

**IMPROVING EFFICIENCY OF THE
HIV RESPONSE IN MALAWI**

Findings from an Optima HIV modelling analysis

2020

DRAFT

Acknowledgements

These results were generated through a collaboration with the following contributors.

Country team

Newton Chagoma, Tione Chilambe Tiwonge Chimpandule, Andreas Jahn, Andrea Kaiser, Ashley Kallarakal, Thokozani Kalua, Chimwemwe Mablekisi, Stone Mbiriyawanda, Rose Nyirenda, Alexandra Quinones Nunura, Erik Schouten, Emanuel Zenengeya

Burnet Institute

Debra ten Brink, Sherrie Kelly, Azfar Hussain, Rowan Martin-Hughes, Anna Roberts, David P Wilson

Global Fund

Laurence Natacha Ahoua, Alexandra Gray, Emmanuel Olatunji, Shufang Zhang

I Abbreviations

AGYW	Adolescent girls and young women
AIDS	Acquired immune deficiency syndrome
ART	Antiretroviral therapy
Clients	Clients of sex workers
FSW	Female sex workers
Global Fund	The Global Fund to Fight AIDS, Tuberculosis and Malaria
HIV	Human immunodeficiency virus
HTS	HIV testing services
MSM	Men who have sex with men
NSP	National Strategic Plan
PITC	Provider-initiated HIV testing and counselling
PLHIV	People living with HIV
PMTCT	Prevention of mother-to-child transmission
PrEP	Pre-exposure prophylaxis
SBCC	Social and behavioral change communication
VMMC	Voluntary medical male circumcision

II Table of contents

Acknowledgements.....	2
I Abbreviations	3
II Table of contents	4
III Figures	5
IV Tables.....	5
V Executive summary.....	6
VI Key recommendations	6
1. Economic development and health financing in Malawi.....	8
1.1 HIV epidemic in Malawi – past, present, and future	8
2. Methodology.....	10
2.1 Objectives.....	10
2.2 Populations modeled	10
2.3 HIV programs modeled	10
3. Results.....	12
Objective 1: To estimate the optimized annual HIV resource allocation to minimize new HIV infections and HIV-related deaths from 2020 to 2025.	12
Objective 2: To estimate the optimized annual HIV resource allocation to minimize new HIV infections and HIV-related deaths from 2020 to 2025 and from 2020 to 2035 under varying budget levels. Using the HIV testing budget from the original optimization for 2020 to 2025, determine how funding should be optimized across HIV testing modalities over this period.	14
Objective 3: To estimate the budget necessary to achieve 2020-2025 NSP targets	18
Objective 4: To estimate the optimized annual HIV resource allocation across the 32 districts	20
HIV prevalence by region.....	20
4. Model limitations.....	21
5. Conclusions	22
References	23
Appendices.....	24
Appendix 1: Model calibration and cost coverage curves	24
Appendix 2: Key model parameters.....	30
Appendix 3: HIV program unit costs, 2019	32
Appendix 4: Optimized spending and coverage per district.....	33

III Figures

Figure 1: Estimated new HIV infections and HIV-related deaths, 1990 to 2019	8
Figure 2: Estimated new HIV infections and HIV-related deaths by population group, 2019.....	9
Figure 3: Annual optimized HIV resource allocation for 2020 to 2025	12
Figure 4: Annual HIV budget optimization for varying budget levels, 2020 to 2025.....	14
Figure 5: Impact of optimization for varying HIV budget levels from 2020 to 2025 on new HIV infections and HIV-related deaths projected to 2035	15
Figure 6: Optimization of HIV testing budget from optimized overall budget at varying budget levels across the HIV testing modalities from 2020 to 2025	16
Figure 7: Annual budget levels and allocations to achieve 2020-2025 NSP coverage targets for 2021 to 2025, with the latest reported budget allocation applied for 2020, and the optimized budget for SBCC, safety nets, and PMTCT applied for 2021 to 2025 as no targets are set for these three programs	19
Figure 8: Estimated impact of achieving 2021-2025 NSP coverage targets through to 2025	20
Figure 9: Optimized re-distribution of annual HIV resources across 32 regions, 2020 to 2025.....	21

IV Tables

Table 1: Optimized annual HIV budget for 2020 to 2025	13
Table 2: Testing modality percentage of total HIV testing budget.....	17
Table 3: 2020-2025 NSP coverage targets for 2021 to 2025	18

V Executive summary

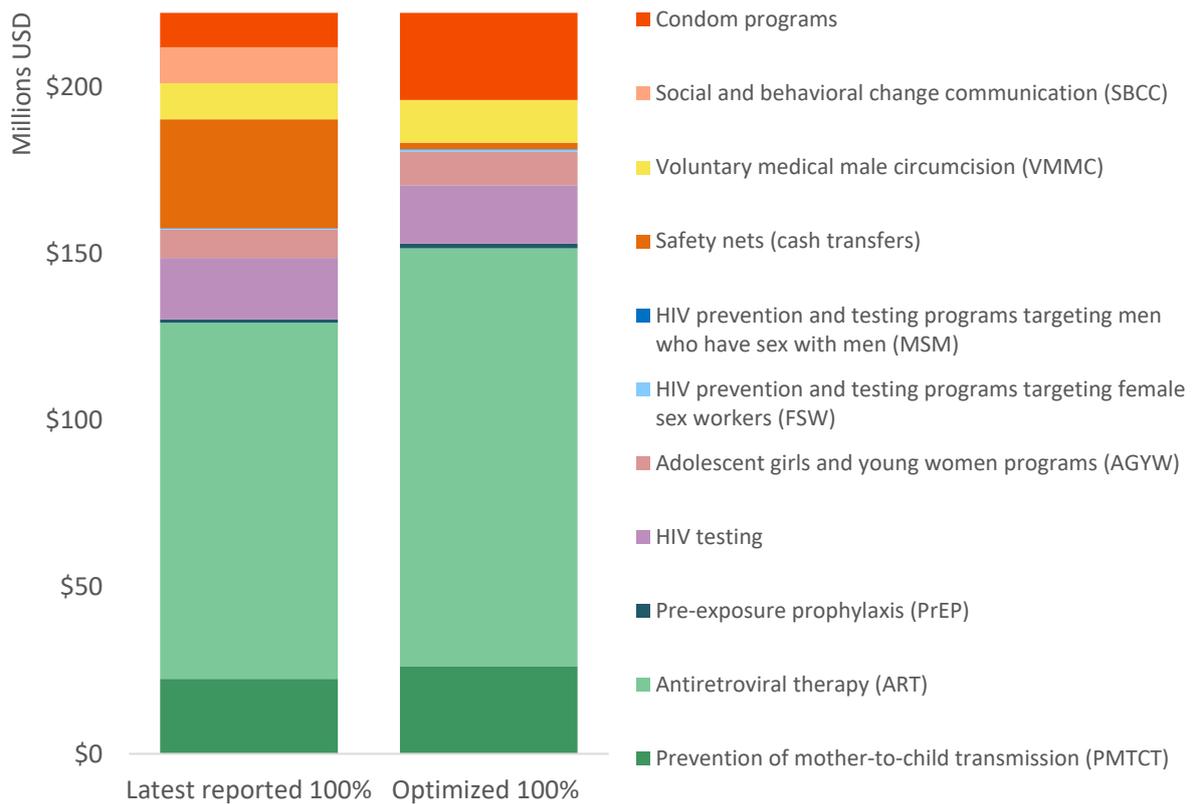
Malawi is a low-income country making significant strides in preventing new HIV infections and HIV-related deaths. Despite these efforts, it is estimated that there were 1 million people living with HIV in Malawi in 2019, with HIV remaining the leading cause of death in the country. However, sustainability of funding for the HIV response is under threat, with donor contributions declining worldwide. Since more than 97% of the HIV program in Malawi is funded by donor financing, it is essential that funds be allocated most efficiently, where they can make the greatest impact.

This report outlines findings from an HIV modeling analysis conducted for Malawi by the country team, the Global Fund to Fight AIDS, Tuberculosis and Malaria, the Clinton Health Access Initiative (CHAI), and the Optima Consortium for Decision Science. For this analysis, the Optima HIV model was applied to estimate the optimized resource allocation to improve the response to the HIV epidemic in Malawi. The aim of this analysis is to inform the 2020-2025 National Strategic Program (NSP) and the 2020 Global Fund funding request. The primary focus of Malawi's 2020-2025 NSP is to end the HIV epidemic in the country by 2030. Recommendations from a previous Optima HIV modeling analysis conducted for Malawi in 2017 included scale-up of treatment and HIV testing for the general population, including a district-level analysis recommending allocation of funding to 'hotspots' to increase impact.

VI Key recommendations

To minimize new HIV infections and HIV-related deaths over the 2020-2025 NSP period, recommendations from this analysis suggest prioritizing scale-up of:

1. antiretroviral therapy (ART),
2. condom programs,
3. prevention of mother-to-child prevention (PMTCT),
4. voluntary medical male circumcision (VMMC),
5. HIV prevention programs targeting adolescent girls and young women (AGYW),
6. pre-exposure prophylaxis (PrEP), and
7. HIV prevention and testing programs targeting female sex workers (FSW),
8. HIV prevention and testing programs targeting men who have sex with men (MSM).



If HIV resources are optimized at the **national level** from 2020 to 2025, then approximately 37,000 more new HIV infections could be averted (over 20% more) and 2,000 more HIV-related deaths could be averted (approximately 5% more) by 2025. Should additional HIV budget become available, it is recommended to proportionally scale-up in priority order antiretroviral therapy (ART), condom programs, prevention of mother-to-child prevention (PMTCT), voluntary medical male circumcision (VMMC), HIV prevention programs targeting adolescent girls and young women (AGYW), pre-exposure prophylaxis (PrEP), HIV prevention and testing programs targeting female sex workers (FSW), HIV prevention and testing programs targeting men who have sex with men (MSM).

At budget levels above 150%, it is recommended to scale-up condom programs ahead of HTS. With a doubling of budget under optimized allocation it is not projected that there will be a doubling in reduction of infections and deaths. A diminishing return on investment at very high budget increase is not surprising, as it will cost more to deliver services to harder to reach populations.

To optimize HIV resources **across districts**, including 28 districts and 4 cities, it is suggested to invest 40% of the national budget to five districts with the highest HIV burden Blantyre City, Lilongwe City, Mulanje, Mangochi, and Zomba. For these districts it is recommended to scale-up investment by ordered priority for ART, VMMC, PMTCT, condoms, HTS, FSW programs, and PrEP. In districts with higher prevalence of HIV, reallocating funds towards VMMC and condom programs is recommended. It was modeled that considering geographical profile for prioritization of funding could result in even more new HIV infections and HIV-related deaths being averted by 2025, 45,000 (over 25% more or 8,000 more than national-level optimization) and 3,300 (almost 10% more or over 1,000 more than national-level optimization) more, respectively.

1. Economic development and health financing in Malawi

Malawi is a land-locked country in Southern Africa, bordered by Mozambique, Tanzania, and Zambia. As a low-income country, Malawi relies heavily on its agricultural sector, leaving it vulnerable to weather circumstances. As such, high rates of poverty persist. In 2016, 52% of the population lived below the poverty line, although extreme poverty declined from 25% in 2010 to 20% in 2016 [1]. Investment in health has increased over the last decade, with the Government of Malawi financing over 50% of the health budget in most recent years [2]. However, almost the entire HIV program in 2017, 97%, was financing by donor funding [2]. Since it is expected that donors will reduce their contributions in the coming years [3], it is essential that available HIV funds be allocated in the most impactful way.

1.1 HIV epidemic in Malawi – past, present, and future

Malawi has a generalized HIV epidemic, accompanied by high HIV prevalence among key populations including female sex workers (FSW) and their clients, and among men who have sex with men (MSM). Tremendous progress has been made in reducing new HIV infections and HIV-related deaths from levels in the mid-2000's onwards; however, in 2019 it was estimated that one million people were living with HIV, with an estimated 30,000 new HIV infections having occurred in the same year. In 2017, HIV remained the leading cause of death in Malawi [4]. New HIV infections and HIV-related deaths have steadily declined since 2004 (figure 1), corresponding to a dramatic scale-up of HIV treatment since then (appendix 1).

