

Sudan's HIV response:
Value for money in a
low-level **HIV epidemic**

Findings from the HIV Allocative Efficiency Study

September 2014



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Abbreviations

AIDS	Acquired immunodeficiency syndrome
ART	Antiretroviral therapy
BOD	Burden of disease
DALY	Disability-adjusted life year
DSA	Disease specific accounts
eMTCT	Elimination of mother-to-child transmission
FSW	Female sex worker
GARPR	Global AIDS Response Progress Report
GDP	Gross domestic product
GNI	Gross national income
HDI	Human development index
HIV	Human immunodeficiency virus
HTC	HIV testing and counselling
IBBS	Integrated bio-behavioural survey
IDU	Injecting drug user
KP	Key population
MCH	Maternal and Child Health
MSM	Men having sex with men
NGO	Non-governmental organization
NHA	National health accounts
NSP	National strategic plan
PCR	Polymerase Chain Reaction
PITC	Provider-Initiated Testing and Counselling
PLHIV	People living with HIV
PWID	People who inject drugs
PMTCT	Prevention of mother-to-child transmission
RH	Reproductive Health
SBCC	Social and Behavior Change Communication
SNAP	Sudan National AIDS Control Program (MOH)
SRH	Sexual and Reproductive Health
STI	Sexually Transmitted Infection
SW	Sex worker

UNAIDS	Joint UN Programme on AIDS
UNDP	United Nations Development Programme
UNFPA	United Nations Population Fund
UNGASS	United Nations General Assembly Special Session
UNICEF	United Nations Children Fund
UNSW	University of New South Wales
VCT	Voluntary counselling and testing
WHO	World Health Organization
YLL	Years of life lost

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Executive summary

This report summarizes the findings of an allocative efficiency analysis on Sudan's national HIV epidemic and response conducted in 2014.

Key Messages:

- Sudan experiences a low-level concentrated HIV epidemic with the highest HIV incidence rates among female sex workers (FSW), men having sex with men (MSM) and clients of sex workers.
- Optimization analyses suggest that in a context of limited resources more HIV funding should be allocated to four priority, high-impact programs: 1) ART, 2) prevention among FSW, 3) prevention among men at higher risk (clients of sex workers) and 4) MSM.
- This will require shifting funding from HIV prevention programs targeted at the general population to programs reaching FSW and MSM, prioritizing geographic zones with the highest HIV prevalence levels if resources are scarce, and identifying opportunities for selected reductions in unit cost and management cost across programs.

Background

HIV allocative efficiency studies are generally trying to answer the question “How can HIV funding be optimally allocated to the combination of HIV response interventions that will yield the highest impact?”. In the first half of 2014, the Sudan National AIDS Programme has reviewed its national strategic plan (NSP) on HIV and AIDS, while at the same time preparing a concept note for submission to the Global Fund for AIDS, Tuberculosis and Malaria, the single largest funding partner of the national HIV response. In this context the government of Sudan approached the World Bank with a request to conduct an allocative efficiency analysis to inform both the prioritization of the national HIV response and the concept note development. Four main policy questions were formulated (Chapter 1) to address: 1) the optimal allocation of funds to minimize HIV incidence, 2) the optimal allocation to minimize disability-adjusted life years (DALYs), 3) resource requirements to achieve moderate and ambitious NSP impact targets and 4) optimal allocations to minimize future spending commitments.

The wider development and health systems context was analysed and trends in HIV and health financing established (Chapter 2). Sudan's population was estimated at 38 million in 2013 with a population growth rate of 1.5% (UN population data). The human development index takes rank 171 of 187 countries included, with life expectancy (68.1 years) and annual income (\$1,848) having positive effects on the ranking and the education situation (only 3.1 years of schooling on average) having a negative effect. The morbidity statistics are dominated by communicable diseases, which in 2012 were responsible for an estimated 63% of causes for years of life lost. Sudan has been an aid recipient with peak levels in 2008. While health has overall been a minor recipient of all aid money, the share of aid for health has increased between 2008 and 2012 from about 6% to about 15%. The proportion of health expenditure supported by external sources fluctuated heavily in recent years (43% in 2010, 64% in 2011 and 29% in 2012). In 2011, total health expenditure amounted to about 8% of GDP, however, public sector health expenditure was only at about 2% of GDP. A large and increasing part of all health expenditure comes from private households through out-of-pocket spending—in 2012, close to USD 3.1 billion was spent on health by private households. Government expenditure on health was 10.6% of total government expenditure in 2012, still some way off the 15% the signatories of the Abuja Declaration pledged to allocate to public health by 2015.

The HIV response has been comparatively well supported by external funding in the past with over two thirds of HIV financing coming from external sources. For every 100 USD in total aid disbursements for health, 15.3 USD were for HIV/AIDS in the period 2002–12. Between 2011 and 2013, domestic public funding for the national HIV response declined from 6.6 million USD to 3.7 million USD, while international funding declined from 14.5 million USD to 9.1 million. Overall funding for the HIV response declined from 23.3 million USD in 2011 to 13.8 million USD in 2013. This suggests a declining basis of sustainable HIV financing in Sudan. Optimal use of limited HIV funding is therefore increasingly important to serve the people in need of HIV services and to achieve the country's HIV impact targets.

Methods

The Optima model, which was applied in this analysis, is a mathematical model of HIV transmission and disease progression (Chapter 3). It is a population-based and flexible model, which provides a formal method of optimization and quantitatively and objectively determines optimal allocations of HIV resources across numerous prevention and treatment programs.

The inputs into the model were gathered through a comprehensive literature review and key parameters defined using a participatory consultation of key stakeholders. During this engagement, ten populations (FSW, their clients, MSM, children and – disaggregated by sex—youth, adults and older people) were defined for inclusion in the model. Seven core HIV programs were identified for optimization: HIV prevention for FSW, MSM, clients of sex workers, general population prevention, HIV testing and counselling for the general population, ART and Prevention of Mother-to-Child Transmission (PMTCT). Key time frames for analysis included 2016, 2020 and 2030. Expenditure from the National AIDS Spending Assessment (NASA) for 2013 was used as a baseline scenario (total spending USD 12.2 million, programmatic spending USD 6.4 million USD).

Optima was calibrated to HIV prevalence data points available from the different populations. Cost-outcome curves were developed for the seven programs included in the analyses. These curves define the relationship between program expenditure and respective outcomes (such as HIV testing rate, condom use per population, or number of people on ART) and form the basis for the optimization analysis. Note that these curves are associated with the technical efficiency and resulting unit costs of a program. However, this analysis was not designed to explore how potential technical efficiency gains would affect outcomes and in turn optimal resource allocation.

Key findings

The epidemic model within Optima was used to develop baseline HIV prevalence and HIV incidence estimates and trends (*Chapter 4*). The following are the main findings of the epidemic modelling:

- Sudan experiences a **low-level concentrated HIV epidemic** with an estimated 6,376 new HIV infections acquired in 2013
- **HIV incidence in 2013 is estimated at 0.44% for FSW, 0.35% for MSM and 0.1% for SW clients**, and at <0.05% in all age and sex strata of the general population
- **31% of all new infections were directly associated with sex work** (incidence in sex workers and their clients)
- Half of all incident **HIV infections occurred in the general adult population** (70% of which among females), but **many of these indirectly arise from sex work-linked transmission** events

- FSW are “net transmitters” whereas female adults in the general population are all “net receivers”. All male populations are “net transmitters” including sex work clients and MSM (the latter therefore suggesting that MSM also transmit to female partners, and a proportion of MSM are indeed married).

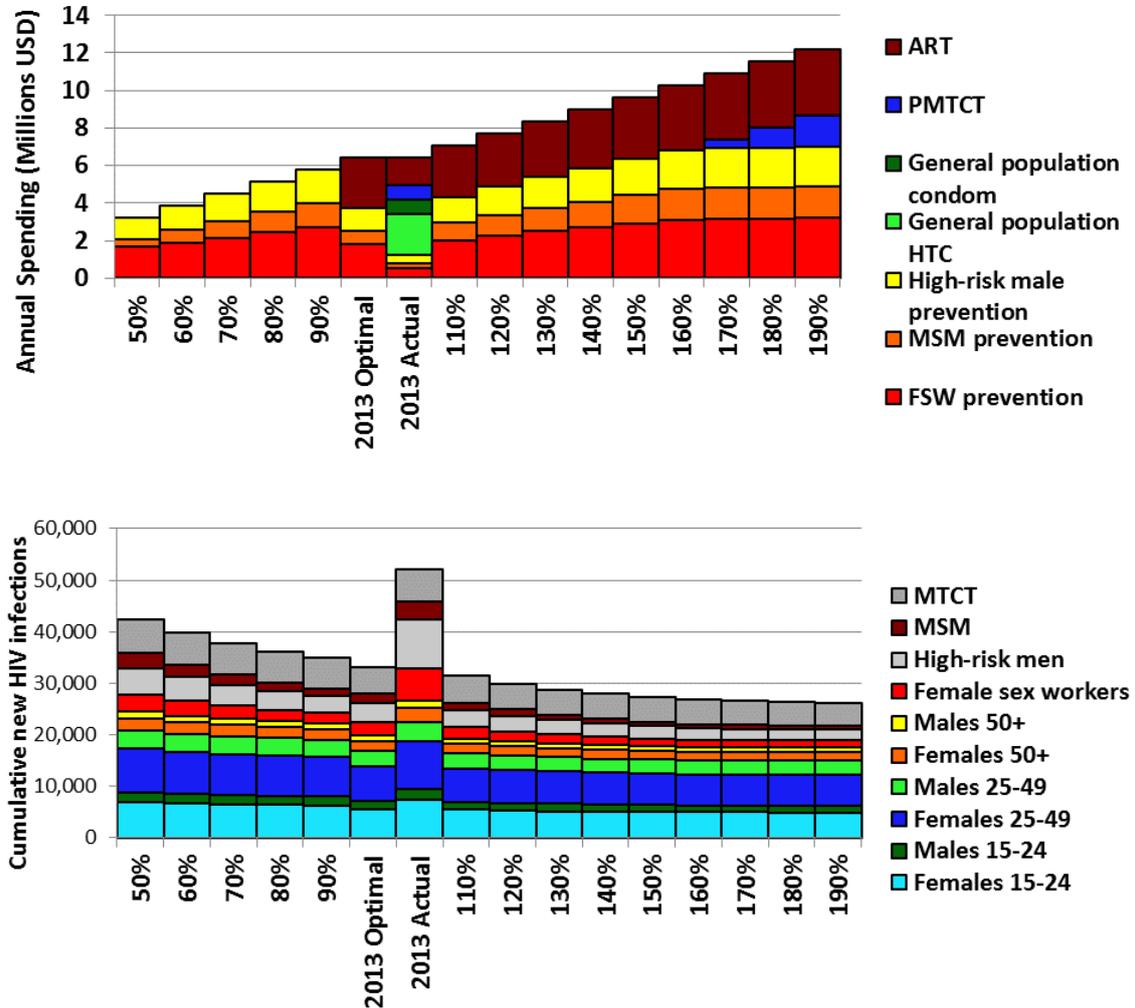
The analysis to determine **optimal allocations for minimizing new HIV** infections (*also Chapter 4*) established the following:

- With the same USD 6.4 million of programmatic spending as in 2013, Sudan could avert an additional 19,000 infections (or 36% of cumulative HIV infections) during the 2014–20 period if these resources were allocated optimally
- These reductions in new infections could be achieved by prioritizing resource allocation to four programs:
 - **ART—22% of all HIV funding instead of 12% as in 2013**
 - **Prevention services for FSWs—15% instead of 4%**
 - **Prevention services for high-risk men/SW clients—10% instead of 4%, and**
 - **Prevention service for MSM—6% instead of 2%**

(note that non-program expenditure for management and strategic information, as well as PLHIV support activities, are not considered in this optimal allocation analysis although they were 47% of all 2013 HIV expenditure)
- In case the Sudan HIV response has more programmatic funding available than the USD 6.4 million in 2013—through mobilizing additional funds or moving management/ coordination costs towards intervention programs—additional HIV incidence reductions can be obtained (*see ES Figure 1 below*)
- Prevention programs for the general population are not part of the optimal mix of investment in any of these scenarios
- At the 2013 level of total HIV funding of USD 6.4 million, **PMTCT is not part of the optimal mix**, a finding that was attributed to the high cost for HIV testing to identify one HIV positive pregnant woman. This finding remained unchanged with a substantially lower unit cost for PMTCT used in the 2015–17 NSP (USD 2,666 per HIV positive woman receiving PMTCT services instead of USD 9,016 based on past program data). With the reduced unit cost, PMTCT enters the allocation mix at 170% of the 2013 programmatic spending amount (USD 10.7 million). According to additional analyses of PMTCT program data, 76% of the 254 PMTCT sites did not identify an HIV positive woman in 2013. This suggests that increasing cost-effectiveness of the program will require geographical prioritization and exploring

synergies with other public health interventions such as syphilis testing and treatment for pregnant women.

ES Figure 1. Optimized allocations to minimize HIV incidence by 2020 at different budget levels, Sudan



Sources: Populated Optima model for Sudan. Prevention packages for key populations include outreach, condoms, HTC, but do not include ART (which is shown separately). Reduced PMTCT unit cost were applied in this analysis. If 2013 PMTCT unit cost was used, PMTCT would not be part of the optimal mix to reduce new infections for scenarios ranging from 50% to 200% of 2013 levels of spending.

In order to minimize HIV-related DALYs in the population by 2020, very similar budget reallocations would need to be made as when aiming for minimal HIV incidence:

- Optimal allocations would avert approximately **29,300 additional HIV-related DALYs (23%)** compared to the non-optimal 2013 allocation pattern
- ART would receive the largest share of the funding since it is the principal intervention to reduce AIDS morbidity and mortality (25% of all HIV funding or 47% of programmatic spending).

- The contribution of the prevention packages regarding HIV case finding remains essential (all prevention packages include HTC). In order to initiate ART in eligible individuals, the HTC activities would have to be targeted to higher-yield sub-populations – key populations (FSW, clients, MSM), TB cases, STI clients, spouses and partners of known PLHIV.

Optimal annual allocations from 2014 to 2030 to minimize fiscal commitments up to 2050 again called for a very similar allocation. This suggests that the model-proposed intervention mix for HIV programs is robust for minimizing different important objectives of preventing HIV transmission, HIV morbidity, HIV mortality and HIV long-term costs.

It was also estimated that the minimum programmatic spending to achieve moderate impact targets of 25% reduction in cumulative HIV incidence and deaths *in the short-term* by 2016 was USD 8.1 million per year until 2016. The modelling suggests that the cost for reaching HIV incidence targets is lower than cost for reaching HIV mortality targets, particularly for more ambitious mortality targets, which require extensive coverage of HIV testing for find cases for ART initiation. Reaching impact targets at lowest costs *in the mid-term* would require an estimated USD 14 million annually for program financing to obtain a 25% incidence and AIDS mortality reduction by 2020 (= 220% of the spend of USD 6.4 million in 2013). Achievement of ambitious targets (50% reduction in HIV incidence and AIDS deaths by 2020) would require an estimated USD 34 million annually for programs (over 5 times spend of USD 6.4 million in 2013).

Another key finding was that targeting programmatic resources almost exclusively to KPs and to ART—while de-prioritizing general population programs—has downstream effects on all population groups and leads to HIV incidence reductions in all populations over the medium term, at lowest cost.

The report brings the results of the analysis together in an overall discussion (*Chapter 5*) and in offers brief conclusions based on the main findings (*Chapter 6*).

Conclusions

Sudan's new 2014 – 2016 HIV strategy already builds on many insights and lessons learnt. This allocative efficiency study led to the main conclusion that Sudan's HIV response allocations could be enhanced by focusing prevention on FSW, their clients and MSM, while scaling up ART based on an HTC strategy that is targeted geographically and to key populations.

The impact of Sudan's HIV response resource allocations could be enhanced by focusing on prevention and ART for key populations for the following five main reasons:

Epidemiologically: The populations causing most HIV transmission (sex workers and their clients, men having sex with men) need to be adequately served to prevent onward transmission of HIV. Treatment as prevention is hampered by low and late case identification and limited ART adherence; supply chains for both HIV reagents and condoms report failures, and condom promotion faces cultural barriers. As a consequence the annual number of new HIV infections is projected to slowly rise unless the HIV response increases its prevention impact.

Programmatically: HIV resources are spent on populations with very low HIV risk of 1 in 5,000–10,000 new infections per year and low AIDS attributable DALYs. PMTCT provision is scaled up to many areas where no HIV case is identified in a whole year; some VCT services experience low demand and until recently targeted low-risk individuals. HIV money needs to be directed towards the key populations who are most likely to be infected, develop AIDS and spread HIV to others. HIV highlights the pernicious health effects of social and legal marginalization and of gender inequalities in Sudan, and offers an opportunity to redress.

Economically: Aid supporting the Sudanese public health sector has in the past prioritized HIV above other diseases. With international and domestic public sector contributions to the HIV response rapidly decreasing over the last three years, bold decisions need to be made to achieve value for money by addressing the epidemic in a cost-effective manner with greater returns on investment.

Fiscally: Every new HIV infection represents a future treatment liability for the Sudanese government. According to our model outputs on future HIV-related healthcare costs, allocating specific shares of HIV resources to key populations and to ART scale-up minimizes long-term fiscal costs for the government.

Sustainability: The results presented in this report can guide Sudan's allocative choices to make the HIV response more sustainable and HIV investments more defensible in a health sector with multiple investment needs. The model-proposed allocation mix for HIV programs is robust for minimizing different important policy objectives of minimizing HIV transmission, HIV morbidity and mortality, and long-term AIDS-related costs. Importantly, the model demonstrates that through indirect effects, HIV impact is obtained in all population groups, even if prevention programs are targeted to populations at higher risk of HIV.

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1. Introduction

1.1 Allocative efficiency in HIV and health

The concept of allocative efficiency takes health interventions (including services, drugs, and other activities, the primary intention of which is to improve health) as inputs and health of the population as an output¹. The term refers to the **maximization of health outcome with the least costly mix of health interventions**. Practically, allocative efficiency of health interventions is about the right intervention being provided to the right people at the right place in such a way that health outcomes are maximised.

HIV allocative efficiency studies are generally trying to answer the question “*How can HIV funding be optimally allocated to the combination of HIV response interventions that will yield the highest impact (achieve HIV response goals in the areas of HIV prevention, treatment, care and support) in the shortest period of time?*”

The dialogue around HIV financing has been changing in recent years, from a focus on universal access and estimation of the total resource need to comprehensively finance universal access, to **prioritized high-impact HIV response scenarios within the realistic constraints of an amount of funding a country is likely to raise**. In connection with this, the following developments can also be highlighted:

- The shared interest to move towards more predictable levels of HIV funding support for countries;
- The promotion of better alignment between HIV investment decisions and "need", informed by disease burden and ability to pay (especially Global Fund);
- The concept of shared responsibility or “fair share” promoted by UNAIDS, calling on governments to contribute public sector funds to the HIV response;
- The stabilization of most HIV epidemics globally, resulting in a change from HIV’s special disease status to a condition with long-term treatment needs similar to some non-communicable diseases in many settings;

¹ WHO (2003). Policy tools for allocative efficiency of health services. By Xingzhu Liu.

- The move from vertical HIV interventions to more integrated HIV and health service provision with strong linkages to TB and SRH services and the management of chronic conditions;
- The change from an HIV/AIDS spending approach towards an investment approach, using longer time horizons, and analytical approaches to determine where investments should be made.

There is wide consensus that **better outcomes could be achieved in many settings with a given amount of HIV money, or given outcomes could be achieved with less HIV money, if the resources are distributed optimally or if resources are technically used in the most efficient ways.** One way in which to do this, is to use mathematical modelling to determine optimal HIV resource allocation. As an HIV allocative efficiency model, Optima is designed to provide investment guidance on allocatively efficient HIV responses. The optimal allocation of resources predicted by the model differs markedly depending on the policy objective(s), and the optimal distribution of resources across programs changes substantially based on the amount of funding available to be allocated.

The Optima model:

- is a mathematical model of HIV transmission and disease progression that is population-based and flexible,
- provides a formal method of optimization and quantitatively and objectively determines optimal allocations of HIV resources across numerous prevention and treatment programs, to address multiple policy objectives,
- estimates intervention impact, cost-effectiveness and return-on-investment, and
- provides analysis on the longer-term financial consequences of HIV infections and HIV investments.

1.2 Objectives of the analysis

In collaboration with Sudan stakeholders, the following different objectives for optimization analysis were set, taking into account that different optimization objectives would yield different optimal funding allocations:

1. Determine the optimal programmatic funding allocations to **minimize HIV incidence** in the mid-term by 2020

2. Determine the optimal programmatic funding allocations to **minimize HIV-attributable DALYs** in the mid-term by 2020 (i.e., lowest cumulative DALYs, highest DALYs averted)
3. Determine the optimal programmatic funding allocations to **achieve specific impact and coverage targets at lowest costs in the medium-term** by 2020

Scenarios:	Reduce HIV incidence by 2020	Reduce AIDS deaths by 2020	ART coverage	PMTCT coverage
Ambitious	50%	50%	80%	80%
Moderate	25%	25%	60%	60%

4. Minimize new spending commitments caused by new HIV infections occurring by 2020/2030
5. Determine the optimal programmatic funding allocations to achieve 25% reductions in HIV incidence and AIDS deaths in the short-term by 2016.

2. Sudan's human development, health and financing context

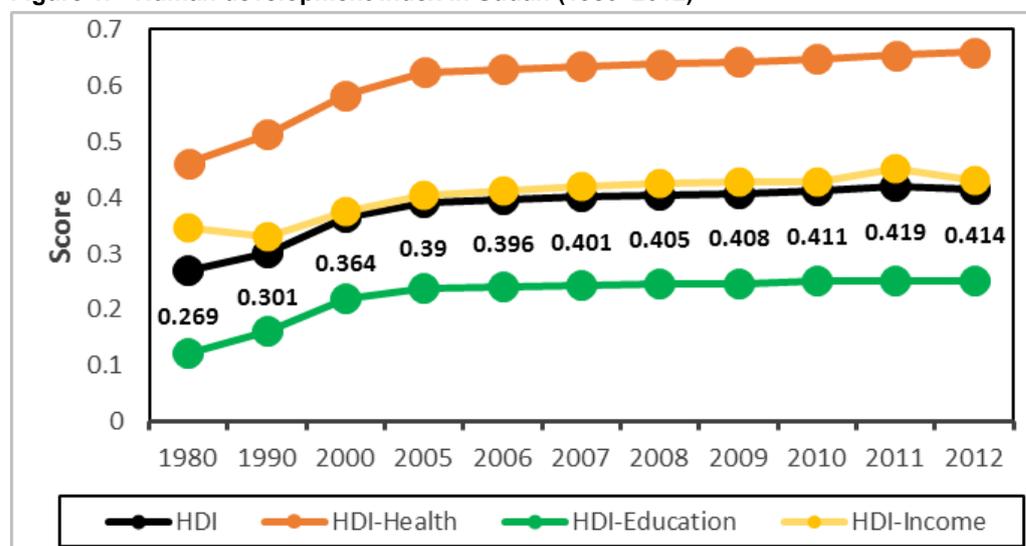
2.1 Human development

Sudan's human development continues to experience various challenges and remains affected by armed conflicts, internal displacement of people, and influx of refugees from Ethiopia, Eritrea, Chad, Central African Republic and South Sudan.

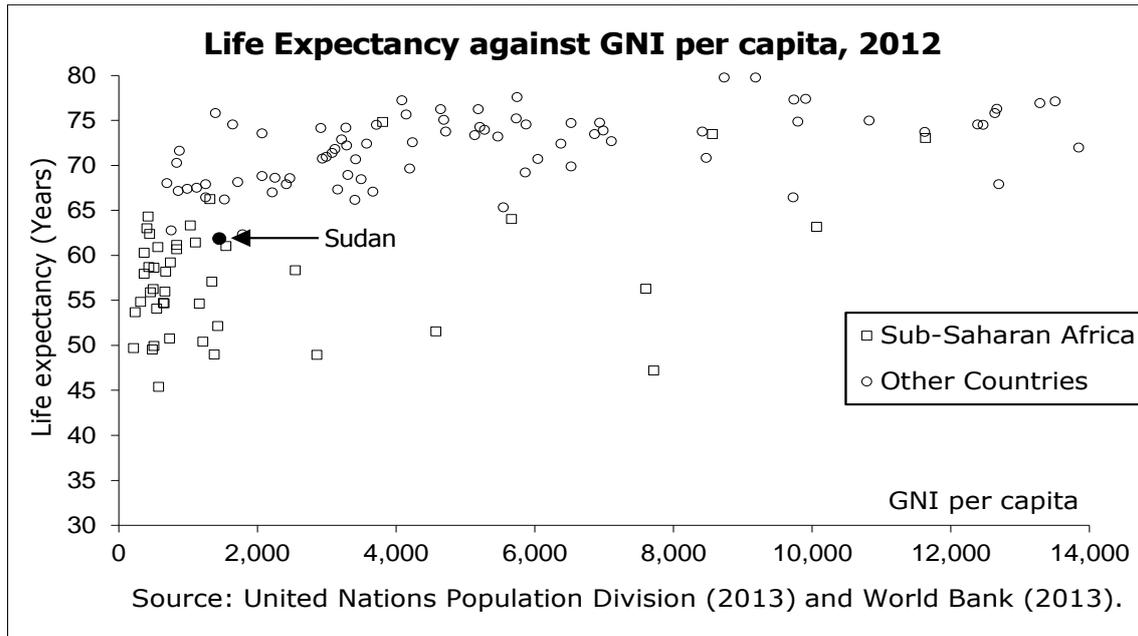
The country takes rank 171 out of 187 countries included in the human development index (HDI) – Sudan's score of 0.414 is below the average of 0.466 for countries with the lowest levels of human development (2013 Human Development Report) – **Figure 1**. Sudan also ranks behind other Arab countries including Yemen and Djibouti ranked at 160 and 164 respectively.

- Sudan's average life expectancy is relatively high at 68.1 years, compared to 59.1 for low-HDI countries. **Figure 2** shows Sudan's life expectancy against GNI per capita in international comparison with sub-Saharan African and other countries.
- The mean years of schooling are only 3.1 and this affects Sudan's HDI negatively.
- The average annual income is \$1,848 compared to \$1,633 for countries in the same bracket.

