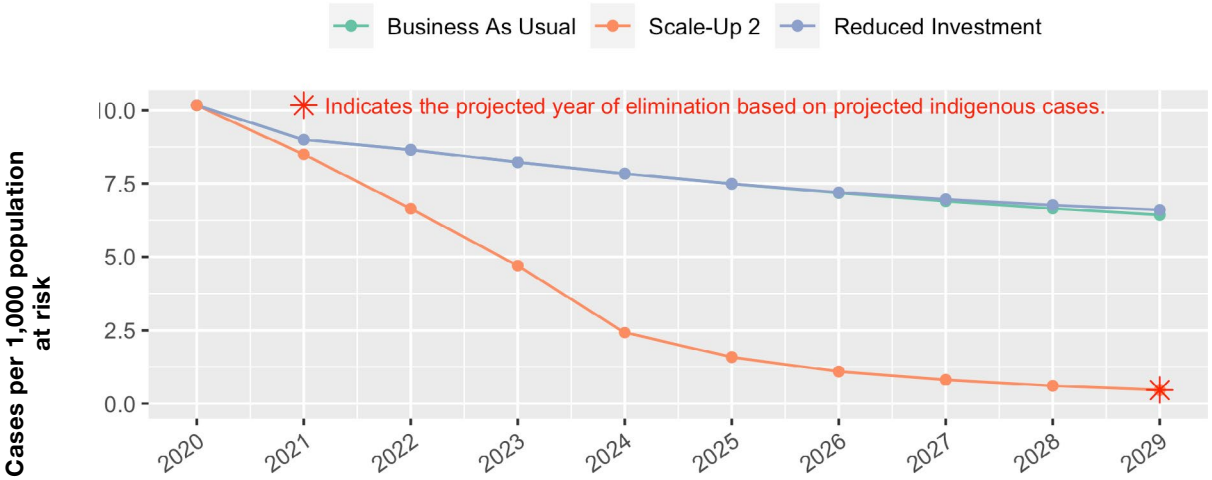
Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Suriname



Projected clinical cases per 1,000 population at risk from 2020 to 2029 in Guyana



Projected clinical cases per 1,000 population at risk from 2020 to 2029 in French Guiana



Conclusions and Recommendations

Suriname

Increased financial investment, strengthened partnerships, and implementation of improved prevention and control interventions have led to dramatic progress in Suriname and have brought the country close to malaria elimination in its remote endemic areas. Remaining malaria transmission risk and incidence are concentrated in border areas with high levels of migration of small scale gold miners between Brazil, French Guiana, and Suriname. To reach its goal of eliminating malaria by 2025, Suriname is focusing malaria elimination efforts on the management of imported cases among mobile, cross-border migrants.[26]

Continuation of current levels of malaria interventions will not allow Suriname to meet its stated goal of eliminating malaria by 2025. Malaria elimination is projected to be reached by 2028 in Suriname if current levels of interventions continue. Business as usual malaria activities within the country are characterized by extensive surveillance, LLIN distribution, and management of imported malaria, with planned increases in the distribution of Malakit in the coming years.

With an additional investment of USD 800,000 per year from 2021 to 2024, Suriname could exceed its national target and eliminate malaria by 2024. Current resources in Suriname are expected to be insufficient to finance this push for elimination. It is projected that Suriname would need an additional total investment of USD 3.1 million from 2021 to 2024 to finance the intensification of malaria interventions and achieve malaria elimination by 2024. If made in coordination with simultaneous intensification of efforts throughout the region, these investments are expected to yield a 20% return on investment in Suriname. These figures are considered conservative as malaria elimination yields benefits outside the scope of our analysis.