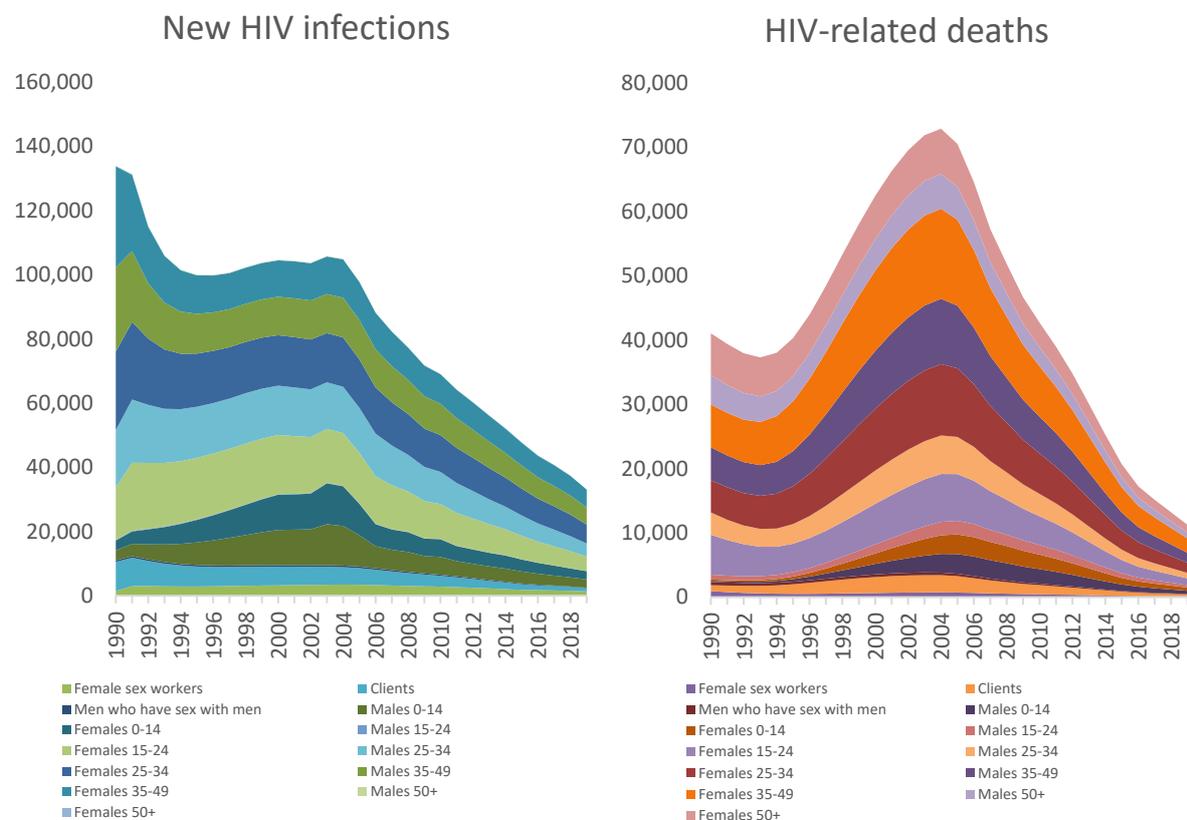


Figure 1: Estimated new HIV infections and HIV-related deaths, 1990 to 2019

Source: Optima HIV model, 2020

It was estimated that almost 60% of new HIV infections and HIV-related deaths occurred in females in 2019 (figure 2).

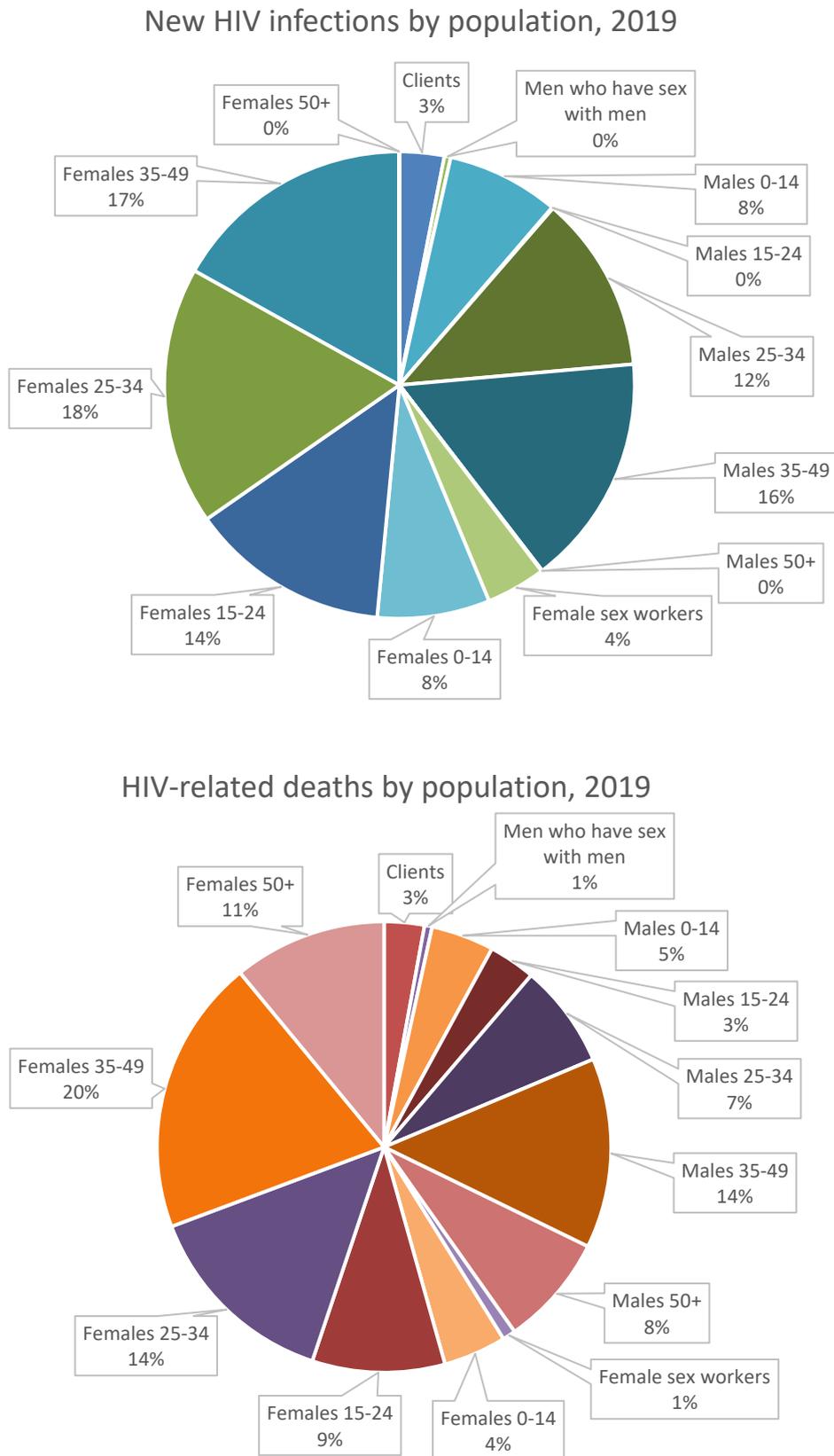


Figure 2: Estimated new HIV infections and HIV-related deaths by population group, 2019
Source: Optima HIV model, 2020

2. Methodology

This analysis was conducted using Optima HIV, an epidemiological model of HIV transmission overlaid with economic and programmatic data that applies a resource optimization algorithm. Optima HIV uses HIV epidemic modelling structure and incorporates parameter values for biological transmission probabilities, CD4 progression, as well as HIV prevalence estimates, sexual behavioral values, and sexual mixing patterns. HIV program cost and coverage data and efficacy estimates are used to develop cost functions, which represent the relationship between cost and coverage and coverage and outcome for each program. Within the model, an optimization algorithm is applied to estimate the optimized distribution of investment across a combination of HIV programs. Constraints were applied within the optimizations to ensure those on treatment remained on treatment unless lost by natural attrition. As such, in the optimized allocation, budgets for antiretroviral therapy (ART) and prevention of mother-to-child transmission (PMTCT) could not be reduced to ensure at least the same number of people were maintained on treatment. Last, for the objective function, the model algorithm aimed to estimate a theoretical optimal distribution of resources and emphasis of different HIV programmatic responses which minimizes both new HIV infections and HIV-related deaths by the target time horizon (2025 or 2035) given the local epidemic parameters and data, cost of delivering services, subject to the constraints as defined. Appendices 1 through 3 show model calibration and cost coverage curves, key model parameters, and unit costs used in this study.

2.1 Objectives

This analysis is an update to an Optima HIV analysis completed in 2017 for Malawi. Similar objectives to the original analysis were modeled here with findings to be used to inform the 2020-2025 National Strategic Plan.

Objective 1. To estimate the optimized annual HIV resource allocation to minimize new HIV infections and HIV-related deaths from 2020 to 2025.

Objective 2. To estimate the optimized annual HIV resource allocation to minimize new HIV infections and HIV-related deaths from 2020 to 2025 and from 2020 to 2035 under varying budget levels. Using the HIV testing budget from the original optimization for 2020 to 2025, determine how funding should be optimized across HIV testing modalities over this period.

Objective 3. To estimate the budget necessary to achieve 2020-2025 NSP targets

Objective 4. To estimate the optimized annual HIV resource allocation across the 32 districts

2.2 Populations modeled

The following key populations were included in this analysis, with general populations including: females aged 0-14 years, males 0-14 years, females 15-24 years, males 15-24 years, females 25-34, males 25-34 years, females 35-49, males 35-49, females 50 years and older (females 50+), and males 50 years and older (males 50+) years, and key populations including female sex workers (FSW), clients of female sex workers, and men who have sex with men (MSM).

2.3 HIV programs modeled

HIV programs included in this modeling analysis are as follows: antiretroviral therapy (ART), condom programs, HIV prevention and testing programs targeting adolescent girls and young women (AGYW),

HIV prevention and testing program targeting female sex workers (FSW), HIV prevention and testing programs targeting men who have sex with men (MSM), HIV testing for the general population, pre-exposure prophylaxis (PrEP), prevention of mother-to-child transmission (PMTCT), safety nets (cash transfers), social and behavior change communication (SBCC), and voluntary medical male circumcision (VMMC). Programs not included in this analysis due to uncertainty or missingness in data and/or program efficacy values were as follows: active defaulter tracing, CD4 count tests, routine adherence support, serum Cryptococcal antigen test, urine lipoarabinomannan (LAM) screening for HIV-TB detection, and viral load monitoring (including genotyping).

Six HIV testing service delivery modalities were modeled including: client-initiated testing, index testing, mobile testing, provider-initiated testing and counselling (PITC), recency testing, and self-testing. Outcome functions for each modality were scored according to unit cost and yield. Since mobile and self-testing are conducted outside of fixed health facilities, they were scored lower due to an expected reduced rate for linkage to care, compared with other modalities. The score for mobile testing was reduced by 70% to reflect a 30% linkage to care rate, and by 40% to reflect a 60% linkage to care rate for self-testing.

3. Results

Objective 1: To estimate the optimized annual HIV resource allocation to minimize new HIV infections and HIV-related deaths from 2020 to 2025.

The US\$222M national HIV budget for Malawi was optimized over the 2020 to 2025 National Strategic Plan period to minimize new HIV infections and HIV-related deaths by 2025. Findings from this analysis suggest prioritizing scale up of ART, condom programs, prevention of mother-to-child prevention (PMTCT), voluntary medical male circumcision (VMMC), HIV prevention targeting adolescent girls and young women (AGYW), pre-exposure prophylaxis (PrEP), and HIV prevention and testing programs targeting female sex workers (FSW) (figure 3, table 1). Since there is often a paucity of and/or uncertainty in behavioural data, the full impact of social and behavior change communication programs may not be captured in this analysis. As well, the multi-sector benefit of safety nets (cash transfers) was outside the scope of this analysis, which can at least partly explain why these programs were not identified for prioritization over this period.