Figure 1. Human development index in Sudan (1980–2012)



Source: <http://hdr.undp.org/en/data>, accessed 3 June 2014

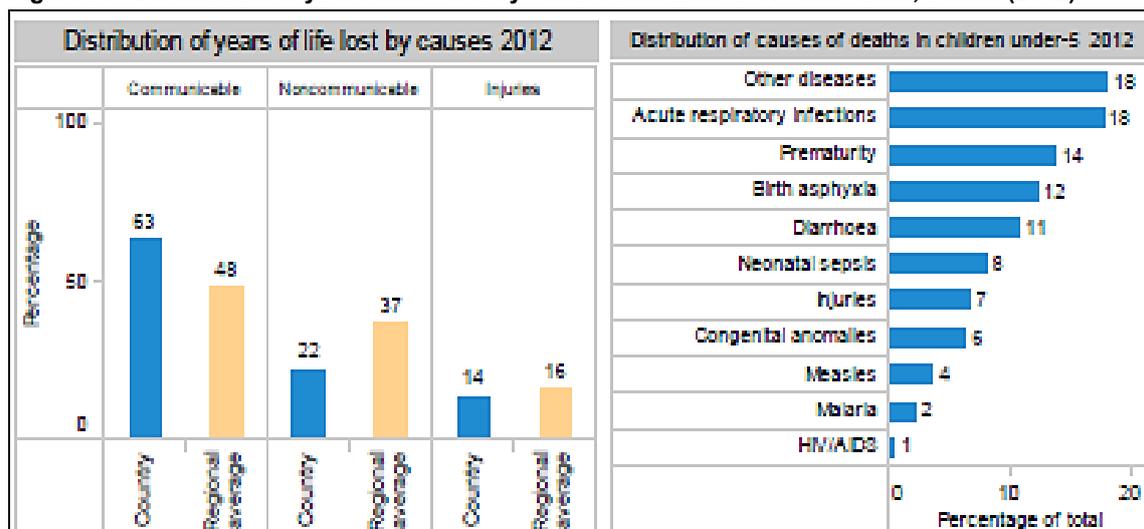
Figure 2. Life expectancy against GNI per capita, Sudan (2012)

2.2 Burden of disease

Sudan's morbidity statistics are dominated by communicable diseases (Figure 3)

- In 2012, an estimated 63% of causes for years of life lost (YLL) were communicable diseases, which is higher than the regional average level (WHO, 2014).
- About 22% of YLL were due to non-communicable diseases, lower than the average level reported for the region.
- Injuries contribute about 14% of all YLL.
- The highest ranking causes for child death in 2012 were acute respiratory infections (18% of all causes), premature birth (14%), birth asphyxia (12%) and childhood diarrhoea (11%)².

² WHO, 2014. Sudan health profile. <http://www.who.int/gho/countries/sdn.pdf?ua=1>, accessed 14 June 2014

Figure 3. Distribution of years of life lost by causes and causes of child death, Sudan (2012)

Source: WHO 2014, Sudan health profile. <http://www.who.int/gho/countries/sdn.pdf?ua=1>, accessed 14 June 2014.

There is a growing body of national data on morbidity and cause-specific mortality. However, the data from the 2010 Global Burden of Disease Study – which provided HIV/AIDS data for countries—cannot be directly used for today’s Sudan (comprising of pre-secession data).

The following incidence rates from disease surveillance and estimations can be highlighted (WHO 2013)³:

- Malaria: 14.8 cases per 1,000 population
- Measles: 260 per 1 million population
- TB notification rate, all forms: 53 per 100,000 population
- Meningococcal meningitis: 911 reported cases
- Syphilis in pregnant women: mean prevalence of 2.3% (2010 ANC surveillance data).

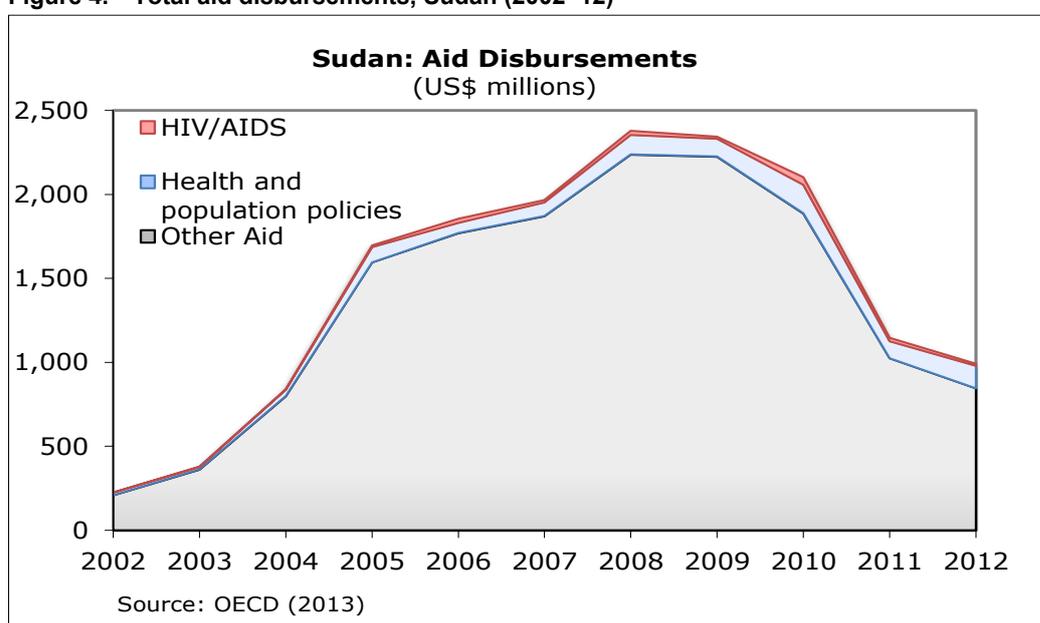
2.3 External aid and health financing

Even though Sudan has historically received large amounts of aid, this peaked in 2008, and health has been a minor component of this aid (see Figure 4).

³ WHO 2013. Demographic, social and health indicators for countries of the Eastern Mediterranean, http://applications.emro.who.int/dsaf/EMROPUB_2013_EN_1537.pdf?ua=1.

- While health has overall been a minor part of all aid, the share of aid for health has increased between 2008 and 2012 from about 6.0% to about 14.9%.
- A large proportion of aid to Sudan is provided in form of humanitarian assistance, which focuses on food security and nutrition, but also includes some health and education programme;
- Regarding external financing of health expenditure, there has been some fluctuation in recent years: In 2009 44.6% of total health expenditure was externally financed, in 2010, 2011 and 2012 the share was 42.5%, 63.5% and 29.4% respectively.

Figure 4. Total aid disbursements, Sudan (2002–12)



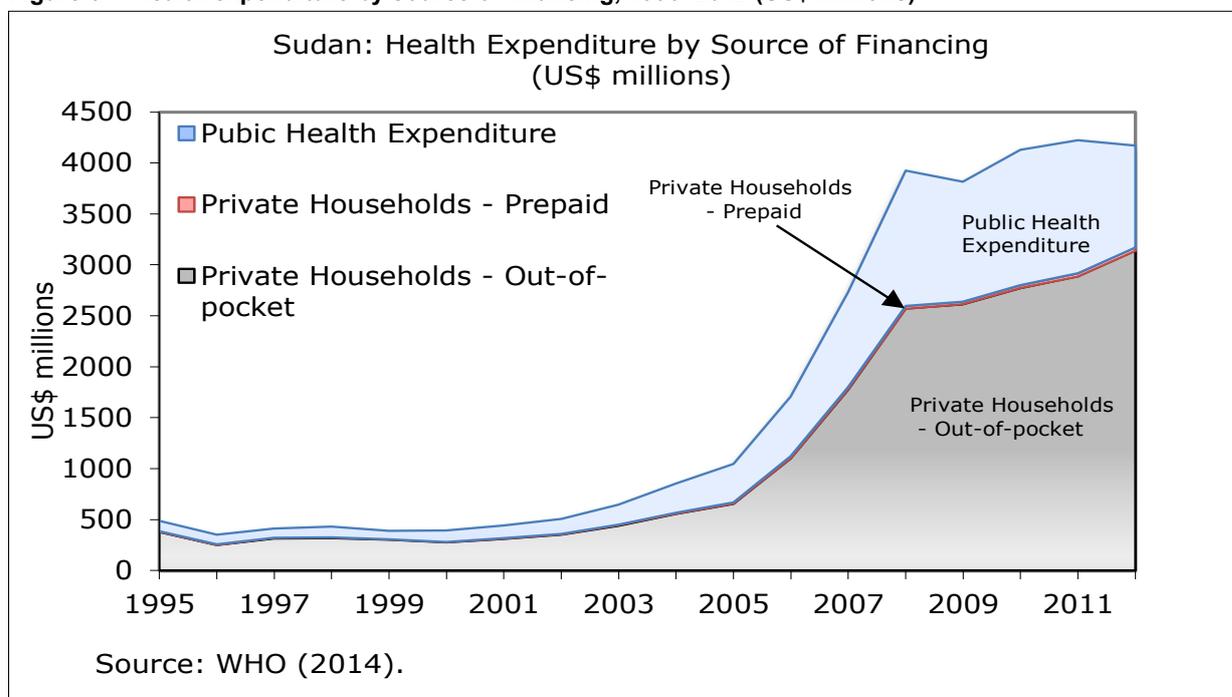
Source: OECD 2013, <http://stats.oecd.org/>

A large and increasing part of all health expenditure comes from private households through out-of-pocket spending (Figure 5).

- In 2012, close to USD 3.1 billion was spent on health by private households, and about USD 1.0 billion came from the public sector.
- There is virtually no pre-paid component in the private household expenditure (i.e. subscription to health insurance schemes is very rare).

- Total health expenditure amounted in 2011 to about 8% of GDP (GDP was approximately USD 1,617/capita in the same year⁴) (WHO, 2013)⁵.
 - However, public sector health expenditure was only at about 2% of GDP in 2011.

Figure 5. Health expenditure by source of financing, 1995–2012 (US\$ millions)



Source: Global health expenditure database, <http://apps.who.int/nha/database/Select/Indicators/en>

According to the Global Health Expenditure Database⁶, government expenditure on health was 10.7% of total government expenditure in 2009, 10.6% in 2010, 10.9% in 2011 and 10.6% in 2012—see Figure 6.

- The share exceeded 12% from 1996 to 1998 (pre-secession data, see footnote).
- The signatories of the Abuja Declaration pledged to allocate at least 15% of their national budgets to public health by 2015⁷.

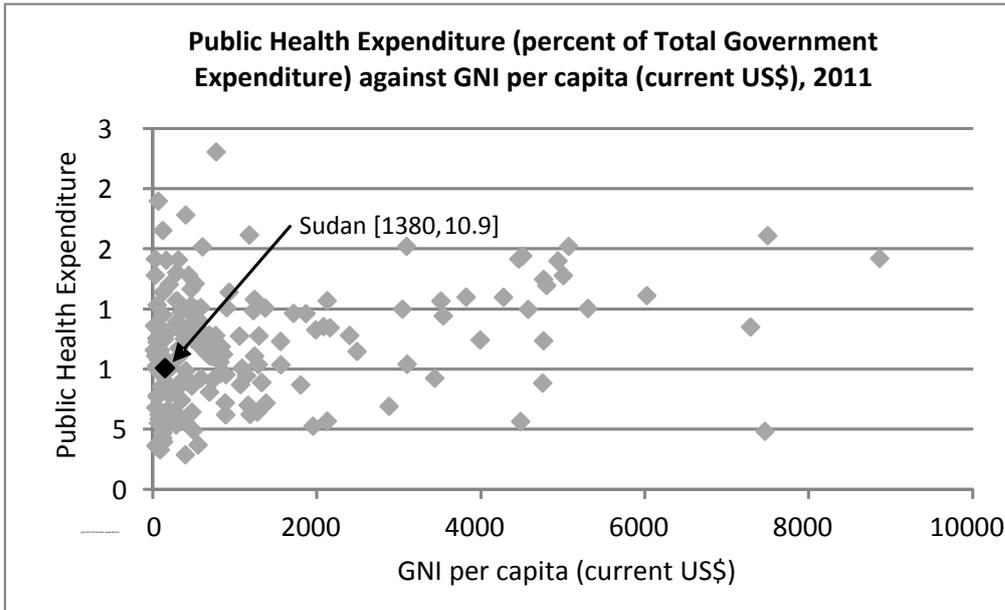
⁴ <http://data.worldbank.org/indicator/NY.GDP.PCAP.CD> (verified on 31 July 2014)

⁵ WHO, 2013 : Global Health Expenditure Database, World Health Organization, Geneva (<http://apps.who.int/nha/database/>, accessed 19 April 2014).

⁶ The Global Health Expenditure Database provides separate estimates for Sudan and South Sudan from 2008 onwards. We therefore believe that the data for 1995-2007 concern the whole former Sudan while from 2008 onwards the data concern the present Sudan

⁷ WHO Global health expenditure database, cited in UNAIDS report “Abuja +12: Shaping the future of health in Africa”, accessed 5 May 2014 http://www.unaids.org/en/media/unaids/contentassets/documents/unaidspublication/2013/JC2524_Abuja_report_en.pdf

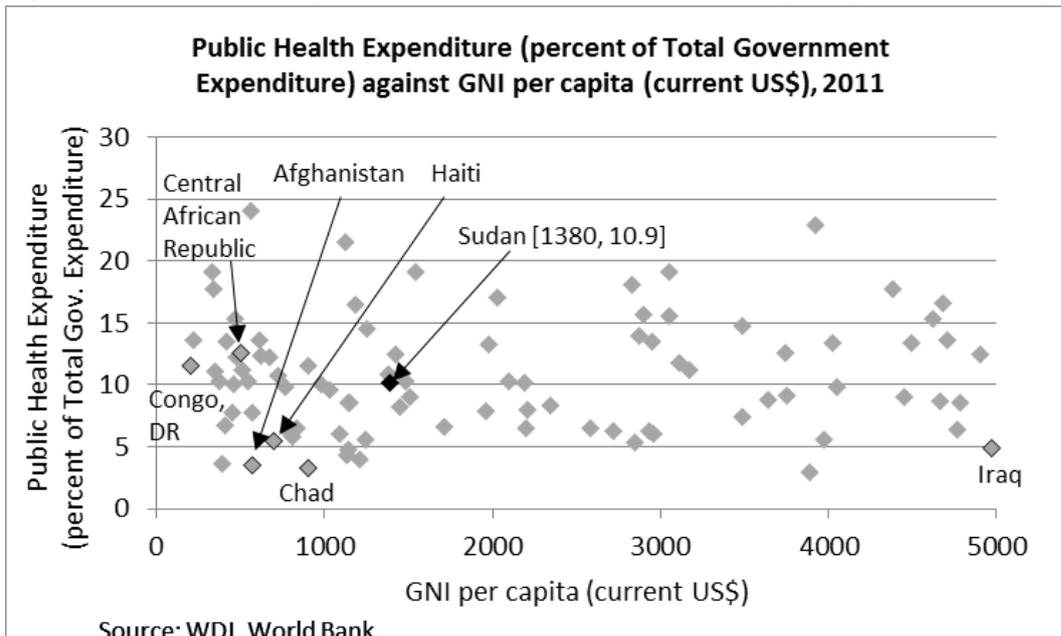
Figure 6. Public health expenditure against GNI per capita, Sudan (2011)



Source: WDI, World Bank

Comparison of Sudan's public health allocation with other post-conflict states shows that Sudan's percentage-allocation is among the higher ones, similar to the Democratic Republic of Congo and Central African Republic (Figure 7). However, considering that Sudan's GNI per capita is much higher than those for the Democratic Republic of Congo and Central African Republic, it could be concluded that Sudan should use its economic situation to increasingly invest in the health of its people (Figure 7).

Figure 7. Public health expenditure in selected countries with GNI per capita below 5000 (2011)



Source: WDI, World Bank.

2.4 HIV/AIDS financing

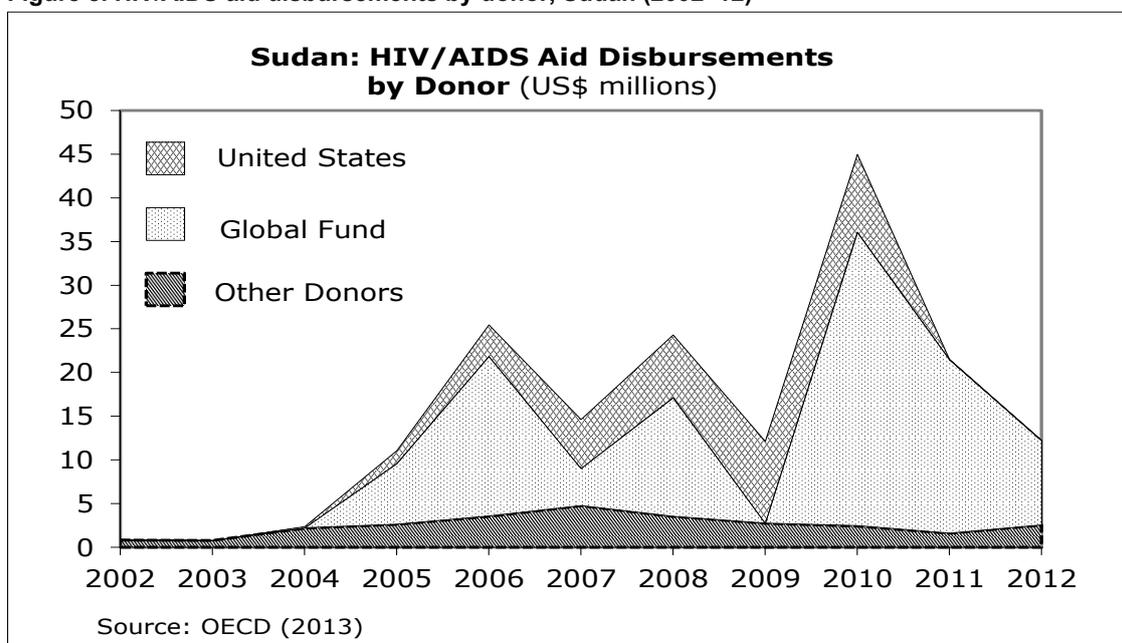
The HIV response has been comparatively well-financed by aid money in the past:

- For every 100 USD in total aid disbursements for health, 15.3 USD were for HIV/AIDS in the period 2002–12. This means that HIV disbursement were 1.0% of all aid disbursements over the 2002–12 period.

Donor disbursements for HIV/AIDS have fluctuated between a low of approximately USD 1 million in 2002 and 2003 to a high of about USD 45 million in 2010 (Figure 8).

- Support from the United States has been significant over 6–7 years, however, the most important source of external funding has been the Global Fund (rounds 3, 5, 10). In 2012 and 2013, Global Fund disbursements were at USD 10.9 million and 8.2 million (with 4.3 million and 1.5 million going into infrastructure development in 2012 and 2013, respectively, these amounts were hence not considered as part of the current HIV program spending).
- Several other donors have over the years contributed annual total funding of about USD 1–5 million (predominantly UN agencies and international NGOs).

Figure 8. HIV/AIDS aid disbursements by donor, Sudan (2002–12)

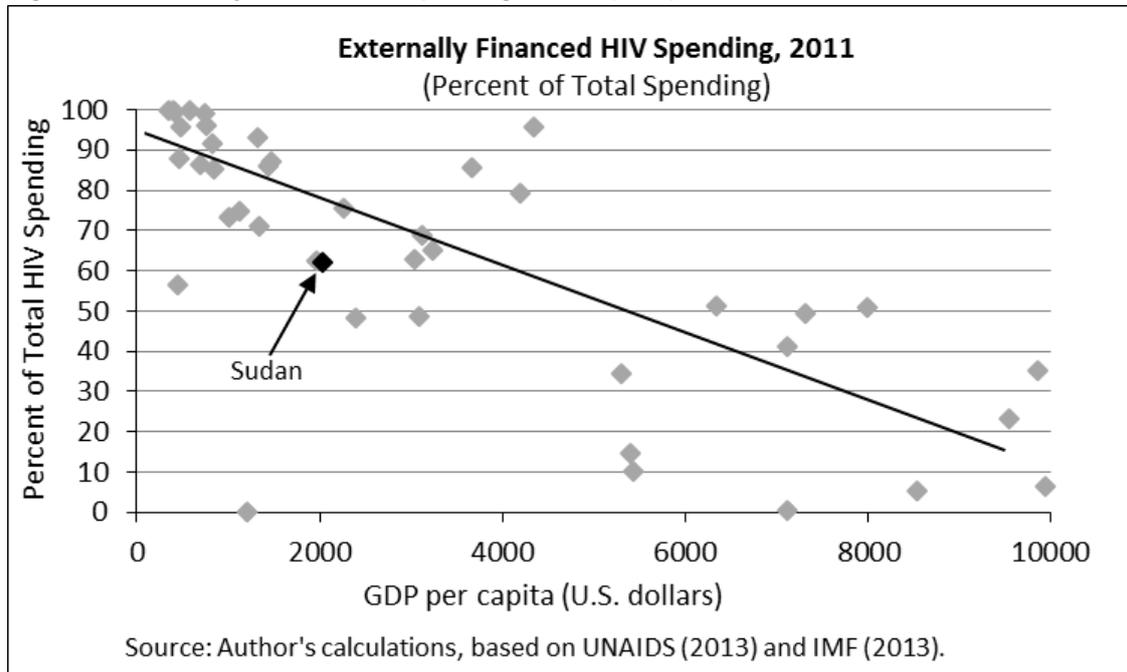


Source: OECD 2013, <http://stats.oecd.org/>

In 2011, an estimated 62% of all reported HIV spending was externally financed (of which 90.8% was from Global Fund), which is an average level when comparing Sudan with countries with similar income levels (Figure 9) (based on 2013

data from UNAIDS and IMF). In terms of both GDP per capita and the share of external funding in HIV, Sudan is on a par with the Republic of Moldova.

Figure 9. Externally financed HIV spending, Sudan (2011)



Sources: UNAIDS 2013 UNAIDS AIDSinfo (<http://www.unaids.org/en/dataanalysis/datatools/aidsinfo/>), IMF 2013, World Economic Outlook Database, April 2013 edition, (Washington DC: IMF).

In 2012, HIV/AIDS consumed:

- About **0.47% of the public sector expenditure on health** (USD 4,693,022 of USD 1.0 billion public sector health spend)
- About **0.45% of total expenditure on health** (USD 18,458,156 of USD 4.1 billion health spend)

The most recent disease-specific accounts available to this analysis were from 2013 (**Table 1**).

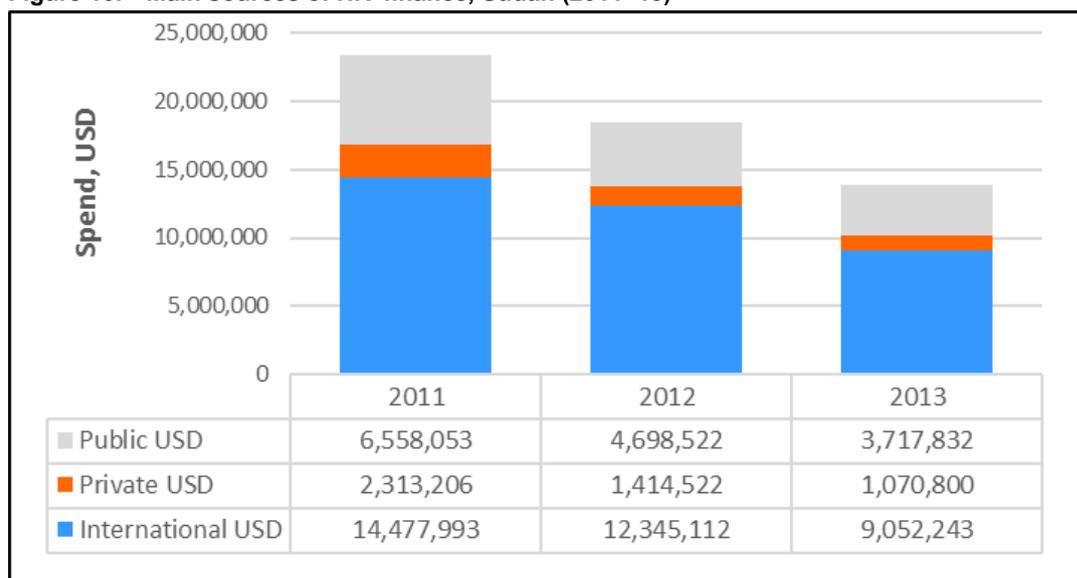
Table 1. Key statistics on HIV spending, Sudan (2013 health accounts)

Total HIV spending in 2013, USD	13,840,875.00
Shares of total HIV spending	
International	65.4%
Domestic public	26.9%
Private (for profit institutions/corporations, household funds and other private sources)	7.7%
Total HIV spending as a share of GDP	0.02%
Total HIV spending per capita, USD	0.36
Total HIV spending per people who live with HIV, USD (based on 2013 expenditure and Spectrum estimate for PLHIV)	216.31
Total HIV spending per key population member, USD (based on 183K FSW, 127 K MSM, 0 PWID)	2.83
Shares of total HIV spending	
Prevention	40.7%
<i>Of which for Most-at-risk populations (SW, MSM, IDU)</i>	15.6%
<i>Of which PMTCT</i>	16.3%
Care and treatment	11.9%
<i>Of which ART</i>	54.1%
Orphans and vulnerable children	n/a
Management	47.46%

Sources: Analysis based on 2013 DSAs, IMF 2013, World Economic Outlook Database, April 2013 edition.

While overall funding for the HIV response declined, the relative contribution of different funding sources stayed at similar levels. Global Fund remained the largest international funding source accounting for 90.3% of international funding. The reductions in GF spending between 2011 and 2013 mainly occurred through reduced infrastructure investment through HIV budgets – **Figure 10**.