Uncertainty in future domestic and donor financing for malaria may pose risks for the sustainability of Suriname's malaria response. If financial support from either the Suriname government or the Global Fund diminishes after 2024, the reduced investment (RI) could lead to disruptions in critical malaria interventions, causing a projected additional 450–700 cases (compared with a BAU scenario) and pushing elimination in Suriname beyond 2030. Advocacy for sufficient financing of Suriname's malaria response beyond 2024 is critical to preventing potential malaria resurgence, which is often the consequence of an underfunded program.[43]

While Suriname is projected to reach malaria elimination in 2024 under both scale-up scenarios (SU1 and SU2), a region-wide intensification of efforts (SU2) would avert more cases and yield higher economic benefit. The economic benefits of a regional approach to malaria elimination in Suriname are modest, but positive: compared with the SU1 scenario, the SU2 scenario would lead to approximate economic savings of USD 200,000 annually by the year 2025. Given the highly mobile nature of the population in the mining region and the concentration of imported cases along border areas, regional coordination is essential in order to realize the maximum benefit of malaria elimination efforts in Suriname.

Improvements in local malaria expenditure tracking and analysis would strengthen evidence related to the cost of malaria interventions, especially as interventions fluctuate with the boom and bust of the local gold mining industry. The cost of malaria elimination in Suriname will likely be heavily influenced by the unknowable future price of gold. Increases in the price of gold raise the cost of LLIN and Malakit distribution and outbreak response within the gold mining regions, as well as heighten demand for malaria services in these regions by drawing more gold miners. Strengthened accounting systems with costs of malaria interventions at the subnational level may allow for a better understanding of the link between gold prices and the cost of Suriname's malaria program. Such knowledge could, in turn, enable improvements in budget planning and cost projections.

Strengthened data on imported malaria cases, as well as on mobile and migrant populations, would improve Suriname's ability to target and tailor interventions in order to tackle cross-border malaria transmission. As Suriname aims for

malaria elimination, it will become increasingly important for speciated data on the size and behavior of mobile and migrant populations to be collected at the subnational level. Of importance, subnational data sharing amongst neighboring countries will bolster Suriname's surveillance efforts and pace towards elimination.

A coordinated regional approach will be required for Suriname to achieve elimination in the short-term. In order to achieve malaria elimination, Suriname will need to secure sustained and sufficient malaria financing past 2024 while concurrently increasing cooperation with neighboring countries (i.e. French Guiana and Brazil) to control transmission among mobile and migrant populations. These efforts will ensure that Suriname can continue to play a key role in regional elimination efforts and prevent the potential reintroduction of local transmission within its borders.

Guyana

The persistent challenge of increasing human activity in the malaria-endemic hinterland continues to threaten progress towards malaria elimination in Guyana. In light of this trend, projections suggest that Guyana will not reach elimination by 2030 through the continuation of current interventions alone.

Guyana will likely only be able to achieve elimination of P. falciparum malaria by 2030 if malaria interventions are scaled up regionally. Intensifying interventions within the country (SU1) could contribute to considerable decreases in cases in the coming years. However, Guyana would not be able to achieve elimination by 2030 under such a scenario. As a result of regional scale-up (SU2), Guyana would be able to achieve *P. falciparum* elimination by 2025 – achieving the national species elimination goal – though *P. vivax* elimination would remain elusive.

For every dollar invested in malaria elimination in Guyana, the estimated return is between USD 2.60 and USD 2.85. Guyana will accrue a significant economic advantage by investing in an accelerated path to malaria elimination. Every dollar invested in malaria elimination in Guyana will generate an estimated economic benefit of USD 2.60. The estimated return per dollar invested increases to USD 2.85 if the entire region jointly intensifies malaria interventions. This implies that the cost of increased investment in malaria elimination efforts is expected to be entirely defrayed by the economic gain resulting from averted malaria cases and deaths. These figures are considered conservative as malaria elimination yields benefits outside the scope of the analysis.

An accelerated regional approach to elimination is economically beneficial for Guyana, with total economic savings projected to exceed USD 11 million annually (compared to a BAU scenario) and USD 3 million annually (compared with a SU1 scenario). Guyana is projected to require an additional USD 7.5 to USD 8.8 million in total over the next four years alone in order to adequately scale-up malaria interventions and realize the economic benefits noted above.

If unheeded, the possible spread of artemisinin resistance could threaten progress towards malaria elimination in Guyana. The potential spread of artemisinin resistance to first-line malaria treatments in Guyana requires continued and enhanced vigilance. If not adequately addressed, this threat could result in an additional estimated 33,000 clinical cases, to the detriment of surveillance and response efforts. It will be critical to continue monitoring the resistance profile of parasites in Guyana and to consider mitigation options if AL resistance occurs. Such mitigation could include ensuring availability of other second line antimalarial agents and updating clinical guidance to ensure that treatment failure is detected and when treatment failure rates reach a prespecified level the first line antimalarial is rotated out.