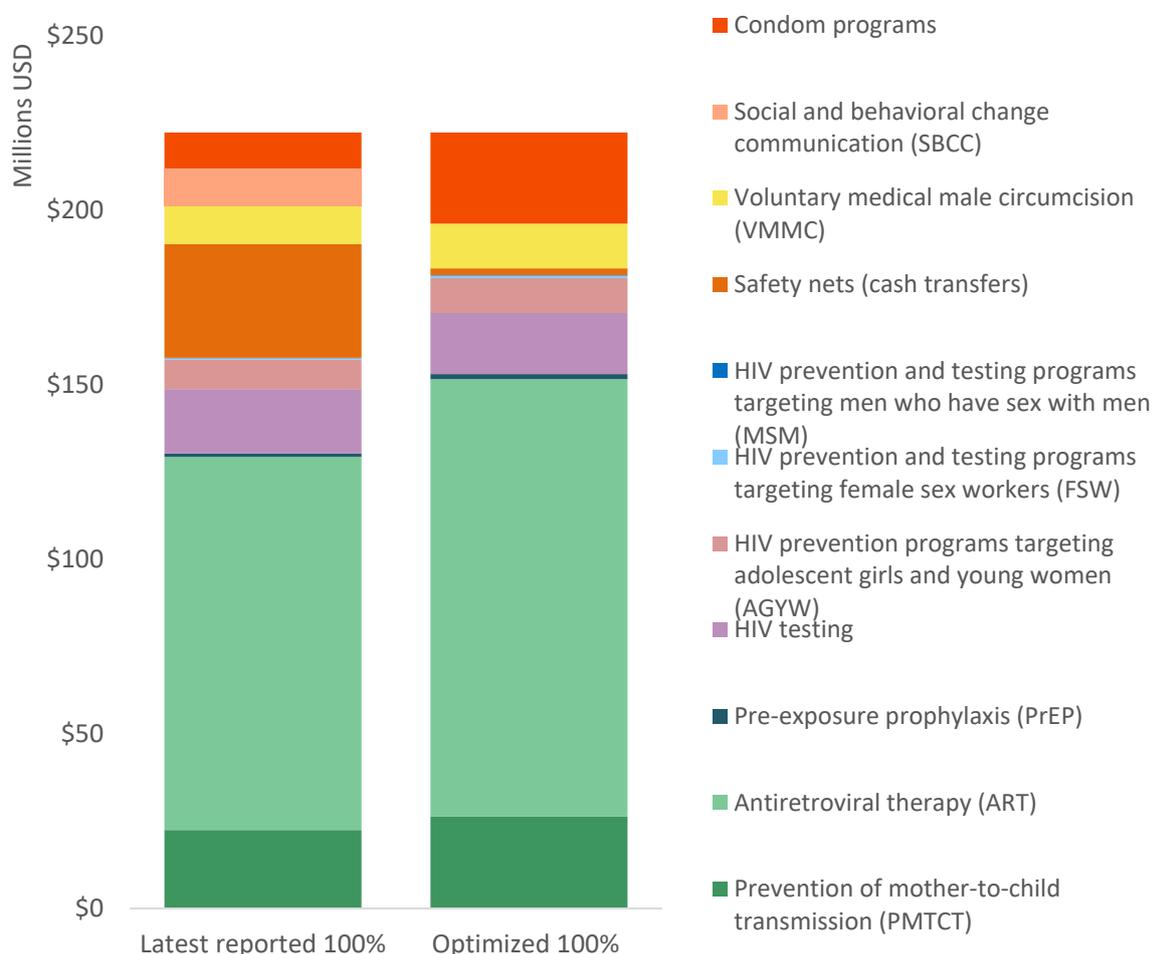


Figure 3: Annual optimized HIV resource allocation for 2020 to 2025

With the same amount of budget, optimized reallocation could result in an additional 37,000 new HIV infections being averted (over 20% more) and 2,000 HIV-related deaths (approximate 5% more) by 2025 (figure 3). Estimates of HIV program spending and coverage under optimized budget are shown alongside those from the latest reported allocation in table 1.

Table 1: Optimized annual HIV budget for 2020 to 2025

HIV program	100% latest reported budget (USD)	100% optimized budget (USD)	100% latest reported coverage	100% optimized coverage
Condom programs	\$10,300,000	\$26,000,000	8,400,000	11,900,000
Social and behavior change communication (SBCC)	\$10,800,000	Not prioritized	7,700,000	Not prioritized
Voluntary medical male circumcision (VMMC)	\$10,800,000	\$12,800,000	90,000	110,000
Safety nets (cash transfers)	\$32,600,000	\$2,000,000	290,000	17,500
Men who have sex with men (MSM) programs	\$140,000	\$150,000	1,600	1,700
Female sex worker (FSW) programs	\$290,000	\$650,000	3,300	7,200
Adolescent girls and young women programs (AGYW)	\$8,500,000	\$10,000,000	90,000	110,000
HIV testing	\$18,400,000	\$17,500,000	2,900,000	3,700,000
Pre-exposure prophylaxis (PrEP) for FSW and MSM	\$1,000,000	\$1,500,000	8,200	11,000
Antiretroviral therapy (ART)	\$107,000,000	\$125,000,000	860,000	1,000,000
Prevention of mother-to-child transmission (PMTCT)	\$22,500,000	\$26,300,000	116,000	136,000
Total	\$222,300,000	\$222,300,000	Not applicable	Not applicable

Objective 2: To estimate the optimized annual HIV resource allocation to minimize new HIV infections and HIV-related deaths from 2020 to 2025 and from 2020 to 2035 under varying budget levels. Using the HIV testing budget from the original optimization for 2020 to 2025, determine how funding should be optimized across HIV testing modalities over this period.

At reduced budget levels, condom programs, ART, and PMTCT should be retained as priority programs (figure 4). Should additional funds become available above the latest reported budget level, it is recommended to scale-up ART, PMTCT, condom programs, HIV testing services (prioritize ahead of condom programs above 150% optimized budget), VMMC, AGYW programs, PrEP, and FSW programs.

The impact of varying budget allocations is illustrated in figure 5. At 100% budget, new HIV infections and HIV-related deaths could be markedly reduced by cost-effectively reinvesting resources; however, as budget levels continue to increase over 200%, the potential reduction of new HIV infections and HIV-related deaths decreases, with smaller gains anticipated.

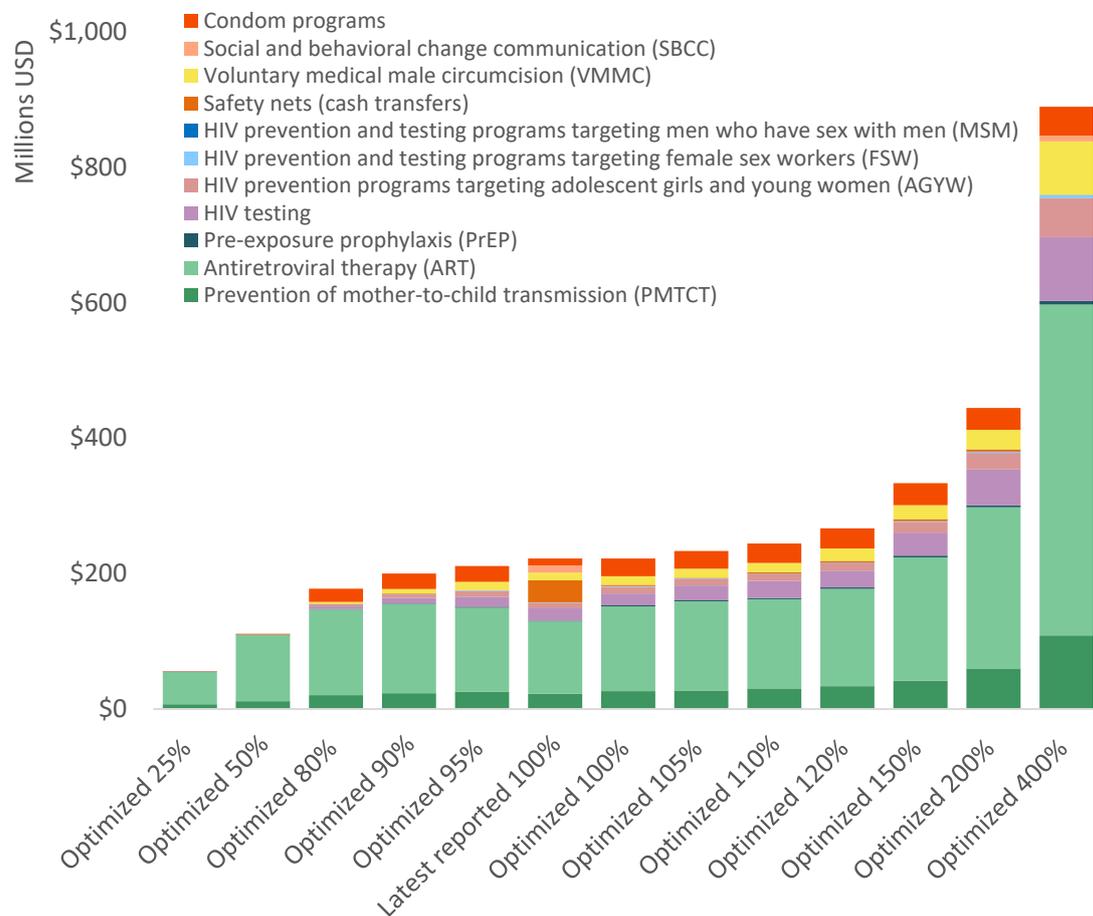


Figure 4: Annual HIV budget optimization for varying budget levels, 2020 to 2025

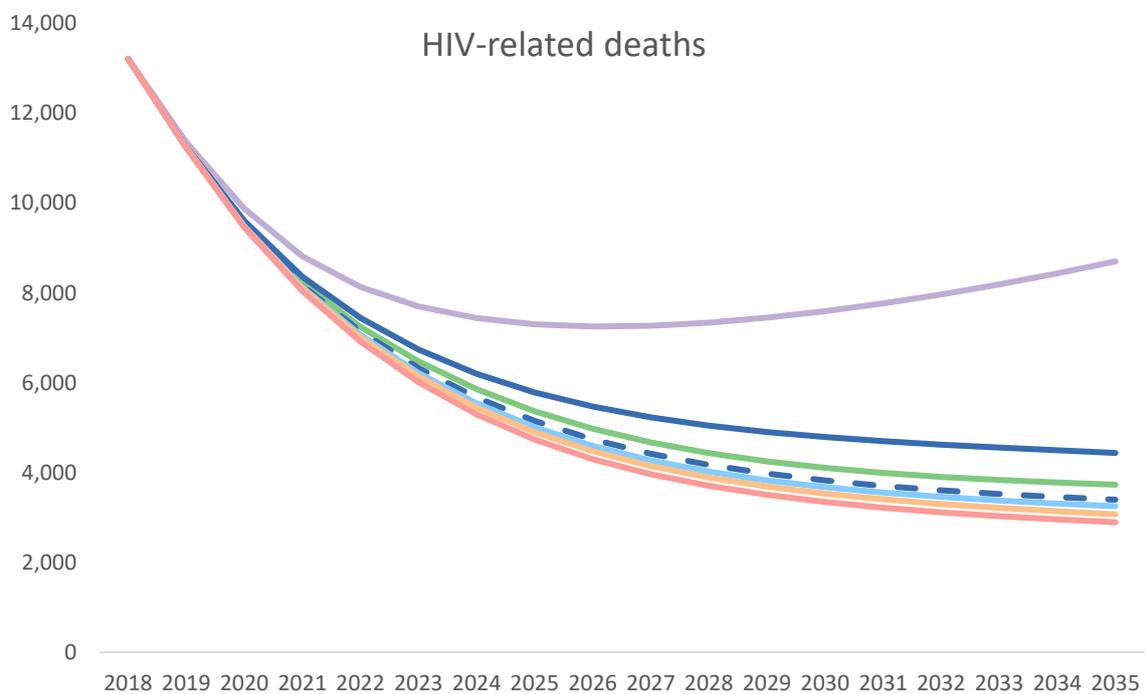
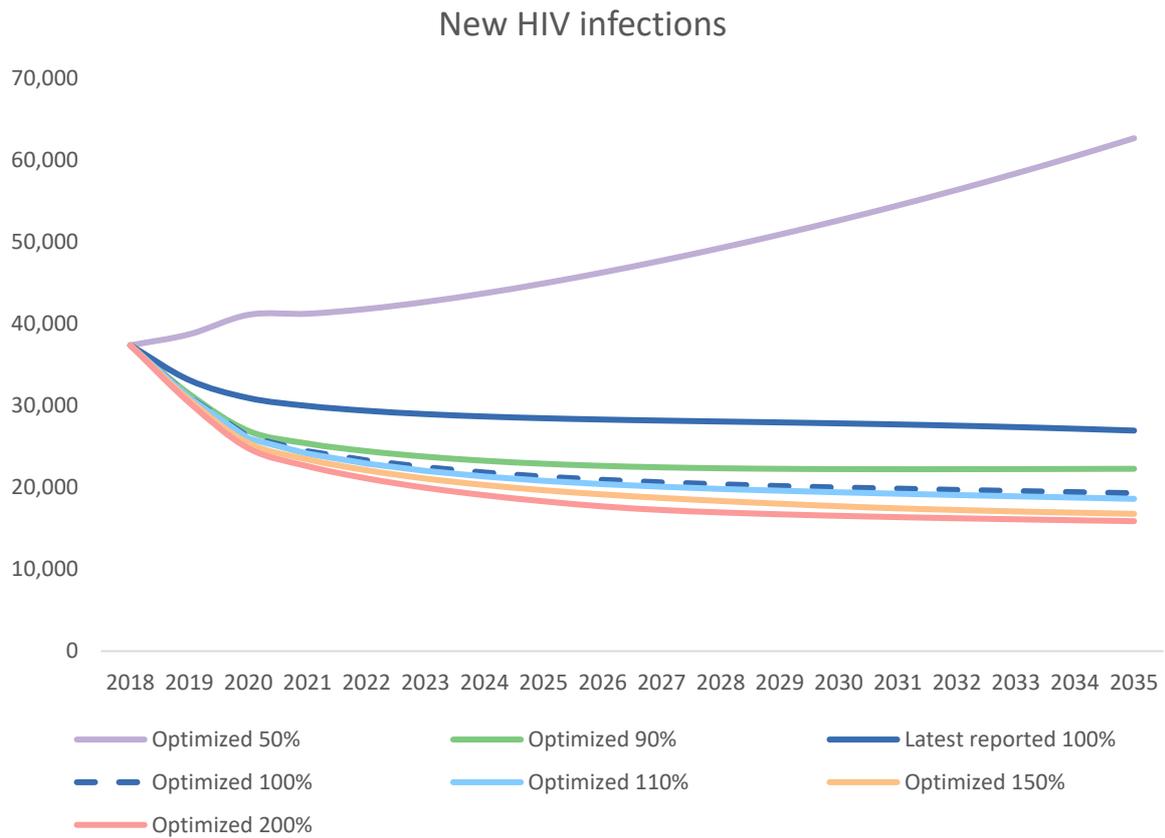


Figure 5: Impact of optimization for varying HIV budget levels from 2020 to 2025 on new HIV infections and HIV-related deaths projected to 2035

Figure 6 and table 2 illustrate allocation of the HIV testing budget from the original optimization across six HIV testing service delivery modalities. The total invested in the six HIV testing modalities was

US\$18.4M within the latest reported budget. With optimization of this total HIV program budget for Malawi, the HIV testing program was allocated slightly less, at US\$17.5M, to allow for treatment and other prevention programs to be prioritized at this budget level. Recommendations to optimize allocation of this \$17.5M across the six HIV testing modalities, include prioritizing index testing, provider-initiated testing, and client-initiated testing (figure 6 and table 2). This is based on unit cost, yield (excluding for recency testing), and assumed linkage to care by testing modality (Appendix 3). If the national budget were to be increased and the resulting optimized allocation for overall HIV testing to be cost-effectively distributed across testing modalities, index testing would still be prioritized, but depending on the budget level, self-testing, client-initiated testing, and provider-initiated testing are recommended to be scaled-up in different priority order.