Figure 10. Main sources of HIV finance, Sudan (2011–13)

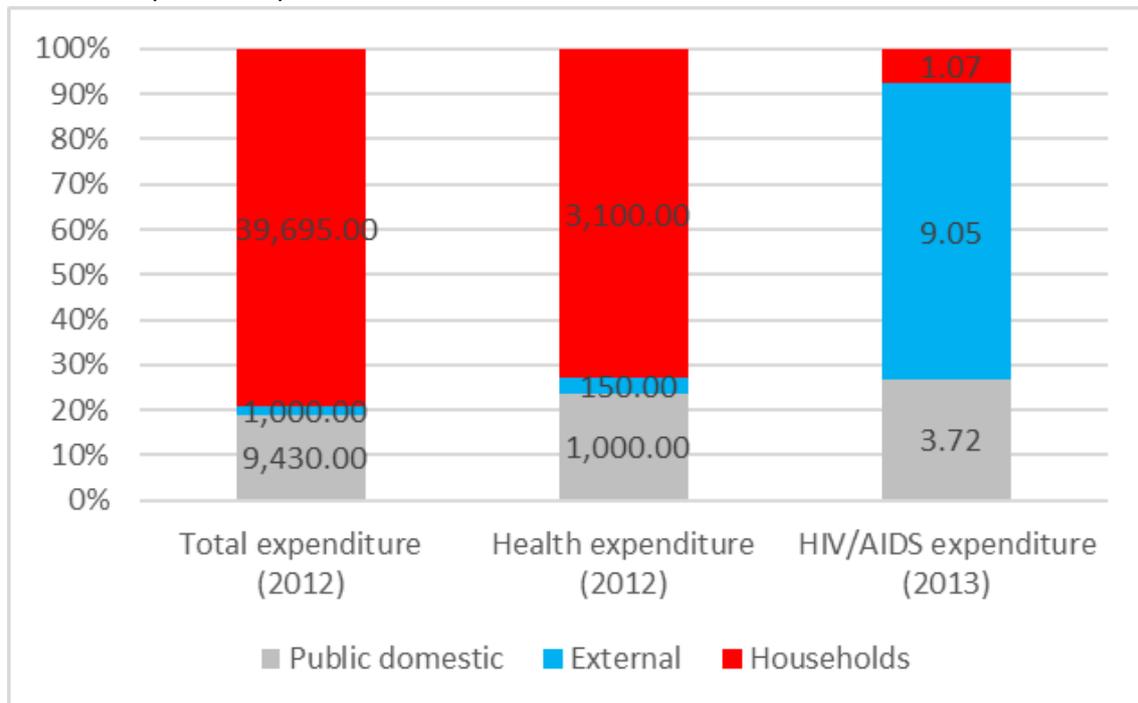


Sources: Based on AIDSinfo (<http://www.unaids.org/en/dataanalysis/datatools/aidsinfo/>) and DSAs 2012 and 2013

Note: private sources include for profit institutions and corporations and other private sources.

The following graph summarizes the expenditure situation in Sudan (**Figure 11**). It depicts the shares of household, state and aid contributions to expenditure in the country, as well as to health and HIV expenditure. It shows that while households face considerable expenditure for health, they don't for HIV thanks to the large contribution from external donors. In general, households seem protected from direct expenditure for HIV prevention and treatment services (note that this does not include impact mitigation services and social protection for people affected by AIDS).

Figure 11. Household, state and aid contributions to Sudan's total health and HIV expenditures in USD million (2011–2013)



Sources: OECD database for external aid, WHO-NHA database for health, 2013 NASA for HIV. World Development Indicators databank for household consumption data.

Note: The total expenditure from households is based on Household final consumption expenditure and is an approximation (<http://data.worldbank.org/indicator/NE.CON.PRVT.CD>), in the absence of a special survey on household expenditure.

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3. Methodology

3.1 Analytical framework

Category	Parameterization in Optima model
Populations defined in model ⁸	<ul style="list-style-type: none"> ▪ Children (0–14) ▪ Young women (15–24) ▪ Young men (15–24) ▪ Adult women (25–49) ▪ Adult men (25–49) ▪ Older women (50+) ▪ Older men (50+) ▪ Sex workers ▪ Clients of sex workers (higher-risk men) ▪ Men having sex with men
Expenditure areas defined in model and included in optimization analysis	<ul style="list-style-type: none"> ▪ Targeted prevention services for FSW (incl. condoms, HTC but excluding ART) ▪ Targeted prevention services for MSM (incl. condoms, HTC, but excluding ART) ▪ Targeted prevention services for higher-risk men/SW clients (not ART) (truckers, city cab drivers, uniformed personnel, mobile farm workers—incl. condoms, HTC) ▪ Prevention for the general population (condoms and sexual risk reduction, not ART) ▪ Services for the general population (HTC) ▪ PMTCT ▪ ART (incl. HTC, clinical/biological monitoring, nutritional supplements etc. as per guidelines)
Expenditure areas not included in optimization (effect on HIV incidence, morbidity/mortality not understood)	<ul style="list-style-type: none"> ▪ PLHIV support ▪ Management

⁸ Other relevant populations, which could not be included due to lack of data: Populations of humanitarian concern, People who inject drugs, Prisoners.

Category	Parameterization in Optima model
	<ul style="list-style-type: none"> Strategic Information
Time frames	<ul style="list-style-type: none"> 2013–17 (end year NSP) 2013–20 2013–30 (global UNAIDS resource needs)
Baseline scenario/counterfactual HIV epidemic projection	<ul style="list-style-type: none"> The baseline scenario is an epidemic projection produced by Optima assuming constant spending of 2013 expenditure allocated as per the 2013 distribution. The epidemic and financial impact of this scenario is used as a counterfactual against which the extent of reductions in new infections, DALYs and deaths as well as savings with optimal allocations are measured.
Baseline scenario funding (2013 NASA year, some once-off infrastructure payments were deducted)	<ul style="list-style-type: none"> USD 12.2 million (all spending categories) USD 6.4 million (programmatic spend)

Note: Some further data and specifications of Optima are presented in **Annex 1**.

3.2 Model calibration

Optima was calibrated to HIV prevalence data points available from the different populations (**Figure 12**), as well as to data points on ART patient numbers (**Figure 13**), in consultation with Sudan stakeholders.

Figure 12. Calibration to Optima model to the HIV epidemic in Sudan.

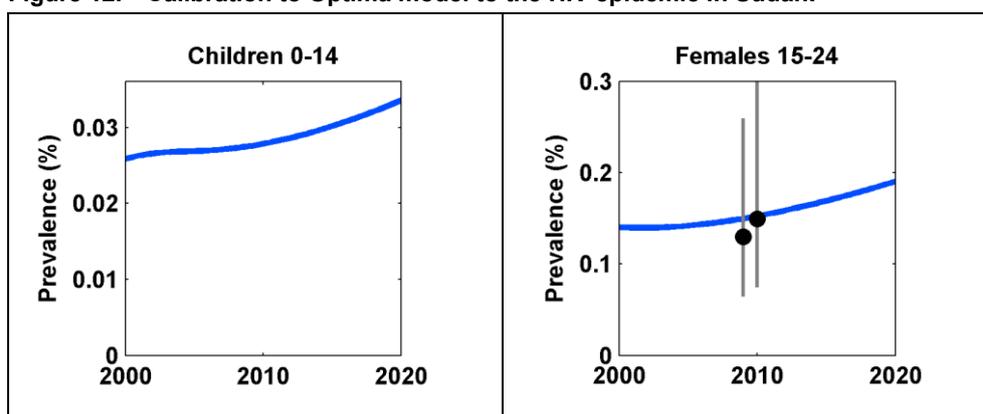
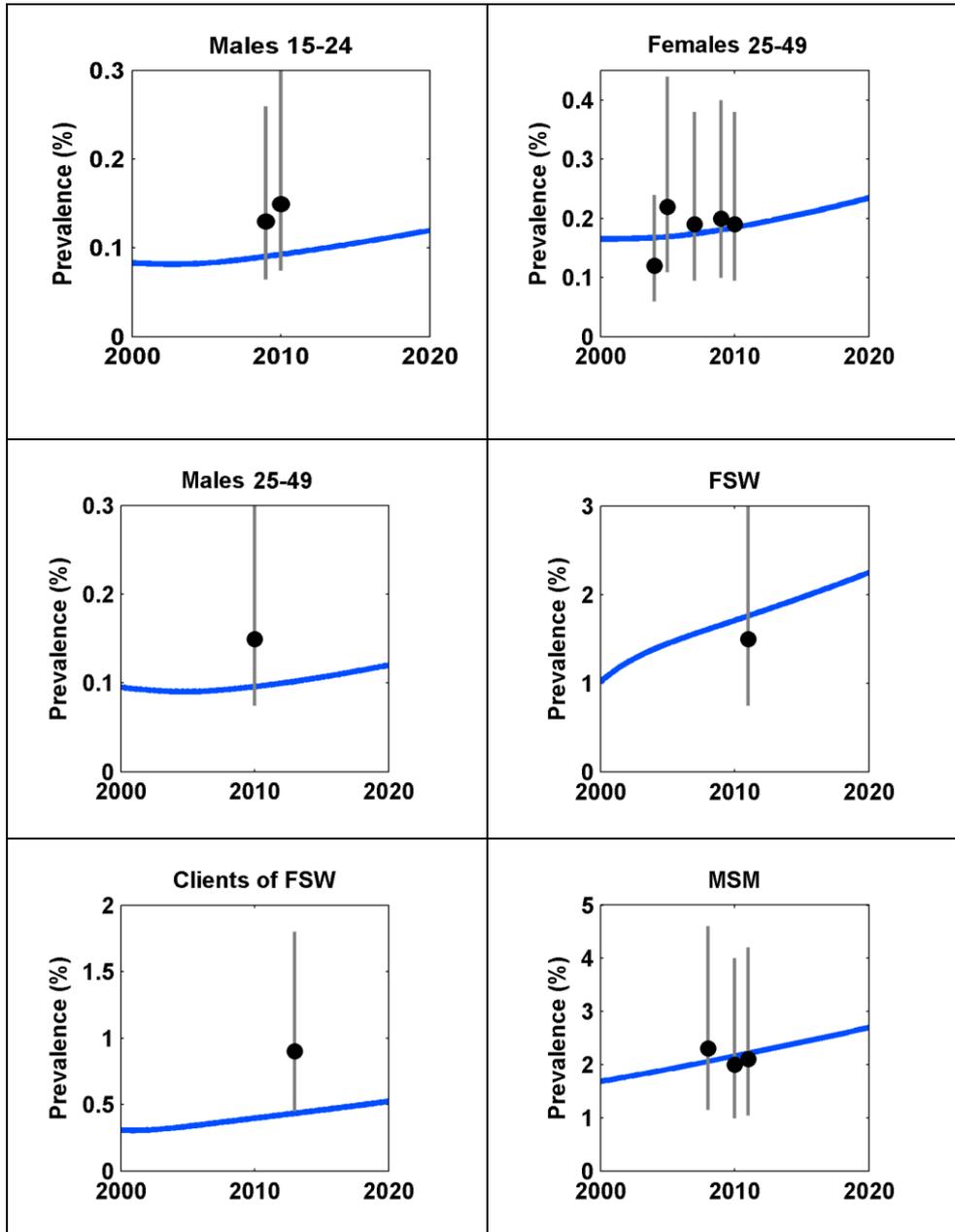
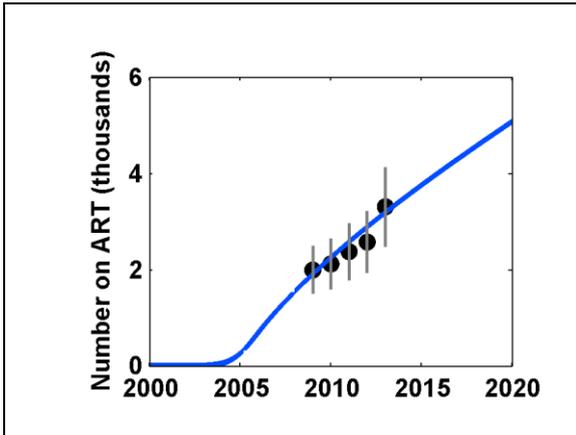


Figure 13 (continued)



Note: Black discs represent available data for HIV prevalence. Lines attached to these discs represent uncertainty bounds. The solid curve is the best fitting simulation of HIV prevalence in each population

Figure 13. Calibration of the Optima model to ART data in Sudan

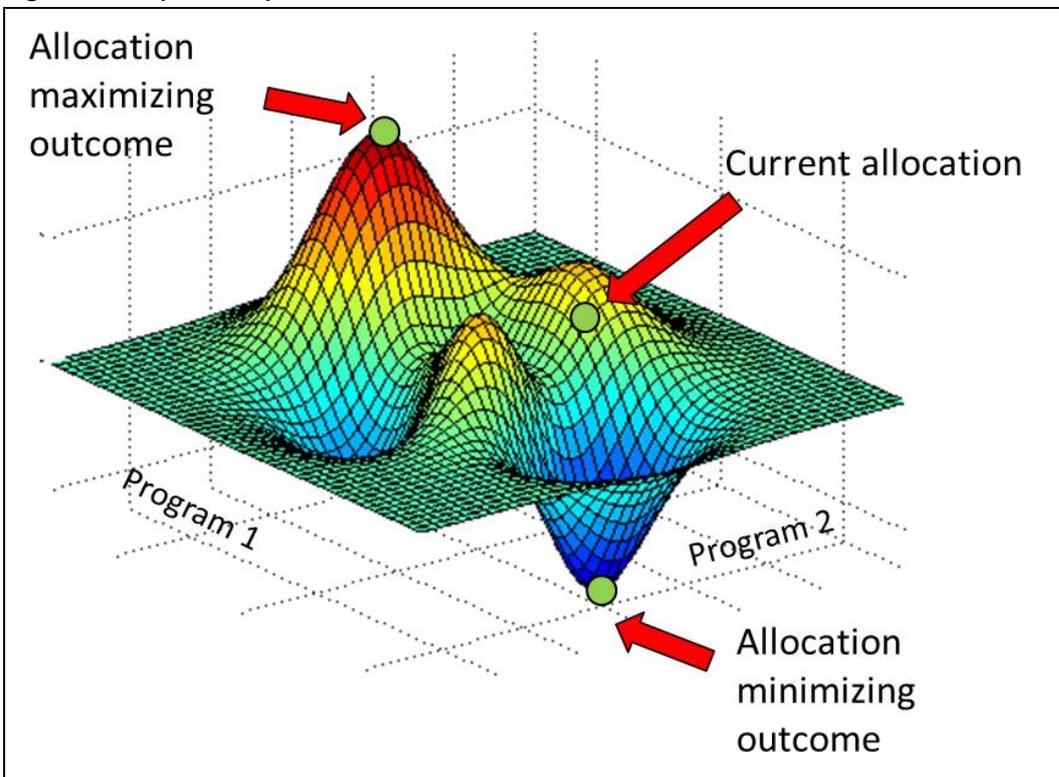


Note: Black discs represent available data for the number of people on first line ART. Lines attached to these discs represent uncertainty bounds. The solid curve is the best fitting simulation of total ART patient numbers.

3.3 Optimization function

The mathematical optimization provided by the Optima model is a formal and precise way to determine the “best” allocation. In this process, different objectives (e.g. minimize HIV incidence, minimize HIV costs) yield different optimal allocations of resources or spending. The model determines the resource allocation required that *best* meets the objective. This process can be graphically depicted as follows:

Figure 14. Optima's optimization function



Source: UNSW unpublished documentation on Optima

Optimization requires the development of cost-outcome curves which define the relationship between program expenditure and respective outcomes (such as HIV testing rate, condom use per population, number of people on ART). The cost-outcome curves are shown in **Annex 2**.

The cost-outcome curves allowed deriving unit costs for each program. This top-down costing approach derives unit costs from expenditure data and reported number of people served or reported program coverage data (**Table 2**). The method may produce different unit costs than when using a bottom-up costing methodology. We developed average costs based on locally reported data (without gaining a detailed understanding of the possible ranges of unit costs due to program scale, provider and location). We then compared our derived unit costs with data from Sudan (NSP costing) and elsewhere (global unit cost repository of Futures Institute⁹, Resource Needs Model Niger) and found that our derived unit costs came in at a similar range, except for PMTCT. For this program, our high unit cost includes the cost of screening the average number of ANC clients to identify one HIV-positive client, and subsequent provision of the PMTCT service package to this expectant mother.

Table 2. Unit costs established in the analysis (USD)

Program	Unit costs in USD
Targeted prevention services for FSW (incl. condoms, HTC outreach)	131
Targeted prevention services for MSM (incl. condoms, HTC outreach)	60
Targeted prevention services for higher-risk men (incl. condoms, HTC)	40
Services for the general population – HTC	22
Prevention for the general population (condoms, youth peer education, IEC, STI)	9
Prevention of mother-to-child transmission (per woman living with HIV identified and provided with PMTTCT)	
Based on historical PMTCT expenditure data and coverage	9,016
Based on newly costed, prioritized NSP – “reduced PMTCT cost”*	2,666
ART incl. first-line drugs, HIV testing and clinical/biological monitoring, nutritional supplements	440

Sources: Units costs are estimated average costs derived from this analysis’ cost-outcome curves (these curves used expenditure data from the 2013 DSAs and data on reported number of people served or reported program coverage data).

Note: * = Using NSP budget data of estimated cost of USD 3,211,901 to identify and provide with PMTCT a total of 1,205 women. 2013 unit cost was primarily driven up by the large number of women to be tested to identify HIV positive pregnant women and the cost of a large effort to roll-out PMTCT to a large number of sites.

⁹ <http://policytools.futuresinstitute.org/UC/>, accessed 6 June 2014.

3.4 Limitations of analysis

3.4.1 Limitations specific to Sudan

Limited/scarc data: Some data are not yet available for the post-2011 Sudan, such as the data from the Global Burden of Disease Study of 2010. A major limitation of trend analysis in the context of Sudan is the fact that different epidemiological data points are not comparable over time, since the sample of sites for collecting HIV bio-markers changed. Future rounds of surveys using similar samples as previous IBBS (integrated bio-behavioural survey) and ANC surveillance rounds will add to improving trend data. In addition, the calibration of the model had overall very few data points available on the HIV prevalence level in each of the chosen populations. There was also a lack of data on historical program spending, and little information to associate program spending to impact or performance.

Populations insufficiently characterized in terms of their HIV risk: Some populations of interest could not be included as separate groups in the analysis due to lack of data. This includes populations of humanitarian concern, migrants, prisoners and people who inject drugs (PWID). The first two are relatively large groups, for which it is not clear whether they are at increased risk of HIV infection. Prisoners and PWID are relatively small groups in Sudan, but potentially at high risk of HIV infection. Including these groups would most likely not have entirely changed the overall picture of analysis, but as additional data becomes available their role in the epidemic could be reassessed at a later stage.

Migration effects: Another limitation are potential effects of the split of Sudan into two countries, which led to population movements of former South Sudanese residents in North Sudan to the South and reduced labour migration from the South to the North. There is limited data available on these effects, but due to differential levels of HIV prevalence, this could potentially influence the analysis.

3.4.2 Limitations of the modelling methodology itself:

- A limitation of our approach is the assumption that all changes in behavior are assumed to be due to changes in program funding. This assumption is common in epidemic models.
- The analysis uses past ratios of expenditure to coverage as a basis for determining program cost rather than unit costs (Wilson et al. in preparation). This approach of using past cost and results has a number of advantages over using projected costs from plans and budgets, which are ultimately predictions of future cost, but also has

a disadvantage as there may be future increases or decreases in cost in relation to new approaches, implementation arrangements or technologies.

- The modelling approach used to calculate relative cost-effectiveness between programs includes assumptions around the impact of increases or decreases in funding for programs. These assumptions are based on unit costs and observed ecological relationships between outcomes of program coverage or risk behaviour and the amount of money spent on programs in the past, and assuming that there would be some saturation in the possible effect of programs with increases in spending.
- The analysis did not determine the technical efficiency of programs as this was beyond the scope of the analysis, however, gains in technical efficiency would lead to different unit costs and therefore affect optimal resource allocation.
- Effects outside the HIV endpoints are not considered (e.g. wider effects of PMTCT within MCH, of condom use as a contraceptive, or effects of sex work interventions on STIs and SRH).
- Our approach does not consider equity or quantification of human rights, stigma and discrimination, ethical, legal or psychosocial implications.
- Other models may produce different projections than those produced by Optima. However, our model's predictions matched Spectrum-predicted trends. It used the best possible data, the combined experience from model application in about 20 countries, and it produced realistic forecasts.

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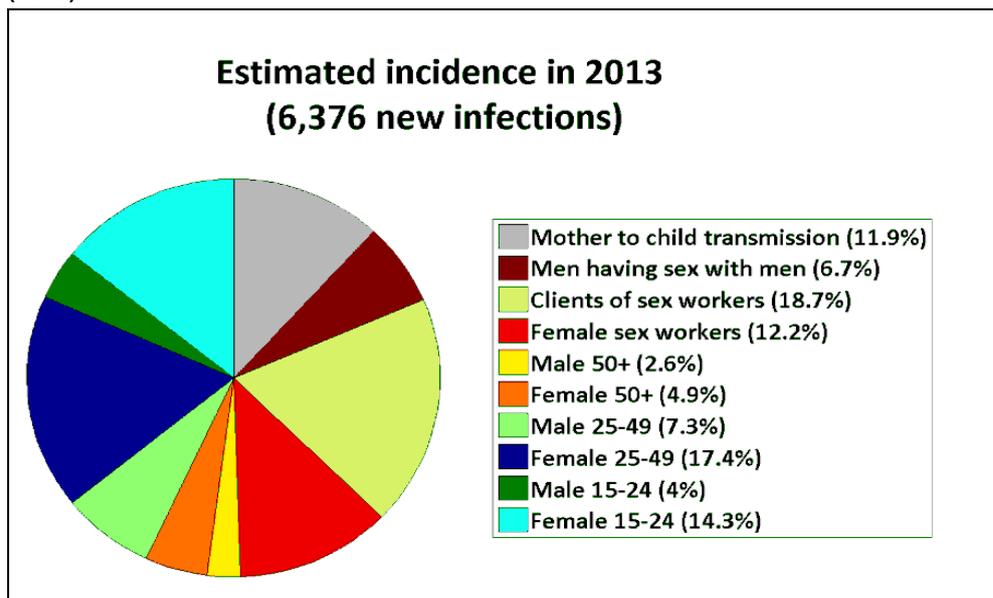
4. Results

4.1 HIV transmission dynamics

It is estimated that there were 6,376 new HIV infections acquired in 2013 (Optima), see Figure 15. Of these:

- 31% were directly associated with sex work (incidence in sex workers and their clients who are higher-risk men but not MSM)
- Half of all incident HIV infections occurred in the general adult population (70% of which among females)—it is subsequently shown in the report that many of these indirectly arise from sex work-linked transmission events.

Figure 15. New HIV infections acquired in different populations, estimated by Optima, Sudan (2013)



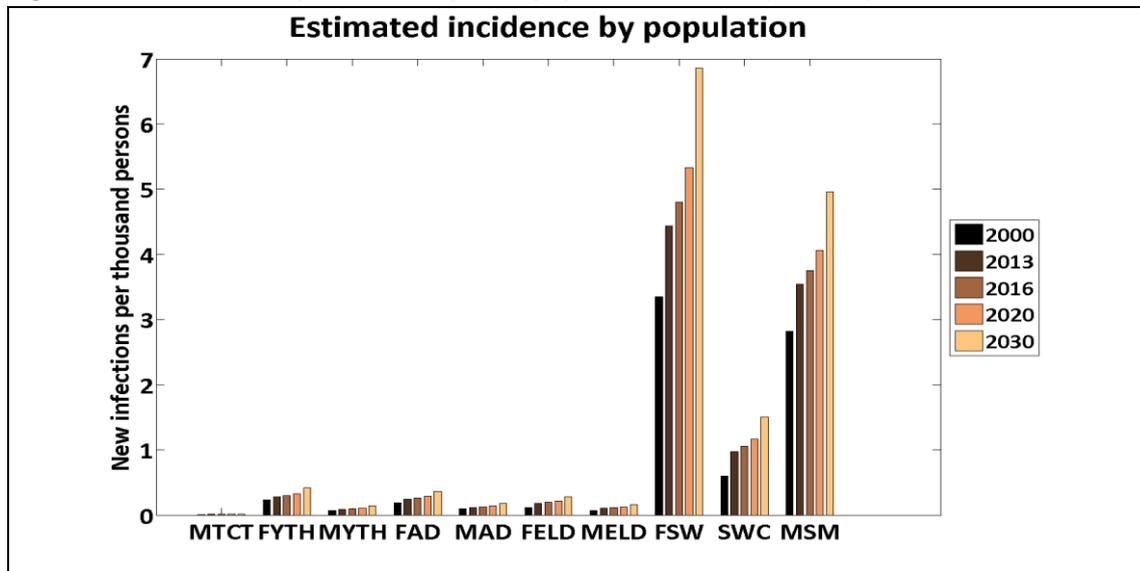
Source: Populated Optima model for Sudan

The risk of infection shows large variation across populations, with FSW and MSM having significantly higher risk, followed by SW clients —Figure 16:

- HIV incidence in 2013 is estimated at 0.44% for FSW, 0.35% for MSM and 0.1% for SW clients, and at <0.05% in all age and sex strata of the general population
- HIV incidence in children is estimated to be <0.01% (most infections in children are expected to occur through mother-to-child-transmission)

- If 2013 programmatic spending levels and allocations continue, the HIV incidence rate is expected to rise, especially in FSW, MSM and clients

Figure 16. Incidence rate per 1,000 in specific populations, Sudan (2000–30)

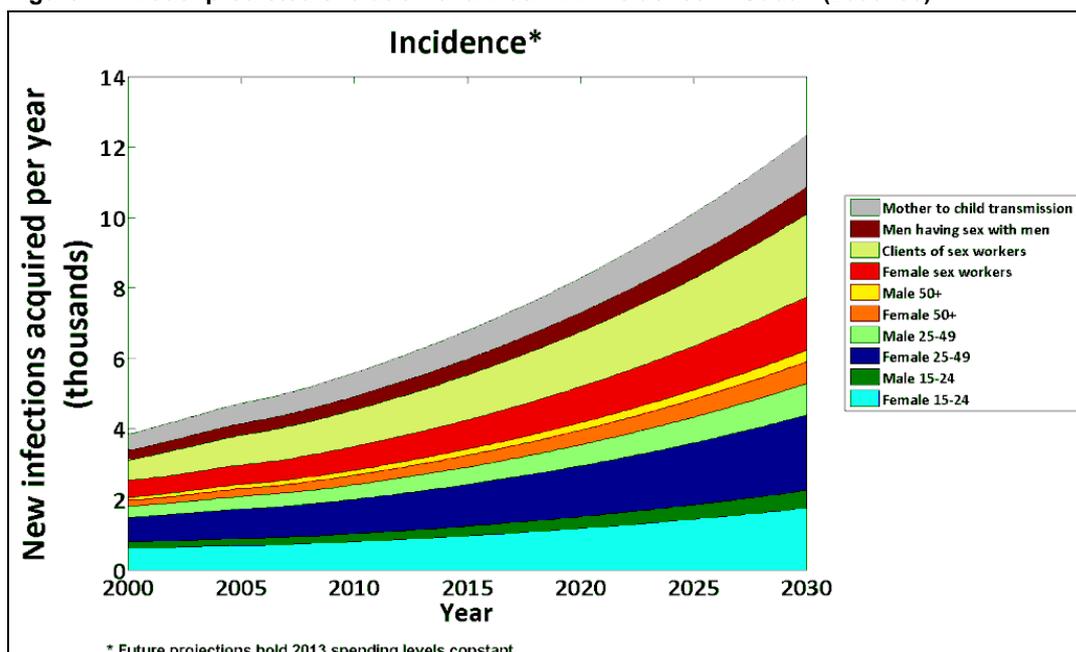


Sources: Populated Optima model for Sudan; Analysis uses 2013 programmatic spending level and allocation up to 2030

Note: MTCT = mother-to-child transmission, FYTH = females 15–24 yrs, MYTH = males 15–24 yrs, FAD=female adults 25–49 yrs, MAD = male adults 25–49 yrs, FELD = females aged 50+ yrs, MELD = males aged 50+ yrs, FSW = female sex worker, SWC = sex work client, MSM = men having sex with men.

