Summary: Cost-effectiveness analysis of targeted end-game interventions against *gambiense* human African trypanosomiasis in the Democratic Republic of Congo

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Abstract

Gambiense *human African trypanosomiasis (gHAT) is marked for elimination of transmission (EoT) by 2030. We examined the cost-effectiveness (CE) of EoT in the Democratic Republic of Congo, which has the highest global gHAT burden. In 165 health zones (HZs), we modelled the transmission dynamics, health outcomes, and economic costs of six strategies during 2024–40, including the cessation of activities after case reporting reduces to zero. Uncertainty in CE was assessed within the net monetary framework, which presents the optimal strategies at a range of willingness-to-pay (WTP) values, denominated in costs per disability-adjusted life-year averted. We assessed the optimal strategy for cost-effectiveness and EoT in each health zone separately, but we present results by health zone as well as aggregated by coordination and for the whole country. Status quo strategies, CE strategies (WTP=$500), and strategies with a high probability of EoT by 2030 are predicted to yield EoT by 2030 in 117 HZs, 130 HZs, and 138 HZs respectively, at a cost by 2040 of $171M (95% PI:$89.5M—283M), $177M (95% PI: $97.9M—289M), $216M (95% PI: $119M–355M). A more lenient timeline of EoT by 2040 could lead to EoT in 153 HZs at a cost of $199M (95% PI: $109M–$327M), leaving 12 HZs shy of the goal. Costs would have to be front-loaded; in 2024, status quo strategies would cost $16.1M (95% PI: $8.44M—23.8M), minimum costs strategies would cost $17.0M (95% PI: $9.31M-–24.9M), and elimination strategies would cost $25.6M (95% PI: $15.8M—36.6M). Investing in EoT by 2030 is predicted to reduce 74% of gHAT deaths from 10,601 (95% PI: 1063—36,124) with status quo strategies to 2654 (95% PI: 301—9454).*

E1 Introduction

This study focuses on the health economic impact of implementing six plausible gHAT control and elimination strategies for the whole of the DRC at the health zone level and under a variety of funding and elimination targets. This is an expansion of previous work described above (see [1]) that focused on five low- to high-risk health zones but scaled up to 165 health zones across the DRC. Model fits and projections are also refined from previous work through the use of an extra four years of gHAT case and screening data (see [2, 3]). Using a modelling framework, we examined the interplay of epidemiological, economic and temporal factors in effective decision-making around gHAT strategies for EoT. The objective of this piece is to estimate future resource needs including the resource implications of pursuing gHAT EoT by 2030 and which of the strategies under consideration has the highest probability of being cost-effective in these different settings.

E2 Methods

E2.1 Data

Historical case data was acquired from the WHO HAT Atlas project, which also includes records of the number of people tested in active screening activities [4]. For cost purposes, populations screened during passive screening were

deduced from two data sources: the historical records of clinics capable of screening with serological tests (RDT or CATT) [5], and records acquired from the PNLTHA for the years 2019–2020. Cost data was acquired from the literature and conversations with program staff ([6, 7], among others).

E2.2 Transmission model fit to data

For this study, we used the previously published Warwick gHAT model [2] consisting of a mechanistic modelling framework to explicitly simulate transmission between humans via tsetse vectors (see Supplementary Figure E1). The model parameterisation has recently been updated by fitting to WHO HAT Atlas data from 2000–2020 for health zones in the DRC that had sufficient data (at least 10 data points, where any year with active screening and any year with non-zero passive case detection count as individual data points). Furthermore, the modelling framework has been updated to capture stochastic dynamics and is better able to estimate the time until EoT. Moreover, we fit also the data to a model variant with animal reservoirs which considers the possibility that animals can acquire and transmit infections to and from tsetse (as per [8] but with an extra four years of data). Our final projections will consist of an "ensemble" of samples of projections from both models – with and without animal reservoirs. The proportion of samples from both models will be determined by the statistical support of each model based on the data. The health zones included in the analysis are described in Table **??**.

E2.3 Epidemiological projections

Projections under six plausible gHAT control and intervention strategies were simulated from 2024–2053 and are displayed in Figure E2; two health zones in the Bas Uéle region – Ango and Doruma – have alternative strategies due to the special situations in these health zones. Each activity is further explained in Table E1. The *Targeted VC* strategy uses an adapted algorithm based on that previously used by LSTM to identify large rivers with recent nearby high case density at which to focus Tiny Target deployment. The *Full VC* strategy, by contrast, involves an expansion of VC interventions, considering the deployment of Tiny Targets throughout all large rivers in a health zone. All strategies feature the continuation of the current PS. All strategies assume that AS will cease after 3 years of AS with zero cases in either AS or PS, followed by another AS in year 5 with no cases. Reactive screening (RS) is triggered if a case is found in PS and stops using the same 3+1 algorithm. VC stops after 3 years of no cases. PS is stopped 5 years after AS and RS have ceased. PS is assumed to remain constant for the duration of our simulations, even after cessation of AS and VC and presumed EoT. Fexinidazole is simulated as being available immediately, but acoziborole is not included in this analysis.

For each case, we model the disease outcomes as depicted in Figure E3.

E2.4 Economic evaluation and investment horizon

We adopted the net-benefits framework, which expresses the probability that an intervention is optimal at a range of thresholds, known as the willingness-to-pay (WTP) thresholds. We computed net monetary benefits by taking the mean difference in costs and monetised health effects (DALYs × willingness-to-pay value). As per recent recommendations from the WHO, we refrained from selecting a specific ICER that would be considered "cost-effective", and we aimed to make recommendations after accounting for uncertainty.

We examined health and cost impacts in the long term (2024–2040) to assess the returns on investments in both augmented disease control and elimination. Costs are presented in their undiscounted version for pragmatic reasons but for the selection of cost-effectiveness, both costs and health outcomes are discounted at a yearly rate of 3%.
A glossary of epidemiology and health economic terms is found in the Supplementary Note 1 and in Section E5 of this summary.

E3 Results

Figure E4 summarises the optimal strategy for each of the 165 health zones included in this analysis at each WTP threshold (status quo, minimum cost, WTP=$250, and WTP=$500) and the strategy necessary to maximise the probability of EoT by 2030 and a more lenient goal date of 2040. For strategies in health zones that yield <90% probability of EoT by either date, the strategy with the maximum probability of EoT is selected. Modelling suggests that 93 health zones could switch strategies to maximize their probability of EoT by 2030. For a more lenient goal of EoT by 2040, 70 health zones need to change strategies from their status quo strategies.

National-level results are summarised in Figure E5. With the current strategies, we expect that 117 (out of 165) health zones will reach EoT by 2030. Switching 93 health zones to EoT-maximising strategies, 21 more health zones

are expected to reach the goal, for a total of 138 health zones. The low expectation of EoT even after we change to strategies with a better probability of EoT is because 47 health zones have a probability of EoT by 2030 < 90% even under the strategy that maximises EoT.

Costs and effects at different levels of investment In terms of total investments, by 2040, the status quo strategies will cost $171M, the minimum cost strategies will cost $162M, cost-effective strategies at WTP=$250/DALY and WTP=$500/DALY will cost $171M and $177M and EoT by 2030 will cost $216M (Figure E7). We further show that a lot of our uncertainty is due to the lack of screening in Bas Uélé in recent years, so if nothing were necessary in that region, EoT by 2030 would cost $206M. Although the increase in costs is 26.3% over the status quo to EoT by 2030 over 17 years, the increase in resources in 2024 to reach EOT would need to increase by almost 59.0% (from $16.1M to $25.6M in 2024) (Figure E6). EoT-maximising strategies will begin to cost less than status quo interventions in 2034 if we look at estimates including Bas Uéle, and by 2033, if we look at estimates excluding Bas Uélé. Delaying the goal until 2040 saves only $17.0M compared to implementing activities aimed at EoT by 2030.

The status quo strategies will bring an expected 10,601 of 237K (discounted) DALYs by 2040 and minimum cost strategies would bring about 9676 deaths or 217K DALYs including Bas Uélé. However, more than 2300 of those deaths are expected to be in the two health zones of Bas Uélé alone. Without Bas Uéle, status quo interventions would bring about 7332 deaths and 168K DALYs, and minimum cost interventions would bring about 7332 deaths and 168K DALYs (Figure E7).

The largest portion of the costs at any level of investment will go to screening activities (see Figure E17). Although the cost of treatment is quite small in relative terms, timely access to treatment is pivotal for strategies to remain effective.

All results are available, stratified by coordination, in Figures E8–E18.

E4 Discussion

E4.1 Conclusion

Financial resources will have to increase for a short period to reach EoT by 2030, but EoT strategies will begin to give returns to investments by 2033–34. Expanded strategies will be necessary in some health zones, particularly in the East where uncertainty makes the analysis favour more intense strategies. In Kongo Central and Equateur Nord, current strategies appear to be on track for EoT by 2030.

Future analysis for the DRC, which is currently outside the scope of this study, will look at 1. the potential impact of strategies that use acoziborole as a single-dose treatment and 2. the premium paid for EoT above and beyond what would be considered a cost-effective use of resources compared to other health programmes using our new "net monetary and elimination benefits" framework [9].

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E5 Glossary of epidemiologic and health economic terms

Box 1: Glossary (adapted from Antillon et. al 2022 [1] under a CC-BY 4.0 licence.)

Epidemiology Terms

Intervention Interventions are separate activities to address a health need (e.g. active screening (AS) or vector control (VC)).

Strategy A strategy combines interventions with specific coverage and in parallel. In this paper, we simulate strategies with and without an improvement in AS and with and without VC (e.g. Strategy 1 is passive screening (PS) and mean AS, and Strategy 6 is PS, intensified AS and full VC).