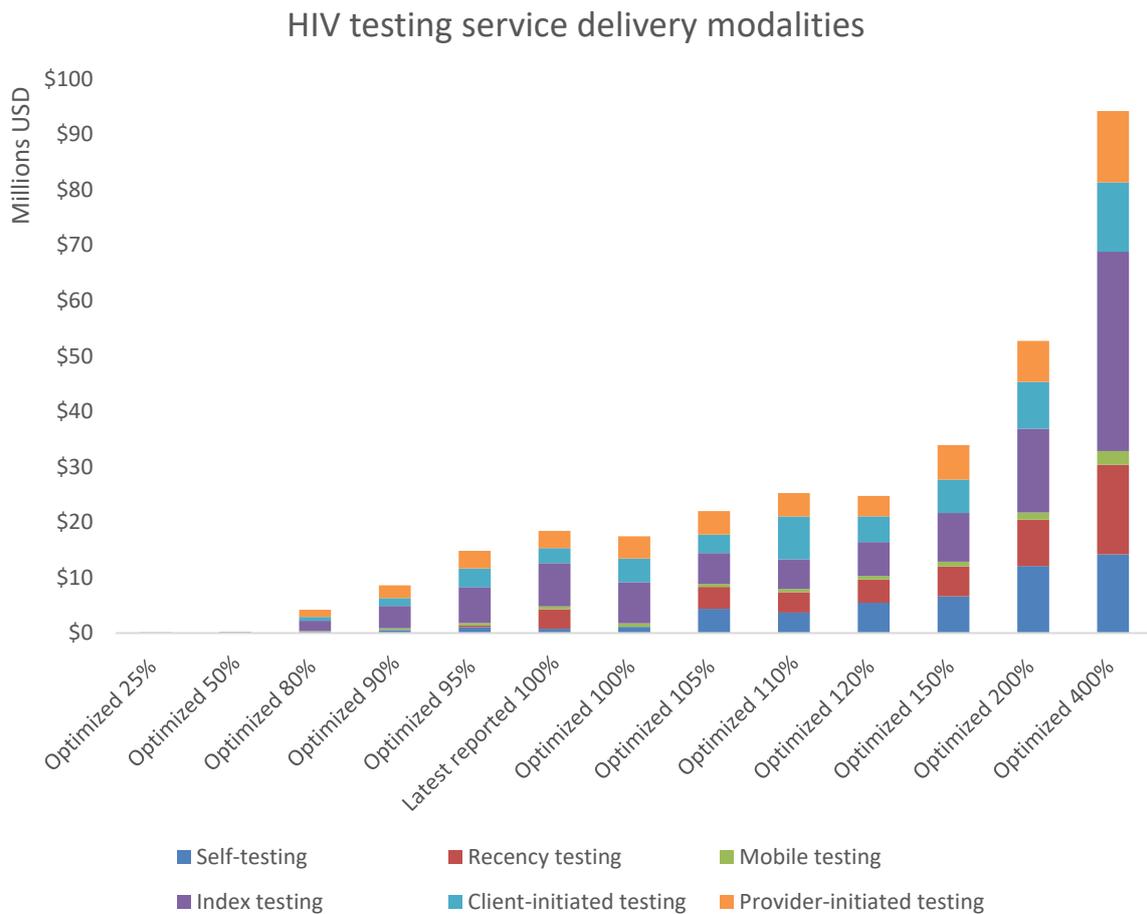


Figure 6: Optimization of HIV testing budget from optimized overall budget at varying budget levels across the HIV testing modalities from 2020 to 2025

Table 2: Testing modality percentage of total HIV testing budget

HIV testing modality	Optimized 50%	Optimized 80%	Optimized 90%	Optimized 95%	Latest reported 100%	Optimized 100%	Optimized 105%	Optimized 110%	Optimized 120%	Optimized 150%	Optimized 200%	Optimized 400%
Self-testing	2%	5%	6%	7%	4%	6%	20%	15%	22%	20%	23%	15%
Recency testing	16%	0%	0%	2%	19%	0%	18%	15%	17%	16%	16%	17%
Mobile testing	4%	3%	4%	3%	3%	4%	3%	2%	3%	2%	2%	3%
Index testing	45%	44%	47%	44%	42%	43%	25%	21%	25%	26%	29%	38%
Client-initiated testing	12%	17%	16%	23%	15%	24%	15%	31%	19%	18%	16%	13%
Provider-initiated testing	20%	31%	27%	21%	17%	23%	19%	17%	15%	18%	14%	14%
Total testing budget	\$243,719	\$4,215,627	\$8,607,238	\$14,834,914	\$18,441,136	\$17,464,499	\$22,024,987	\$25,259,381	\$24,766,261	\$33,924,570	\$52,745,488	\$94,224,538

Objective 3: To estimate the budget necessary to achieve 2020-2025 NSP targets

For the 2020-2025 National Strategic Plan (NSP) period, annual coverage targets for 2021 to 2025 for condom programs, VMMC, FSW programs, MSM programs, HIV testing, HIV prevention programs for AGYW, PrEP for FSW and MSM, and ART were used (table 3) to estimate the additional budget and allocation to achieve these targets. For 2020, coverage levels from the latest reported budget were used. The NSP target for PrEP included coverage of AGYW; however, PrEP was not specified as targeting AGYW in the model, therefore only budget requirements to reach FSW and MSM PrEP coverage targets were included. NSP targets for AGYW included covering a certain number of high-risk adolescent girls and young women aged 15-24 years (defined as the portion of AGYW with HIV prevalence greater than or equal to 3%), as well as a certain number of AGYW at low-risk (those having a prevalence of HIV below 3%). Since the AGYW population was not originally specified in the Optima model by risk or HIV prevalence level, the total targeted coverage for this group was used. Since no targets are set in the 2020-2025 NSP for social behaviour change communication (SBCC), safety nets (cash transfers), and prevention of mother-to-child transmission (PMTCT), optimized coverage levels and allocation generated from objective 1 of this study were applied for these three programs from 2021 to 2025.

Table 3: 2020-2025 NSP coverage targets for 2021 to 2025

HIV program	Latest reported coverage	NSP coverage targets				
	2020	2021	2022	2023	2024	2025
Condom programs (people covered)	10,066,140	10,183,153	10,483,160	10,792,264	10,798,539	11,117,670
VMMC	90,141	150,000	200,000	190,000	180,000	180,000
HIV prevention and testing for FSW	3,272	23,467	27,268	31,686	36,819	42,783
HIV prevention and testing for MSM	1,566	5,248	5,835	6,489	7,216	8,024
HIV prevention for AGYW*	89,855	122,400	153,700	170,040	189,280	208,800
HIV testing (people tested)	2,964,986	5,518,749	5,995,362	6,462,406	6,919,100	7,364,618
PrEP for FSW and MSM	8,267	2,000	2,600	3,914	3,914	3,914

ART	862,582	941,578	967,770	987,979	1,003,174	1,015,291
No targets are set in the NSP for the following programs, optimized coverage levels were applied from 2021 to 2025						
SBCC	8,707,527	0	0	0	0	0
Safety nets (cash transfers)	289,749	17,000	17,000	17,000	17,000	17,000
PMTCT	116,209	136,000	136,000	136,000	136,000	136,000

*Sum of coverage targets for high-risk AGYW (HIV prevalence $\geq 3\%$) and lower-risk AGYW (HIV prevalence $< 3\%$)

Figure 7 illustrates the estimated annual budget requirements for 2021 to 2025. In 2021 the budget is increased by approximately \$2M and increased each year until 2025 to achieve increasing coverage targets. Increasing or decreasing coverage levels, and thus budgets, for SBCC, safety nets, and PMTCT, for which no targets were set so optimized budgets were applied, would have an impact on the infections and deaths that could be averted.

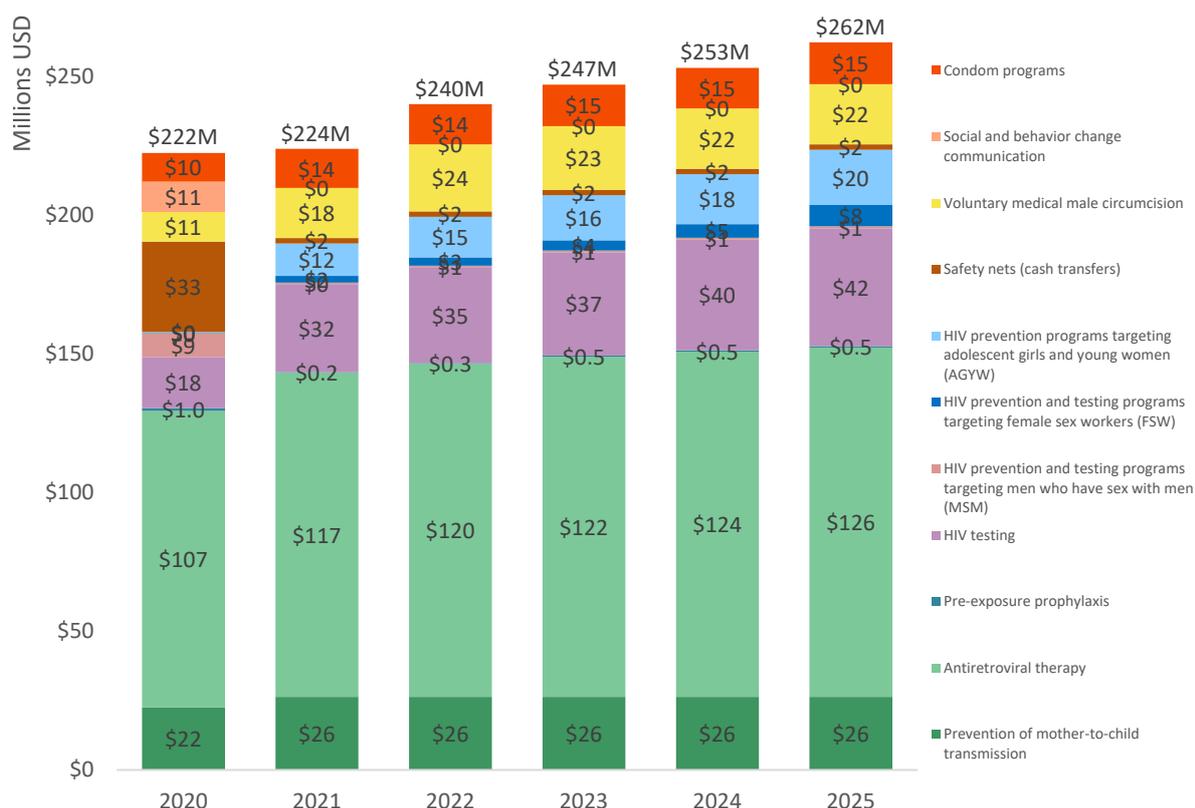


Figure 7: Annual budget levels and allocations to achieve 2020-2025 NSP coverage targets for 2021 to 2025, with the latest reported budget allocation applied for 2020, and the optimized budget for SBCC, safety nets, and PMTCT applied for 2021 to 2025 as no targets are set for these three programs

The potential impact of these reallocations with increased annual budgets to achieve 2020-2025 NSP coverage targets for 2021 to 2025 is illustrated in figure 8. With an additional US\$114M over the latest reported budget to achieve 2021-2025 NSP coverage targets, over 21,000 more new HIV infections

(approximately 15% more) and approximately 1,600 HIV-related deaths (approximately 5% more) could be averted by 2025.