Strengthening risk stratification and imported case data will improve Guyana's ability to target and tailor interventions, thereby allowing more efficient use of resources in expanding access to services and interventions where they are most needed. Guyana intends to invest in the scale-up of passive case detection in regions with high malaria prevalence. This scale-up will require Guyana to strengthen health system operations in the hinterland for the purpose of reporting detected cases; providing high quality testing; monitoring treatment-seeking behavior; and ensuring adherence to treatment in order to track the efficaciousness of artemisinin-based drugs. Guyana recently embarked on a nation-wide stratification of malaria risk in order to identify transmission foci. However, this data was not available for use in the current study. The inclusion of this dataset containing speciated imported cases at the foci level, coupled with the administration of studies on barriers in accessing care, would allow Guyana to target improvements in surveillance.

Advocacy for domestic financing for malaria and multisectoral engagement, particularly with the growing oil sector, could strengthen the sustainability of the malaria response. The economic future of and trajectory of malaria elimination in Guyana are closely tied to expected oil revenues. Presently,

the gold and timber industries draw many to work in Guyana's hinterlands, which hold the country's greatest malaria transmission risk and incidence. However, as the nascent off-shore oil industry develops in Guyana, it may redirect workers from high-risk malaria-endemic regions in the interior to coastal areas with reduced malaria risk. Further, forecasted revenue from the oil industry is anticipated to enable Guyana to increase its domestic financing for malaria by nearly 60%. However, it is important to note that Guyana's expected financial windfall has not yet been realized. The productivity of the oil industry in Guyana and the ways in which potential benefits resulting from the industry's growth may be realized remain to be seen. The mobilization of increased financial resources will be critical in facilitating the adequate scale-up of interventions in Guyana as planned and, by extension, in ensuring that progress towards elimination can be realized by 2030.

Guyana's elimination success is dependent upon regional cooperation. Therefore, a focused and coordinated regional effort would accelerate elimination in Guyana. Given the possible threat of drug resistance, such acceleration is critical. According to the scenarios modeled in this study, the achievement of malaria elimination in Guyana is highly dependent on progress throughout the region. As such, Guyana will need to increase cooperation with its neighbors in order to attain elimination. Regional cooperation will also be essential to sustaining progress and preventing reintroduction across the region.

French Guiana

According to the information provided by local health officials for this study, current malaria activities are minimal in scope and data availability is sparse. The relative scarcity of accessible data on malaria transmission, current or future planned interventions, and program costs is an important caveat for interpreting study results for French Guiana.

French Guiana will likely only be able to eliminate malaria before 2030 if interventions are scaled up regionally. According to model predictions, French Guiana will not eliminate malaria before 2030 if it continues to implement current levels of interventions under a business as usual scenario. Under a scenario involving simultaneous regional scale-up (SU2), French Guiana is expected to accelerate its pace towards elimination, with elimination of *P. falciparum* projected for 2024 and elimination of *P. vivax* projected for 2029.

The economic benefits of accelerating malaria elimination in French Guiana are projected to be substantial and amount to nearly USD 1 million annually by 2028. The modeling indicates that regional scale-up (SU2) would result in economic savings for French Guiana by the year 2023. These expected savings are predicted to grow to nearly USD one million annually by 2028.

Improved data for decision-making to target and tailor interventions would increase high-risk populations' access to malaria interventions. In order for French Guiana to make substantial progress towards elimination, it must address gaps in interventions, such as access to treatment and distribution of effective LLINs. Increased specificity in case surveillance data, particularly in high-transmission areas, would allow for a more targeted approach in reaching and providing malaria services to high-risk migrant populations engaged in gold mining. Given the interconnectivity between French Guiana and its neighbors, investment in cross-border efforts and data sharing platforms will be critical to achieving malaria elimination both within French Guiana and across the Guyana Shield region.