Elimination of transmission (EoT) Globally this is the 2030 goal for gHAT; here we also consider local EOT for health zones. The feasibility of EoT is expressed as a probability equal to the proportion of our simulations in which new infections are zero before a given year (usually 2030).

Objective The objective is the overarching goal of the decision maker; this could be EoT by 2030, minimising costs, or delivering a cost-effective programme compared to other diseases. We assume the objective is country-wide and different regions may need different strategies to meet the objective.

Disability-adjusted life-year (DALY) In order to present the burden of disease as one common metric across diseases, DALYs are calculated in cost-effectiveness analyses. This is the sum of the years lived with disability due to the disease and the years of life lost by fatal cases.

Health Economics Terms

Parameter uncertainty Uncertainty in the level of transmission or the costs of interventions due to unknown underlying parameters (see Supplementary Note 3 for an explanation of our parameterisation of the health outcomes and cost model).

Willingness-to-pay (WTP) or cost-effectiveness threshold The amount of money that payers would pay to avert one DALY arising from the disease in the analysis (gHAT). No specific threshold is recommended, but a recent analysis shows that the WTP in DRC is between 5–230 USD per DALY averted [10–12].

Incremental cost-effectiveness ratio A ratio of marginal cost for a marginal benefit, calculated as follows:

$$\text{ICER} = \frac{\Delta\text{Costs}}{\Delta\text{DALYs}} = \frac{\text{Costs}_{\text{strategy}} - \text{Costs}_{\text{next best}}}{\text{Effects}_{\text{strategy}} - \text{Effects}_{\text{next best}}}$$

Cost-effective strategy The strategy where the ICER is less than the WTP (or cost-effectiveness threshold). We say that the cost-effective strategy is “conditional" on the WTP.

Dominated strategy A strategy that costs more than the minimum cost intervention while reducing the burden by a smaller degree. This strategy ought not to be implemented.

Weakly dominated strategy (or strategies under extended dominance) A strategy in which the ICER is higher than the next more expensive strategy. This strategy is less efficient than the next more expensive one and should not be implemented. For further illustration of weak dominance, see Supplementary Section, page 46 of Antillon et. al 2022 [1].

Net monetary benefit The net benefits (NMB) framework is derived from ICERs but also takes uncertainty into account.

$$\text{NMB}|\text{WTP} = \text{WTP} \times \Delta\text{DALYs} - \Delta\text{Costs}$$

The optimal strategy at a given WTP is the strategy with the highest mean NMB at that value of WTP.

Optimal strategy Analogous to the cost-effective strategy when no uncertainty is assumed, this is the strategy that is recommended by the NMB framework.

E6 Tables and Figures

Term	Description
Active screening (AS)	Mobile teams travelling to at-risk villages to test any person willing to participate
High risk	Individuals with the greatest risk of gHAT infection
Intensified (Int.) active screening (Int. AS)	Screening coverage (% people) at either the historic maximum or at 30% if the historic maximum is lower than this value
Intervention	Tools, treatments or approaches used to prevent or treat the infection
Low risk	Individuals with the lowest risk of gHAT infection
Mean active screening (Mean AS)	Screening coverage (% people) at the mean of the last five years for a region
Passive screening (PS)	Testing self-presenting individuals for gHAT at fixed health facilities
Reactive screening (RS)	Testing in specific locations in response to cases detected through passive screening
Treatment	Treatment of confirmed cases with either fexinidazole (oral drug course) if eligible, or pentamidine or NECT. Acoziborole (oral single-dose cure) may be used in the future if approved but is not considered in this analysis.
Vector control (VC)	Methods used to reduce or eradicate the vector, e.g. tsetse, that transmits infection
Targeted vector control (Targeted VC)	An adapted method based on that previously used by LSTM to identify areas with high case density at which to focus Tiny Target deployment efforts along waterways
Full vector control (Full VC)	Considers the deployment of Tiny Targets throughout all waterways in a health zone

Table E1: **Terms used to describe the interventions and the strategies**

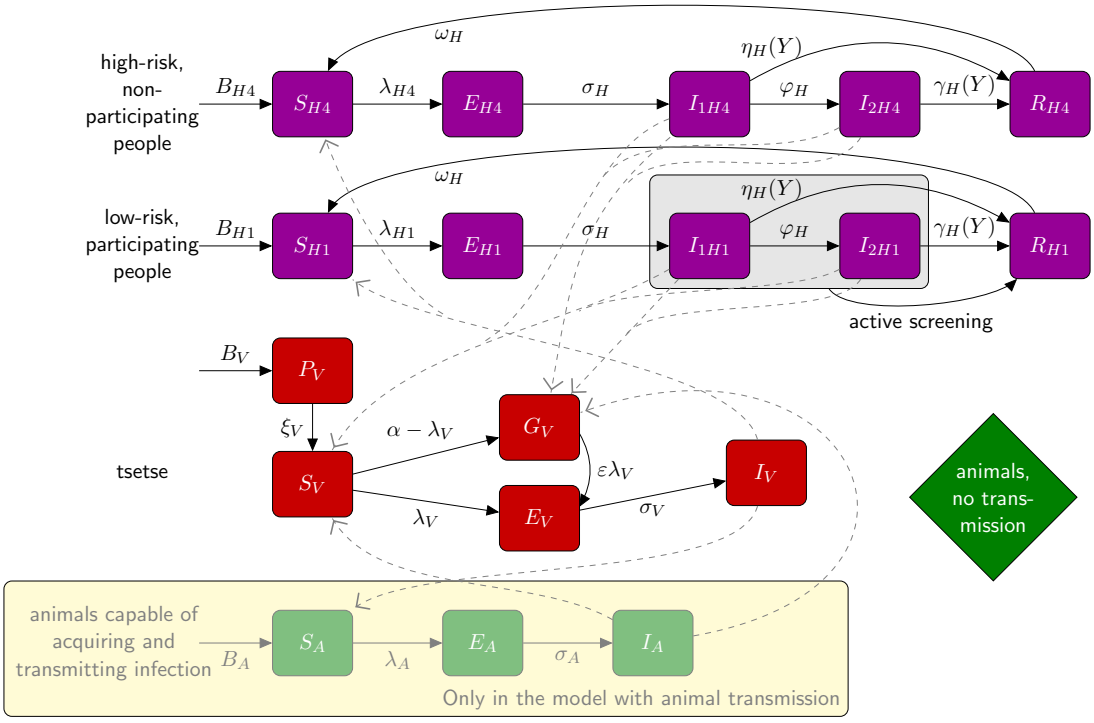
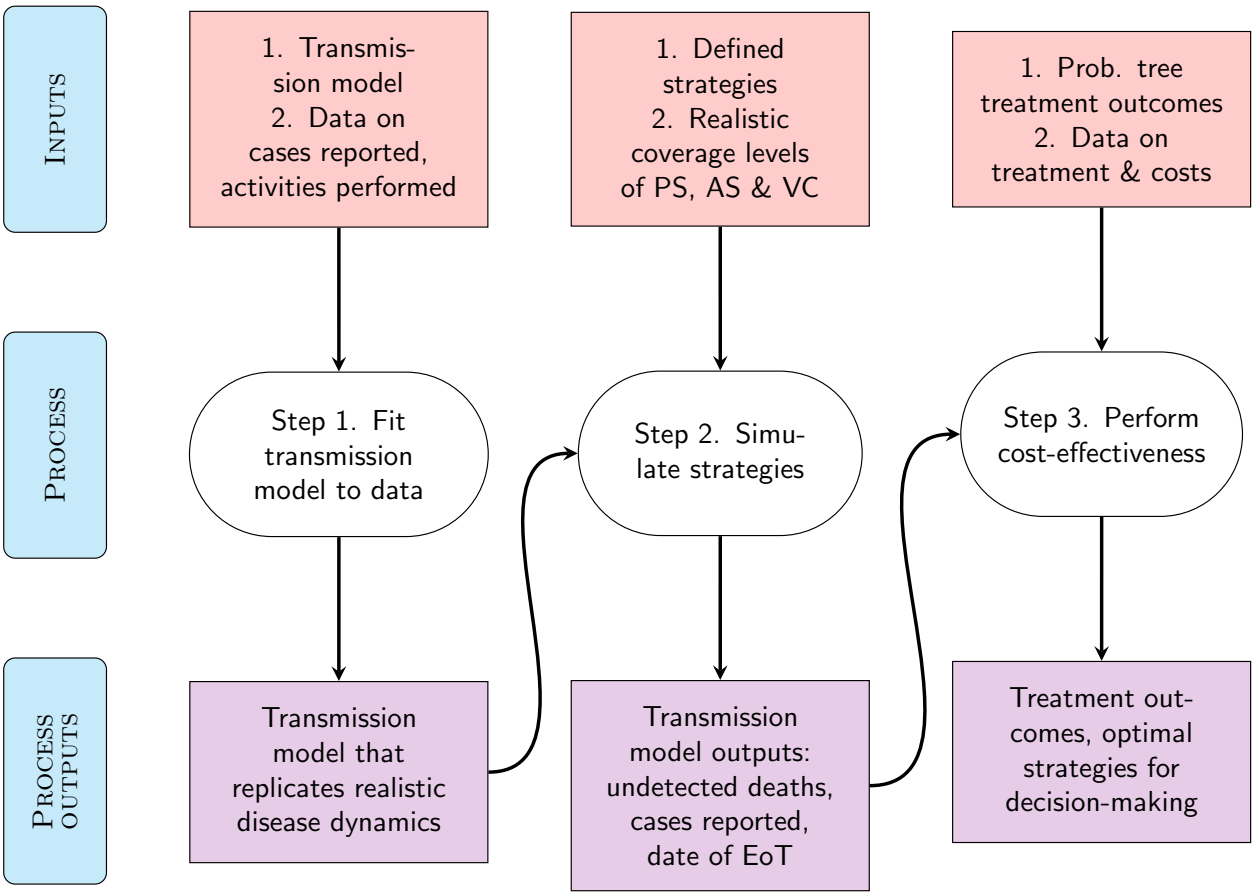
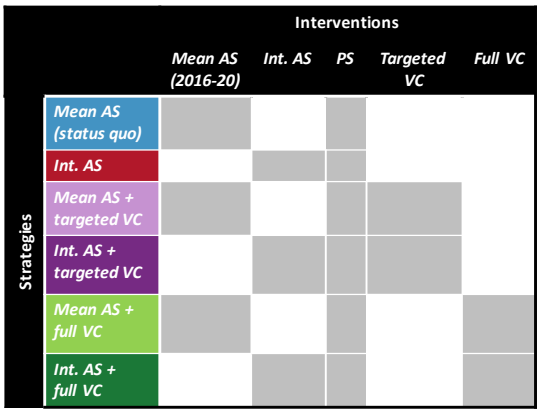


Figure E1: Warwick gHAT intervention model compartmental diagram. Purple boxes denote human infection/risk compartments, red boxes denote tsetse infection compartments, and green boxes denote non-human animal infection compartments (only in the model variant with possible animal transmission). Solid lines represent the transition between infection states, and dashed lines are transmission pathways. Reproduced from [8] under a CC-BY licence.