If the 2013 programmatic expenditure was held constant, increased HIV incidence rates (Figure 16), combined with the population growth rate of about 1.5%, would lead to significant increases in the number of new HIV infections in all population groups in the medium term—Figure 17.

Figure 17. Model-predicted evolution of annual HIV incidence in Sudan (2000–30)



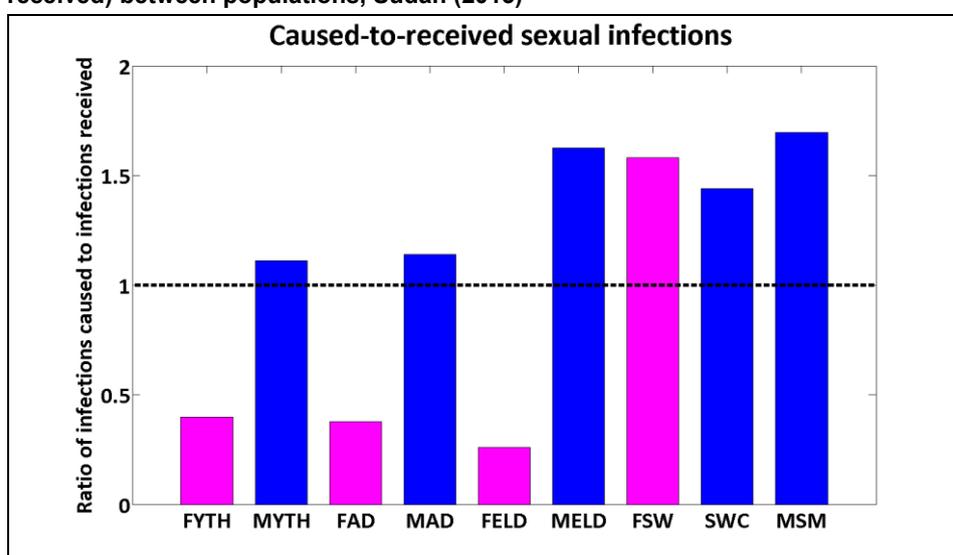
* Future projections hold 2013 spending levels constant

Sources: Populated Optima model for Sudan

Ratios of HIV infections transmitted to infections received per population help understand the transmission dynamics between populations (Figure 18):

- All male populations (in blue) are “net transmitters”, especially men aged 50 years and above, sex work clients and MSM (the latter therefore suggesting that MSM transmit to populations other than MSM, who will be female partners of MSM as many MSM are married)
- FSW are also net transmitters, whereas female adults in the general population are all “net receivers” (all female populations in pink)

Figure 18. Ratios of HIV transmission (infections caused) versus HIV acquisition (infections received) between populations, Sudan (2013)

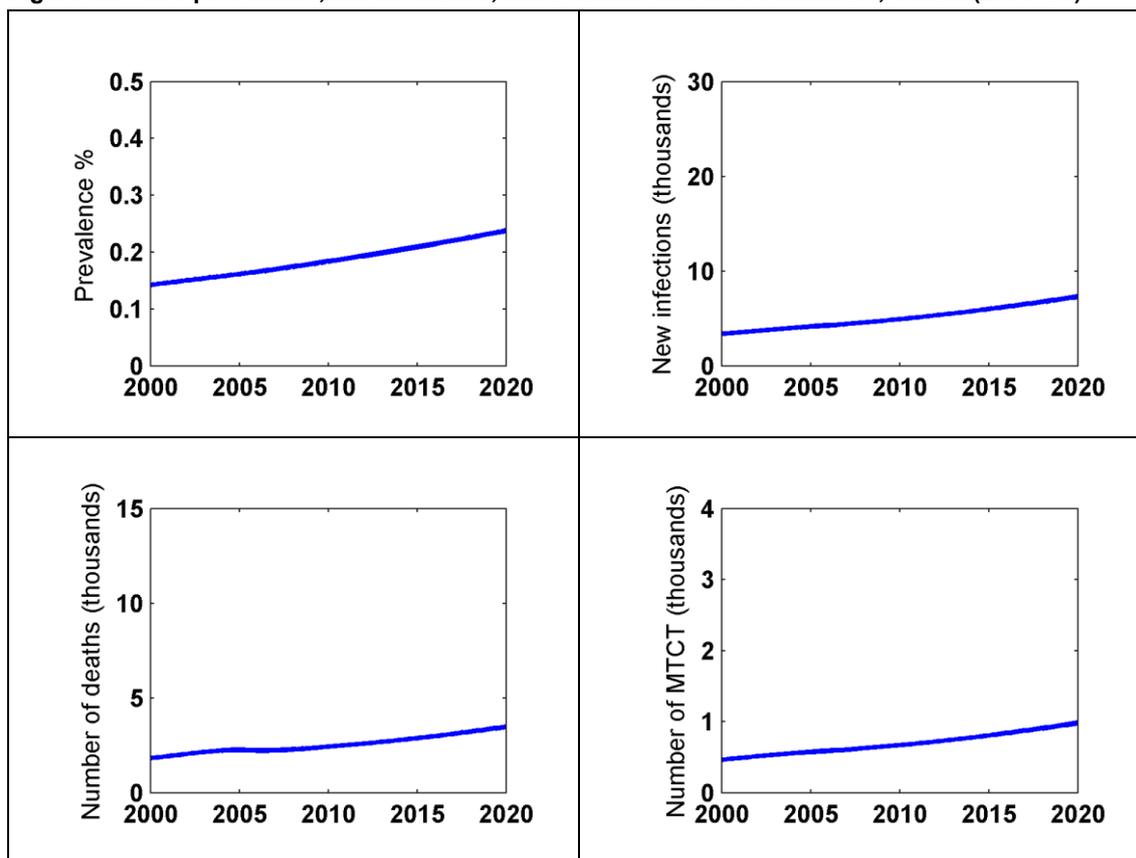


Sources: Populated Optima model for Sudan

Note: Female populations in pink, male populations in blue. MTCT = mother-to-child transmission, FYTH = females 15–24 yrs, MYTH = males 15–24 yrs, FAD = female adults 25–49 yrs, MAD = male adults 25–49 yrs, FELD = females aged 50+ yrs, MELD = males aged 50+ yrs, FSW = female sex worker, SWC = sex work client, MSM = men having sex with men.

Optima projects slowly increasing trends for HIV prevalence, HIV incidence, AIDS deaths and MTCT numbers—Figure 19. These trends are similar to those projected by Spectrum (**Annex 3**). The temporal increase in HIV prevalence arises through the combined effects of HIV incidence and ART. The average population growth of about 1.5% as per UN Population Division estimates contributes to the rise in new infections, mother-to-child transmission and deaths.

Figure 19. HIV prevalence, HIV incidence, AIDS deaths and MTCT numbers, Sudan (2000–30)



Sources: Populated Optima model for Sudan

4.2 Program data on maternal HIV prevalence

This analysis evaluated the 2013 PMTCT program delivery statistics to contribute to the policy dialogue on investing in this program targeting members of the general population within a context of a low-level HIV epidemic. It also served to inform the modelling scenarios for optimal resource allocation (subsequent report sections). The overall policy question is whether Sudan should invest in PMTCT, and if so, should it be selectively scaled up in certain areas of the country.

PMTCT has been developed and scaled up rapidly, from 71 PMTCT sites in 2011 to 227 in 2013, allowing the HIV testing of 84,916 pregnant women in 2013 (UNGASS progress report 2014)¹⁰. No testing could be offered yet for early infant diagnosis by Polymerase Chain Reaction (PCR) test, and there is no nationally collated data to indicate the outcomes of mother baby pairs.

¹⁰ Sudan report 2014 http://www.unaids.org/en/dataanalysis/knowyourresponse/countryprogressreports/2014countries/SDN_narrative_report_2014.pdf, accessed 4 June 2014

In 2013, about 150 HIV positive mothers were diagnosed in the PMTCT services, which translates to 2% of women estimated to be in need of PMTCT (UNGASS report, based on Spectrum¹¹). With this scale of the PMTCT program, the government considers the impact of PMTCT in prevention of vertical transmission to be very limited. The reported key challenges are in integrating human resource and HIV supplies management between of the RH and HIV service delivery, curative and laboratory directorates at all levels to work together to increase the coverage and quality of services in PITC in RH health facility outlets and at community level and linked detected positive cases to HIV care (UNGASS report).

In summary, the 2013 PMTCT site statistics are as follows:

- 254 PMTCT sites reported HIV testing data (see **Figure 20** for site specific HIV prevalence levels based on 2013 program statistics – GARPR report has lightly lower number of 227 PMTCT sites).
- Of all PMTCT sites, 24% (62) reported identifying at least one HIV-positive pregnant woman, 76% (192) did not find any HIV positive woman.
- Six sites reported five or more HIV diagnoses: Kassala Saudi Hospital (12), Omdurman, Khartoum (11), Er Roseires, Blue Nile (9), Madani, GA (7), SFGA PHC Center, NK (5) and Elehtiati Elmarkzi, RS (5).
- The nine sites with maternal HIV prevalence levels of 1% and above are shown in **Table 3** (sites with less than 50 women tested are excluded in the table, but shown in **Figure 20**).

Table 3. PMTCT sites reporting HIV prevalence of 1% or higher, Sudan (2013)

PMTCT site	State	HIV prevalence, % (n/N)
Elmikilab	RN	3.07 (5/163)
Yashfeen	SD	2.80 (4/143)
Er Roseires	BN	2.51 (9/358)
Deim Eltjani	RS	1.92 (1/52)
Al Junaynah	GED	1.83 (2/109)
Elehtiati elmarkzi	RS	1.30 (5/385)
Wadabook	BN	1.27 (2/157)
Elthawra halfa	KAS	1.15 (1/87)
Elwahda Janoob	SD	1.11 (2/180)

¹¹ Authors' calculation: 7.2% (150 HIV+ among an estimated 2,070 pregnant women expected to be positive: 1.3 million pregnancies x 0.16% HIV prevalence in ANC sentinel surveillance).

The average HIV prevalence in PMTCT clients per state is depicted in Figure 21. Red Sea and Kassala lead the statistics (0.39%), followed by Blue Nile (0.25%), Khartoum and North Darfur (0.24%) and Central Darfur (0.20%). Sinnar reported no cases (0/3350 tested), and similarly East Darfur also did not report cases (0/821).

Figure 20. HIV prevalence at PMTCT sites, Sudan (2013, includes 192 sites with no HIV cases)

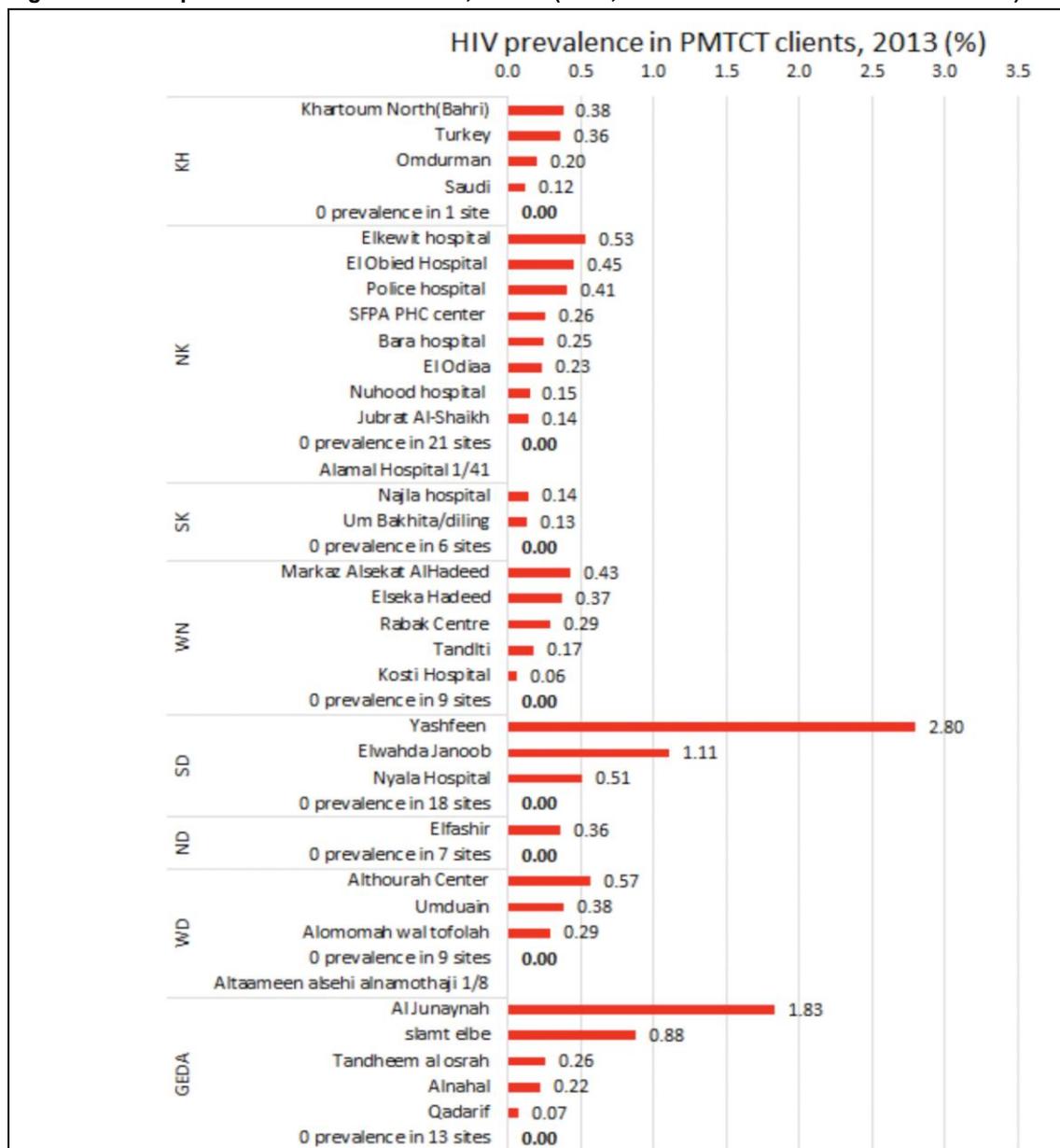
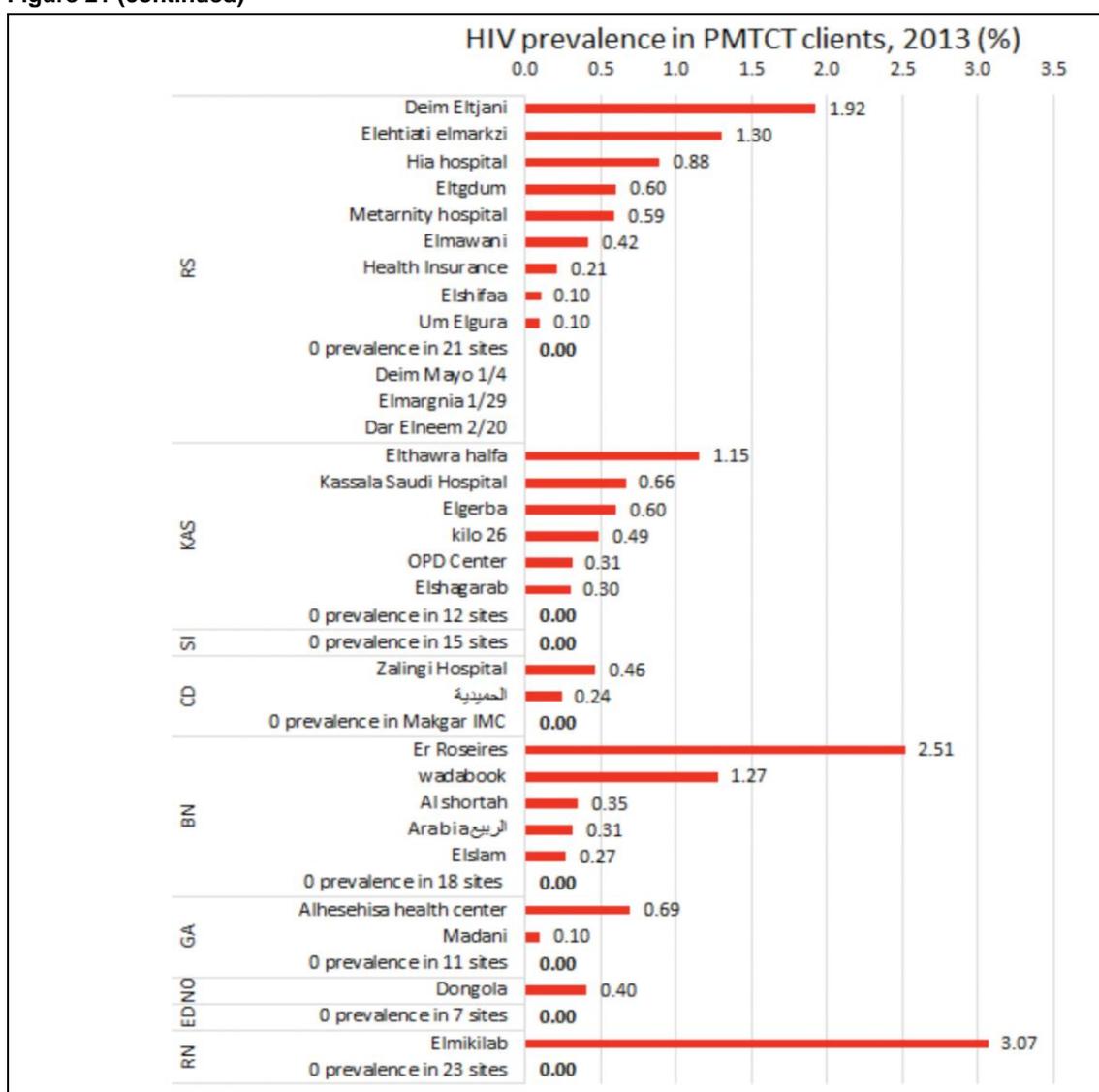
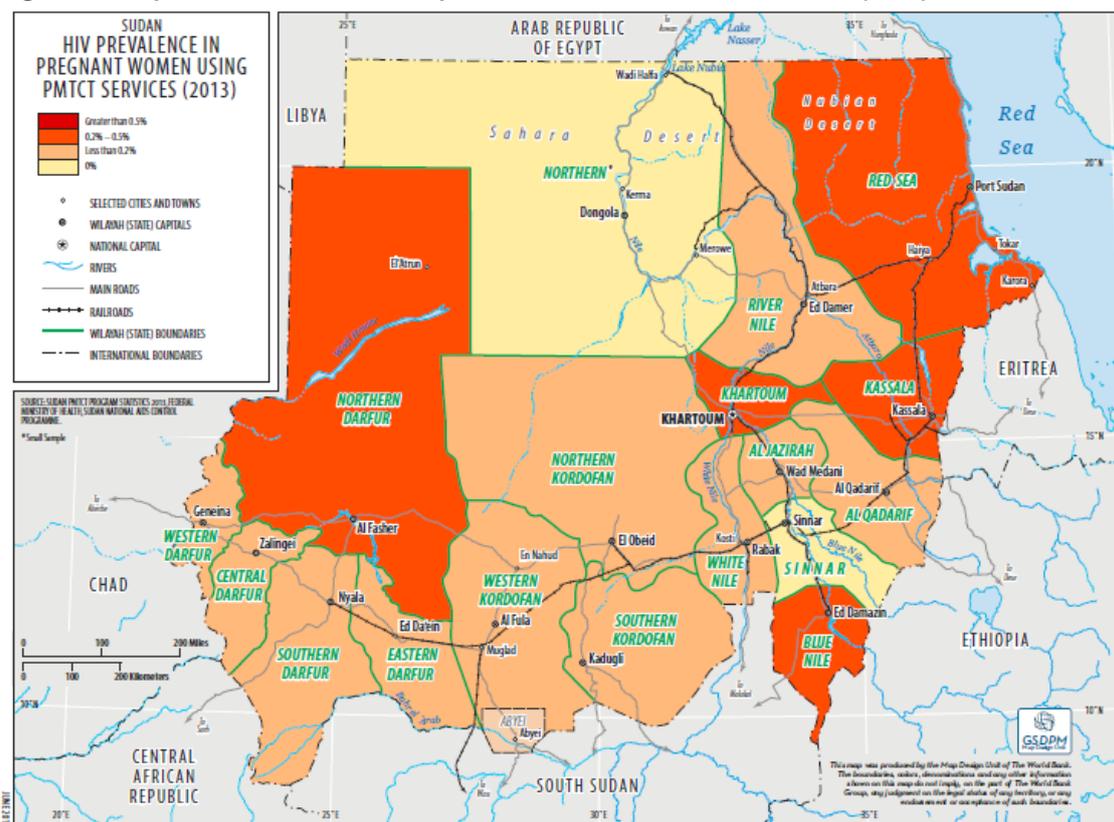


Figure 21 (continued next page)

Figure 21 (continued)



Source: Sudan PMTCT program statistics 2013, Federal Ministry of Health, Sudan National AIDS Control Programme.

Figure 21. Spatial distribution of HIV prevalence in PMTCT clients, Sudan (2013)

Source: Sudan PMTCT program statistics 2013, Federal Ministry of Health, Sudan National AIDS Control Program.

Note: Northern state had a very small sample size (248 women screened, one HIV case). Northern Darfur only had positive cases in Al Fashir in the south (4/1119), a market town and new economic centre. All other 7 PMTCT sites had no cases, the full colouring in of the state needs to be interpreted in this way.

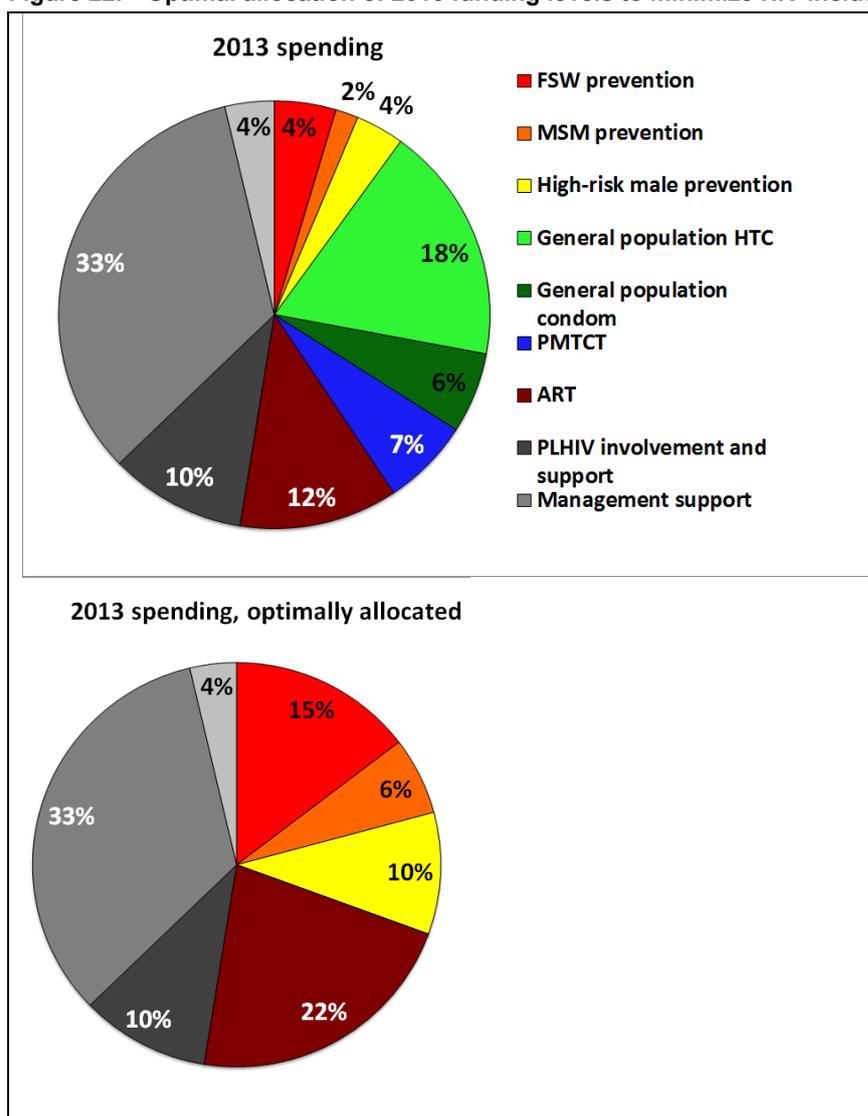
4.3 Optimized allocations to minimize HIV incidence

The key analytical work in this study was on **optimal resource allocation to meet specific HIV objectives, using the Optima model**. In this section we present findings on optimized allocations for minimizing new HIV infections.