Regional

Malaria in the Guyana Shield does not belong to any one country. Though each has varying levels of endemicity, all countries in the Guyana Shield contribute to the regional burden of malaria. The region is characterized by economic migration between and within countries, movement that facilitates high rates of cross-border malaria transmission. Due to the interconnectedness of the region, the achievement and maintenance of malaria elimination in any one country will likely remain dependent on progress made by the region as a whole. Thus, a regional approach and collaboration between countries are essential, and elimination must be a regional goal.

In the Guyana Shield, a simultaneous reduction in the burden of malaria across countries is projected to be more impactful than the control or elimination of malaria in any one country in isolation. The hypothetical scenario (SU2) under which all countries scale up interventions or reduce malaria transmission demonstrates how the region may benefit from this type of coordinated approach to malaria response. Projected findings demonstrate that more malaria cases would be averted and elimination would be achieved sooner if the region collectively scaled up interventions.

Investing in malaria elimination across the region is expected to generate a total economic benefit of over USD 80 million from 2021 to 2029, relative to a business as usual approach. In aggregate, findings estimate that every dollar invested in malaria elimination in the region would result in USD 2.30 in economic benefit to the region. A regional approach to malaria elimination would enable Suriname and Guyana to save almost USD 8 million in direct health-care spending on malaria from 2021 to 2029, relative to the malaria initiatives outlined in the business as usual scenario.

The extent to which the above regional benefits are sustained will depend upon the strength of surveillance in the region. Health systems that have the capacity to adequately test and report on speciated imported cases will be able to measure and respond to rises in cases with agility. The region must take steps to strengthen the regional surveillance network and improve communication and cooperation between countries in order to facilitate increased access to care for mobile and migrant populations. This is of particular importance as the threat of artemisinin resistance to current antimalarial drugs is monitored in the region. In taking such actions, the Guyana Shield has the potential to leverage the connectedness of the region to accelerate progress towards malaria elimination.

Development of a regional mechanism for co-ordination of malaria response efforts across the Guyana Shield will be critical for intensifying regional elimination efforts. Despite the interconnectedness of malaria transmission throughout the region, there is currently no mechanism in the Guyana Shield for formal coordination of malaria control and elimination efforts. This type of mechanism could enable more efficient use of financial resources to target interventions where they're most needed. Cross-cutting political commitment and capacity strengthening to mobilize and absorb resources will be critical to intensifying efforts towards malaria elimination in the Guyana Shield.

Appendices

Appendix A. Epidemiological Model Description

A dynamic epidemiological-economic model was developed to project rates of decline of *P. falciparum* and *P. vivax* malaria transmission from 2021 to 2030 and determine the costs for elimination in the Guyana Shield. A full description of the mathematical model is available on Github and Zenodo.[28,16] A brief summary, adapted from Silal et. al (2019) follows.[28]

The multi-species model includes transmission models for both *P. falciparum* and *P. vivax* and incorporates interactions between the two species of malaria. Key features of the *P. falciparum* model include four infection classes: severe; clinical; asymptomatic and detectable by microscopy; and asymptomatic and undetectable by microscopy. Each infection class has an associated level of infectiousness based on infectivity data. The probability that individuals will enter any given class of infection is dependent on their immunity status. It is assumed that untreated individuals will transition from higher to lower severity infection classes as they recover, and that they can be boosted to higher severity classes through superinfection. It is assumed that treated individuals will test positive for histidine-rich protein 2 after clearance of asexual parasitaemia for different durations, depending on the detection limit of the test used.

A companion compartmental model was developed for the transmission of *P. vivax* malaria. Its formulation is similar to the *P. falciparum* model with respect to the four infection classes, though there are key differences between the two model structures. *P. vivax* infections are characterized by malaria relapses, arising from persistent liver stages of the parasite (hypnozoites). It is assumed that hypnozoites may persist in the liver even after infections clear (dependent on a probability), and that these hypnozoites may trigger relapses of infection. In order to account for glucose-6-phosphate dehydrogenase (G6PD) deficiency testing and radical cure, the relationship between G6PD deficiency and *P. vivax* malaria is incorporated in the model through separate treatment regimens. As in the case of the *P. falciparum* model, it is assumed that untreated individuals will transition from higher to lower severity infection classes as they recover, and that they can be boosted to higher severity classes through superinfection.