(a) Process of analysis



(b) General set of strategies.



(c) Special set of strategies.

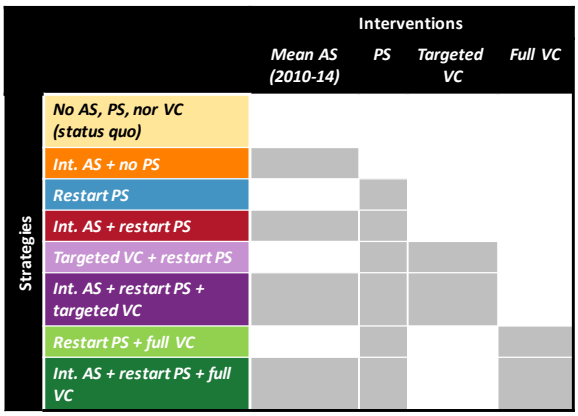


Figure E2: a) Process of analysis. b) Future strategies simulated in most health zones. *Mean AS* is equal to the mean coverage of AS between 2016–2020, *Int. AS* is 30% or the historical maximum coverage between 2000–2020, whichever is higher. c) Future strategies simulated in Ango, Ganga, and Doruma health zones of the Bas Uélé region. We do not simulate mean AS from 2016–2020 in these health zones as there was no AS during this period, hence *Restart PS* is effectively equivalent to this strategy. In these health zones, we take *Int. AS* to be the mean of 2010–2014 when MSF was operating in the region. In all health zones, the *Targeted VC* strategy only simulates VC along rivers in regions with high case density, and because the cases may be diffuse in some health zones, this strategy is not present in some health zones. Whereas the *Full VC* strategy involves the deployment of Tiny Targets throughout all large rivers in a health zone, regardless of the density of the cases. *Intervention cessation:* All strategies assume that AS will cease after 3 years of AS with zero cases in either AS or PS, followed by another AS in year 5 with no cases. RS is triggered if a case is found in PS and stops using the same 3+1 algorithm. VC stops after 3 years of no cases. PS is stopped 5 years after AS and RS have ceased. See the glossary and Table 8 for details of abbreviations.

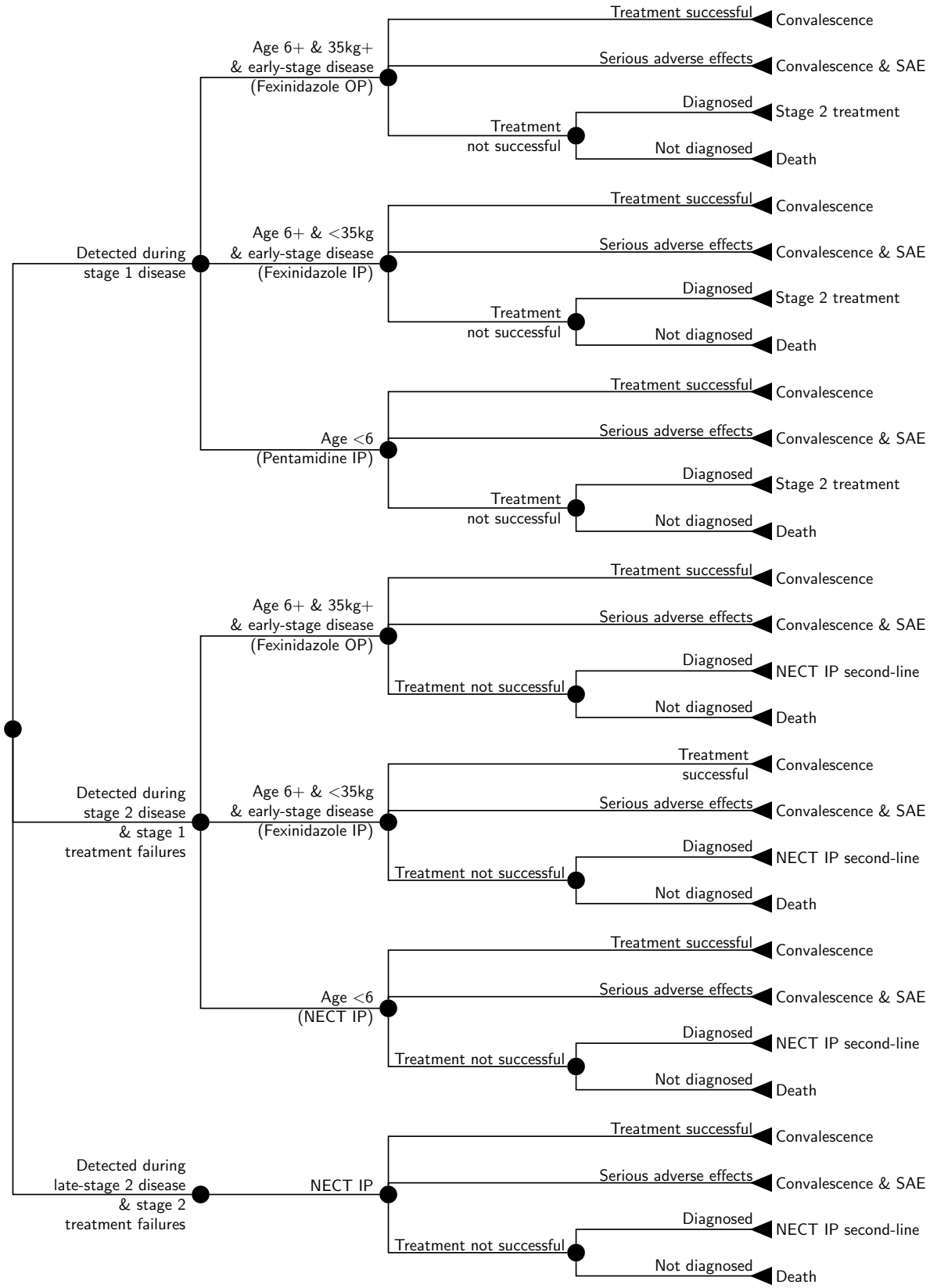


Figure E3: Treatment model. Treatment for diagnosed gHAT patients is modelled as a branching tree process of possible health outcomes, including eligibility for novel fexinidazole. Abbreviations: SAE: Serious adverse events, IP: inpatient care, OP: outpatient care.