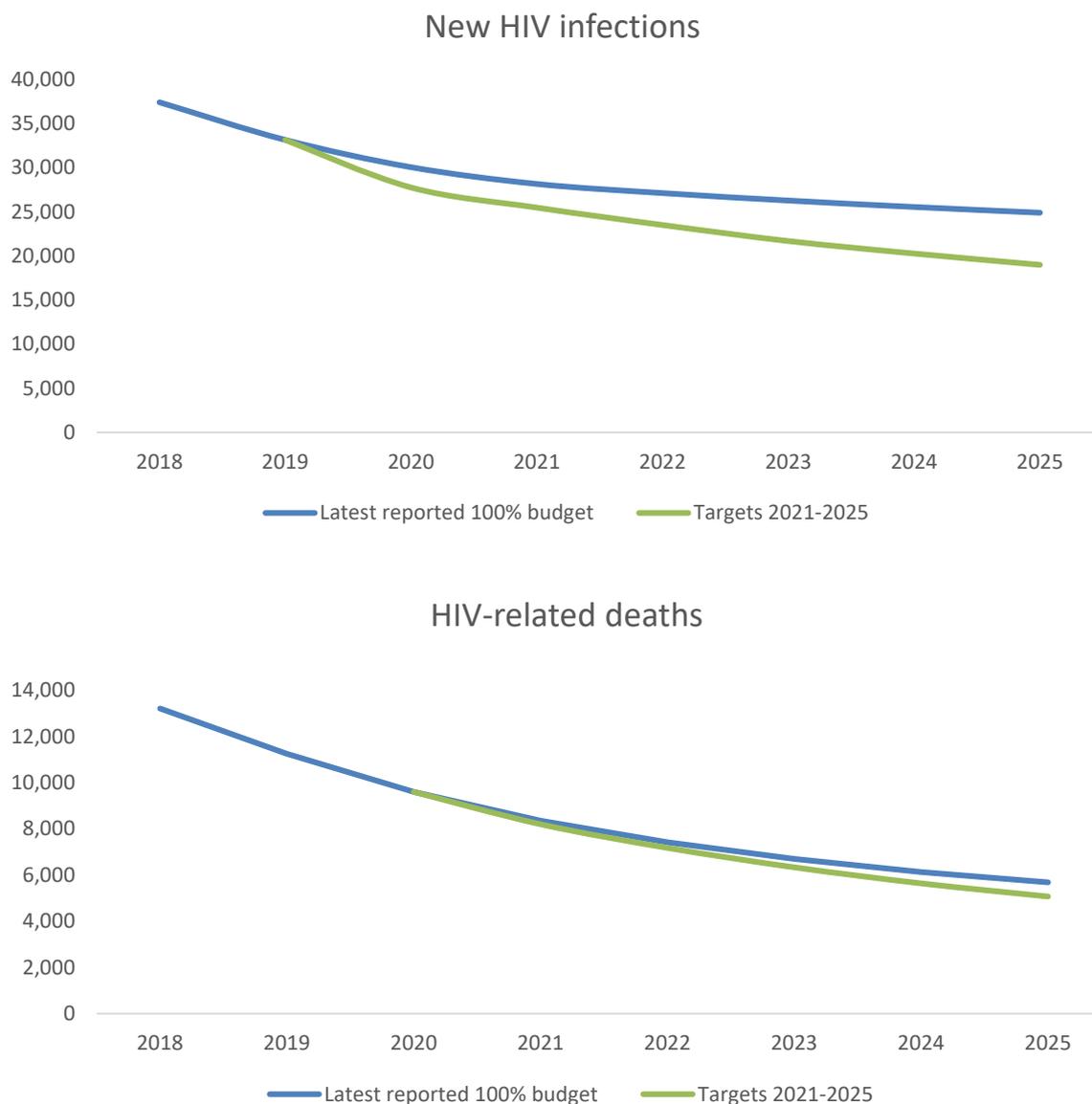


Figure 8: Estimated impact of achieving 2021-2025 NSP coverage targets through to 2025

Objective 4: To estimate the optimized annual HIV resource allocation across the 32 districts

For this objective, the HIV budget was optimally redistributed across the 32 districts (28 districts and 4 cities) to minimized new HIV infections and HIV-related deaths by 2025.

HIV prevalence by region

Across the 28 districts and 4 cities in Malawi, 2019 HIV prevalence estimates for all age groups varied from 1.7% in Ntchisi to 12% in Blantyre City. It was estimated that there were less than 1,000 people living with HIV (PLHIV) in Likoma district in 2019, while for Blantyre City it was almost 100,000. Estimates of HIV prevalence and PLHIV by district and city for 2019 are listed in appendix 4.

Figure 9 shows the ranked order of districts for redistributed HIV funds and the annual optimization of those funds from 2020 to 2025. The top five districts by amount of funding to be redistributed, are

Mangochi, Lilongwe City, Blantyre City, Zomba, and Mulanje. For these districts it is recommended to scale-up investment by ordered priority in treatment, VMMC, condom programs, and HIV testing, prevention programs targeting female sex workers, and PrEP. In districts with higher prevalence of HIV, reallocating funds towards VMMC and condom programs is recommended. Geographical optimal allocation of funds could result in an additional 45,000 new HIV infections and 3,300 HIV-related deaths averted, therefore increasing the potential impact compared to the national optimization. Appendix 5 lists estimated spending and coverage by district.

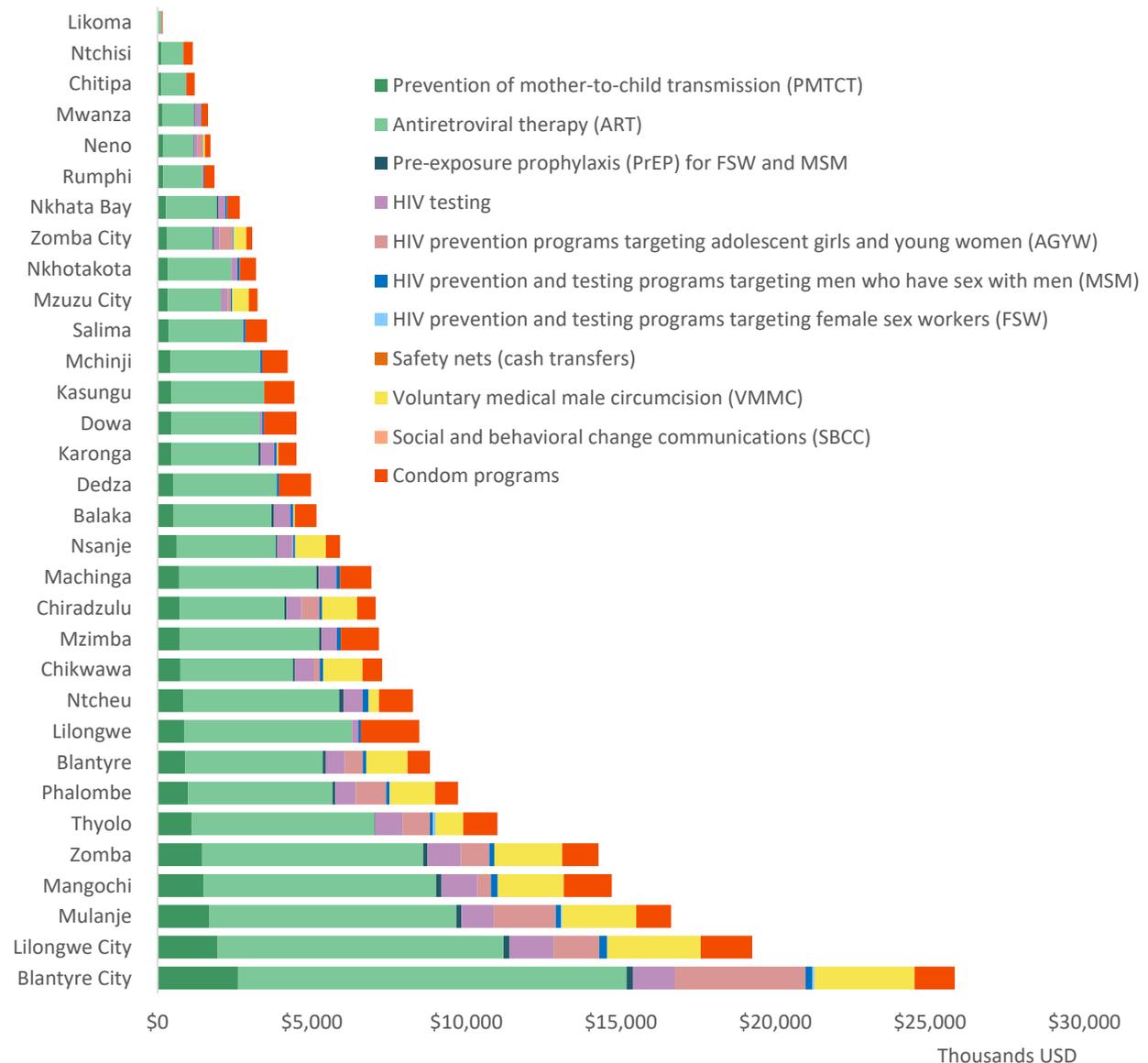


Figure 9: Optimized re-distribution of annual HIV resources across 32 regions, 2020 to 2025

4. Model limitations

As with any modelling study, there are limitations in this analysis. The following key limitations should be considered when interpreting results and recommendations. First, limitations in data availability

and reliability can lead to uncertainty around projected results. Although the model optimization algorithm accounts for inherent uncertainty, it might not be possible to account for all aspects of uncertainty because of poor quality or insufficient data, particularly for key cost values that inform cost functions. Coupled with epidemic burden, cost functions are a primary factor in modeling optimized resource allocations. For the district-level analysis, since HIV prevalence estimates are not available for each key population for every district, this analysis was informed using overall HIV prevalence and numbers of people living with HIV (PLHIV) per district for the latest reported years. HIV prevalence values by population were then derived using overall district prevalence and PLHIV. HIV Program cost and coverage values were also not available by district, so baseline spending by program we derived based on national level and derived population prevalence values. Second, we used context-specific values and expert opinion where available, otherwise evidence from systematic reviews of clinical and research studies were used to inform model assumptions. Third, the HIV testing modality analysis was informed by unit cost, yield (not applicable for recency testing), and assumed linkage to care by modality. Finally, these findings are only modeled projections and have not been confirmed in a practical setting in Malawi. The country model used in this study has been calibrated to reflect country- and UNAIDS-endorsed epidemiological estimates, but validation of results suggesting optimized reallocations will lead to minimization of infections and deaths in real-world practice has not been done. Shifting resources following evidence from this study will not always be feasible and may not necessarily be politically favourable but should be considered if there is the will to make a greater impact.

5. Conclusions

If the latest reported HIV budget is optimized from 2020 to 2025 by scaling-up investment in priority order of antiretroviral therapy (ART), condom programs, prevention of mother-to-child prevention, voluntary medical male circumcision (VMMC), HIV prevention targeting adolescent girls and young women (AGYW), pre-exposure prophylaxis, and HIV prevention and testing programs targeting female sex workers (FSW), more new HIV infections and HIV-related deaths can be averted. Within the HIV testing optimized budget, it is recommended to prioritize index, provider-initiated, and client-initiated testing. With increasing budget, investment in these seven programs should be proportionately increased. If the budget is optimized over a longer time period from 2020 to 2035, it is recommended to scale-up ART, condoms, PMTCT, VMMC, and HIV prevention and testing programs for FSW. It is also estimated that an additional \$114M will be required to achieve the 2020-2025 NSP coverage targets over the NSP period. However, it was modeling that more infections and deaths could be averted if the latest reported budget were optimized, rather than increasing the budget to meet set NSP coverage targets.

Optimization of HIV resources across the 28 districts and four cities in Malawi, considering burden by district, suggests shifting funds towards five districts with the highest HIV burden (Blantyre City, Lilongwe City, Mulanje, Mangochi, and Zomba) and prioritizing towards the highest-impact interventions, including those listed for national optimization, but including HIV prevention and testing for men who have sex with men rather than for FSWs. If geographical epidemic profiles are considered for prioritizing resources, then even more infections and deaths could be averted by 2025.