The *P. falciparum* and *P. vivax* models are independent models for the same population. The models are intertwined at each time step to incorporate interactions between the two species in the following manner:

Dual treatment (Treatment of a mixed infection)

An untreated population that is simultaneously infected with both *P. falciparum* and *P. vivax* malaria, and that is being treated for *P. vivax* malaria with artemisinin-based combination therapy (ACT) or a drug that is effective against both species, will also be cured of its *P. falciparum* malaria. Likewise, ACT for a *P. falciparum* infection will also cure a *P. vivax* infection, though hypnozoites may be present after the *P. vivax* infection clears.

Triggering

It has been hypothesized that the subsequent appearance of *P. vivax* implies that a *P. falciparum* episode reactivates *P. vivax* hypnozoites. This is incorporated into the model as follows: a population experiencing a clinical *P. falciparum* infection has a higher probability of experiencing *P. vivax* relapse compared with the rest of the population.

Masking

Different brands of rapid diagnostic tests (RDTs) have different targets. Thus, it may be the case that non-*P. falciparum* malaria is masked by *P. falciparum* malaria. In order to account for this, it is assumed in the model that 5% of *P. vivax* cases are treated as *P. falciparum* cases and will not be candidates for radical cure. It is important to note that much of the malaria diagnoses made in the region rely upon microscopy, which differentiates between species.

Interventions

Interventions specific to each of the three countries are described in the main text. The following section provides insight into how the impact of these interventions is generally captured in the model.

Table 19. Intervention descriptions

Intervention	Description
Passive Treatment	Treatment probabilities for different avenues of treatment are dependent on the following factors: treatment-seeking; testing; receipt of treatment; and diagnostic sensitivity.
Long Lasting Insecticide-Treated Nets	Net distribution as a proportion of the population at risk, net loss, and the life of the net are used to compute cumulative coverage. Together with usage and ability to prevent transmission, cumulative coverage is used to decrease malaria transmission.
Indoor Residual Spraying	The number of people protected by IRS as a proportion of the population at risk and the life of the insecticide are used to compute cumulative coverage. Together with the ability to prevent transmission, cumulative coverage is used to decrease the malaria transmission rate.
Active Case Detection	Incidence is assumed to trigger additional screening of individuals. Due to clustering of infection, these individuals are modeled as having amplified rates of infection compared with the general population. These newly identified cases are assumed to be treated.
Tafenoquine (TQ)	This intervention involves switching from a 14-day regimen of Primaquine (PQ) to a 1-day regimen of new treatment (Tafenoquine, or TQ). Adherence and recovery time are modified. In settings where the replacement of PQ with TQ for treatment of *P. vivax* is modeled, the change is assumed to commence in 2023 in order to allow time for licensing and incorporation into national treatment guidelines.
Proactive Screening	The content of this intervention is the same as that of active case detection, with the modification that screening capacity is determined beforehand.

Note on Tafenoquine: Tafenoquine (TQ) presents the opportunity for a single-dose treatment of *P. vivax* malaria. TQ has been approved by the United States Food and Drug Administration and the Australian Therapeutic Goods Administration for use in adults aged 16 years or older. However, there are key safety challenges associated with the drug, as both TQ and PQ may trigger acute haemolytic anaemia in patients with a deficiency of the G6PD enzyme. For TQ in particular, a quantitative measurement of G6PD status is required. The WHO is currently developing guidance on TQ use accompanied by a G6PD test.[44] A recent Cochrane review on the use of TQ for the prevention of relapses in the treatment of *P. vivax* malaria found that there was little to no difference in the prevention of relapses between a single dose of TQ (300mg) and a standard PQ treatment regimen (5 mg/day for 14 days for adults). The aforementioned study also found little or no difference in the occurrence of overall adverse events when comparing TQ use to the use of a placebo or PQ. However, the study produced inconclusive results regarding whether TQ causes more serious adverse events, such as a drop in blood hemoglobin.[45]

Note on data included: This model has been validated with national and subnational data that are subject to a degree of uncertainty. It was not always possible to obtain historical intervention coverage data. Where data were available, interventions were modeled at the subnational and national level. Where data were not available, assumptions were made based upon literature and were validated by NMPs, where possible. Such assumptions resulted in model predictions that provide broad-stroke guidance rather than a detailed sub-national strategy design. All models are simplifications of reality and are subject to uncertainty regarding knowledge of the disease, health systems, and population and vector behavior. Therefore, projections should be contextualized within local disease settings and interpreted with caution.