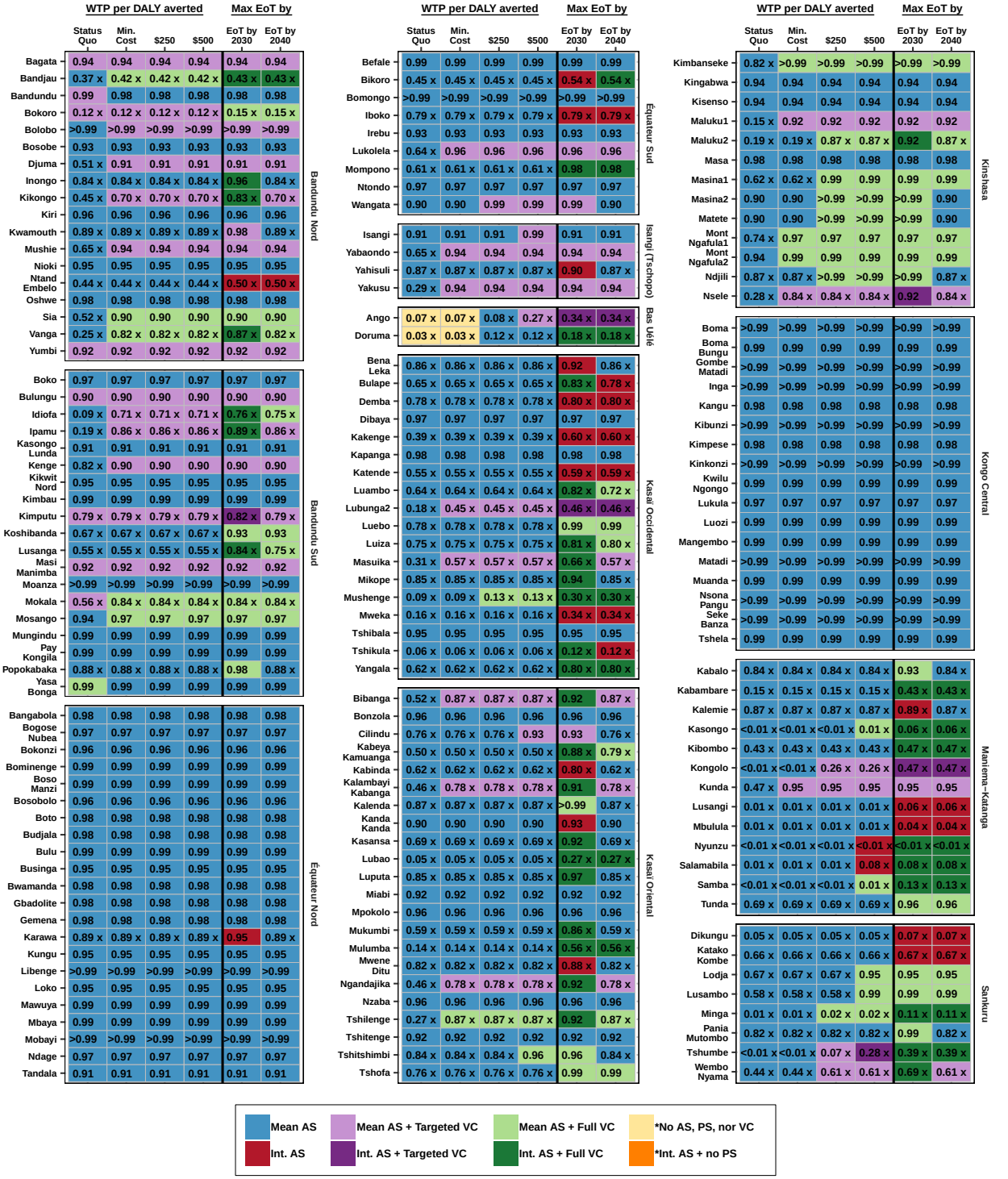
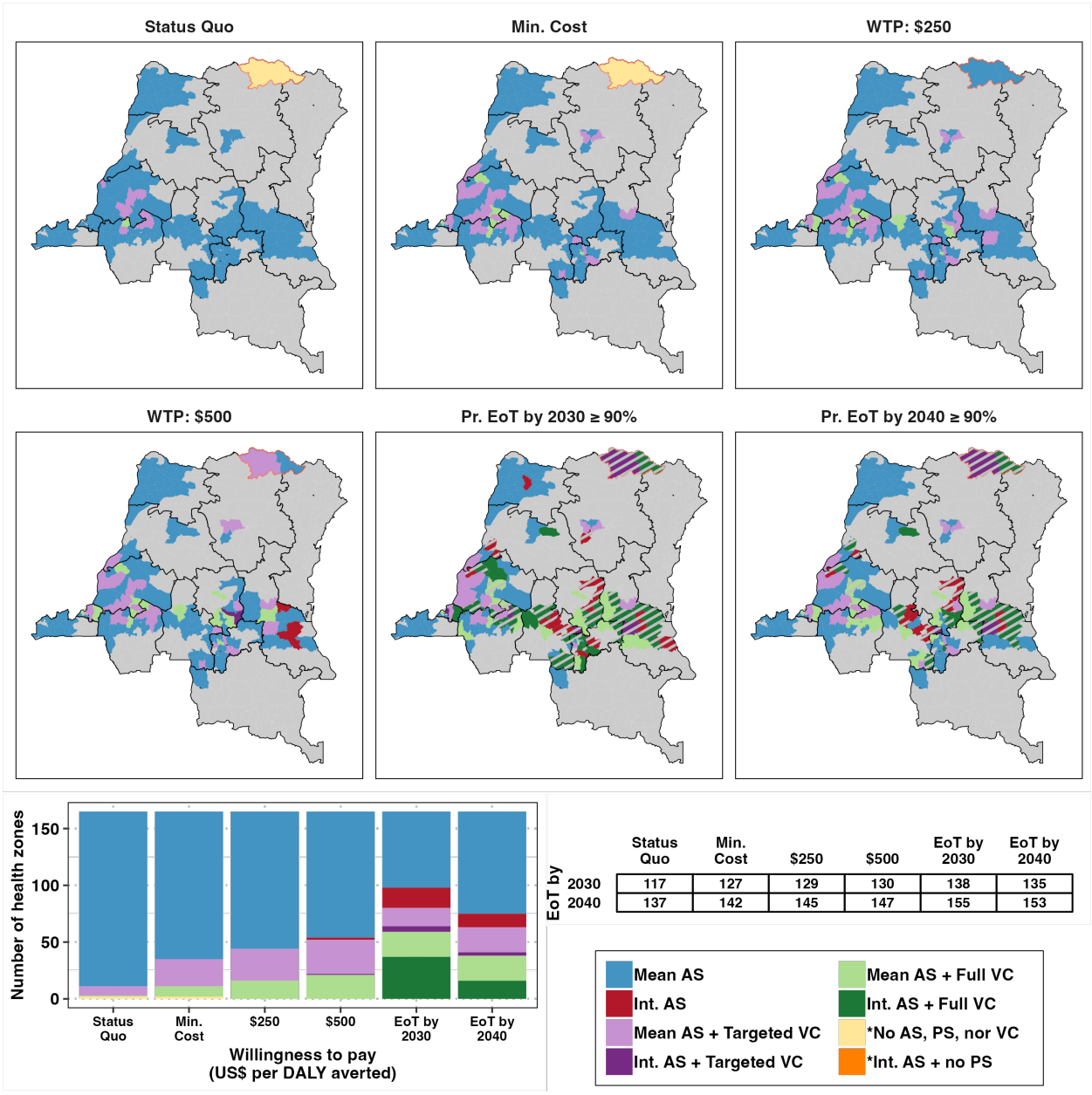


Figure E4: Table indicating optimal strategies according to economic or elimination goals for the whole of the DRC, (time horizon 2024–2040 and 3% discounting). Optimal strategies in each health zone of DRC compared to the status quo strategy (first column) depending on the level of investment (denominated by USD per DALYs averted, or by the date by which EOT is intended.



EoT by	Status Quo	Min. Cost	$250	$500	EoT by 2030	EoT by 2040
2030	117	127	129	130	138	135
2040	137	142	145	147	155	153

Figure E5: **Maps of optimal strategies according to economic or elimination goals for the whole of the DRC (time horizon 2024–2040 and 3% discounting, based on fits to 2000–2020 data).**

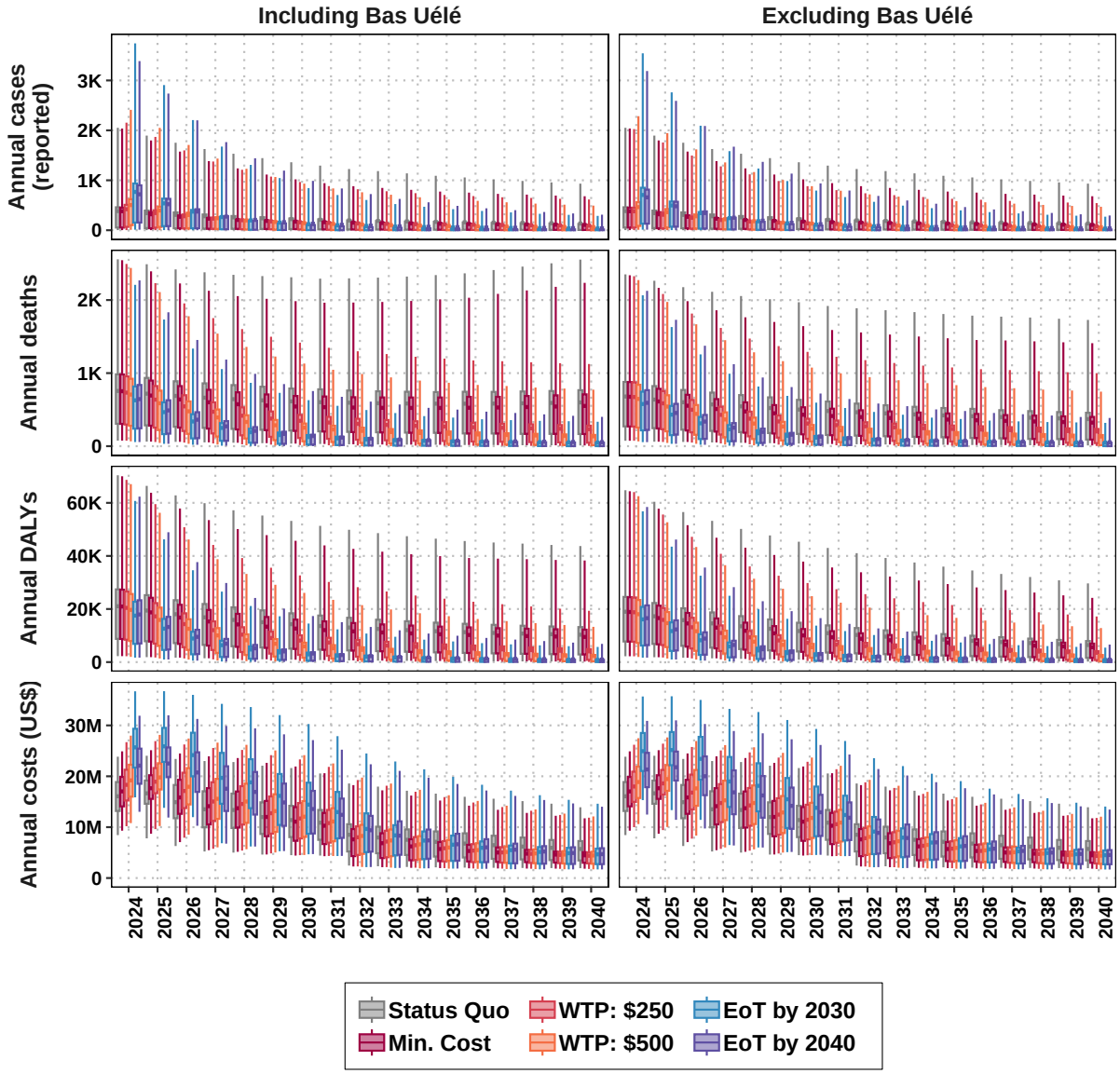


Figure E6: **Total Deaths, DALYs and Costs in all the DRC with optimal strategies with 3% discounting over the time horizon 2024–2040 based on fits to 2000–2020 data.**