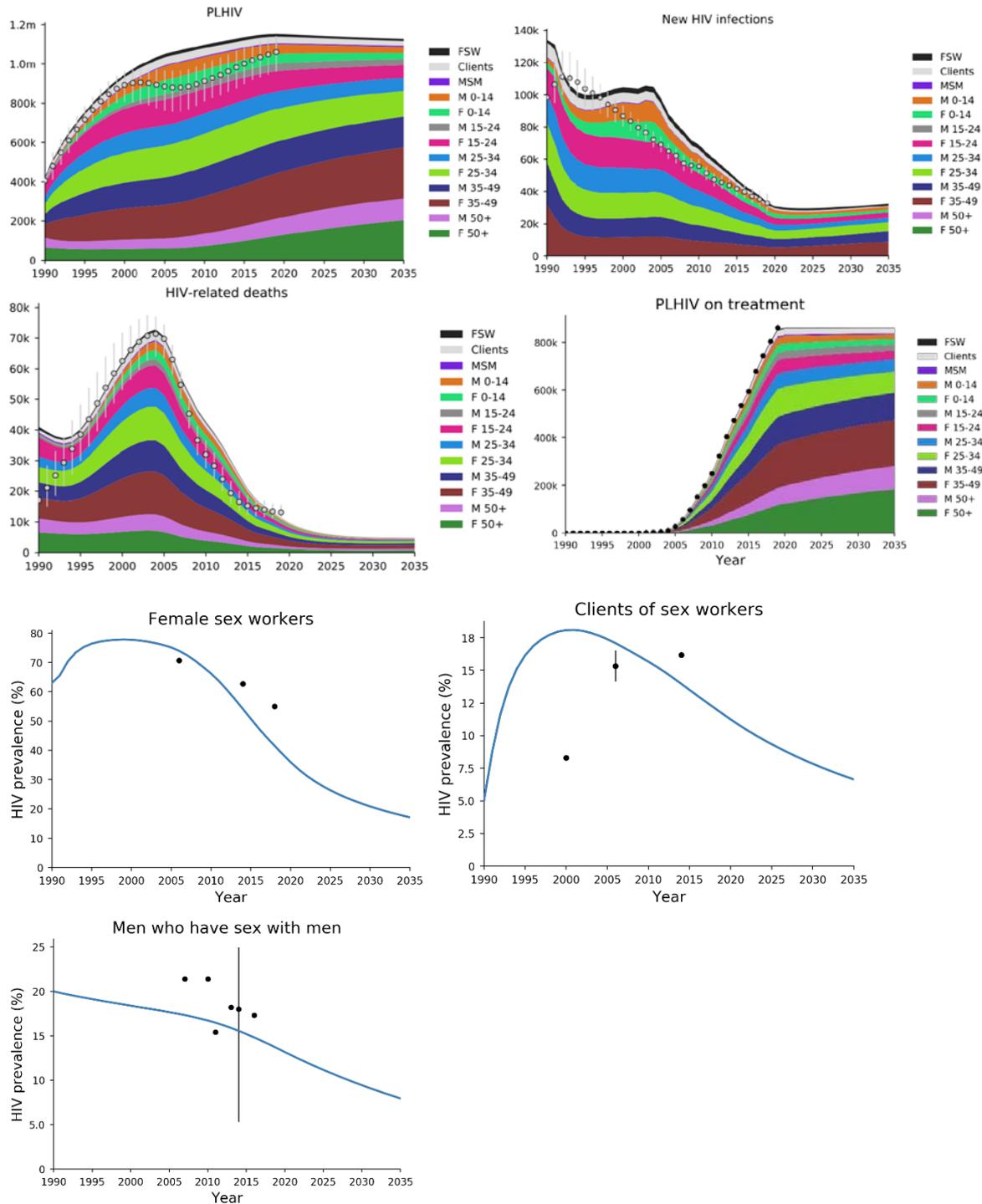
References

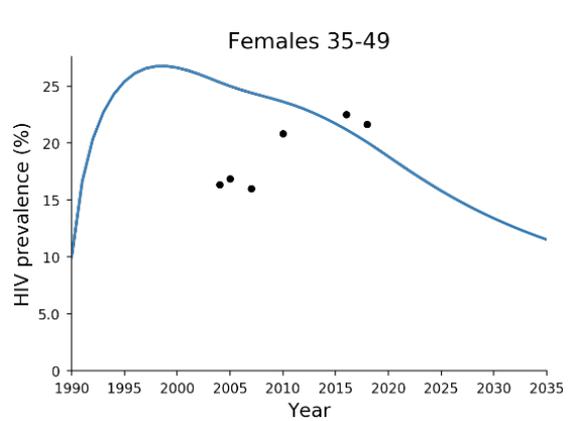
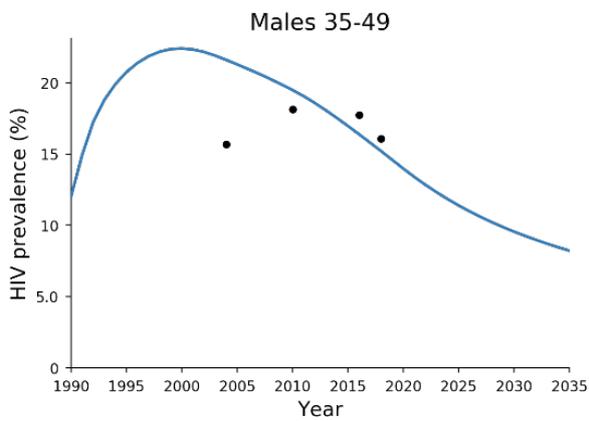
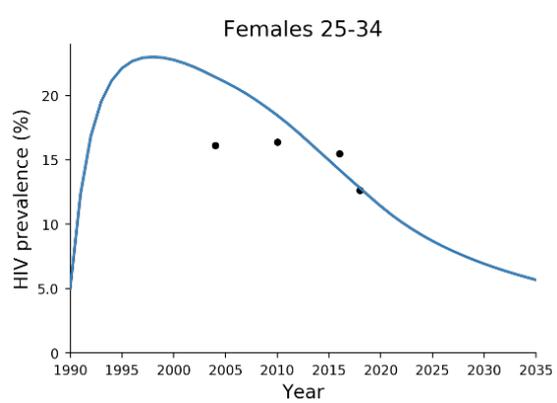
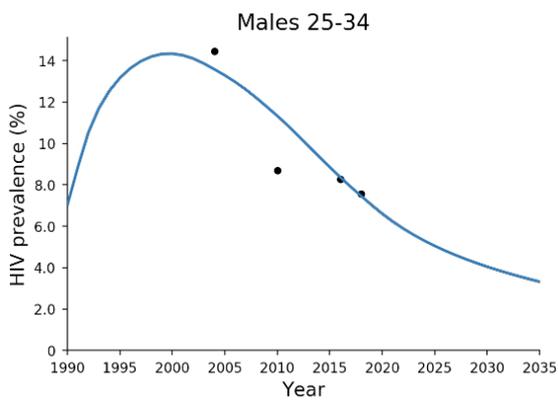
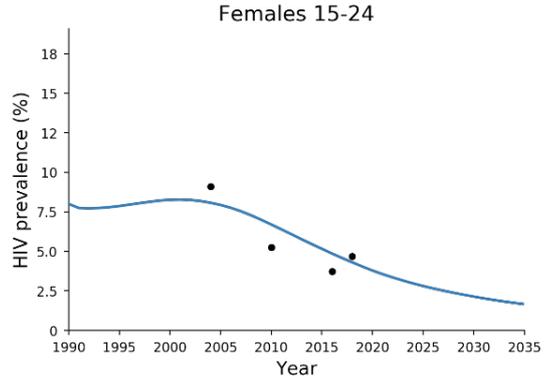
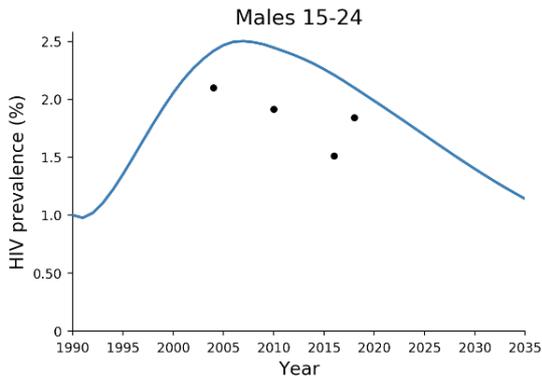
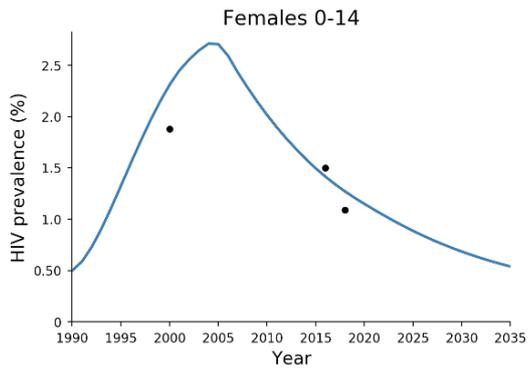
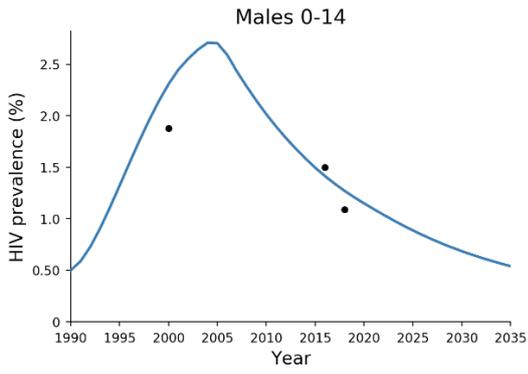
1. The World Bank Group. Malawi - Overview 2019 [Available from: <https://www.worldbank.org/en/country/malawi/overview>].
2. UNAIDS. Financial Dashboard - Malawi Geneva2018 [Available from: <http://hivfinancial.unaids.org/hivfinancialdashboards.html#>].
3. Kates J, Wexler A, Foundation KF, Lief E, UNAIDS. Donor government funding for HIV in low- and middle-income countries in 2017. Menlo Park: Kaiser Family Foundation; 2018.
4. Wang H, Abajobir AA, Abate KH, Abbafati C, Abbas KM, Abd-Allah F, et al. Global, regional, and national under-5 mortality, adult mortality, age-specific mortality, and life expectancy, a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet*. 2017;390(10100):1084-150.

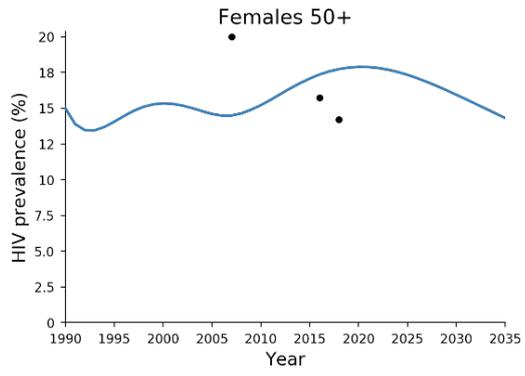
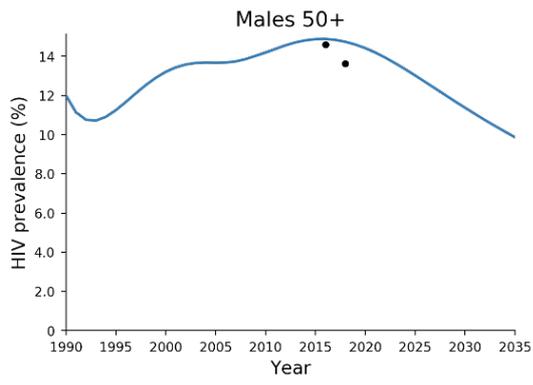
Appendices

Appendix 1: Model calibration and cost coverage curves

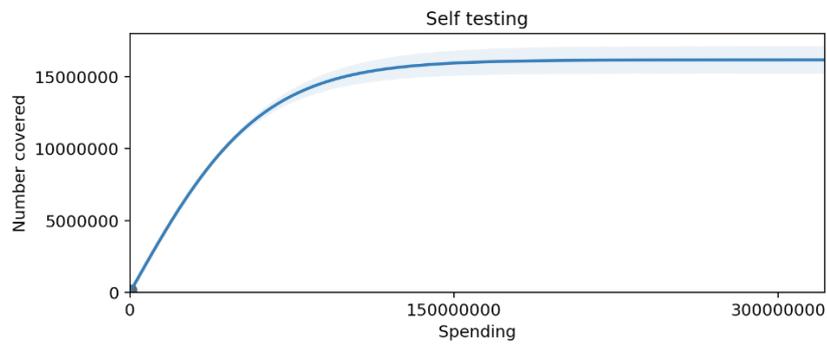
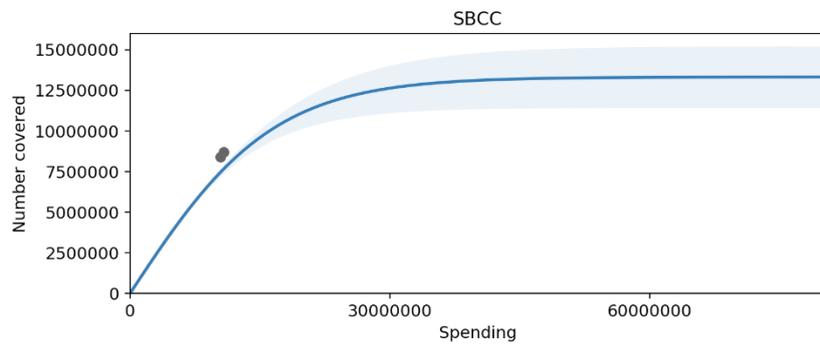
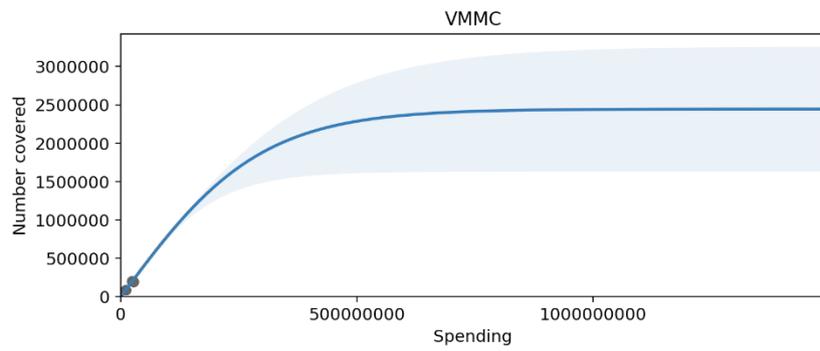
Model calibration