Table 20. Detailed parameter table

Parameter	French Guiana	Guyana	Suriname
Stable population growth rate	0.0277[46]	0.005[47]	0.009[47]
Treatment			
Probability of Passive treatment-seeking	0.45[48]	0.3[49]	0.45[48]
Proportion of suspected cases that are tested	1[50]	1[50]	1[51]
Proportion of positive diagnoses that are treated	0.5[50]	0.65[52]	1[52]
Vector Control			
LLIN Usage rates	0.5 (assumption)	0.33[7,49]	0.7 (stable population) 0.34 (mobile/migrant population)[40,41]
LLIN retention (proportion of nets no longer in circulation in years 2 and 3 after distribution	0.2/0.5[53,54]	0.2/0.5[7,53]	0.2/0.5[53,54]
Effectiveness of LLIN in reducing transmission	40%[48]	40%[48]	40%[48]
Effectiveness of IRS in reducing transmission	25%[48]	25%[48]	25%[48]

All other model parameters may be found on the online METCAP Model. [55]

Appendix B. Economic Costs and Benefits Estimation

The aim was to estimate both the total direct healthcare cost and indirect cost of each scenario under consideration in Guyana, Suriname, and French Guiana. To estimate total direct healthcare costs, both an ingredients costing approach and a top-down approach were used. Both approaches were employed so that cost estimates were sensitive to changes in the use of healthcare resources under each scenario, while still capturing broader health system costs and real-world inefficiencies. Importantly, the costs incurred under each scenario were not estimated within the context of idealized or perfectly efficient healthcare systems. Rather, estimated scenario costs capture the real-world difficulties—and, consequently, the necessary spending—associated with providing malaria interventions within the Guyana Shield region.

Indirect cost estimates capture only those costs incurred due to malaria morbidity and mortality and do not encompass broader economic costs that may be difficult to estimate.

While both Suriname and Guyana provided detailed healthcare resource cost data, historical budgets, and NMSP costing, data available for French Guiana were limited. In order to overcome this limitation, the costs used for French Guiana were extrapolated from Suriname and available literature.

Guyana and Suriname each provided a budgeted NMSP, with line-by-line accounting of the malaria-related expenditures each country program expected to incur in order to meet the goals outlined in its NMSP. Since the SU1 scenario was designed to reflect interventions outlined in the NMSPs, the budgeted NMSPs served as a starting point for costing this scenario.

Budget line items in the NMSPs for Guyana and Suriname were categorized into specific malaria program activities, such as active case detection, passive case detection, proactive case detection, healthcare services, distribution of nets, treatment, the Malakit program, and healthcare system spending. These activities were considered to broadly reflect program management and health system strengthening initiatives. Using international commodity prices and outputs from the epidemiological model under the SU1 scenario, commodity spending was extracted from all disaggregated spending categories. In order to generate unit price estimates of various malaria program activities, the remaining spending on malaria activities was divided by respective malaria services output by the epidemiological model under scenario SU1. These unit price estimates are listed below (Table 21). Rather than specifying healthcare system unit prices by particular malaria program activities, these prices were calculated as spending per capita. Healthcare system unit prices encompass costs associated with surveillance, training, program management, and other health system strengthening activities.

Spending on malaria under the SU1 and SU2 scenarios was calculated by first obtaining the products of malaria service unit prices and the quantities of annual services delivered by the epidemiological model under both scenarios. These products were then summed. Secondly, healthcare system spending was added to this summed quantity in order to arrive at an estimate of total spending on malaria. Healthcare system spending was calculated by multiplying the healthcare system unit price by the total population estimate.