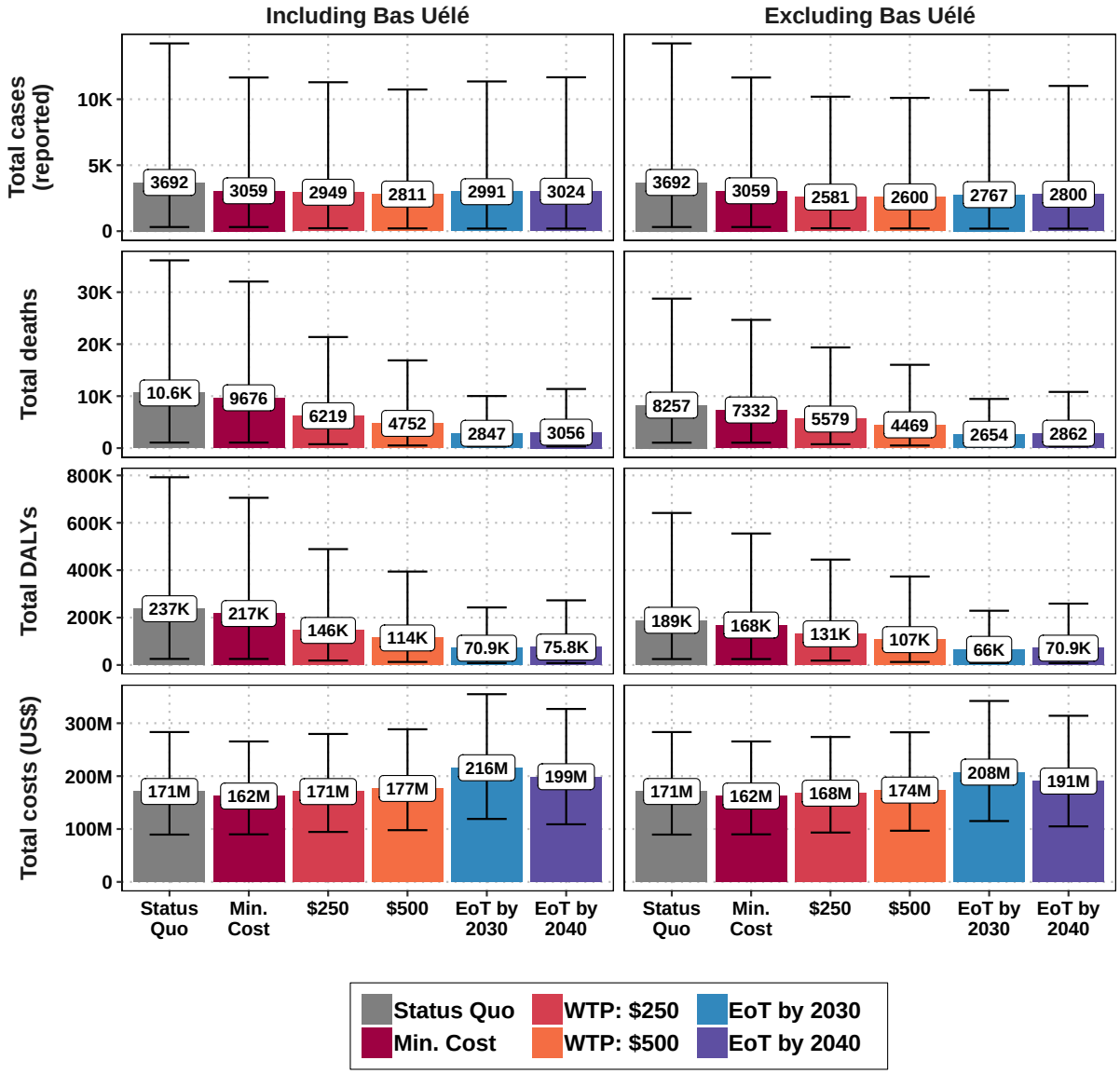


Figure E7: **Total Deaths, DALYs and Costs in all the DRC with optimal strategies with 3% discounting over the time horizon 2024–2040 based on fits to 2000–2020 data.**