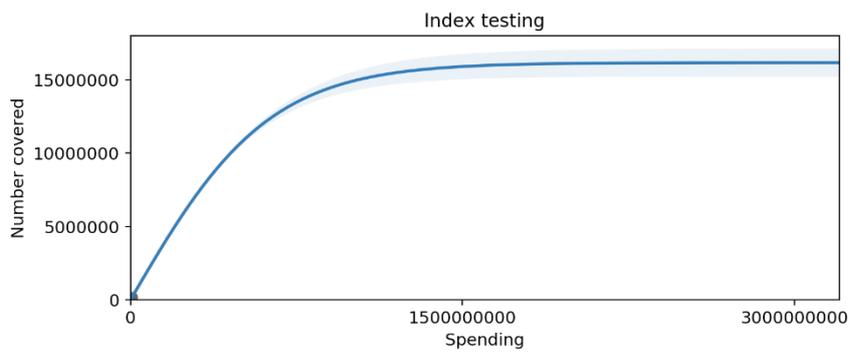
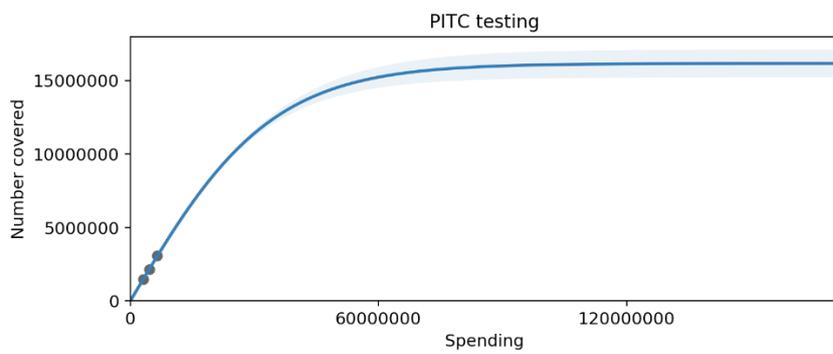
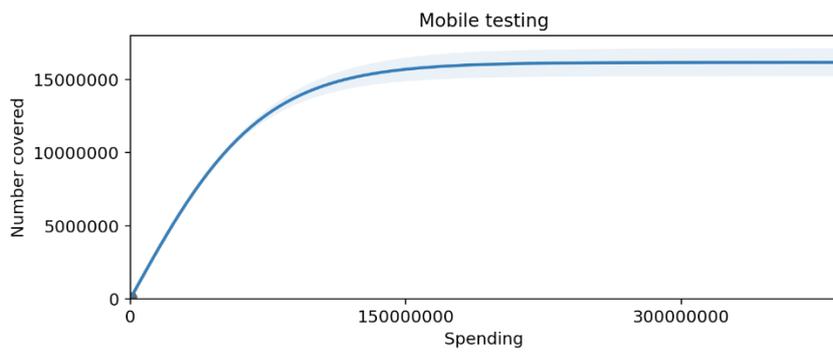
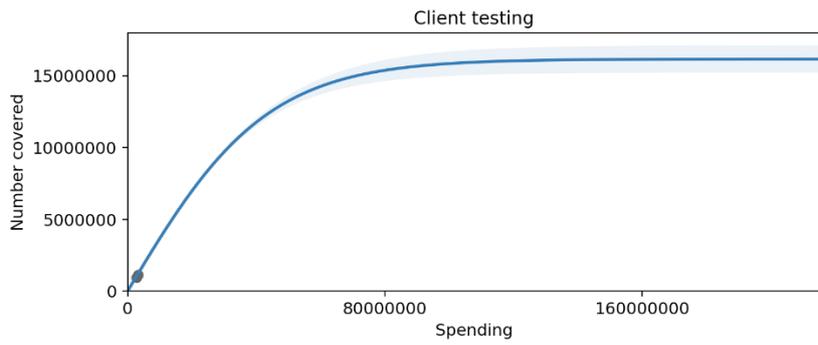
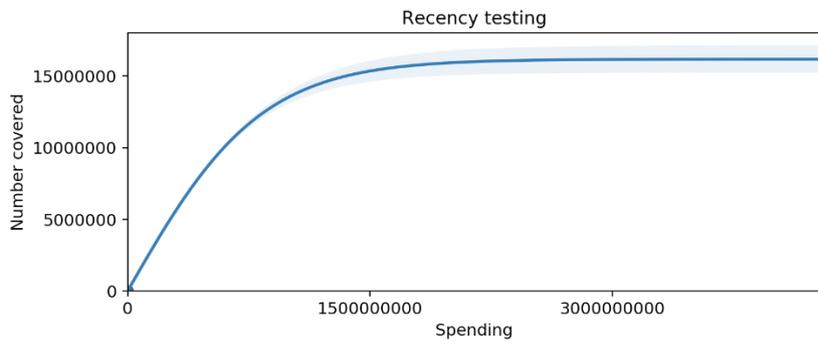


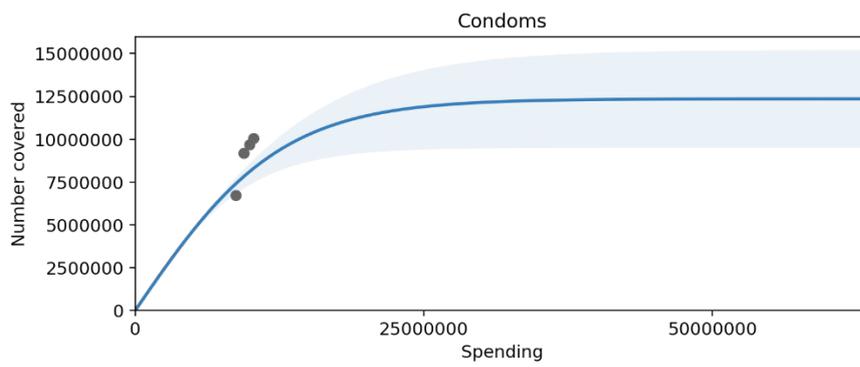
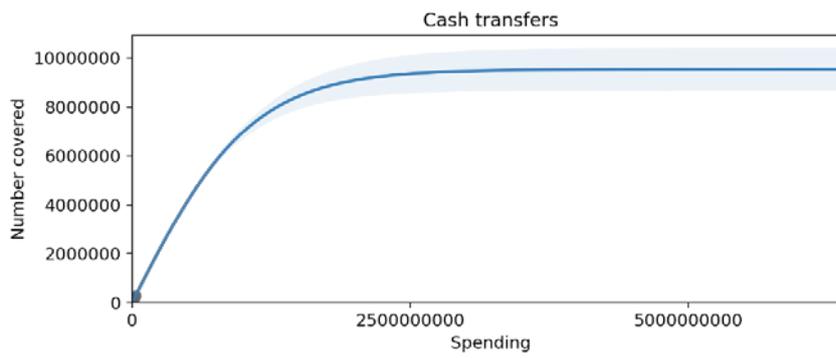
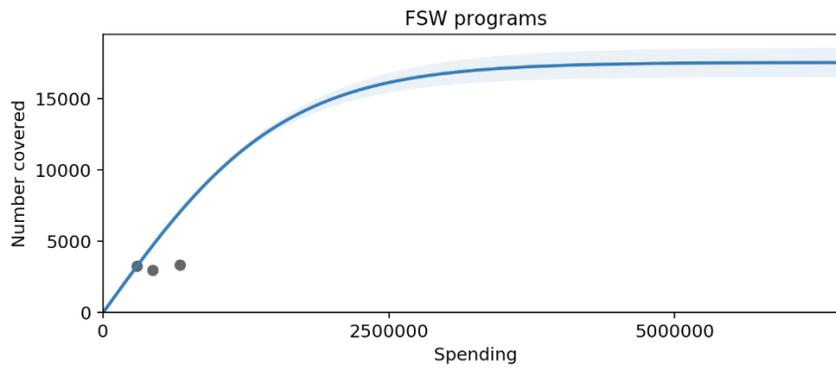
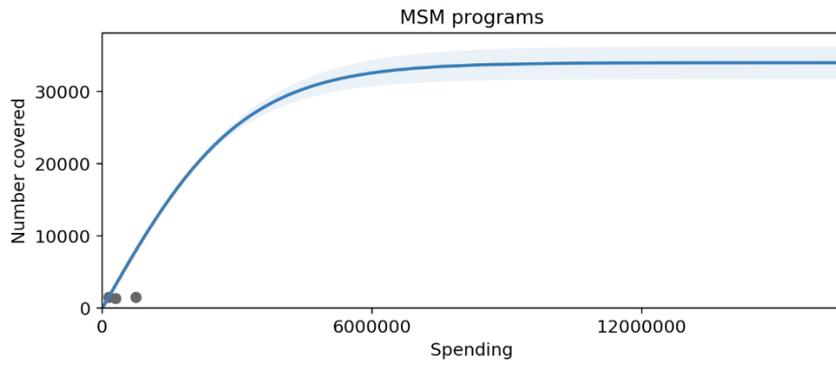


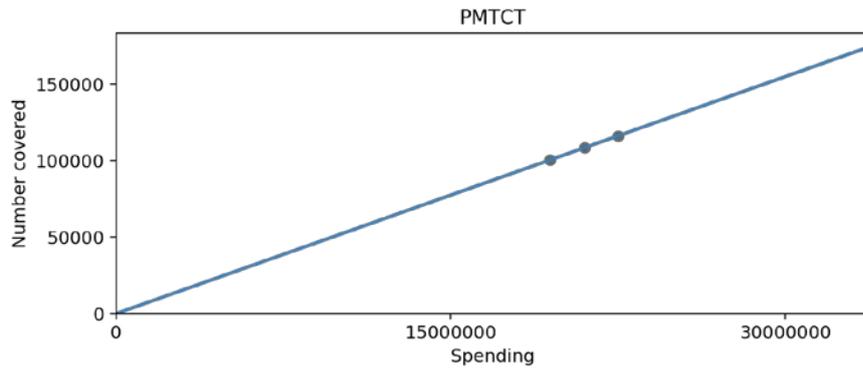
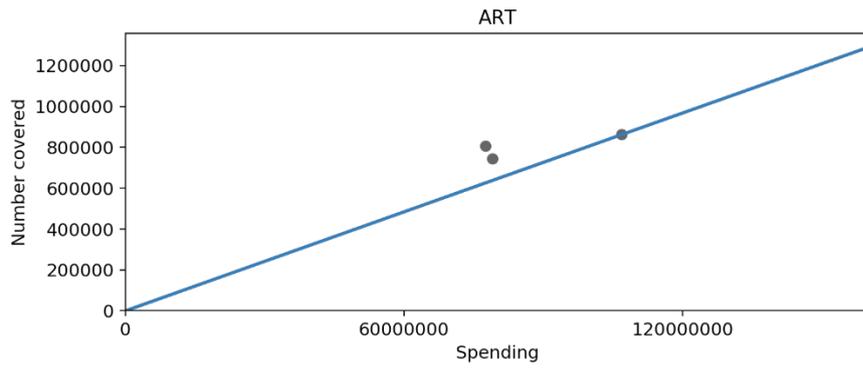


Cost coverage curves









Appendix 2: Key model parameters

Interaction-related transmissibility (% per act)	
Insertive penile-vaginal intercourse	0.04%
Receptive penile-vaginal intercourse	0.08%
Insertive penile-anal intercourse	0.09%
Receptive penile-anal intercourse	1.38%
Intravenous injection	0.80%
Mother-to-child (breastfeeding)	36.70%
Mother-to-child (non-breastfeeding)	20.50%
Relative disease-related transmissibility	
Acute infection	5.60
CD4(>500)	1.00
CD4(500) to CD4(350-500)	1.00
CD4(200-350)	1.00
CD4(50-200)	3.49
CD4(<50)	7.17
Disease progression (average years to move)	
Acute to CD4(>500)	0.24
CD4(500) to CD4(350-500)	0.96
CD4(350-500) to CD4(200-350)	3.00
CD4(200-350) to CD4(50-200)	3.74
CD4(50-200) to CD4(<50)	1.50
Changes in transmissibility (%)	
Condom use	95%
Circumcision	58%
Diagnosis behavior change	0%
STI cofactor increase	265%
Opiate substitution therapy	54%
PMTCT	90%
Pre-exposure prophylaxis	73%
Unsuppressive ART	30%
Suppressive ART	92%
Disutility weights	
Untreated HIV, acute	0.15
Untreated HIV, CD4(>500)	0.01
Untreated HIV, CD4(350-500)	0.02
Untreated HIV, CD4(200-350)	0.07
Untreated HIV, CD4(50-200)	0.27
Untreated HIV, CD4(<50)	0.55
Treated HIV	0.05
Treatment recovery due to suppressive ART (average years to move)	
CD4(350-500) to CD4(>500)	2.20
CD4(200-350) to CD4(350-500)	1.42
CD4(50-200) to CD4(200-350)	2.14
CD4(<50) to CD4(50-200)	0.66
Time after initiating ART to achieve viral suppression (years)	0.20
Number of VL tests recommended per person per year	1.00