The analysis suggests that in order to minimize HIV incidence by 2020 at 2013 programmatic funding levels, allocations need to shift to FSW, client and MSM interventions as well as ART, and away from programs targeted at the general population (which has below 0.05% HIV incidence) – Figure 22.

- Analysis assumes 2013 expenditure amounts are annually available until 2020 (total annual budget of USD 12.2 million, of which USD 6.4 million is being optimized for HIV impact)
- All prevention programs include condoms, HTC, SBCC, ART includes HIV testing. Packages do not include enabling environment expenditure

Figure 22. Optimal allocation of 2013 funding levels to minimize HIV incidence by 2020, Sudan



Sources: Populated Optima model for Sudan. Note that prevention packages do not include ART here and that ART is shown separately for all populations combined.

Note: Expenditure areas not included in optimization (effect on HIV incidence, morbidity/mortality not understood): PLHIV involvement and support, Management, and Strategic information.

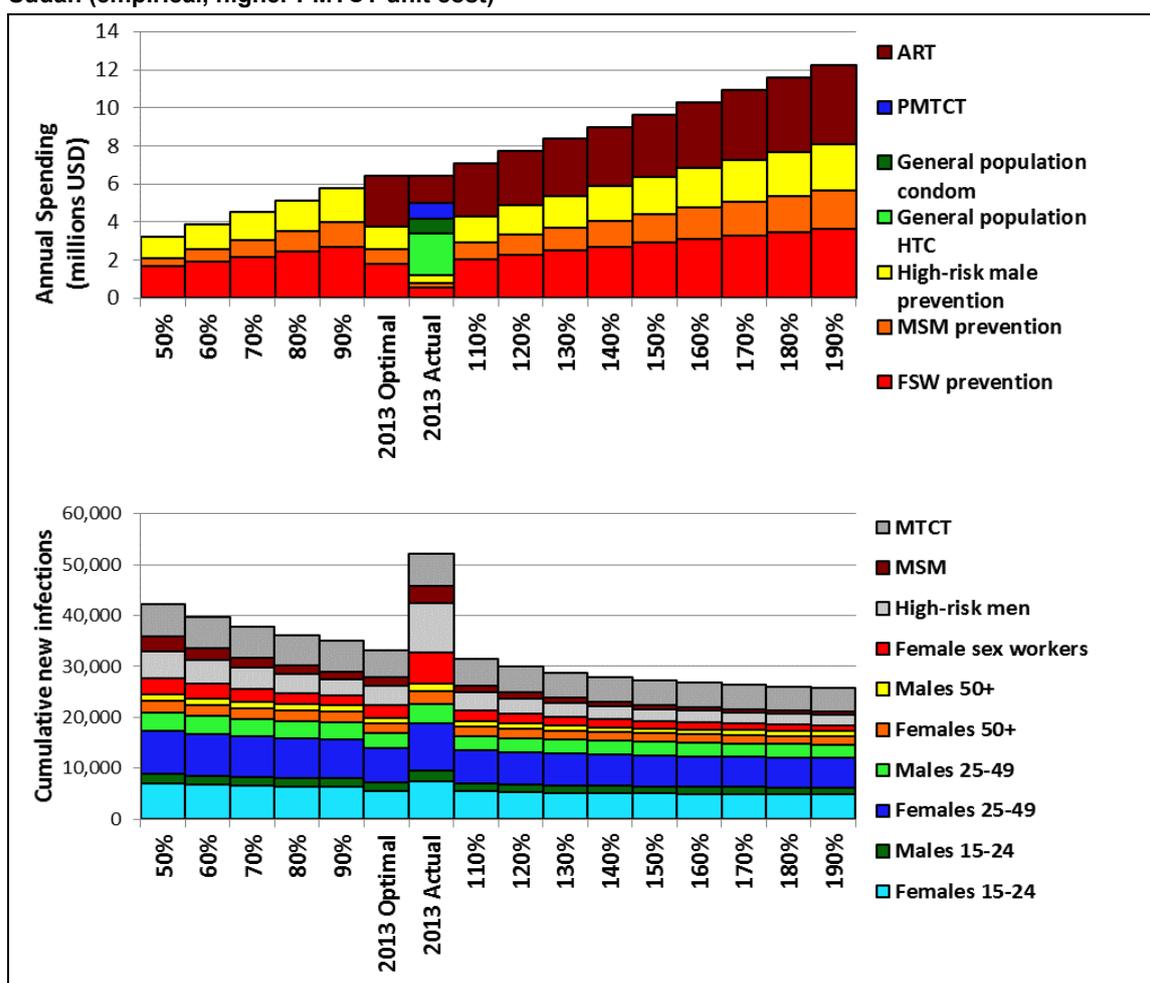
At the 2013 resource level, PMTCT is not part of the optimal mix. In the course of the optimization analysis, it became evident that it would be policy-relevant to run **two different scenarios on PMTCT allocations**, to give specific input into the allocative decision-making on PMTCT. One scenario uses the PMTCT unit cost derived from empirical data (expenditure and number of PMTCT beneficiaries), which results in a unit cost of USD 9,016 (see **Table 2**). Secondly, the optimization analysis used the PMTCT unit cost based on projections by government within the framework of the new, prioritized NSP, which is USD 2,666 (**Table 2** and table annotation). This lower unit cost will have arisen in a more established PMTCT program delivered at scale and which is targeted for better cost-effectiveness, as per the key guiding principles of the NSP. The results of the two scenarios, using different PMTCT unit costs are described

in the following sections. Note that in **Figure 22**, PMTCT is not part of the optimal mix even at the lower unit cost.

With the same USD 6.4 million, Sudan could avert an additional 36% of cumulative HIV infections during the 2014–20 period if these resources were allocated optimally—Figure 23:

- The Sudan HIV response can become more allocatively efficient by prioritizing expenditure for higher-risk groups (SW, clients, MSM) and ART-eligible PLHIV, and de-prioritizing expenditure for the low-risk general population, reducing the cumulative HIV incidence by approximately 19,000 infections or 36% by 2020 (this optimal allocation also reduces cumulative deaths by 6,744).
- In case the Sudan HIV response has more programmatic funding available than the USD 6.4 million in 2013—through mobilizing additional funds, moving management/coordination funds towards intervention programs—additional HIV incidence reductions can be obtained.

Figure 23. Optimized allocations to minimize HIV incidence by 2020 at different budget levels, Sudan (empirical, higher PMTCT unit cost)



Sources: Populated Optima model for Sudan. Prevention packages do not include ART (which is shown separately).

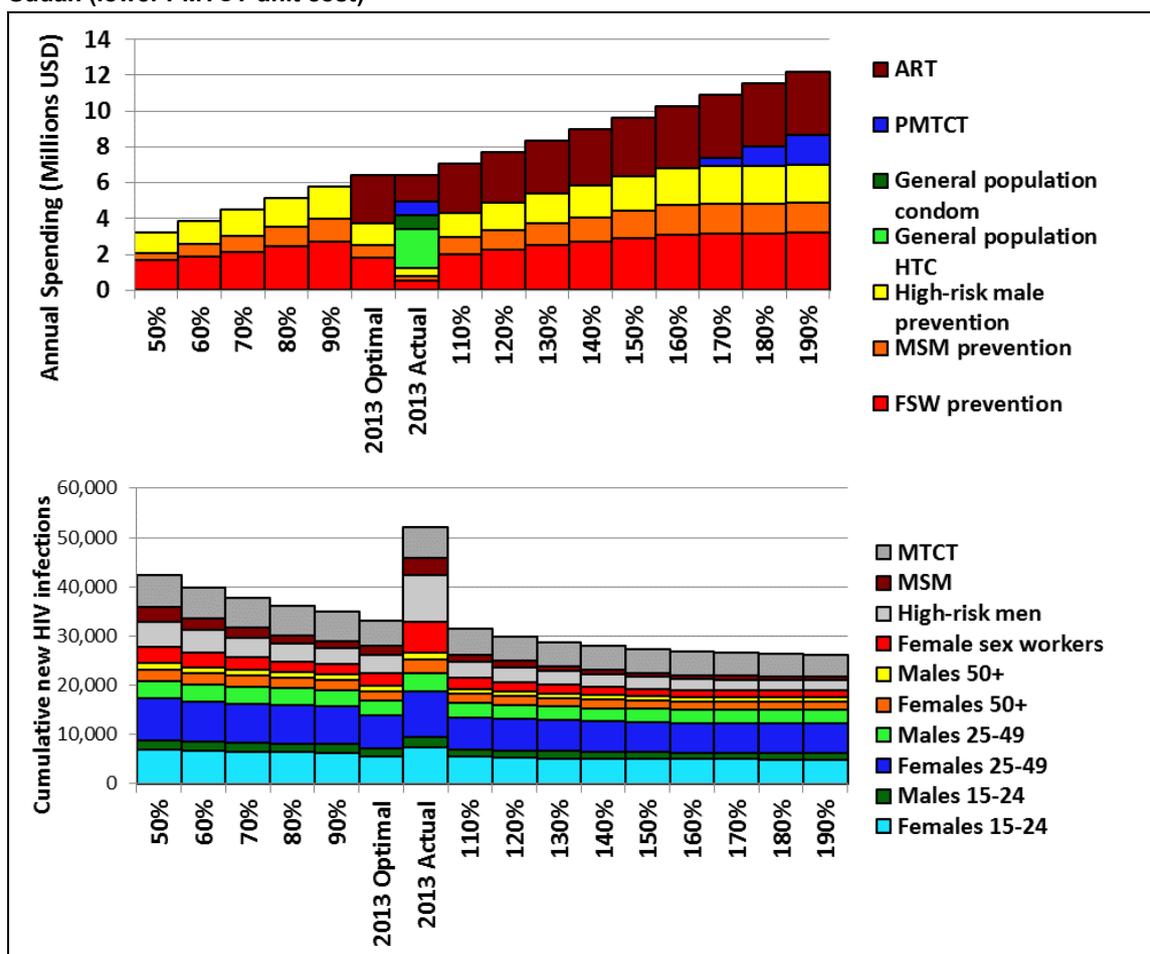
The following observations can be made when comparing **optimal allocations for reducing new infections** for different funding amounts:

- For any total investment between 100% and 190% of 2013 spending, optimization suggests that investment should be focused on four programs: prevention among FSW, MSM and men at higher risk (sex work clients) as well as ART.
- If only 50% to 90% of 2013 spending is available, optimization suggests that investment should be focused on prevention among FSW, MSM and higher risk men (sex work clients).¹²
- General population expenditure only starts to come into the allocation mix at 700% of budget (not shown in figure).

Even if the lower unit cost for PMTCT from the 2015–17 NSP is applied, PMTCT only enters the allocation mix at 170% of the 2013 programmatic spending amount (USD 10.7 million) (**Figure 24**). Additional analysis suggested that PMTCT would only receive substantial proportions of funding if unit cost was reduced to around USD 500 for identifying one HIV positive woman. However, this is difficult to achieve in a context of HIV prevalence of below 0.2% among pregnant women, where over 500 HIV tests are required to identify one HIV positive woman. This suggests that in the context of limited resources, PMTCT targeting to geographical areas with higher HIV prevalence would be needed to make PMTCT programs cost-effective compared to other HIV prevention interventions and ART.

¹² The fact that ART receives a large portion of funding at 100% of 2013 spending, but is not part of the package at lower amounts of investment might appear counter-intuitive, but is due to a combination of reasons. It needs to be considered that this is the optimal mix for *reducing new infections* and that the prevention programs for key populations included in the optimal mix can achieve moderate increases in condom use at relatively low cost (for reducing deaths and DALYs, ART is part of the optimal mix at all levels of investment). In addition, the initial set up cost for a program, which in the model is reflected in the cost-outcome curves, implies that with limited resources running several programs at low intensity is not cost-effective and therefore only a small number of programs can be run cost-effectively in scenarios with low resource availability. Furthermore, if two programs have very similar cost-effectiveness, optimization will not propose a split of funding between the two programs, but propose funding the slightly more cost-effective program. Only once a tipping point is reached, where the set up and basic running cost for a program is reduced through economies of scale, funding for a program becomes part of the optimal mix. After this tipping point is reached like it is the case for ART between 90 and 100% of current funding, the allocation to the program can be substantial as its unit cost will be lower than the unit cost of the “competing” program. This explains why at 100% of 2013 spending, ART enters the optimized mix of allocations for reducing new infections and already receives over one third of programmatic spending.

Figure 24. Optimized allocations to minimize HIV incidence by 2020 at different budget levels, Sudan (lower PMTCT unit cost)



Sources: Populated Optima model for Sudan. Prevention packages do not include ART (which is shown separately)

Table 4 provides the Optima estimations on condom use and HIV testing rates as a function of optimized spending levels in the different populations for both PMTCT spending scenarios.

Table 4. Optimized spending amounts to minimize HIV incidence and estimated behavioral outcome, Sudan

Program area	Percentage allocation of total budget		Estimated behavior as a function of spending		
	2013	Optimized spending	Outcome	2013	Optimized spending
FSW, prevention	4%	15%	Testing rate	7.7%	34.6%
			Condom use (regular)	5.0%	7.1%
			Condom use (casual)	10.7%	26.1%
			Condom use (commercial)	21.4%	38.0%
MSM, prevention	2%	6%	Testing rate	4.9%	23.5%
			Condom use (regular)	19.0%	21.0%
			Condom use (casual)	19.0%	45.9%
			Condom use (commercial)	19.0%	61.0%

Table 4 (continued on next page)

Table 4 (continued)

Program area	Percentage allocation of total budget		Estimated behavior as a function of spending		
	2013	Optimized spending	Outcome	2013	Optimized spending
High-risk males (SW clients), prevention	4%	10%	Testing rate	3.3%	4.5%
			Condom use (regular)	0.1%	0.1%
			Condom use (casual)	7.5%	10.7%
			Condom use (commercial)	21.4%	38.0%
General population, HTC	18%	0	Testing rate	3.3%	3.3%
General population, condom	6%	0	Condom use (regular)	0.1%	0.1%
			Condom use (casual)	7.5%	6.1%
PMTCT	7%	0	Pregnant women covered	3.4%	0.0%
ART	12%	22%	# people on ART	3307	6756

Sources: Populated Optima model for Sudan.

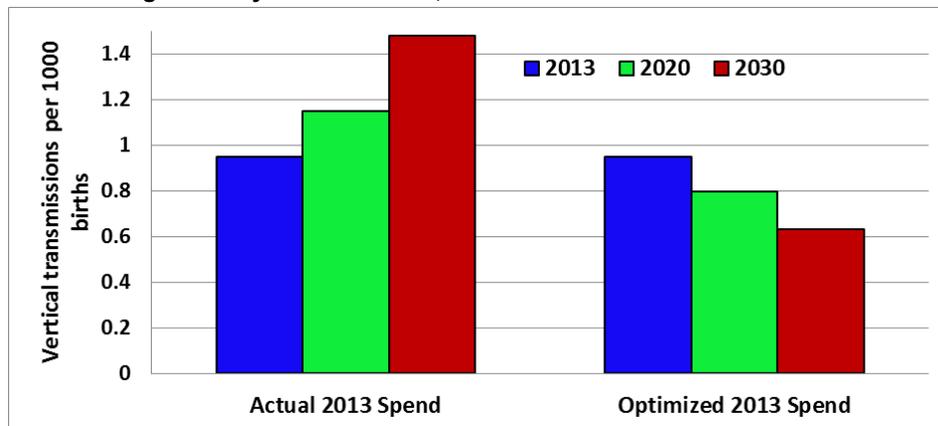
Note: Prevention packages do not include ART here and that ART is shown separately for all populations.

The baseline and optimal allocation were also compared in terms of their impact on vertical transmission by 2020 and 2030. The projected rate of HIV-positive infants is shown in **Figure 25**, for two allocation scenarios: the 'baseline' scenario, in which the programmatic spending continues as it was in 2013; and an optimized scenario, in which we assume that the 2013 budget is annually available and is optimized to minimize incidence by 2020. The model assumed that in the absence of intervention, the probability of vertical transmission from HIV-positive women to their babies is 38% for breastfeeding mothers and 25% for non-breastfeeding mothers.

- In the baseline scenario, all programs are funded at the level of 2013 budgets, which means PMTCT programs receive 7% of all programmatic funding. Prevention among key populations and ART receive less funding than in the optimized scenario. Due to the limited coverage that can be reached with the limited resources in a national PMTCT program, the impact of PMTCT program funding on vertical transmission remains low. Increases in new infections among key populations and their downstream effects on pregnant women will lead to increasing mother-to-child transmission.
- In the optimized scenario, PMTCT programs drop out of the HIV allocation mix, but nevertheless *the projected number of HIV-positive infants per 1,000 live births declines relative to the baseline scenario because of the reduction in HIV infections in females (an indirect effect of the key population interventions and ART scale-up).*

- In both scenarios, there is either no or very small reach of PMTCT, and the overall rate of vertical transmission from HIV-positive women to their babies stays at almost the same levels.

Figure 25. Projected rate of vertically infected children under different allocation scenarios of 2013 funding levels by 2020 and 2030, Sudan



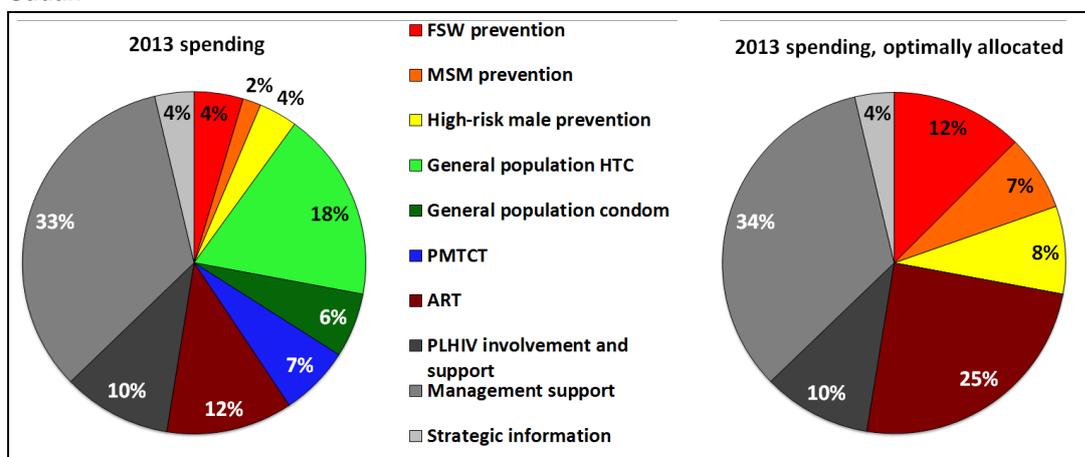
Sources: Populated Optima model for Sudan.

4.4 Optimized allocations to minimize HIV-related DALYs

In order to minimize HIV-related DALYs in the population by 2020 (i.e., lowest cumulative DALYs, highest DALYs averted), very similar budget reallocations would need to be made as when aiming for minimal HIV incidence—Figure 26:

- ART would receive more funding since it is the principal intervention to reduce AIDS morbidity and mortality (25% instead of 22% for the HIV incidence objective)

Figure 26. Optimal allocation of 2013 funding levels to minimize HIV-related DALYs by 2020, Sudan

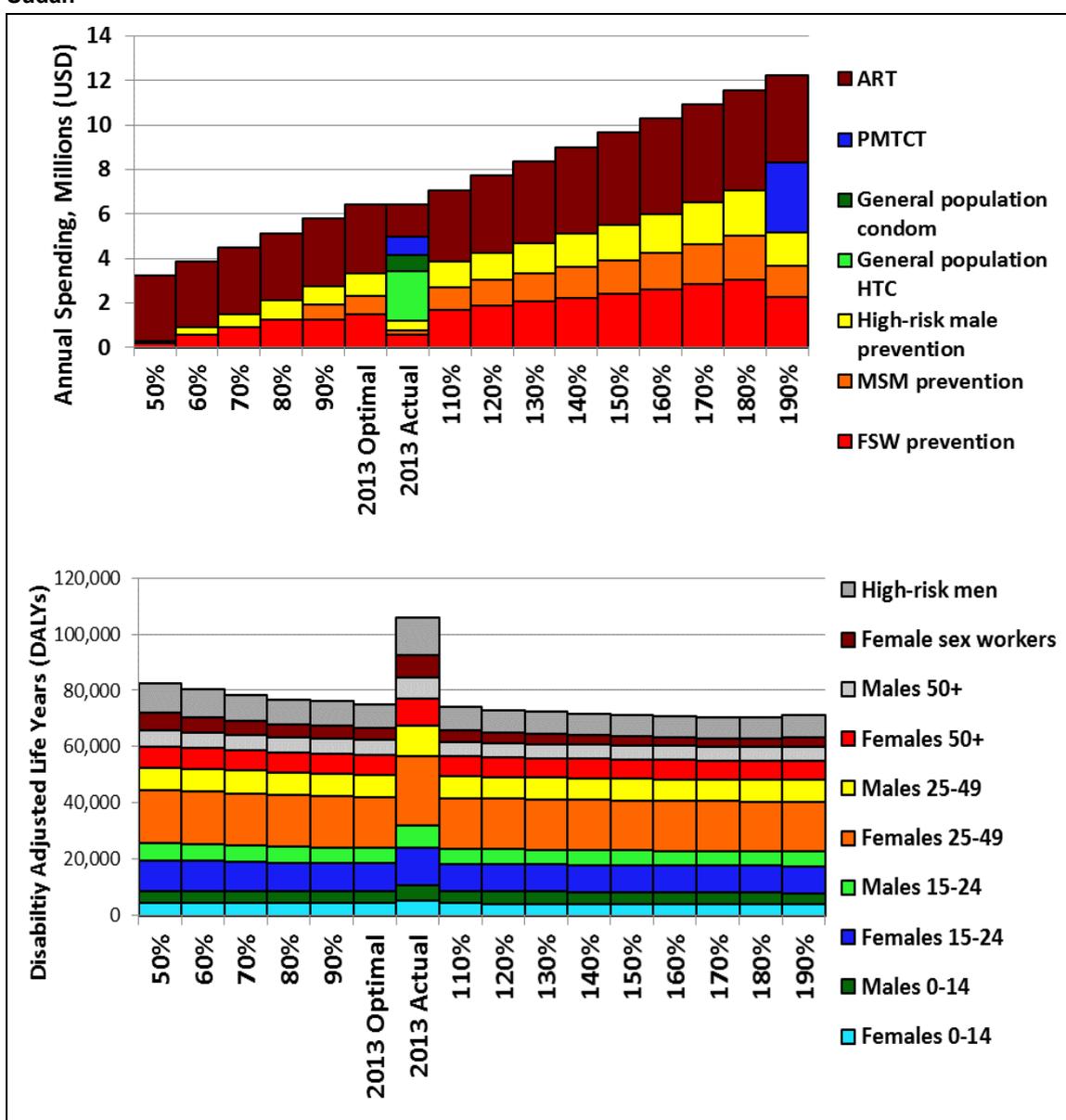


Source: Populated Optima model for Sudan.

Note: Prevention packages do not include ART (which is shown separately). Expenditure areas not included in optimization (effect on HIV incidence, morbidity/mortality not understood): PLHIV involvement and support, Management, and Strategic information.

- With a quarter of the total HIV response budget going to ART in this scenario, the contribution of the prevention packages regarding HIV case finding is essential (all prevention packages include HTC). In order to initiate ART in eligible individuals, the HTC activities would have to be targeted to higher-yield sub-populations – key populations (FSW, clients, MSM), TB cases, STI clients, spouses and partners of known PLHIV.
- Programmatic funding as available in 2013 (USD 6.4 million) would avert additional DALYs if allocated optimally. This would avert approximately **29,300 additional HIV-related DALYs (23%)** compared to the non-optimal 2013 allocation pattern.

Figure 27. Optimal allocations to minimize HIV-related DALYs by 2020 at different budget levels, Sudan



- With increasing availability of funding, the optimal mix would only include ART and prevention for key populations up to 180% of 2013 spending. PMTCT would become part of the mix of allocations at 190% of 2013 spending. General population prevention would not be part of the optimal mix for reducing DALYs.
- If less funding than in 2013 was available, ART would remain the key investment to reduce DALYs, while HIV prevention in sex work settings would also remain part of the optimal mix, but its share reduced at lower funding levels.

4.5 Optimized allocations to minimize the costs of reaching 2020 impact and coverage targets

The Optima model was also used to determine the optimal HIV program resource allocations to achieve specific impact and coverage targets at lowest costs by 2020. For the purpose of this analysis, two impact and coverage scenarios were defined as follows:

Scenarios:	Impact: Reduce HIV incidence by 2020	Impact: Reduce AIDS deaths by 2020	Coverage: ART	Coverage: PMTCT
Ambitious	-50% (to 3,188)	-50% (to 1,359)	80%	80%
Moderate	-25% (to 4,782)	-25% (to 2,038)	60%	60%

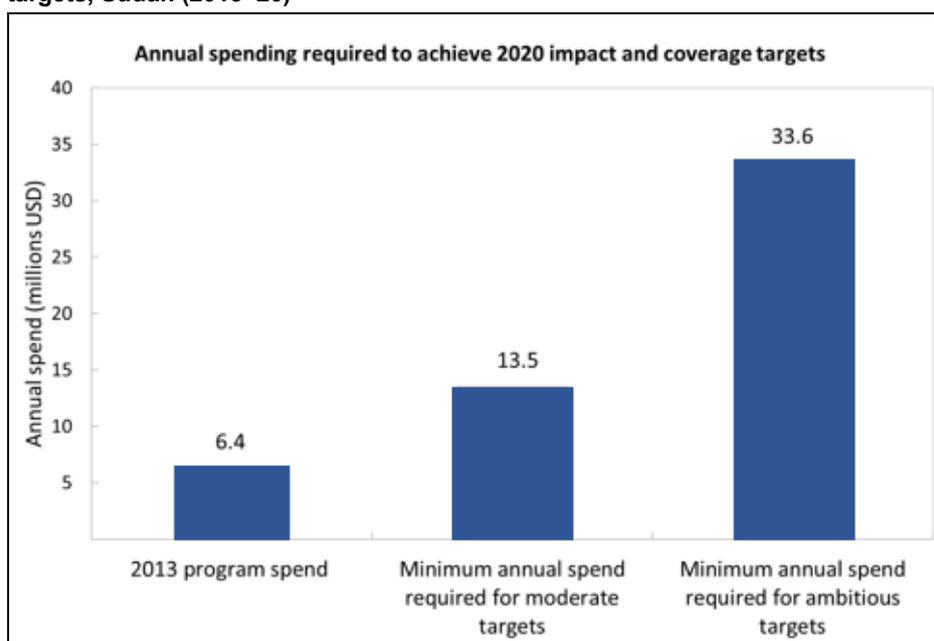
Meeting impact targets:

- Ca. USD 14 million annually for programs could lead to achievement of the moderate targets of 25% incidence and AIDS mortality reduction by 2020 (= 220% of the spend of USD 6.4 million in 2013)
- Achievement of ambitious targets (50% reduction in HIV incidence and AIDS deaths by 2020) would require an estimated USD 34 million annually for basic programs (= over 5 times the spend of USD 6.4 million in 2013)

We found that reaching 60% PMTCT coverage would in the Sudan context be very resource intensive. The model predicted that meeting the 60% PMTCT target would absorb 50% of all program spend.