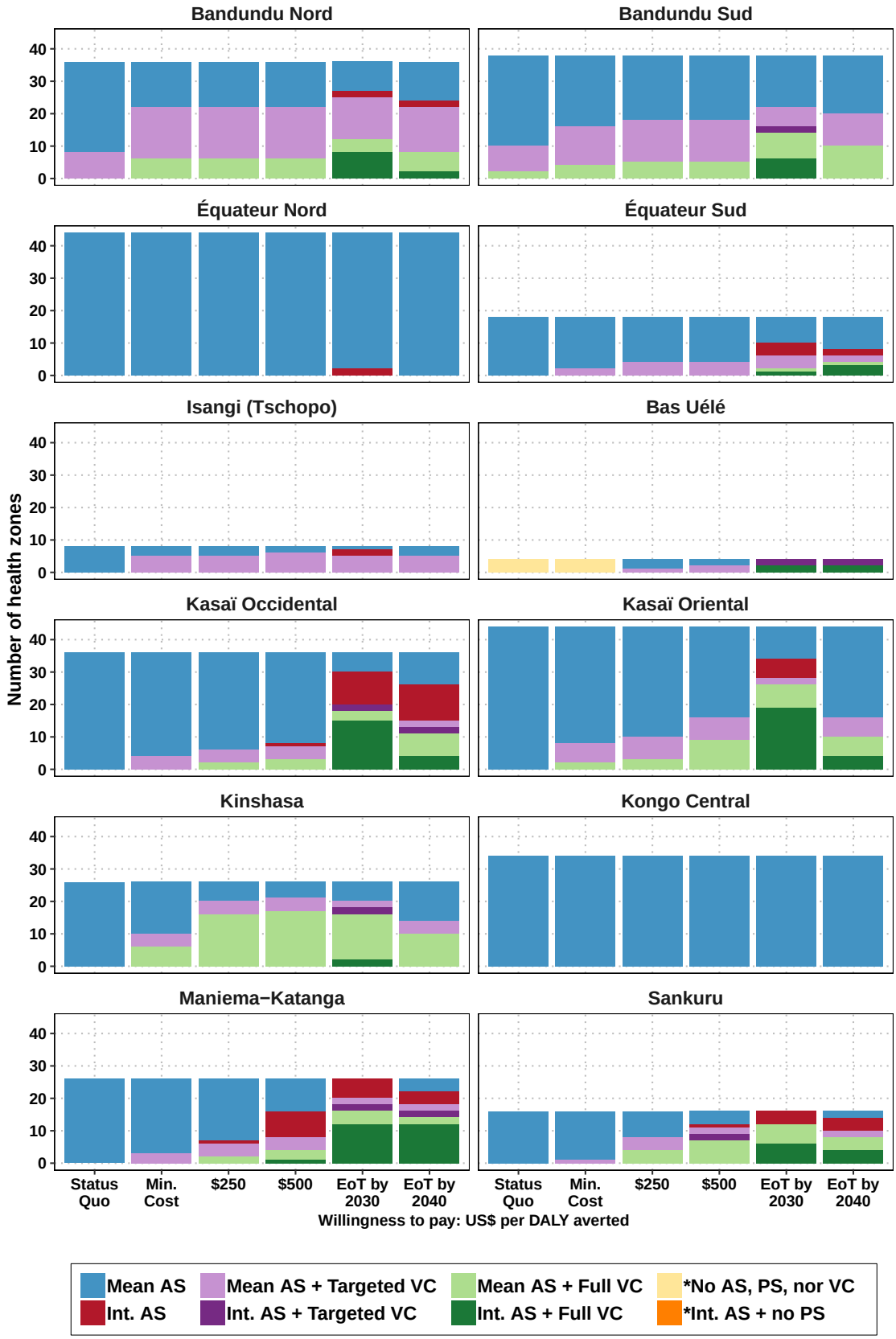


Figure E8: **Histrogram of optimal strategies by coordination**

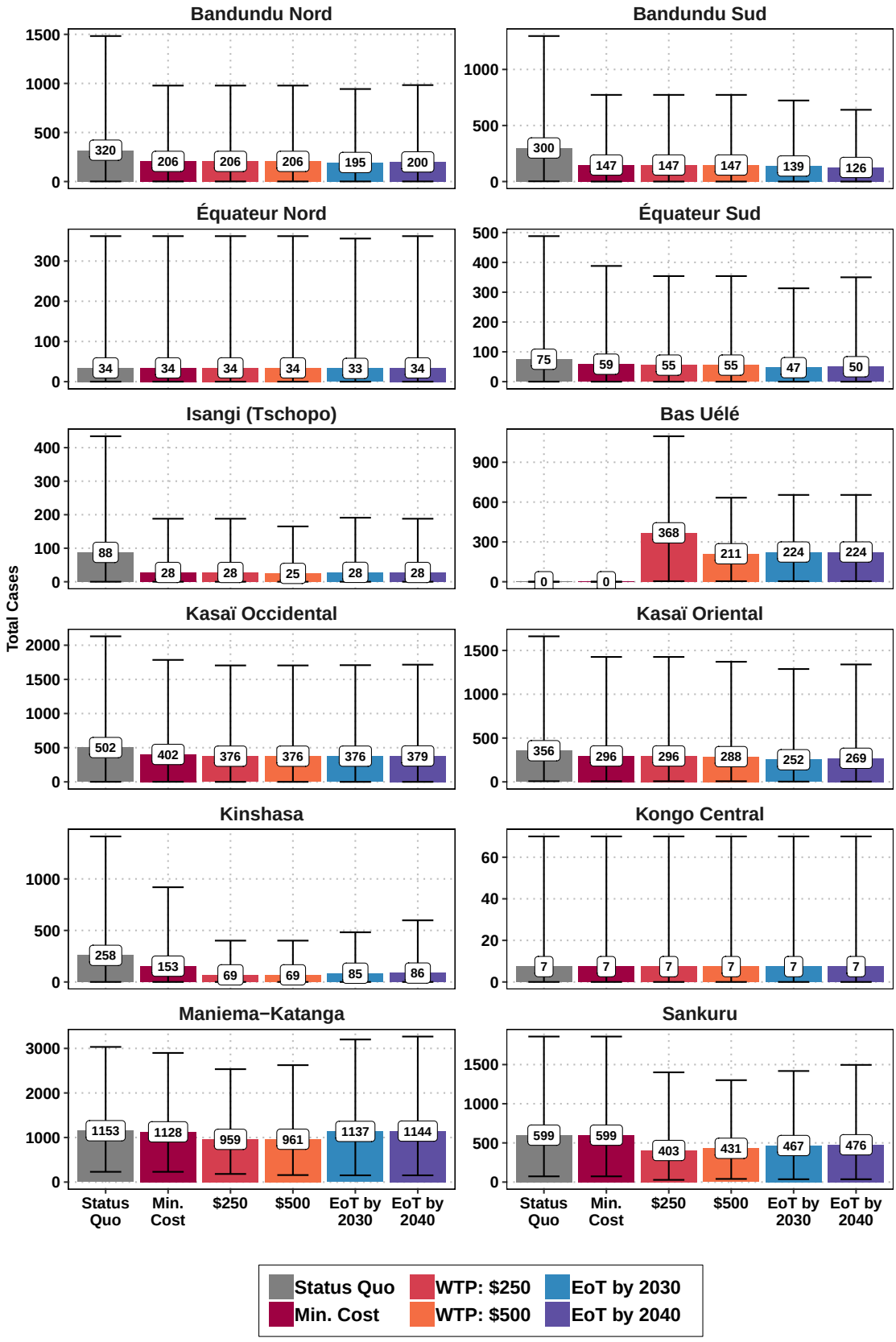


Figure E9: **Total cases 2024–2040 across different levels of investment.**

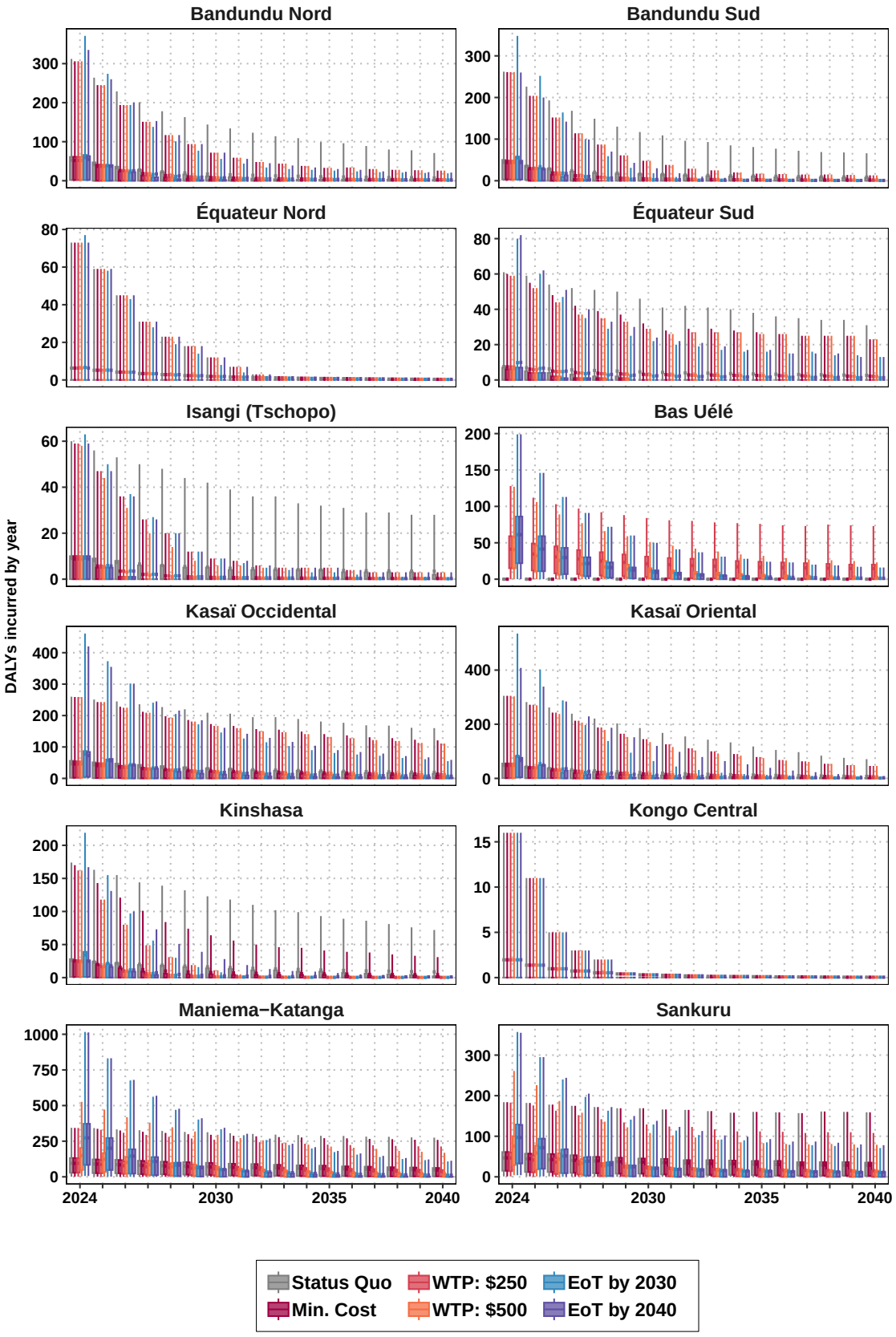


Figure E10: **Cases by year 2024–2040 across different levels of investment.**

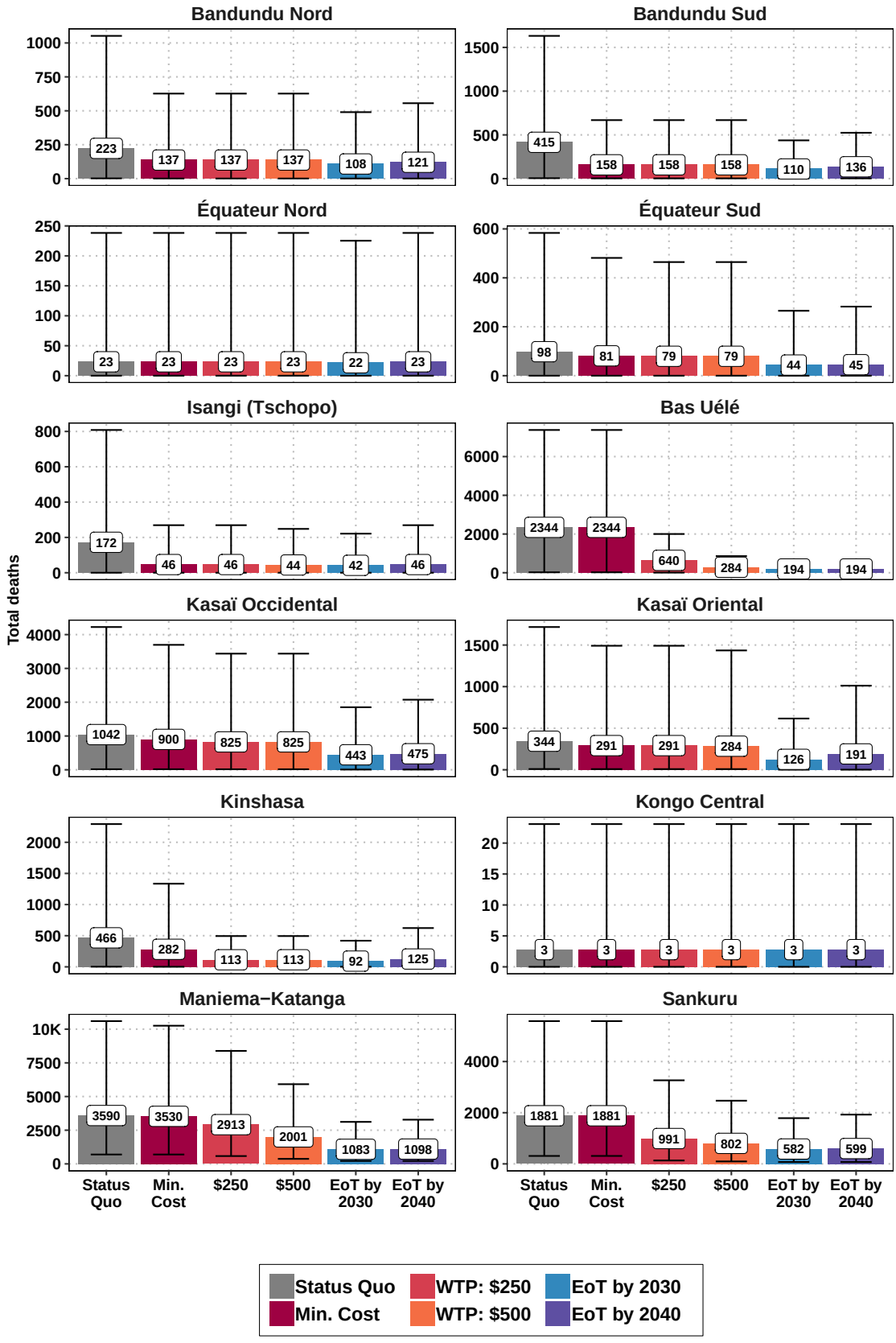