CD4 change due to non-suppressive ART (%/year)	
CD4(500) to CD4(350-500)	2.60%
CD4(350-500) to CD4(>500)	15.00%
CD4(350-500) to CD4(200-350)	10.00%
CD4(200-350) to CD4(350-500)	5.30%
CD4(200-350) to CD4(50-200)	16.20%
CD4(50-200) to CD4(200-350)	11.70%
CD4(50-200) to CD4(<50)	9.00%
CD4(<50) to CD4(50-200)	11.10%
Death rate (% mortality per year)	
Acute infection	0.36%
CD4(>500)	0.36%
CD4(350-500)	0.58%
CD4(200-350)	0.88%
CD4(50-200)	5.90%
CD4(<50)	43.20%
Relative death rate on suppressive ART	30.00%
Relative death rate on non-suppressive ART	84.17%
Tuberculosis cofactor	217.00%

Appendix 3: HIV program unit costs, 2019

HIV programs	100% latest reported budget (USD)	100% latest reported coverage	Unit cost (USD)		
Adolescent girls and young women (AGYW) programs	\$8,517,740	89,855	\$94.79		
Antiretroviral therapy (ART)	\$106,859,061	862,582	\$123.88		
Condom programs	\$9,558,251	10,066,140	\$1.02		
HIV prevention and testing programs targeting female sex workers (FSW)	\$239,940	3,272	\$89.84		
HIV prevention and testing programs targeting men who have sex with men (MSM)	\$143,675	1,566	\$91.74		
Pre-exposure prophylaxis (PrEP)	\$1,016,400	8,400	\$121.00*		
Prevention of mother-to-child transmission (PMTCT)	\$22,498,118	116,209	\$193.60		
Safety nets (cash transfers)	\$32,601,709	289,749	\$112.30		
Social and behavioral change communication (SBCC)	\$10,809,565	8,707,527	\$1.24		
Voluntary medical male circumcision (VMMC)	\$32,601,709	289,749	\$112.30		
HIV testing modalities	100% latest reported budget (USD)	100% latest reported coverage	Unit cost (USD)	Yield	Assumed linkage to care
Self-testing	\$783,675	209,539	\$3.74	5.30%	60%
Recency testing	\$691,187	13,490	\$51.24	NA	100%
Mobile testing	\$516,213	117,055	\$4.41	3.70%	30%
Index testing	\$7,413,154	191,406	\$38.73	6.50%	100%
Client-initiated testing	\$2,574,826	960,756	\$2.68	2.70%	100%
Provider initiated testing	\$3,100,506	1,472,740	\$2.11	1.80%	100%
<i>Total HIV testing</i>	<i>\$15,079,561</i>	<i>NA</i>	<i>NA</i>	<i>NA</i>	<i>NA</i>

*For 2020

Appendix 4: Optimized spending and coverage per district

Estimates for HIV prevalence and people living with HIV (PLHIV) for all ages by district or city, 2019

District	HIV prevalence	PLHIV
Balaka	6.0%	27,703
Blantyre	7.9%	38,010
Blantyre City	11.0%	96,327
Chikwawa	6.5%	38,819
Chiradzulu	8.4%	31,826
Chitipa	2.6%	6,173
Dedza	3.1%	26,040
Dowa	2.4%	18,908
Karonga	5.1%	19,419
Kasungu	2.7%	22,712
Likoma	5.5%	847
Lilongwe	2.6%	43,050
Lilongwe City	8.2%	87,694
Machinga	4.6%	35,853
Mangochi	6.3%	76,720
Mchinji	3.6%	21,931
Mulanje	10.1%	75,819
Mwanza	5.1%	7,019
Mzimba	3.9%	35,802
Mzuzu City	7.1%	17,273
Neno	6.4%	9,271
Nkhata Bay	4.7%	13,831
Nkhotakota	4.1%	16,474
Nsanje	8.1%	25,860
Ntcheu	5.2%	35,907
Ntchisi	1.8%	5,627
Phalombe	9.3%	43,636
Rumphi	4.1%	9,584
Salima	3.8%	18,471
Thyolo	7.7%	59,115
Zomba	7.7%	60,768
Zomba City	11.9%	13,768
Total	5.6%	1,040,257

Source: Naomi model, 2020

Annual optimized HIV program budget allocations across districts for 2020 to 2025

Districts	AGYW	ART	Condoms	FSW programs	HIV testing	MSM programs	PMTCT	PrEP	VMMC
Balaka	\$0	\$3,165,923	\$698,889	\$95,367	\$530,518	\$11,627	\$520,114	\$80,644	\$36,319
Blantyre	\$4,229,350	\$12,567,349	\$1,299,528	\$228,333	\$1,347,611	\$64,570	\$2,610,608	\$213,375	\$3,235,491
Blantyre City	\$582,924	\$4,451,114	\$724,022	\$109,523	\$619,446	\$0	\$892,512	\$99,349	\$1,334,357
Chikwawa	\$189,806	\$3,648,426	\$642,319	\$107,789	\$610,106	\$11,524	\$735,693	\$64,263	\$1,259,678
Chiradzulu	\$577,922	\$3,392,181	\$597,120	\$86,327	\$481,412	\$0	\$714,190	\$70,932	\$1,137,046
Chitipa	\$0	\$799,903	\$270,882	\$8,284	\$0	\$0	\$121,499	\$0	\$0
Dedza	\$0	\$3,353,269	\$1,033,361	\$74,835	\$0	\$0	\$502,344	\$0	\$0
Dowa	\$0	\$2,846,193	\$1,052,075	\$53,310	\$87,686	\$0	\$454,805	\$0	\$0
Karonga	\$0	\$2,806,855	\$586,258	\$80,360	\$451,451	\$9,355	\$454,805	\$65,913	\$39,073
Kasungu	\$0	\$3,004,240	\$975,188	\$0	\$0	\$0	\$448,068	\$0	\$0
Likoma	\$0	\$99,835	\$22,939	\$2,570	\$14,861	\$0	\$16,393	\$566	\$4,822
Lilongwe	\$1,484,198	\$9,249,267	\$1,668,471	\$255,517	\$1,414,220	\$4,501	\$1,947,342	\$198,995	\$3,019,765
Lilongwe City	\$0	\$5,432,445	\$1,893,953	\$83,852	\$204,576	\$0	\$857,400	\$0	\$0
Machinga	\$0	\$4,434,433	\$1,016,779	\$114,106	\$575,904	\$789	\$700,201	\$76,688	\$0
Mangochi	\$431,816	\$7,525,265	\$1,555,842	\$221,396	\$1,164,503	\$4,348	\$1,487,454	\$177,345	\$2,130,019
Mchinji	\$0	\$2,885,863	\$818,958	\$73,623	\$7,776	\$0	\$426,314	\$0	\$0
Mulanje	\$2,010,401	\$7,985,974	\$1,121,044	\$173,298	\$1,041,604	\$32,661	\$1,681,368	\$165,462	\$2,402,295
Mwanza	\$8,000	\$1,012,604	\$212,737	\$29,188	\$170,429	\$4,115	\$164,876	\$27,238	\$0
Mzimba	\$0	\$4,501,442	\$1,232,674	\$126,185	\$505,658	\$0	\$724,863	\$71,768	\$0
Mzuzu City	\$98,691	\$1,723,413	\$279,751	\$48,971	\$215,383	\$2,456	\$327,270	\$2,070	\$535,853
Neno	\$152,979	\$985,598	\$184,596	\$21,193	\$120,440	\$326	\$173,456	\$17,921	\$57,460
Nkhata Bay	\$0	\$1,648,283	\$406,087	\$65,170	\$226,752	\$660	\$269,224	\$43,645	\$460
Nkhotakota	\$0	\$2,060,347	\$521,912	\$83,775	\$196,587	\$699	\$322,399	\$0	\$0
Nsanje	\$24,794	\$3,210,985	\$457,868	\$62,182	\$485,302	\$8,265	\$614,583	\$51,411	\$989,781
Ntcheu	\$0	\$5,037,739	\$1,103,177	\$190,782	\$624,650	\$158	\$836,503	\$139,293	\$333,443
Ntchisi	\$0	\$718,312	\$306,309	\$0	\$0	\$0	\$115,368	\$0	\$0
Phalombe	\$983,207	\$4,675,187	\$747,791	\$110,675	\$660,506	\$8,983	\$984,314	\$92,881	\$1,462,765
Rumphi	\$0	\$1,253,573	\$333,241	\$31,494	\$36,950	\$0	\$186,376	\$0	\$0
Salima	\$0	\$2,395,300	\$691,942	\$68,649	\$20,517	\$0	\$358,059	\$3,618	\$0
Thyolo	\$888,310	\$5,904,949	\$1,106,375	\$95,199	\$881,392	\$86,606	\$1,113,224	\$25,325	\$898,726
Zomba	\$417,897	\$1,471,236	\$188,535	\$29,855	\$200,369	\$14,428	\$309,754	\$26,683	\$402,019
Zomba City	\$929,196	\$7,150,331	\$1,180,032	\$162,813	\$1,073,031	\$0	\$1,444,313	\$139,828	\$2,192,153
Total	\$13,009,491	\$121,397,834	\$24,930,655	\$2,894,621	\$13,969,640	\$266,071	\$22,515,692	\$1,855,213	\$21,471,525

Annual HIV program coverage from optimization across districts for 2020 to 2025

District	AGYW	ART	Condoms	FSW programs	HIV testing	MSM programs	PMTCT	PrEP	VMMC*
Balaka	0	25,529	307,107	698	151,173	126	2,687	531	301
Blantyre	6,057	35,858	314,524	743	167,267	0	4,610	603	10,966
Blantyre City	36,645	100,914	551,090	1,358	326,101	660	13,483	1,154	26,354
Chikwawa	1,996	29,426	368,496	847	173,144	125	3,800	482	10,395
Chiradzulu	5,959	27,330	247,156	582	130,054	0	3,689	449	9,328
Chitipa	0	6,456	154,454	91	0	0	628	0	0
Dedza	0	27,060	555,552	758	0	0	2,595	0	0
Dowa	0	22,969	528,686	561	32,025	0	2,349	0	0
Karonga	0	22,630	255,220	583	127,694	101	2,349	437	324
Kasungu	0	24,245	555,278	0	0	0	2,314	0	0
Likoma	0	805	10,256	21	4,243	0	85	5	40
Lilongwe	0	43,842	1,076,735	904	76,618	0	4,429	0	0
Lilongwe City	15,359	74,530	698,328	1,669	364,495	49	10,058	1,264	24,806
Machinga	0	35,770	509,720	998	186,945	9	3,617	585	0
Mangochi	4,541	60,693	789,068	1,744	337,531	47	7,683	1,242	17,610
Mchinji	0	23,284	410,167	695	2,079	0	2,202	0	0
Mulanje	19,835	64,282	476,396	1,138	267,711	348	8,684	954	19,663
Mwanza	84	8,164	91,998	211	47,242	44	852	170	0
Mzimba	0	36,320	634,147	1,156	159,748	0	3,744	567	0
Mzuzu City	1,037	13,895	151,802	359	64,572	27	1,690	17	4,419
Neno	1,595	7,948	93,188	184	38,479	4	896	131	477
Nkhata Bay	0	13,296	195,455	460	72,912	7	1,391	305	4
Nkhotakota	0	16,622	265,691	617	70,415	8	1,665	0	0
Nsanje	261	25,857	206,121	464	118,611	89	3,174	346	8,113
Ntcheu	0	40,618	465,215	1,144	190,957	2	4,321	866	2,766
Ntchisi	0	5,798	198,068	0	0	0	596	0	0
Phalombe	9,950	37,648	303,093	722	169,834	98	5,084	570	11,985
Rumphi	0	10,113	157,769	287	13,206	0	963	0	0
Salima	0	19,326	331,055	617	5,477	0	1,849	30	0
Thyolo	9,240	47,599	497,314	876	251,958	827	5,750	207	7,445
Zomba	9,663	57,609	517,081	1,181	281,173	0	7,460	910	18,016
Zomba City	3,909	11,826	72,586	177	45,493	132	1,600	148	3,280
National total	126,131	978,262	11,988,816	21,845	3,877,157	2,703	116,297	11,973	176,292

*No district had circumcision coverage >85% by 2025 (excluding traditional circumcisions from 2017 to 2025) other than Machinga district which had 91% circumcision coverage reported for 2016 (source: Malawi Demographic and Health Surveys, any provider)