Figure 28 shows the minimal annual resource allocation required to achieve the 2020 impact and coverage targets; **Figure 29** shows the minimal annual resource allocation required to achieve the 2020 impact targets only.

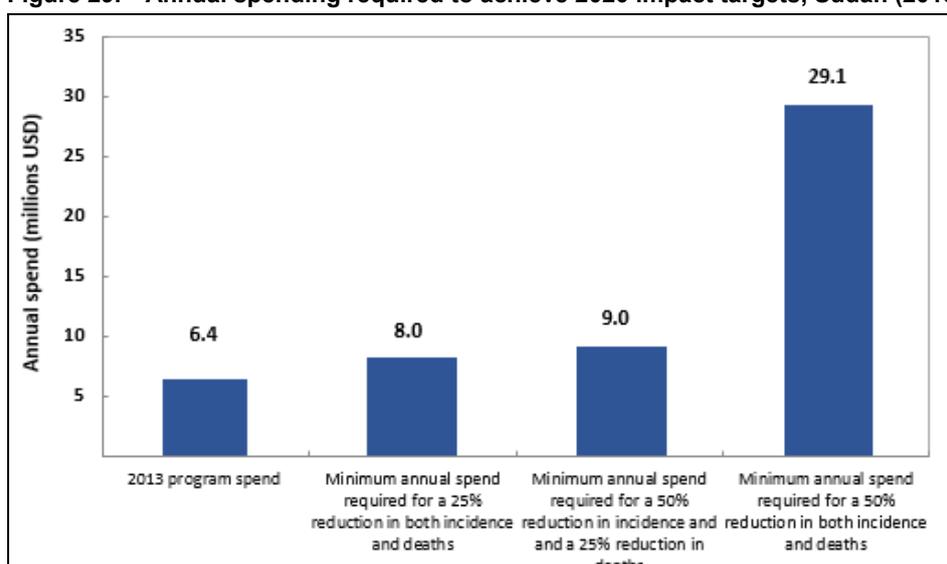
Figure 28. Annual resource allocation to minimize spending to achieve 2020 impact and coverage targets, Sudan (2013–20)



Sources: Populated Optima model for Sudan

Note: Moderate targets = 60% coverage of ART and PMTCT, 25% reduction in HIV incidence and AIDS deaths. Ambitious targets = 80% coverage of ART and PMTCT, 50% reduction in HIV incidence and AIDS deaths.

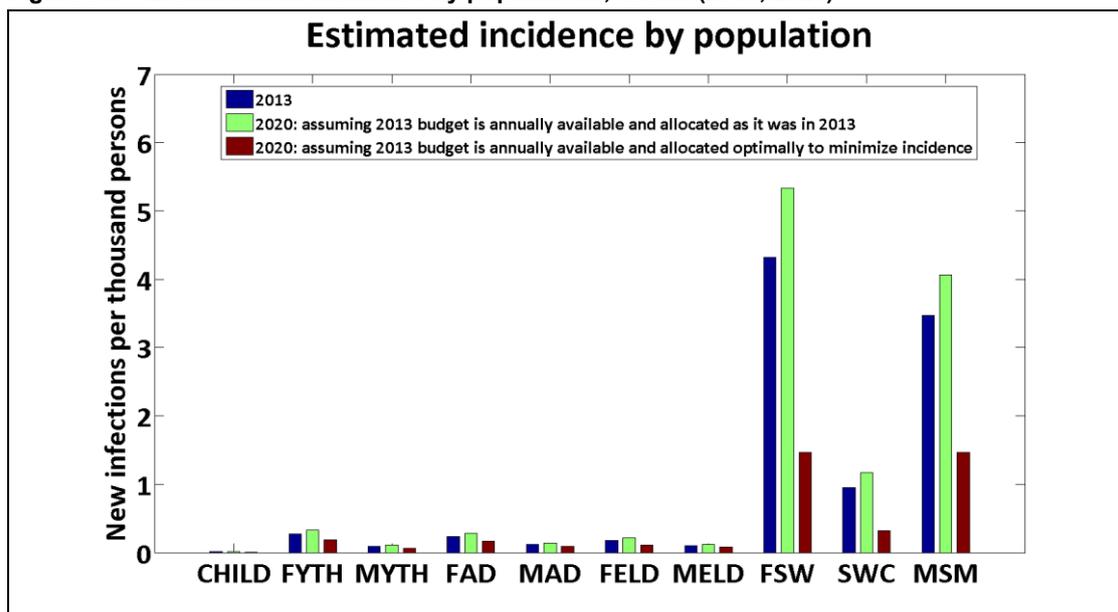
Figure 29. Annual spending required to achieve 2020 impact targets, Sudan (2013–20)



Sources: Populated Optima model for Sudan

The prevention impact of optimal allocation of USD 6.4 million (2013 programmatic expenditure) is shown in **Figure 30**. The key message is that **an allocatively more efficient HIV response—targeted to key populations and prioritizing HIV treatment—would reduce HIV incidence in all population groups**. This is to be expected in a low-level HIV epidemic, where transmission in the general population is largely fuelled by new infections occurring in the key populations.

Figure 30. Estimated HIV incidence by populations, Sudan (2013, 2020)



Sources: Populated Optima model for Sudan.

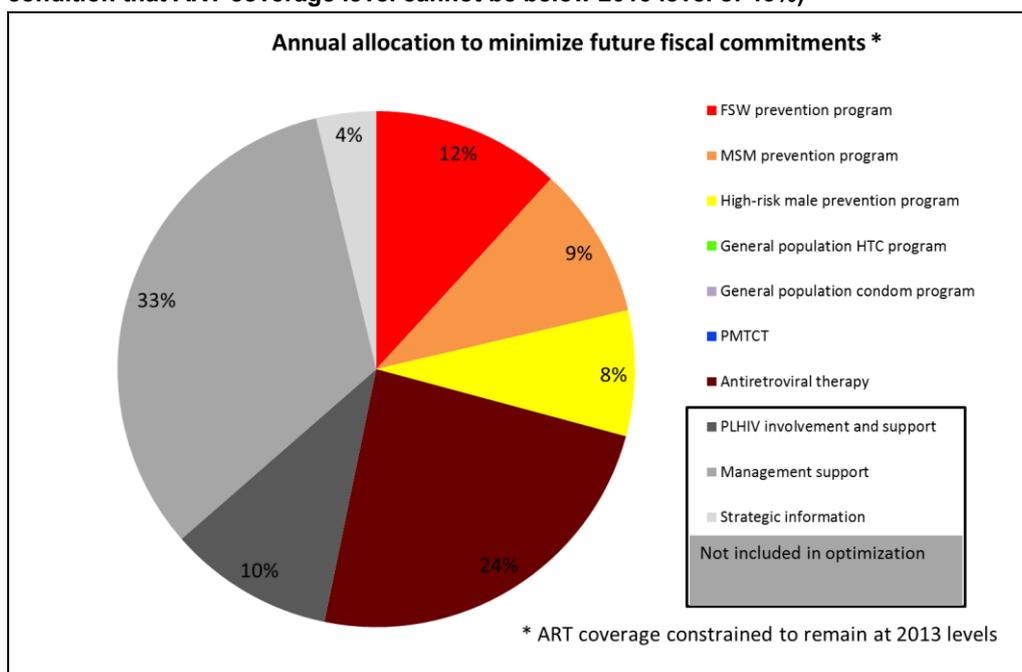
Note: MTCT = mother-to-child transmission, FYTH = females 15–24 yrs, MYTH = males 15–24 yrs, FAD = female adults 25–49 yrs, MAD = male adults 25–49 yrs, FELD = females aged 50+ yrs, MELD = males aged 50+ yrs, FSW = female sex worker, SWC = sex work client, MSM = men having sex with men.

4.6 Optimized allocation to minimize spending commitments caused by HIV infections

Each existing HIV infection represents a future treatment liability. The government will have to pay for the care and treatment costs associated with HIV infections for the rest of PLHIVs' life. An important objective is therefore be to minimize HIV-related fiscal costs by preventing new HIV infections while maintaining a given level of treatment for those in need. This objective does require an ART coverage condition, otherwise the cheapest (but unacceptable option) would be to let people die of HIV/AIDS related conditions without spending on their treatment and care. Our analysis therefore assumed that the ART coverage level would not be allowed to drop below the 2013 level. **Figure 31** shows the annual allocation mix 2014–30 that will reduce the long-term fiscal commitments up to 2050.

- The longer-term objective of minimizing fiscal commitments for health care of people living with HIV requires a **very similar allocation mix** to the mid-term objectives of minimizing HIV incidence and DALYs (for a summary, see **Table 5** in section 5.3. of the discussion chapter).

Figure 31. Annual HIV allocations 2014–30 to minimize fiscal commitments until 2050, Sudan (with condition that ART coverage level cannot be below 2013 level of 46%)



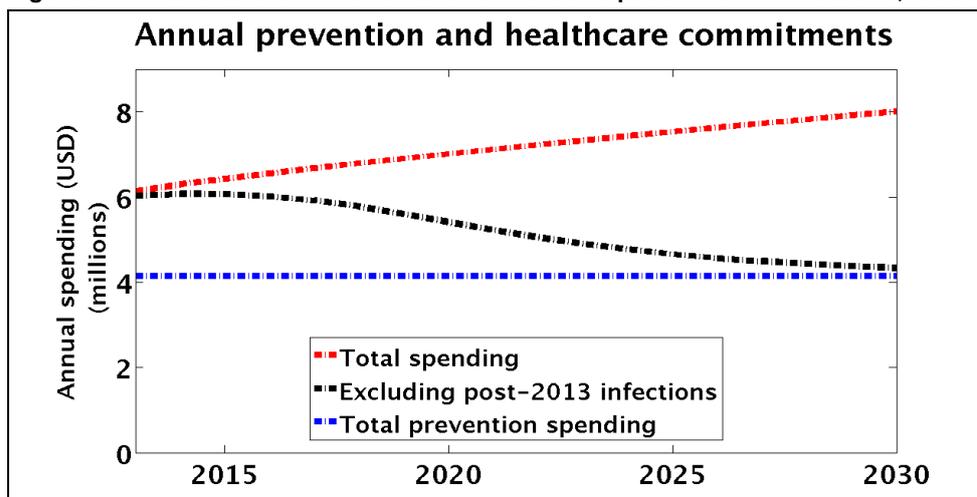
Source: Populated Optima model for Sudan.

Note: Prevention packages do not include ART (which is shown separately)

Figure 32 explores further the future HIV spending needs up to 2030, again under the condition of not allowing ART coverage to go below the 2013 level of 46% (HIV prevention costs are kept constant for this projection). Unit costs are as per **Table 2**. Average health care costs per PLHIV per year are set at USD 141.55. ART costs, averaging at USD 440 overall, are split into costs of first-line ARVs (USD 193.50) and second-line ARVs (USD 1,059.38).

- HIV response costs are projected to rise gradually as new HIV infections occur and new and old HIV infections require treatment, with the additional effect on costs as the Sudan population grows.
- New, post-2013 HIV infections play an important part in overall future treatment commitments.
- **This projection emphasizes the need for higher-impact HIV prevention targeting in order to reduce the projected future health care costs.**

Figure 32. Healthcare commitments for current and post-2013 HIV infections, Sudan



Source: Populated Optima model for Sudan.

Note: Prevention packages do not include ART (which is shown separately)

4.7 Optimized allocations to minimize the cost of achieving 2016 impact targets

Lastly, the modelling looked at the optimization objective of minimizing spending to achieve impact targets of 25% reduction in HIV incidence and deaths *in the short-term*, by 2016.

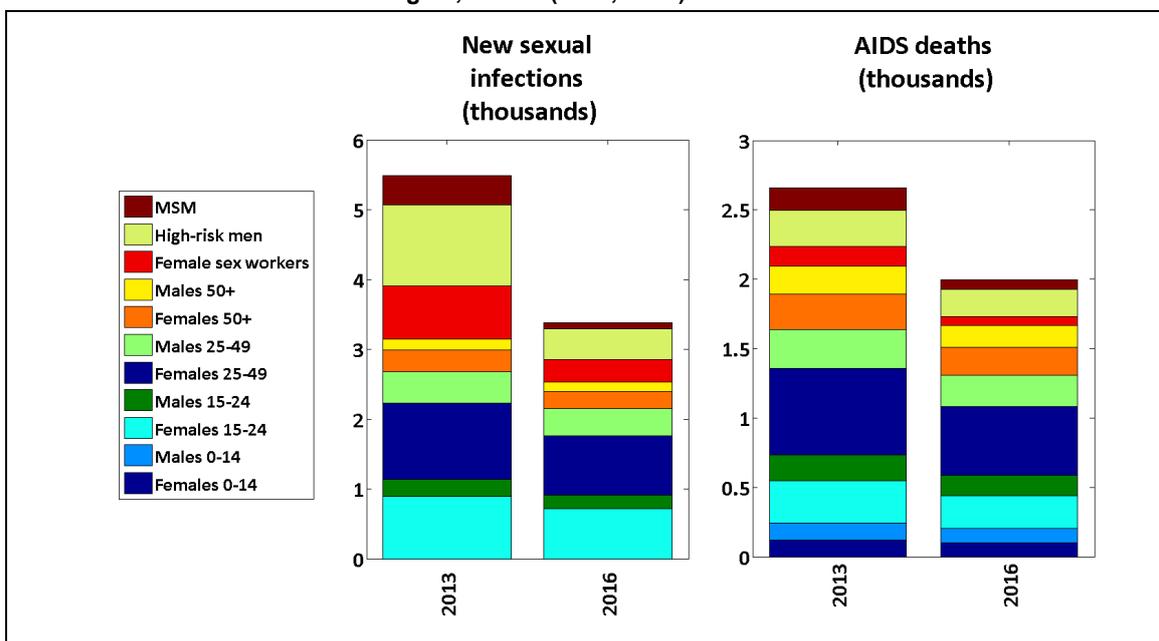
The modelling analysis estimates that about USD 8.1 million would need to be allocated annually to four priority interventions until 2016. This would lead to the achievement of the 2016 impact targets (of 25% reduction in HIV incidence and deaths).

- ART and prevention services for FSW, their clients and MSM would need to be prioritized.
 - Allocations to ART would increase from 23% to 40% of all programmatic funding
 - Instead of allocating 9% of all programmatic funding to FSW interventions, 23% would be allocated.
 - Other increases would be from 7% to 16% (high-risk males/clients), and from 3% to 21% (MSM).
- Programs targeted at the low-risk general population would need to be de-prioritized (HCT, condoms), and the same would apply to PMTCT.

Such annual investment of USD 8.1 million, optimally allocated to achieve the impact targets, would reduce HIV incidence and deaths in all populations—**Figure 33.**

- The HIV incidence target would, according to our model prediction, be exceeded while the AIDS death target of 25% reduction would be achieved.
- Reducing deaths beyond a certain level becomes very expensive as more lower-risk people need to be screened to identify HIV cases and eventually treat them to ensure their survival.

Figure 33. Population-specific impacts of optimally allocated HIV funding required to reach overall HIV incidence and death targets, Sudan (2013, 2016)



Source: Populated Optima model for Sudan

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5. Discussion

5.1 Epidemic spread and potential

Although Sudan has a low-level HIV epidemic, HIV prevalence levels have recently been measured as high as 7.7% in FSW in Red Sea and about 10% in non-Sudanese FSW in Kassala, and 6.3% in MSM in Kassala and 4.1% in South Darfur. In the general population, HIV prevalence reached 0.54% in Red Sea, and 0.39% in PMTCT clients in Red Sea and Kassala. However, many other population groups encounter very low HIV risks. The epidemic spread is therefore highly variable by population group and location, and this knowledge must be used in HIV strategy and decision-making.

Considering the large differential in HIV prevalence between the main key populations (FSW and MSM) and the general population, it follows that these key populations drive HIV incidence via their sexual contacts. Our epidemic modelling analysis identified FSW, MSM and SW clients as net transmitters. Men above 50 years of age also showed up as net transmitters in the analysis, this could be due to male circumcision (which is known to reduce men's chance to acquire HIV in a risk contact), or advanced, untreated HIV infections in this demographic.

According to the Optima model, 31% of transmission events in 2013 were directly associated with sex work, and our model outputs suggest that many infections in the general population have indirectly arisen from sex work-linked transmission events. It was estimated that in every ~200 FSW, there was a new HIV infection in 2013, and in every ~300 MSM and every ~1,000 SW clients there was a new infection. **In the general population, new infections in females were much rarer (circa 1 per 5,000), and very rare in males (circa 1 per 10,000).** Different sets of survey data on FSW and MSM suggest low HIV comprehensive knowledge (3 – 40%); low (11%) consistent condom while less than a quarter (4 – 24%) ever had an HIV test.

Since measured data on temporal HIV trends are scarce, the projected course of the epidemic is uncertain. Our analysis predicted that there may be a small increase in the HIV incidence rate in adults and children if interventions remain at the same level. However, even small increases in the HIV incidence rate, combined with the underlying population growth, can lead to significant additional HIV burden

over longer time frames. Our projections indicate that if expenditure in each HIV program was kept constant until 2030, the number of new infections per year could double between 2013 and 2030. Due to the lack of supportive survey data, such predictions need to be treated with caution. But the findings of this analysis suggest that **Sudan's HIV epidemic *may not contract* without decisive action on allocative choices leading to better impact of the HIV investments.**

5.2 Funding for health and HIV interventions

Sudan's health and HIV programs are supported by external financing; 29–64% of all health spend (2009–12 range) and 62% of HIV spend (2011) was financed from external sources. Although total aid disbursements have decreased gradually since 2008, aid for health was essentially maintained, indicating the relative importance given to health within the country assistance strategies. In 2012, 15 dollars of every 100 *aid dollars* were for health. Equally, 15 dollars of every 100 *health-aid dollars* were for HIV over the period 2002–12. Given that HIV remains a minor cause of disease burden across the country, the data suggest that HIV/AIDS attracts relatively more *aid money* than other disease conditions i.e. 15.3% allocated to HIV within all health aid. Looking at total health expenditure, HIV/AIDS consumes a small amount—in 2012, less than half a percent of all health expenditure was for HIV/AIDS (USD 18.5 million of USD 4.1 billion total health spend).

Much of Sudan's health expenditure is by private households. In 2012, private out-of-pocket expenditure exceeded USD 3 billion while the public sector spent about USD 1.0 billion. **The proportion of total government expenditure for health was at 10.6% in 2012, according to the NHA database,** and it remains to be seen if Sudan raises this proportion further and attains the 15% by 2015, in line with the Abuja Declaration.

Annual donor funding for HIV/AIDS has fluctuated heavily, suggesting that program sustainability and predictability of available resources is a challenge for program implementation. In the last three years, the total HIV expenditure has decreased, essentially due to steeply decreasing external support from USD 14.5 million in 2011 to 12.3 in 2012 and 9.1 in 2013.

According to national resource tracking data of 2013, a relatively low proportion of HIV funding was directed to key populations—approximately 6% of all HIV expenditure was for FSW and MSM programs.

This situation, characterized by:

- a stable or possibly growing HIV epidemic,
- the low-level type of the HIV epidemic but low spending on key population interventions,
- high fluctuation in external funding support for HIV and health
- generally decreasing HIV budgets, and
- the need to demonstrate value for money for investors in the HIV response

called for an analysis of the allocative efficiency of the HIV response and the modelling of impact of HIV investment options.

5.3 Optimal HIV resource allocation for impact and sustainability

The National HIV strategy has been updated to cover the period 2015–17 (NSP III). There was an intention to scale-up interventions and targets that will impact HIV infection and death rates. This allocative efficiency analysis generated estimates and investment scenarios to support the Sudanese government in designing an impactful and cost-effective HIV response.

The analysis had several optimization objectives which included optimal HIV incidence and HIV-related DALY impact, minimal costs to attain international HIV incidence and AIDS mortality targets, minimal future spending commitments, and minimal expenditure to reach the NSP impact targets. We defined moderate and ambitious target levels to explore annual resource needs. The time horizons of 2013 to 2016, 2020 and 2030 were used. We defined 10 populations in the Optima model, but were not able to include other relevant populations (populations of humanitarian concern, PWID, prisoners) due to lack of data. Seven programs (or service packages) with direct HIV impact were defined and included in the optimization steps. All prevention programs included condoms, HTC and SBCC, and the ART package included HIV testing. One programmatic expenditure, PLHIV support, was included in the overall discussion but not in the optimization due to lack of data on the relationship between this expenditure and HIV impact. We used USD 6.4 million as the baseline scenario for program-related annual HIV expenditure, and USD 12.2 million for total HIV spend (data derived from 2013 DSA). In the course of the analysis, we ran

two scenarios concerning PMTCT unit costs to give specific input into the allocative efficiency of investing in this program.

We found that an allocatively efficient HIV response geared towards minimizing HIV incidence could avert an additional 19,000 (36%) of new HIV infections by 2020. It would also avert an estimated additional 6,744 AIDS deaths. Optimal allocative efficiency would be obtained if investment in FSW interventions tripled (from 4% to 15%) and more than doubled for client interventions (from 4% to 10%), if MSM spend significantly increased (from 2% to 6%), and ART spend was raised (from 12% to 22%). Programs for the low-risk, general population would only become important at 700% of the baseline budget (USD45 million). In general, higher funding levels would buy further HIV incidence reduction, but optimal allocation of baseline-level resources was more important than more funding for medium-term HIV incidence reduction up to 2020.

PMTCT would not receive funding up to 200% of total 2013 spending, if 2013 unit costs were used (Table 2) due to its low HIV impact in a low-level epidemic and the fact that vertical transmissions are not usually transmitted onward in a time frame of 15–20 years (any vertically infected children would need to survive and become sexually active to pose a transmission risk). **Only with a very substantial reduction of unit cost as envisaged in the 2015–17 NSP budget, PMTCT would receive funding if 170% or more of 2013 spending was available.** If less funding is available, not investing in PMTCT would create fiscal space for other, higher-impact HIV programs (essentially HIV prevention for KPs) and thereby indirectly avert more new HIV infections in children. For PMTCT programs to be cost-effective, further reductions in cost per HIV positive pregnant woman identified would be required. The 2015–17 NSP budget already foresees important unit cost reductions compared to 2013 spending, and these would primarily arise by better geographical targeting of PMTCT. The 2015–17 NSP also includes syphilis testing in parallel to HIV testing. Cost-effectiveness of the program might also be achieved by routine diagnosis and treatment of syphilis among pregnant women and thereby reducing stillbirths and neonatal syphilis.

Optimizing resource allocation for averting HIV-related DALYs instead of HIV incidence required a similar intervention mix but with even higher allocations to ART. At 2013 levels of spending, the scenarios for reducing DALYs and new infections included the same four key interventions (ART and prevention among FSW, MSM and higher risk men). With reduced availability of funding, further prioritization would be needed. If only 50% of 2013 funding was available, prevention among key populations

would receive all funding for minimizing incidence, and ART plus FSW prevention would receive virtually all funding for reducing DALYs. In any case, the strong focus on ART would require excellent targeting of HTC efforts in order to identify HIV cases, and strong pre-ART services to ensure ART initiation of PLHIV as soon as eligible for treatment.

Optimal annual allocations from 2014 to 2030 to minimize fiscal commitments up to 2050 again called for a very similar allocation mix. This suggests that the model-proposed intervention mix for HIV programs is robust for minimizing different important objectives of preventing HIV transmission, HIV morbidity, HIV mortality and HIV long-term costs. Table 5 shows a summary of the model outputs.

Table 5. Optimal allocation of 2013 funding levels until 2020, for the different optimization objectives

Program area	2013	Optimization objective		
	Actual	Minimize HIV incidence	Minimize HIV-related DALYs	Minimize fiscal commitment to 2030 (ART coverage \geq 46%)
FSW, prevention	4%	15%	12%	12%
MSM, prevention	2%	6%	7%	9%
High-risk males (SW clients), prevention	4%	10%	8%	8%
General population, HTC	18%	0	0	0
General population, condom	6%	0	0	0
PMTCT	7%	0	0	0
ART	12%	22%	25%	24%

Sources: Populated Optima model for Sudan.

Note: Prevention packages do not include ART here and that ART is shown separately for all populations.

Our other optimization objectives produced relevant findings for short- to medium-term coverage targets. Model outputs on resource requirements suggested that achieving high PMTCT coverage is very costly and has low impact. In addition, the modelling analysis showed that achieving a large reduction in deaths is more resource intensive than a large reduction in HIV incidence. Preventing deaths requires identification of a large proportion of PLHIV, getting them enrolled into treatment and realizing high ART adherence. As HIV infection is already disseminated to some extent in the wider population (but with low probability of onward transmission), case finding for ART is a challenge outside the KPs. In contrast, HIV incidence reductions can be achieved with selective program scale-up among higher-risk populations, with secondary HIV prevention benefits in all other population groups. **One of our key**

findings was that targeting programmatic resources almost exclusively to KPs and to ART—while de-prioritizing general population programs—leads to HIV incidence reductions in all populations over the medium term, at lowest cost. We also estimated the minimum spending to achieve the impact targets of 25% reduction in HIV incidence and deaths by 2016, which was about USD 8.1 million per year until 2016, with the HIV incidence target more feasible than the mortality target.