Figure E11: **Total deaths 2024–2040 across different levels of investment.**

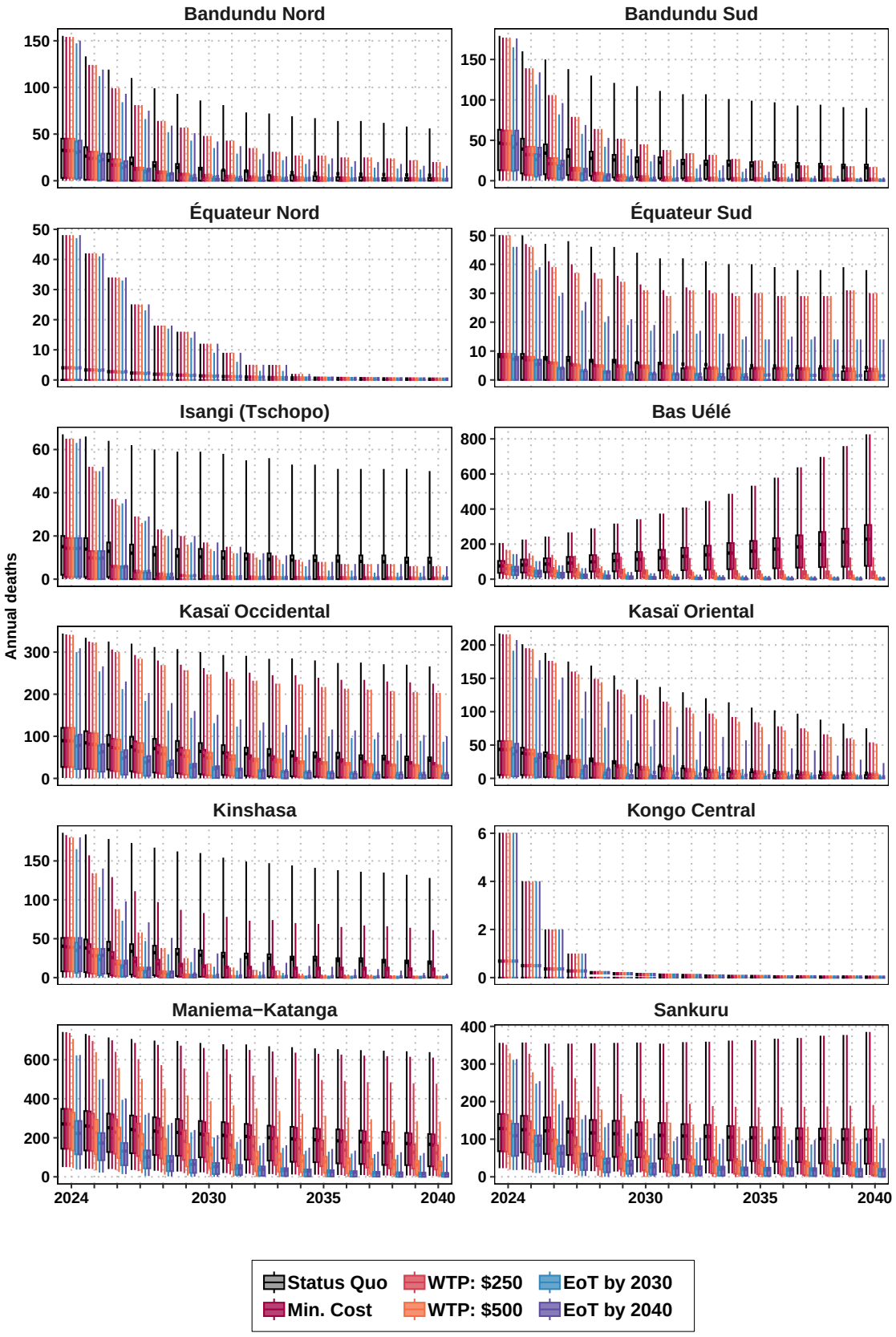


Figure E12: **Deaths by year 2024–2040 across different levels of investment.**

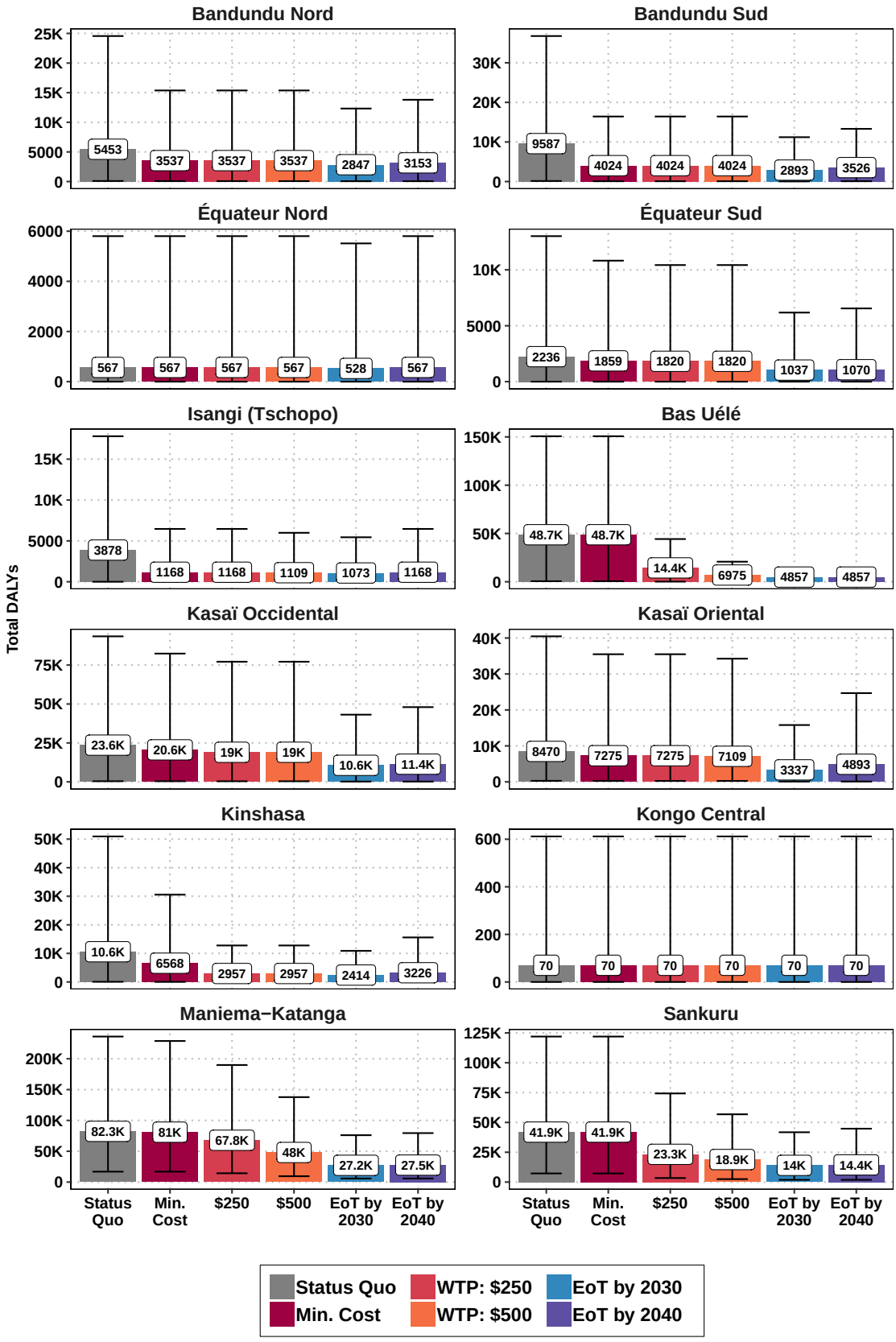


Figure E13: **Total DALYs 2024–2040 across different levels of investment. Abbreviations: DALYs: disability-adjusted life-years.**