In order to calculate future spending on malaria under the BAU scenario, healthcare system unit prices were extracted under this scenario. This was accomplished by first summing the products of the estimated unit prices and quantities of malaria-related services delivered in 2019. Secondly, this summed value was subtracted from total malaria spending in 2019, as provided by Global Fund funding landscape documents. The remaining amount served as an estimate of healthcare system spending under a business as usual scenario. This estimate was denominated by the total population in order to calculate the healthcare system unit price within the BAU scenario. Once the healthcare system unit price was obtained, total healthcare spending under the BAU scenario was calculated using a method similar to the approach employed in calculating malaria spending under the SU1 and SU2 scenarios.

Spending on malaria in French Guiana was estimated by relying on literature and data derived from Suriname. Intervention spending in French Guiana was estimated by using unit costs from Suriname, while spending on IRS was estimated using unit prices from a meta-analysis.

Notably, the approach to costing each scenario involves several assumptions. For example, this approach assumes that the quality of services delivered under all three standard scenarios is the same. In reality, due to enhanced training and other health system investments, the quality of services delivered under the SU1 and SU2 scenarios may be higher than that of services delivered under the BAU scenario. Further, the method of estimating healthcare system spending assumes that such spending is independent of malaria incidence or burden. There will likely be some variation in healthcare system spending as malaria is eliminated, but such variation is predicted to be minimal. This conclusion draws from the fact that many contributors to healthcare system spending, such as program management and training, are forecasted to remain mostly independent of malaria burden for the foreseeable future.

Finally, in-country malaria program officials noted that the cost of delivering services varies dramatically within each country due to the difficulty of traveling within the hinterland regions and the cost of traveling in gold mining regions. The costing approach outlined above assumes that national unit prices apply in each country. This assumption remains valid as long as the proportion of malaria services delivered within each subnational region remains relatively constant. However, in Suriname, the proportion of malaria services delivered may vary across resorts over time due to the country's proximity to malaria elimination and associated sporadic outbreaks. This reality required that measures be taken in order to adjust for variations in price levels within Suriname. Since no subnational price level adjustments were available for Suriname, a price level adjustment method that distinguished between gold mining regions and the rest of the country was developed. This price level adjuster was constructed by averaging the ratios of commodity costs (e.g. sugar, liter of fuel, etc.) in a gold mining region in Suriname and the cost of these goods in the rest of the country. Data regarding commodity costs were obtained through personal communications and downloaded from Suriname's General Bureau of Statistics. The above price level adjuster was used to inflate the unit prices of malaria services delivered in the gold mining regions of Suriname.

Table 21. Unit cost table

Country	Category	Item	Price (USD)	Source
All	**Commodity**	LLINs	5	Personal correspondence and Global Fund funding landscape documents
		LLINs for hammocks	10	Personal correspondence and Global Fund funding landscape documents
		RDT (pack of 25)	29	Personal correspondence
		Slide for microscopy (1 unit)	1.2	Personal correspondence
		Primaquine (diphosphate) 7.5 mg tabs, blister 10 x10	3.8	WAMBO Price Schedule
		Artemether 20 mg + Lumefantrine 120 mg tabs, blister 4 x 6, box/30	18	WAMBO Price Schedule
		Malalkits	8.33	Personal correspondence
Suriname	**Malaria program services**	LLIN distribution (per net)	2.74	Calculated from epidemiological model and NMSP data
		Treated patient (per patient)	1.68	Calculated from epidemiological model and NMSP data
		Outpatient visit	16.17	Personal correspondence
		Inpatient admission	126.78	Personal correspondence
		Activate case detection (per person screened)	32.07	Calculated from epidemiological model and NMSP data
		ProActivate case detection (per person screened)	12.92	Calculated from epidemiological model and NMSP data
		Healthcare system unit cost related to malaria under scale-up scenarios (e.g. surveillance, monitoring and evaluation, program management. Measured as per person)	4.86	Calculated from epidemiological model and NMSP data
		Healthcare system unit cost related to malaria under business as usual (e.g. surveillance, monitoring and evaluation, program management. Measured as per person)	3.09	Calculated from epidemiological model and NMSP data
Guyana	**Malaria program services**	LLIN distribution (per net)	1.76	Calculated from epidemiological model and NMSP data
		Treated patient (per patient)	1.95	Calculated from epidemiological model and NMSP data
		Outpatient visit	5.32	WHO-CHOICE[56]
		Inpatient admission	33.46	WHO-CHOICE[56]
		Activate case detection (per person screened)	22.25	Calculated from epidemiological model and NMSP data
		Healthcare system unit cost related to malaria under scale-up scenarios (e.g. surveillance, monitoring and evaluation, program management. Measured as per person)	6.21	Calculated from epidemiological model and NMSP data
		Healthcare system unit cost related to malaria under business as usual (e.g. surveillance, Monitoring and evaluation, program management. Measured as per person)	4.41	Calculated from epidemiological model and NMSP data
French Guiana	**Malaria program services**	IRS per person covered	4.22	Literature value[57]