ART investment showed up in all optimizations as an allocatively efficient choice. In 2013, reported treatment adherence was 69.1%, 55.5%, 42.5% at 12, 24 and 60 months, respectively (GARPR report 2014). This is significantly lower than the WHO-reported LMIC average of 86%, 82% and 72%, respectively (WHO 2013 progress report). Improvements at different stages of the treatment cascade are in progress, but it is reported that practical constraints like availability of HIV test kits, shortages in trained staff and confusion around roles and responsibilities can slow down actual implementation progress. Improved ART adherence, but also earlier treatment initiation, are important clinical and public health goals for the Sudanese ART program.¹³ Our analysis suggested older men being net HIV transmitters and it is plausible that low ART access plays a role.

Two particular HIV programs show low impact in our modelling analysis: HTC services for the general population, and the PMTCT program. Based on the reported VCT statistics, the VCT centres have on average screened very few people per time unit. Re-purposing these services to target higher-risk populations is an important step to take ART to scale. For PMTCT, this analysis was able to use site-statistics and it was evident that also the PMTCT sites will need review. Given that there are some PMTCT sites with higher prevalence of positive women (9 of 254 sites reporting prevalence of 1% or greater), it seems important to maintain a geographically prioritized PMTCT program. This analysis suggests that a national scale-up of the PMTCT program cannot be justified based on cost-effectiveness considerations in the Sudanese context, where 75% of the PMTCT sites (192 sites) did not identify a single case of HIV during 2013. Nevertheless, there are a few high-priority sites which reported HIV prevalence above 1% in expectant mothers. HIV prevalence in expectant mothers mirrors HIV prevalence patterns in the wider population and is geographically heterogeneous. The Optima model estimates that about 12% of all new infections are

¹³ The 2013 HIV test treat and retain cascade analysis, described in the GARPR report 2014, found that 18% of PLHIV know their HIV status and were mostly in late stages of disease. 2012 data from Omdurman ART center in Khartoum state, the largest center in Sudan, showed that 81% of newly diagnosed PLHIV were stages 3 and 4.

vertically transmitted, but that reaching national PMTCT coverage of 60% or higher is very costly and the investment could have higher prevention impact if allocated to other HIV programs. Also, with the prevalence of maternal syphilis at about 2.3%, it would appear that screening pregnant women routinely for syphilis is a better health investment in the context of overall expansion and improvement of maternal, neonatal and child health services.

In our optimization analysis, the outputs all point to the importance of increasing HIV program coverage in FSW and their clients, as well as MSM, and concomitantly decreasing the investment in the general population program (Table 5). For this to succeed, a conducive environment is required to enable key populations to freely access the commodities and services they need. Although our expenditure analysis did not include costs for advocacy and communication, **we acknowledge the importance of investing in working with community leaders, gatekeepers, politicians, regulatory bodies and opinion makers like the press.** The increased implication of civil society organizations and PLHIV groups in Sudan is a positive sign. Official reports talk about the opposing religious views on HIV interventions, key population targeting and condom promotion. They also highlight how late many PLHIV arrive for treatment, due to stigma and low service use by marginalized populations. Sudan has formulated its strategy for key populations: *“to provide or link specifically tailored prevention services to key populations (MSM, FSW and their clients) and vulnerable groups (prisoners, refugees, internally displaced populations, cross-border populations, tea-sellers, raksha and truck drivers, university students, soldiers and policemen). The service package constitutes of peer education, condom distribution, information exchange communication, HIV counselling and testing, STI diagnosis and treatment, and reproductive health services”* (GARPR report 2014). **This KP strategy now needs to be taken to scale, condom procurement problems need to be prevented, and condoms promoted in a culturally acceptable way.**

A recent modelling analysis by Steen et al. (2014)¹⁴ on the effect of sex work interventions in a Kenyan setting is informative for the Sudan situation too:

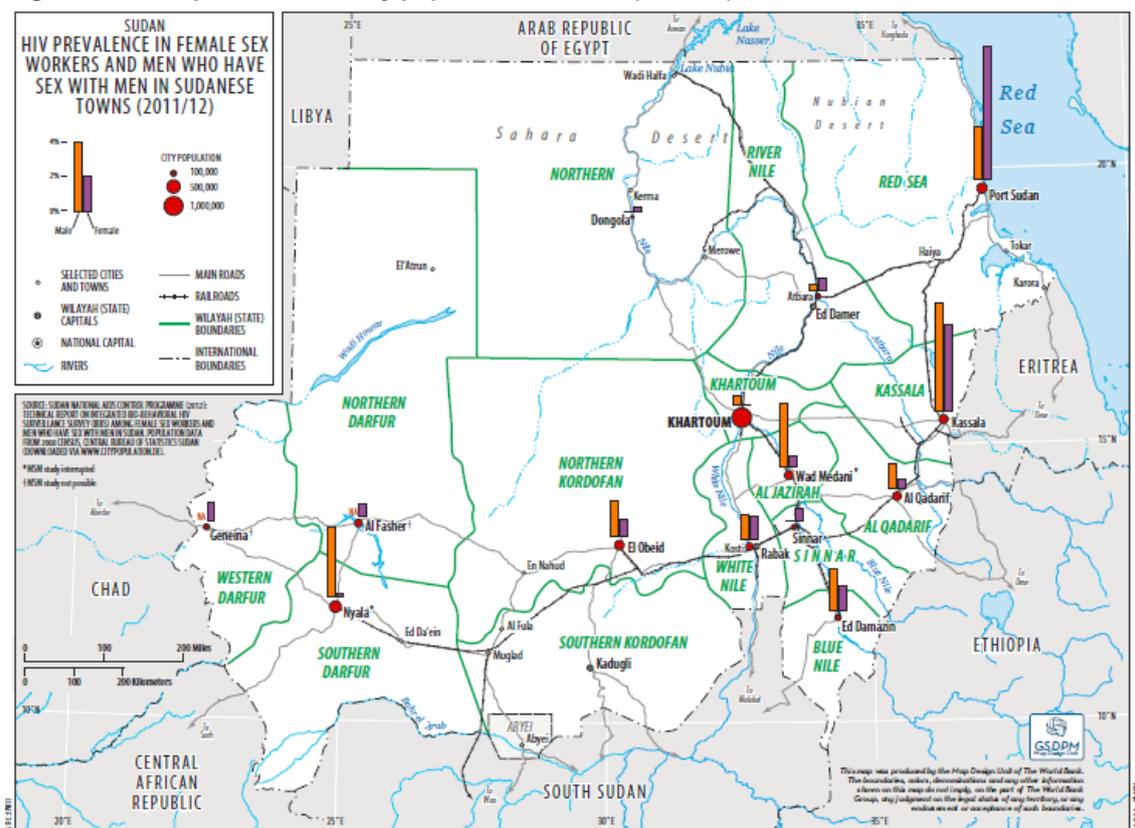
Removing transmission from sex work would have resulted in 66% lower HIV incidence and 56% lower prevalence after 20 years. High rates of condom use in sex work had the greatest effect, whereas STI treatment contributed to HIV declines at lower levels of condom use. Interventions reaching the 40% of sex

¹⁴ Steen, R., et al. (2014). Looking upstream to prevent HIV transmission: can interventions with sex workers alter the course of HIV epidemics in Africa as they did in Asia? AIDS 2014, 28.

workers with most clients reduced HIV transmission nearly as much as less targeted approaches attempting to reach all sex workers. The authors conclude that ‘upstream’ transmission in sex work remains important in advanced African HIV epidemics. **Feasible condom and STI interventions that reach the most active sex workers can markedly reduce the size of HIV epidemics** (extracted from Steen, et al. 2014).

For key population service planning, more needs to be known in Sudan about the heterogeneous target groups (typologies, venue profiling), the gaps in current service provision (programmatic mapping), and population size by location (geographic mapping). Little is known about the scale of injecting drug use and HIV in people who inject drugs—the 2011 Integrated Bio-Behavioral HIV Surveillance Survey (IBBS) found that 2.1% of MSM and 0.9% of FSW injected drugs in the past 12 months with ranges of 0 to 5% and 0 to 8%, respectively, in different sites. It was, however, noted by a key informant that questions on injections may not only be interpreted in the context of illicit drug use, but include misreporting of hormonal contraceptive use by FSW or other (medical) injections. **Figure 34** shows HIV prevalence levels in FSW (purple) and MSM (orange) by area of recruitment into the IBBS. Such strategic data on **local epidemics** are highly valuable for geographic prioritization of investment in KP services.

Figure 34. HIV prevalence in key populations, Sudan (2011/12)



Sources: Sudan National AIDS Control Programme (2012): Technical Report on Integrated Bio-behavioral HIV Surveillance Survey (IBBS) among Female Sex Workers and Men Who Have Sex with Men in Sudan

5.4 Reducing HIV response costs through more efficient processes in implementation and management

There are ongoing efforts in Sudan to restructure HIV and health programs based on bottleneck and situational analyses, joint program reviews, and lessons learnt. For instance, the Federal Ministry of Health issued a directive for the **integration** of all the nine vertical HIV and health programs with the aim to reduce the fragmentation of the health system and efficiently expand HIV interventions within existent pathways in a cost effective manner e.g. incorporating HIV supply chain within the existent central medical stores supply system (GARPR narrative report 2014). Another important integration effort is happening specifically between reproductive health and HIV. These integration initiatives preceded the official ministerial directives and their experience is used to guide the integration process that is currently implemented at federal level.

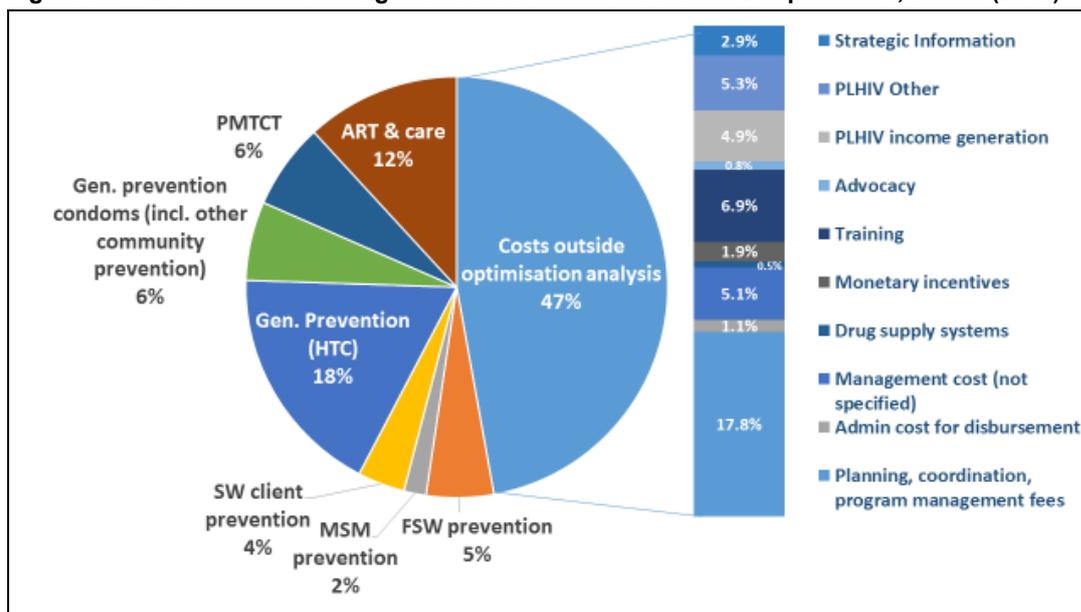
In ART, the current emphasis is not to increase the number of HIV treatment outlets but to increase detection of HIV cases, improve the efficiency of **linkage** of HIV detected cases to care services and to address attrition factors and provide support to

retain them within care. Such attempts to integrate HIV and improve linkages between services will help to make the HIV response more technically efficient and sustainable, and reduce costs which arise in vertical programs. Another important effort is linkage between public sector programs and civil society in the form of working partnerships. These multi-sectoral partnerships are especially important for providing comprehensive services for key populations and ensuring an enabling environment for service provision to key population members.

Official reports also present the **joint monitoring missions** by developmental agencies and government counterparts as an additional interaction mechanism which can help increase efficiency and reduce the waste of HIV resources. Similarly, **joint training** between HIV and other health programs, and between public and civil society sectors are ways to promote integrated service delivery and has the potential for cost-saving synergies, as promoted for HIV and reproductive health services in Sudan.

This analysis focused on optimizing likely future budgets, and it was observed that more impact could be gained in the HIV response if there was additional funding for HIV interventions. One strategy to increase the programmatic budget is to identify savings which could be made in non-programmatic expenditure areas such as management and coordination. **Figure 22** showed that a third of the total HIV expenditure of 2013 was for management support (and 4% for strategic information). **Figure 35** illustrates the relative shares of different management expenditures in Sudan's 2013 HIV spend. Almost 18% of the HIV response budget was used for planning, coordination and program management fees.

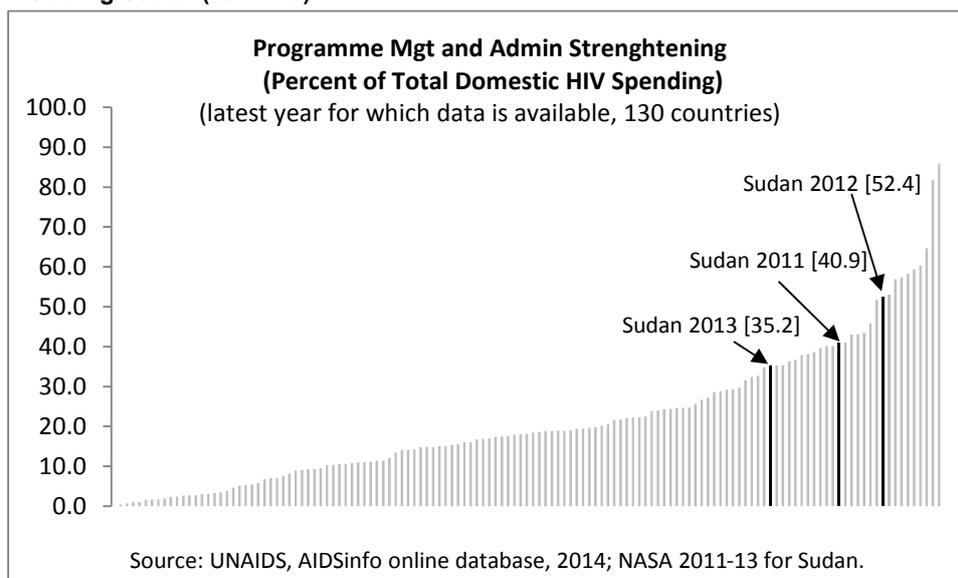
The graph also shows **PLHIV income generation expenditure, which has a unit cost of around USD 700 per person/year. This intervention reaches around 300 persons of an estimated 43,000 PLHIV in 2013, i.e., 0.7%, and it therefore very small scale as of now.** The PLHIV income generation activities are designed as a revolving fund and consume a substantial portion of the PLHIV associations' budgets (PLHIV association with federal headquarters and 15 representations in different states).

Figure 35. Breakdown of management costs within the total HIV expenditure, Sudan (2013)

Source: Disease specific accounts 2013, Sudan.

Note: Expenditure for upgrading /construction of infrastructure in 2013 is not included here, although it is included in the "program management and administration" category of the NASA/DSA resource tracking system.

With the decreasing overall budgets for the HIV response in the last three NASA years 2011–13, the *share* of program management expenditure has also decreased (Figure 36). International comparison shows that while Sudan's management expenditure was very high in 2011 and 2012 (41% and 52%), it reduced to 35% in 2013 (the graph uses the total management expenditure from the NASA system which includes some infrastructure and M&E expenditure).

Figure 36. Share of HIV expenditure for program management and administration in 130 countries including Sudan (2011–13)

Source: UNAIDS, AIDSinfo online database, 2014; NASA 2011-13 for Sudan.

Source: UNAIDS AIDSinfo online database (<http://www.aidsinfoonline.org/devinfo/libraries/asp/dataview.aspx>). Reference years are spread from 2005 to 2013, but most data refer to 2011 or 2012 (data for Sudan refer to 2010, 2011, 2012).

Note: Expenditure for upgrading /construction of infrastructure is included as per NASA classification.

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6. Conclusions

Sudan's 2014–16 National HIV Strategy already builds on many insights and lessons learnt. This allocative efficiency study was conducted to specifically support decision-making on relative HIV allocations within the overall HIV response, and demographic as well as geographic targeting and prioritization of HIV interventions. It led to the main conclusion that **Sudan's HIV response allocations could be enhanced by focusing prevention on FSW, their clients and MSM, while scaling up ART based on an HTC strategy that is targeted geographically and to key populations.**

Sudan's HIV response resource allocations should focus on key populations because of the following reasons:

1. Epidemiologically: Sudan has a low-level HIV epidemic which is unlikely to be generalized in its context of near-universal male circumcision. However, the populations causing most HIV transmission (FSW, their clients, MSM) are not adequately served to prevent onward transmission of HIV; treatment as prevention is hampered by low and late case identification and limited ART adherence; supply chains for HIV reagents and condoms report failures and condom promotion faces cultural barriers. As a consequence **the annual number of new HIV infections is projected to slowly rise unless the HIV response increases its prevention impact.**
2. Programmatically: HIV resources are spent on populations with very low HIV risk of 1 in 5,000–10,000 new infections per year and low AIDS-related DALYs. PMTCT provision is scaled up to many areas where no HIV case is identified in a whole year; some VCT services experience low demand and until recently targeted low-risk individuals. **HIV money needs to be directed towards the key populations who are most likely to be infected, develop AIDS and spread HIV to others, with a focus on those typologies of sex workers and MSM with high partner acquisition rates.** HIV highlights the pernicious health effects of social and legal marginalization and of gender inequalities in Sudan, and offers an opportunity to redress.
3. Economically: Aid supporting the Sudanese public health sector has in the past prioritized HIV above other diseases (15 of every 100 health-dollar given was for HIV), and the HIV response is heavily reliant on external support (averaging at

64% in the 2011–13). With international and domestic public sector contributions to the HIV response rapidly decreasing over the last three years, **bold decisions need to be made. Better value for money needs to be achieved, by addressing the epidemic in a targeted, cost-effective manner leading to higher returns on investment.**

4. Fiscally: Every new HIV infection represents a future treatment liability for the Sudanese government. According to our model outputs on future HIV-related healthcare costs, **allocating specific shares of HIV resources to key populations and to ART scale-up minimizes long-term fiscal costs for the government** (and the same allocative split between HIV interventions also reduces HIV incidence and averts the maximum of HIV-related DALYs).
5. Sustainability: The results presented in this report can guide Sudan's allocative choices to make the HIV response more sustainable and HIV investments more defensible in a health sector with multiple investment needs. The **model-proposed allocation mix for HIV programs is robust for minimizing different important policy objectives of minimizing HIV transmission, HIV morbidity and mortality, and long-term AIDS-related costs. Importantly, the model demonstrates that through indirect effects, HIV impact is obtained in all population groups, even if prevention programs are targeted to populations are higher risk of HIV.**

On the use of the Optima model:

1. Optima provided policy-relevant information for HIV allocative decision making in Sudan and highlights once more the need for **updated strategic information** especially on key populations driving HIV incidence, as well as for **detailed programmatic and expenditure tracking data.**
2. It is very useful to explore the logic chain of an NSP result framework with a mathematical model like Optima, which relates HIV spending to targets at the levels of sexual behaviour, HIV program coverage and epidemic impact, and helps test assumptions on the resource needs to achieve objectives—in Sudan, it appears for instance that **meeting the NSP's HIV incidence target requires less resources than the AIDS mortality target** or a moderate PMTCT coverage target. Future results frameworks would benefit from model-informed targets.

Annex 1. Technical data in Optima model

1.1. Data Collation and Synthesis

Performing our evaluations of HIV prevention and treatment programs required a large amount of data describing the HIV epidemiology, population demographics, acquisition-related behavior, clinical characteristics, and HIV program and health costs.

1.1.1. Data Collation

To evaluate programs, their funding, coverage and outcomes we collated data from all available publications, documents, reports, and data files. The data included:

1. Estimated population sizes for the general population and the key populations or most at-risk populations (MARPs).
2. The epidemiological characteristics of the HIV epidemic. Specifically we obtained data on:
 - HIV prevalence;
 - Annual HIV diagnoses;
 - Number of people currently on first- and second-line antiretroviral therapy (ART);
 - Number of people on ART;
 - Number of reported or estimated mother-to-child transmissions.
3. Descriptions of risk behaviors, HIV transmission patterns, and health-care seeking behavior. We used this data to understand modes of HIV transmission between populations and the risk of HIV acquisition. Specific data collected includes:
 - Sexual behaviors (e.g., number of sexual partners and level of condom usage in sexual acts);
 - Rates at which people in specific populations test for HIV.
4. HIV Program funding, spending data from National AIDS Spending Assessments and health utilities for PLHIV at all stages of disease progression.

Disability Weights

In our analysis, we used disability-adjusted life years (DALYs) to measure the overall impact of HIV programs and for basic health economic calculations. The most thorough empirical study of disability weights is the 2010 Global Burden of Disease

Study [2]. This study reports DALYs for people with symptomatic HIV, AIDS, and HIV but on effective HIV treatment (Annex Table 6).

Annex Table 1. Disability weights for HIV related health states from the 2010 Global Burden of Disease Study.

Health State	Estimated DALY (95% uncertainty interval)
HIV: symptomatic, pre-AIDS	0.221 (0.146–0.310)
HIV/AIDS: receiving antiretroviral treatment	0.053 (0.034–0.079)
AIDS: not receiving antiretroviral treatment	0.547 (0.382–0.715)

Based on the results from the Global Burden of Disease Study [2] we assigned a disability-weight for HIV-positive people in each CD4 count category (**Error! Reference source not found.**).

Annex Table 2. Assumed disability-weights for DALY calculations.

Population category	Assumed Disability-Weight
HIV-negative (non-PWID and PWID on opiate substitution therapy)	0
HIV-negative (PWID)	0.25
Untreated HIV-positive: CD4 > 500	0.221
Untreated HIV-positive: 350 < CD4 < 500	0.221
Untreated HIV-positive: 200 < CD4 < 300	0.221
Untreated HIV-positive: CD4 < 200	0.547
Treated HIV-positive: CD4 > 500	0.053
Treated HIV-positive: 350 < CD4 < 500	0.053
Treated HIV-positive: 200 < CD4 < 300	0.053
Treated HIV-positive: CD4 < 200	0.053

Note: The disability-weight for HIV-positive PWID is the maximum of the value for HIV-negative PWID and the corresponding HIV-positive category disability weight.

1.1.2. The Optima Model

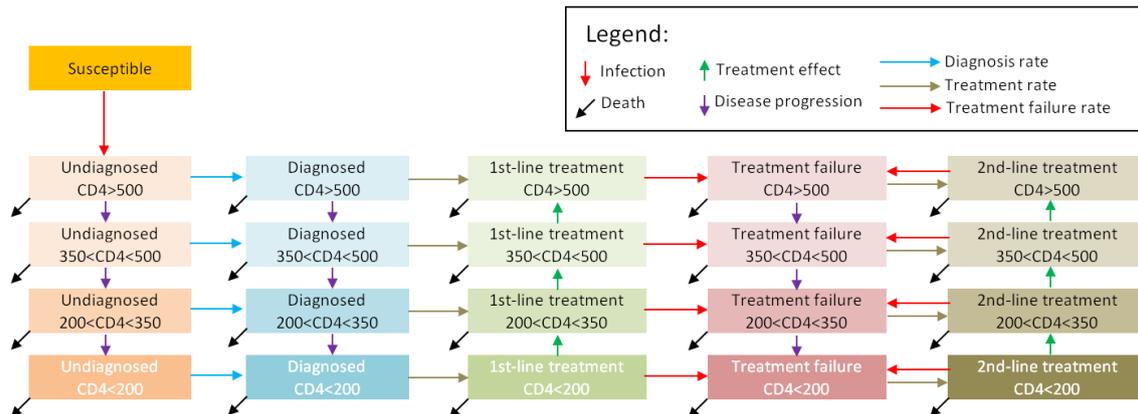
We use the Optima model to calculate the change in HIV incidence and the number of HIV/AIDS deaths due to changes in funding. Optima is sufficiently flexible to track epidemics and behavioral parameters over time to produce long-term forecasts, and to allow us to conduct allocative efficiency analyses. Optima uses best-practice HIV epidemic modeling techniques and incorporates realistic biological transmission processes, detailed infection progression, and sexual mixing patterns and drug injection behaviors. Optima describes the impact of HIV programs indirectly through their influence on behavioral and clinical parameters.

1.1.3. Model of HIV Transmission and Progression

Optima incorporates a model of HIV transmission and progression. The model uses a coupled system of ordinary differential equations to track the transmission of HIV and the movement of infected people between 21 health states (Annex figure 1). The model

distinguishes people who are undiagnosed, diagnosed, and on effective anti-retroviral therapy (ART). Diagnosis of HIV-infected individuals occurs based on a HIV testing rate dependent on CD4 count and population type. Similarly, diagnosed individuals begin treatment at a CD4 count dependent rate. The model tracks those on successful first- or second-line treatment (who have an increasing CD4 count) and those with treatment failure.

Annex Figure 1. HIV Infection Progression



HIV infections occur through the interaction between different populations via regular, casual, or commercial sexual partnerships.

The force-of-infection for a population determines rate at which uninfected individuals within the population become infected. This depends on the number of risk events individuals are exposed to in a given period and the infection probability of each event. Sexual transmission risk depends on:

- The number of people in each HIV-infected stage (that is, the prevalence of HIV infection in partner populations)
- The average number of casual, regular and commercial homosexual and heterosexual partnerships per person
- The average frequency of sexual acts per partnership
- The proportion of these acts in which condoms are used
- The efficacy of condoms
- The extent of male circumcision
- The prevalence of ulcerative STIs (which increase transmission probability)

The stage of infection (chronic, AIDS-related illness/late stage, or on treatment) for the HIV-positive partner in a sero-discordant couple also influences transmission risk—due to different levels of infectiousness in each infection stage.

Mathematically, we calculate the force-of-infection using:

$$\lambda = 1 - (1 - \beta)^n$$

where λ is the force-of-infection, β is the transmission probability of each event, and n is the effective number of at-risk events (thus n gives the average number interaction events with infected people where HIV transmission may occur). The value of the transmission probability β is inversely related to CD4 count, differs for different modes of transmission (heterosexual or homosexual intercourse, intravenous drug injection), and may be modified by behavioral interventions (for example, condom use or circumcision). The number of events n not only incorporates the total number of events, but also other factors that moderate the possibility that these events are capable of transmitting infection, such as condom use or circumcision. There is one force-of-infection term for each type of interaction (for example, casual sexual relationships between low-risk males and indirect female sex workers), and the force-of-infection for a given population will be the sum of overall interaction types.

Optima calculates the number of children infected through mother-to-child transmission using the birthrate and prevalence of HIV in female population groups. Children who are breastfed have a higher risk of acquiring HIV than those who are not breastfed in the model. Prevention of mother-to-children programs reduce the overall probability of children acquiring HIV through a multiplicative factor equal to one minus the product of the efficacy of PMTCT and coverage of PMTCT.

In addition to the force-of-infection rate, in which individuals move from uninfected to infected states, individuals may move between health states via seven other pathways:

- Individuals may die, either due to the background death rate (which affects all populations equally), due to injecting behavior, or due to HIV/AIDS (which depends on CD4 count)
- In the absence of intervention, individuals progress from higher to lower CD4 counts
- Individuals can move from undiagnosed to diagnosed states based on their HIV testing rate, which is a function of CD4 count (for example, people with AIDS

symptoms have a higher testing rate) and population type (for example, IDUs usually get tested more frequently than low-risk males).

- Diagnosed individuals may move onto treatment, at a rate dependent on CD4 count
- Individuals may move from treatment to treatment failure, and
- From treatment failure onto second-line treatment
- Finally, while on successful first- or second-line treatment, individuals may progress from lower to higher CD4 count.

In total, the model for Sudan accommodates 210 compartments (10 populations each with 21 health states), and the change in the number of people in each compartment is determined by the sum over the relevant rates described above multiplied by the compartments on which they act. For example, the number of individuals in the compartment corresponding to undiagnosed female sex workers with a CD4 count between 200 and 350 cells/ μL changes according to the following equation:

$$\frac{dU_{FSW200-350}}{dt} = U_{FSW350-500}\tau_{350-500} - U_{FSW200-350}(\mu_{200-350} + \tau_{200-350} + \eta_{FSW350-500})$$

where $U_{FSW350-500}$ is the current population size of people with undiagnosed HIV and with a CD4 count between 350 and 500 cells/ μL , $U_{FSW200-350}$ is the population size of the compartment with lower CD4 count (200–350 cells/ μL), τ is the disease progression rate for the given CD4 count, μ is the death rate, and η is the HIV testing rate. (Note: this example does not consider movement between populations, such as female sex workers returning to the low-risk female population and vice versa.) Each compartment (boxes in Figure 37) corresponds to a single differential equation in the model, and each rate (arrows in Figure 37) corresponds to a single term in that equation.

Most of the parameters in the model are related to calculating the force-of-infection; a list of model parameters is provided in Annex table 3. We interpret Empirical estimates for model parameter values in Bayesian terms as prior distributions.

Annex Table 3. Input parameters of the model

	Biological parameters	Behavioral parameters	Epidemiological parameters
<i>Population parameters</i>	Background death rate		Population sizes (TP)
<i>HIV-related parameters</i>	Sexual HIV transmissibilities* (H) STI-related transmissibility increase* Condom efficacy* Circumcision efficacy* HIV health state progression rates (H) HIV-related death rates (H)	Number of sexual partners* (TPS) Number of acts per partner* (S) Condom usage probability* (TP) Circumcision probability* (T)	HIV prevalence (TP) STI prevalence (TP)
<i>MTCT parameters</i>	Mother-to-child transmission probability	Birth rate PMTCT access rate (T)	
<i>Treatment parameters</i>	ART efficacy* ART failure rates	HIV testing rates (TPH)	Number of people on ART (T)

Note: T = parameter value changes over time; P = parameter value depends on population group; H = parameter depends on health state; S = parameter depends on sexual partnership type; * = parameter is used to calculate the force-of-infection.

1.1.4. Calibration to the HIV epidemic data

We calibrated Optima to Sudan's HIV epidemic to match available population group HIV prevalence data, overall annual diagnoses, and the uptake of ART. While primarily calibrated to match epidemiological data, Optima also optimizes input parameters to match available demographic, behavioral, biological and clinical data. Given the challenges inherent in quantifying all known constraints on an epidemic, we calibrated the model manually, with oversight by and collaboration with in-country stakeholders where possible.

1.1.5. Reconciliation with cost-outcome relationships

The parameter values for the best-fit simulation in 2013 need to match the outcome values corresponding to the estimated 2013 spending levels in the cost-outcome relationships (described in detail in Annex 2). Otherwise, there will be a mismatch in parameter values for future projections and a sharp change in epidemiological trends even if there is no change in spending. Depending on the parameters affected or the available country data, we either adjust the calibration to match the data used in the logistic cost-outcome curves or adjust the cost-outcome curves to match the calibration.

1.2. Optimal allocation

To investigate the potential impact of future HIV prevention programs we ran model projections into the future from 2013 under different investment or programmatic scenarios.

1.2.1. Optimization of Program Allocation

The primary aim for our analysis is to determine the allocation of resources or spending required that best meet the specific objectives described in Section 1.2.

For each of these objectives we used Optima with the best-fitting simulation and an adaptive stochastic linear gradient-descent optimization method [15] to determine the allocation of funding best achieving these objectives for a specific budget. In this method, Optima starts with a fixed budget with program funding allocated randomly. At each step of the optimization process Optima determines the expected behavioral and clinical parameters associated with each program's funding level using the logistic cost-outcome relationships.

Annex 2. Cost-outcome curves

A central component of our analyses is the relationships between the cost of HIV prevention programs and the resulting outcomes. Such relationships are required in our analyses, to understand how incremental changes in spending ultimately affect HIV epidemics and determine the optimal funding allocation. Our analysis requires country-specific relationships for each risk-population and prevention program. A large amount of behavioral and spending data is required, to inform such relationships.

We used an ecological “top-down” approach to relate program cost and outcomes. For each risk population, we derived a set of relationships directly linking estimated funding to behavioral data for the population’s primary risk-behavior. We describe our approach in detail below. To produce these relationships we assume indirect costs have no direct impact on HIV transmission parameters; but changes to HIV programs may affect these costs to supply additional condoms, clean syringes, and methadone, for example. A limitation of our approach is the assumption that all changes in behavior are assumed to be due to changes in program funding.

2.1. Methodological details

We use a logistic or sigmoid function to model cost-outcome relationships. This type of function can incorporate initial startup costs, which may have no direct effect on a behavioral outcome, and allow changes in behavior to saturate at high spending levels. Using our data synthesis, we identified years where both spending data and outcome data were available for each model population. We then used this data to fit a four parameter logistic function of the form

$$f(x) = A + \frac{B-A}{1+e^{-D(x-C)}}$$

where x is the estimated amount of funding for the population, A is the lower asymptote value, B is the upper asymptote value, C is the point of maximum change, and D is the growth rate. Our fits were further constrained using an assumed range for the maximum/saturation value of the outcome. We estimated this saturation range subjectively, based on data from high income countries where funding is effectively unlimited.

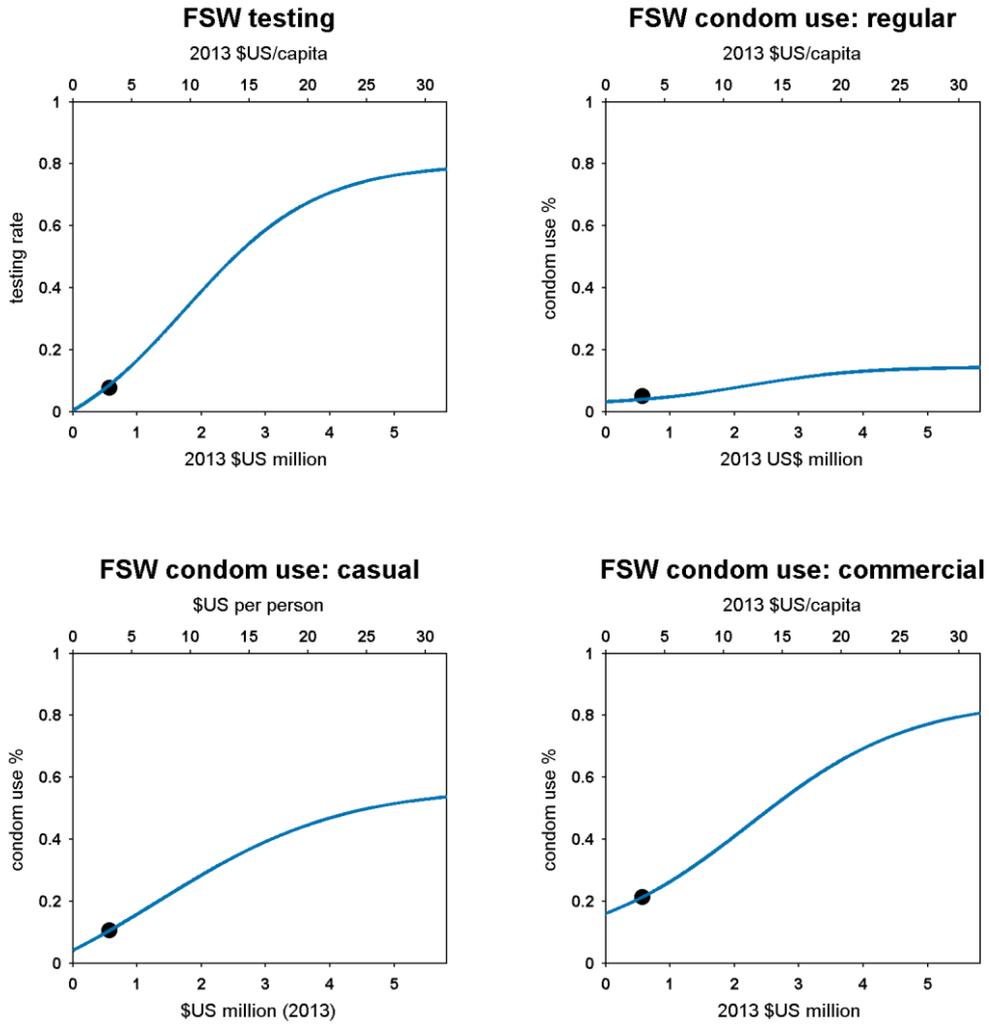
We fitted the logistic function to the available data and saturation range using Matlab[®] 2013a with a trust region reflective algorithm [13]. We then adjusted each fit to reflect assumed zero spending values and expected changes in outcomes with increases in spending—with further adjustments to remove unrealistic trends, to

reconcile with calibrated outcome values, and in response to feedback from in-country stakeholders.

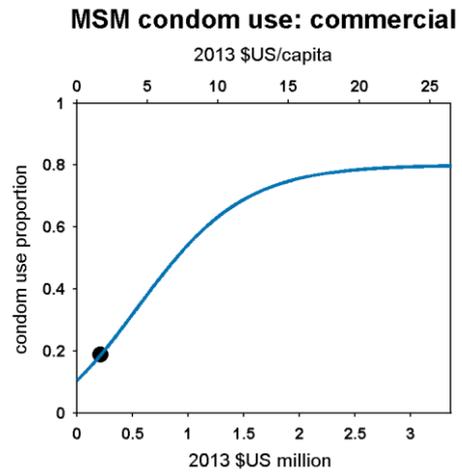
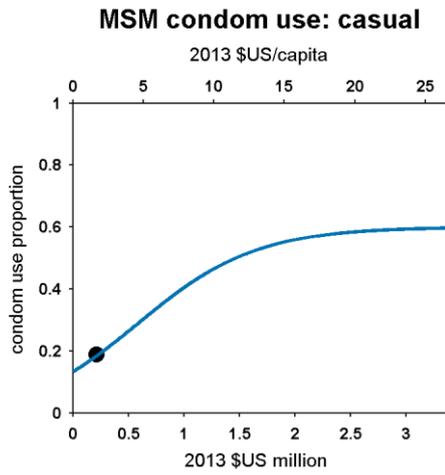
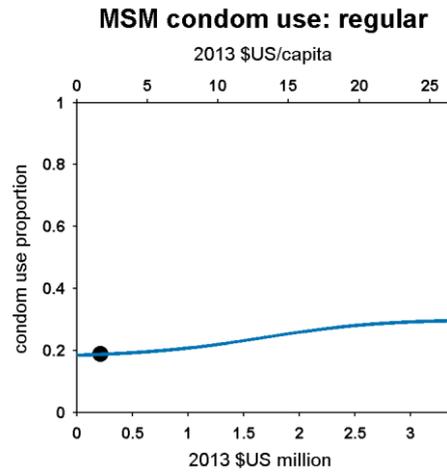
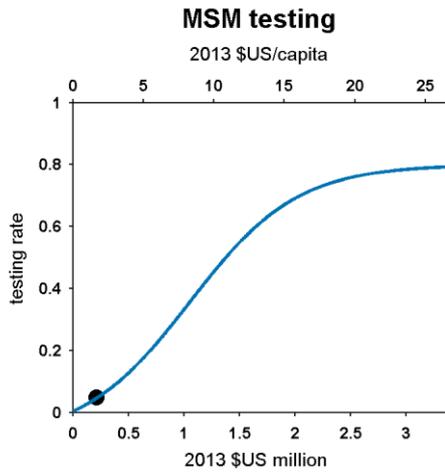
Summary of cost-outcome relationships with the target populations of interventions and the associated outcomes (**Annex Figure 2**).

Annex Figure 2 (a–g). Cost-outcome curves

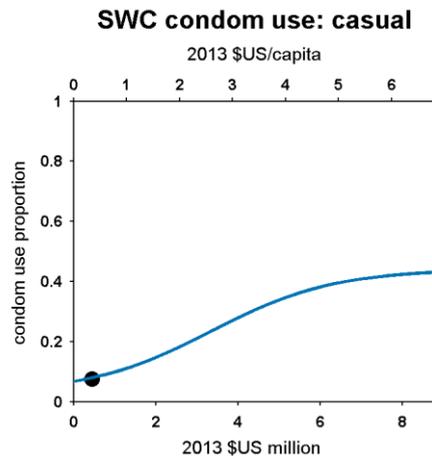
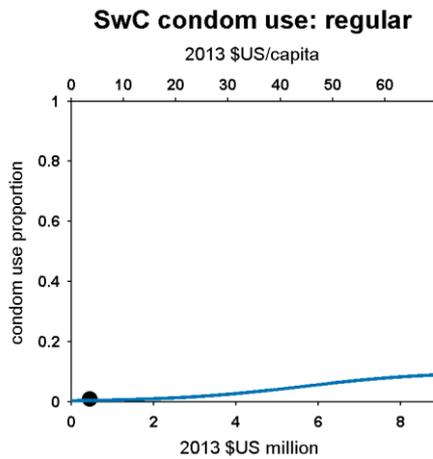
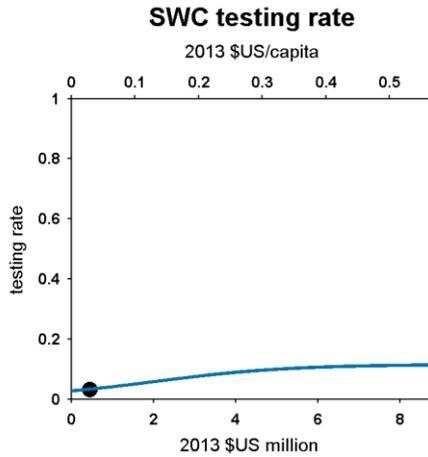
a) **Targeted FSW intervention package:** Funding is assumed to affect HIV testing and condom use.



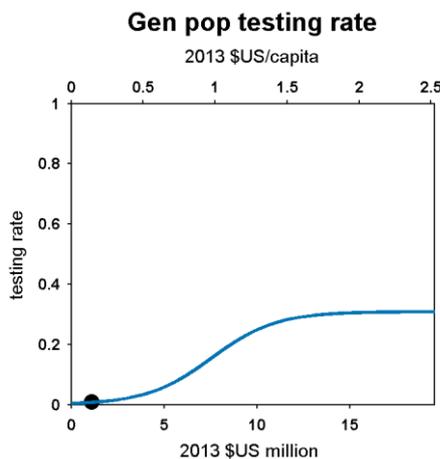
b) **Targeted MSM intervention package:** Funding is assumed to affect HIV testing and condom use.



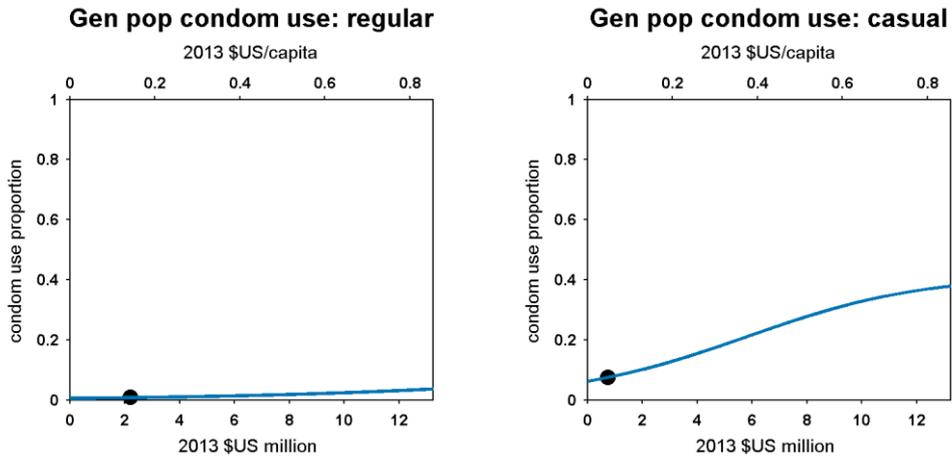
c) Prevention services for high-risk males: Funding for this program is assumed to affect testing and condom use for high-risk males.



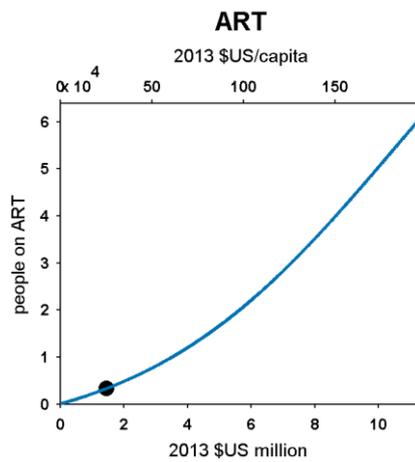
d) Prevention services for non-key populations—General population HTC
Funding for this program is assumed to affect testing for males and females aged 15–49.



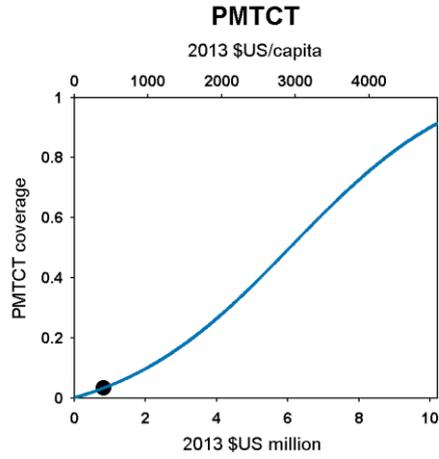
e) Prevention services for non-key populations—General population condom program: Funding for this program is assumed to affect condom use for males aged 15–49.



f) Antiretroviral therapy



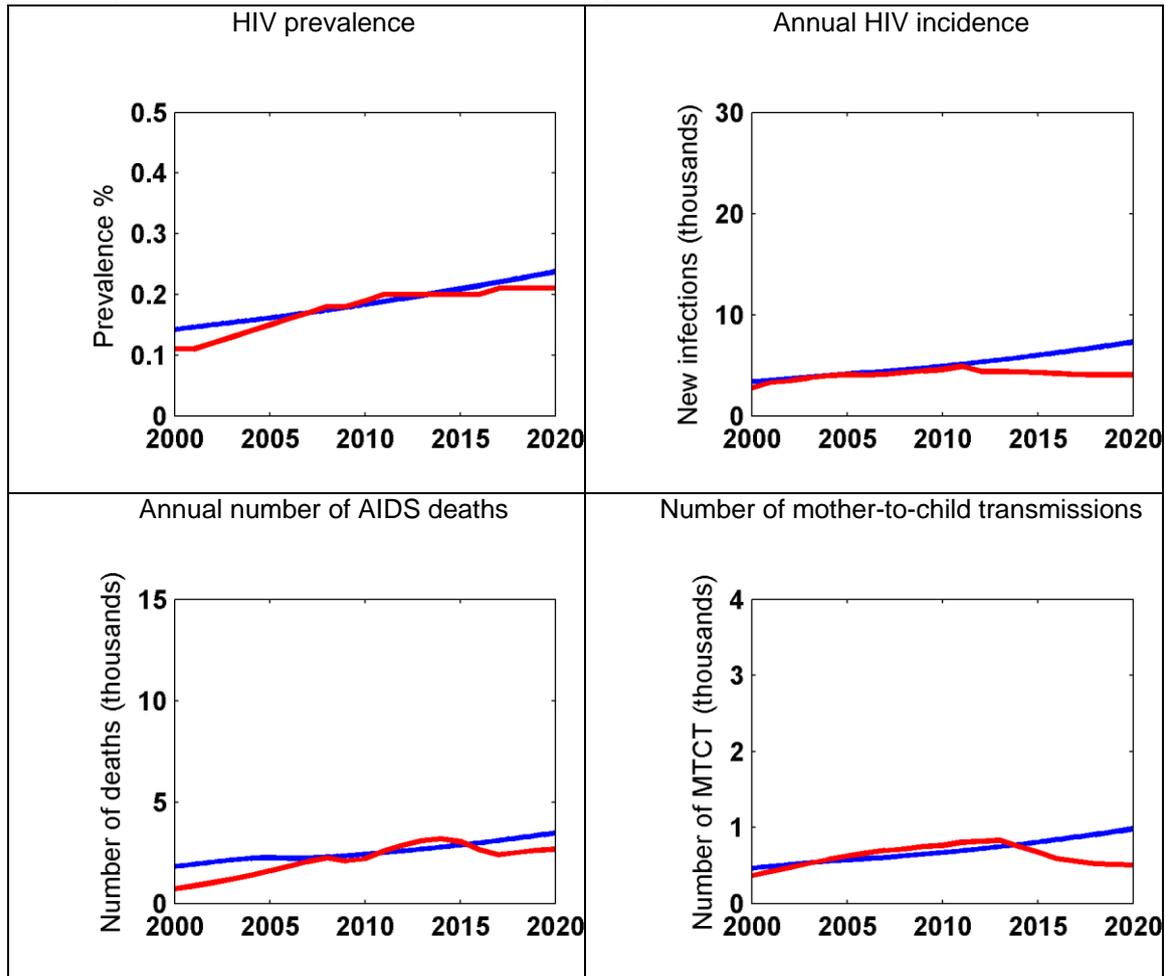
g) Prevention of Mother-to-Child Transmission: PMTCT rates are currently extremely low, and it is assumed that coverage rates will initially be a little slow to respond to increased funding.



Annex 3. Comparison of epidemic modelling outputs

The epidemic trends predicted by Optima are broadly in line with those predicted by Spectrum (**Annex Figure 3**).

Annex Figure 3. Comparison of epidemic modelling outputs



Note: Optima = blue, Spectrum = red. HIV prevalence/incidence based on people 15+ years in Optima and Spectrum

References in annexes

- [1] CRAIG, A.P., et al., Spending of HIV resources in Asia and Eastern Europe: systematic review reveals the need to shift funding allocations towards priority populations. 2013.
- [2] Salomon, J.A., et al., Common values in assessing health outcomes from disease and injury: disability weights measurement study for the Global Burden of Disease Study 2010. *The Lancet*, 2013. **380**(9859): p. 2129–2143.
- [3] L, Z., et al., HIV prevalence in China: integration of surveillance data and a systematic review. *Lancet Inf Dis*, 2013. **13**(11): p. 955–963.
- [4] Zhang, L., et al., High HIV Prevalence and Risk of Infection Among Rural-to-Urban Migrants in Various Migration Stages in China: A Systematic Review and Meta-Analysis. *Sexually Transmitted Diseases*, 2013. **40**(2): p. 136–147.
- [5] Chow, E.P.F., D.P. Wilson, and L. Zhang, HIV and syphilis co-infection increasing among men who have sex with men in China: a systematic review and meta-analysis. *PLOS One*, 2011. **6**(8): p. e22768.
- [6] Zhuang, X., et al., HIV and HCV prevalence among entrants to methadone maintenance treatment clinics in china: a systematic review and meta-analysis. *BMC Infectious Diseases*, 2012. **12**: p. 130.
- [7] The World Bank databank. Inflation, consumer prices (annual %). [<http://databank.worldbank.org/data/> accessed 1/05/2013].
- [8] The World Bank databank. PPP conversion factor (GDP) to market exchange rate ratio. [<http://databank.worldbank.org/data/> accessed 1/05/2013].
- [9] Bollinger, L., K. Cooper-Arnold, and J. Stover, Where are the gaps? The effects of HIV-prevention interventions on behavioral change. *Studies in family planning*, 2004. **35**(1): p. 27–38.
- [10] Bollinger, L.A., How can we calculate the "E" in "CEA"? *Aids*, 2008. **22**:S51–S57.
- [11] Hull, P., et al., Gay community periodic survey: Sydney February 2012, in Sydney: National Centre in HIV Social Research, The University of New South Wales 2012.
- [12] Zablotska, I.B., et al., Behavioural surveillance among gay men in Australia: methods, findings and policy implications for the prevention of HIV and other sexually transmissible infections. *Sexual Health*, 2011. **8**(3): p. 272–279.
- [13] Moré, J.J. and D.C. Sorensen, Computing a trust region step. *SIAM Journal on Scientific and Statistical Computing*, 1983. **4**(3): p. 553–572.
- [14] Bates, D.M. and D.G. Watts, *Nonlinear Regression Analysis and Its Applications* (1988): John Wiley & Sons, NY.
- [15] Avriel, M., *Nonlinear programming* (2003): *Dover Publications*.