Appendix C. Comparison of Intervention Packages

Table 22. Comparison of intervention packages

Scenario	Suriname	Guyana	French Guiana
Business as Usual (BAU)*	Routine facility-based treatment with ACTs and PQ Active case detection in all resorts (100% of cases followed-up) Proactive case detection in selected resorts (SR0101, SR0106, SR0401, SR0905, SR0906) LLIN distribution in selected resorts (SR0101, SR0104, SR0106, SR0401, SR0604, SR0902, SR0904, SR0905, SR0906) with 2016–2018 distribution levels scaled for population growth assuming 1.8 people per net coverage equating to a 3 year distribution of >70% of the population in the resorts included for distribution Malakit screening and follow-up in border resorts (Tapanahony, Albina, Blauwgrond) for travelers into French Guiana with scale-up in distribution planned for 2021	Routine facility-based treatment with ACTs and PQ Active case detection in regions 1,7,8,9 LLIN distribution in regions 1,7,8,9 with 2017–2018 distribution scaled for population growth assuming 1.8 people per net coverage equating to a 3 year distribution of >70% raw coverage of the population in the regions included for distribution	Routine facility-based treatment with ACTs LLIN distribution to population at risk with 2017–2019 distribution scaled for population growth assuming 1.8 people per net coverage equating to a 3 year distribution of 70% of the population at risk IRS continued at 2019 levels, equating to 0.5% per annum
Scale-Up 1 (SU1)*	Business as Usual + Switch from 14-day PQ to TQ for all *Pv* cases, starting in 2023 LLIN distribution to same resorts as increased to 85% coverage SU1 in Guyana	Business as Usual + Treat 100% of positive cases Switch from 14-day PQ to TQ for all *Pv* cases, starting in 2023 Increase treatment seeking from 34% to 78% (Method: increase passive case detection with RDT posts and kit distribution through SBCC efforts) LLINs to all regions with active foci (regions 1,2,3,4,7,8,9,10) with increased distribution in regions 1,2,3,4,10 and maintained distribution in regions 7,8,9 scaled for population growth assuming 1.8 people per net coverage equating to a 3 year distribution of >85% of the population in the regions included for distribution Enhance SBCC activities to increase usage of LLINs from 54% to 70% SU1 in Suriname	Business as Usual

Scale-Up 2 (SU2)	Scale-Up 1 (includes SU1 in Guyana) + SU2 in French Guiana Decreased imported transmission from Brazil and Venezuela	Scale-Up 1 (includes SU1 in Suriname) + SU2 in French Guiana Decreased imported transmission from Brazil and Venezuela	Business as Usual + Switch from 14-day PQ to TQ for *Pv*, starting in 2023 Introduce single low dose PQ for treatment of *Pf* Gradually introduce active case detection (increase from 50% to 100% over 3 years) Universal coverage of LLIN distribution (>85% coverage) Enhance SBCC to increase usage of LLINs (from 23% to 70% usage) SU1 in Suriname and Guyana Decreased imported transmission from Brazil and Venezuela
Reduced Investment (RI)*	Routine facility-based treatment with ACTs and PQ	Business as Usual	Routine facility-based treatment with ACTs
Artemisinin Resistance (AR)*	Business as Usual	Routine facility-based treatment with ACTs and PQ Probability of treatment failure for ACTs increases from 5% in 2020 to 35% by 2025, after which the drug is replaced with a hypothetical alternative.	Business as Usual

*Assumes a stable trend in imported cases from Brazil and Venezuela.

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