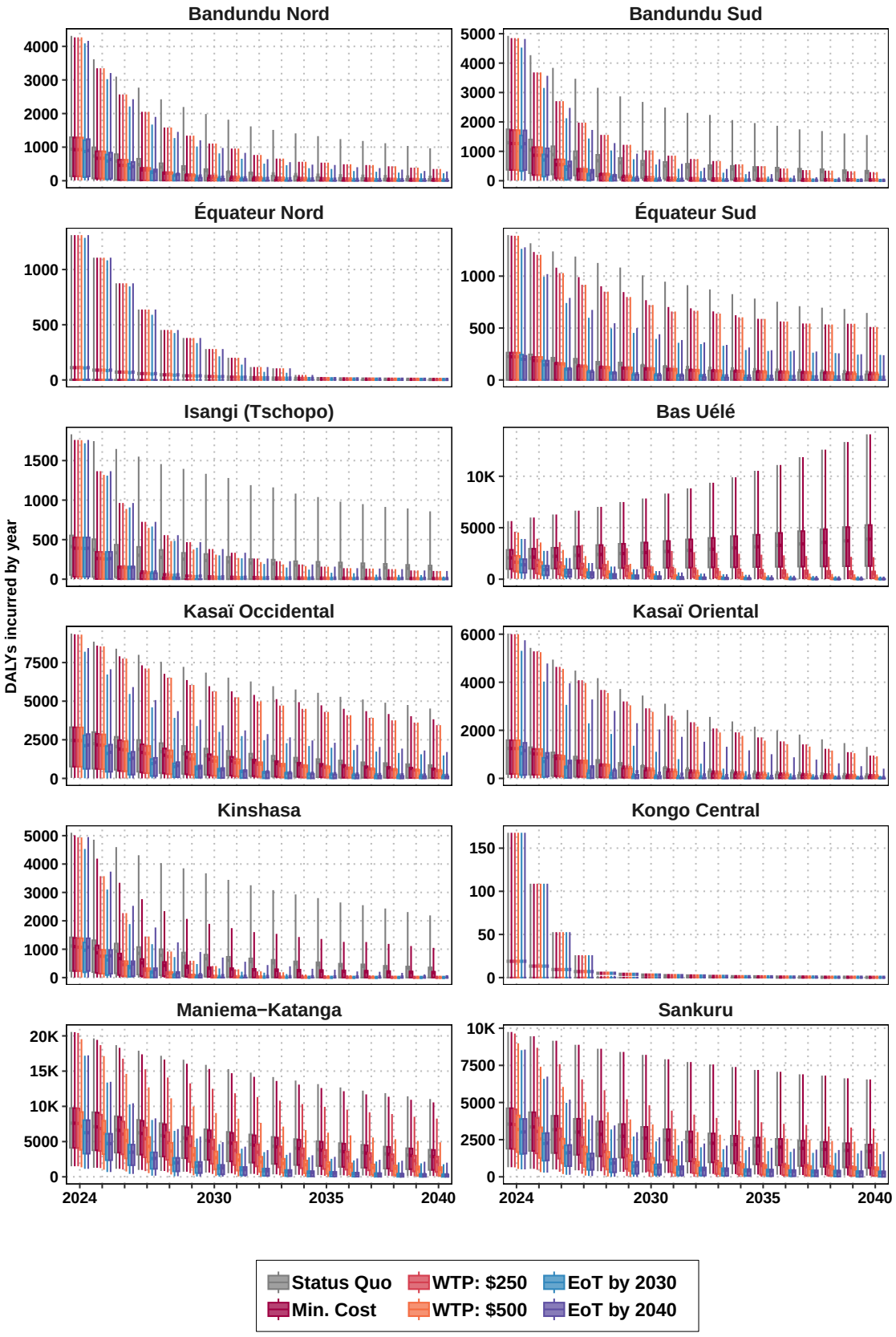


Figure E14: **DALYs by year 2024–2040 across different levels of investment.**

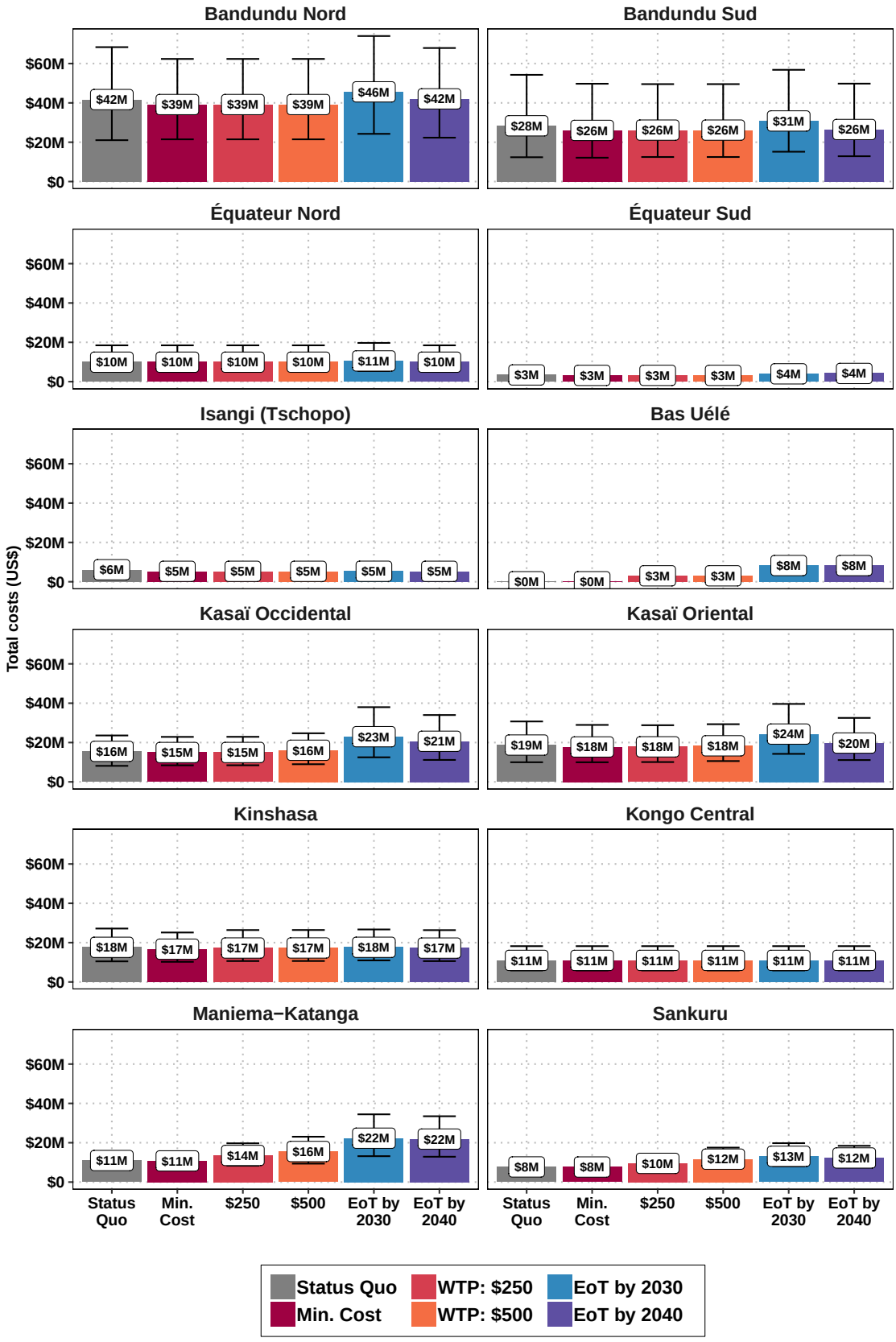


Figure E15: **Total costs 2024–2040 across different levels of investment.**

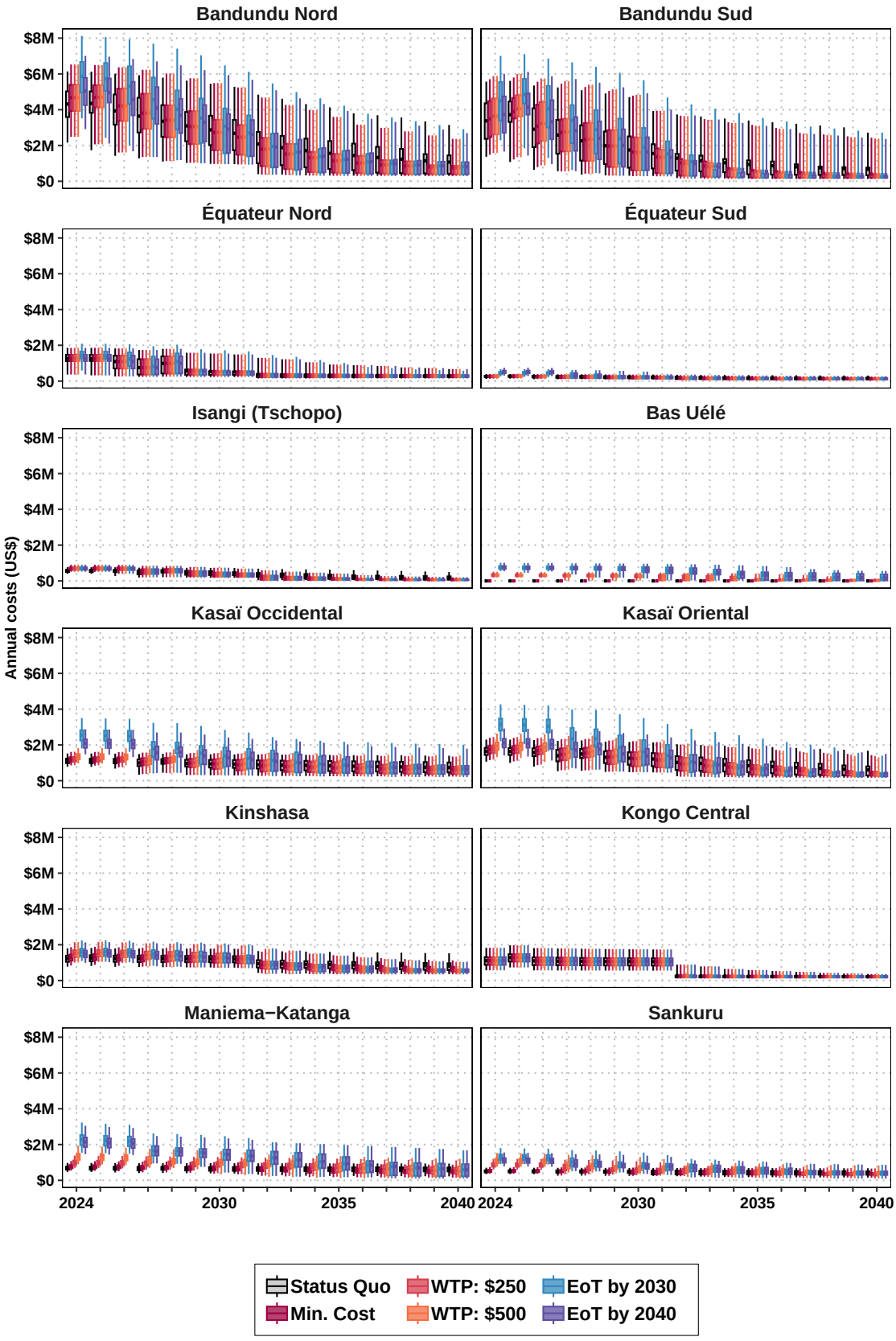


Figure E16: **Annual costs 2024–2040 across different levels of investment.**

E6.1 Resource forecasts

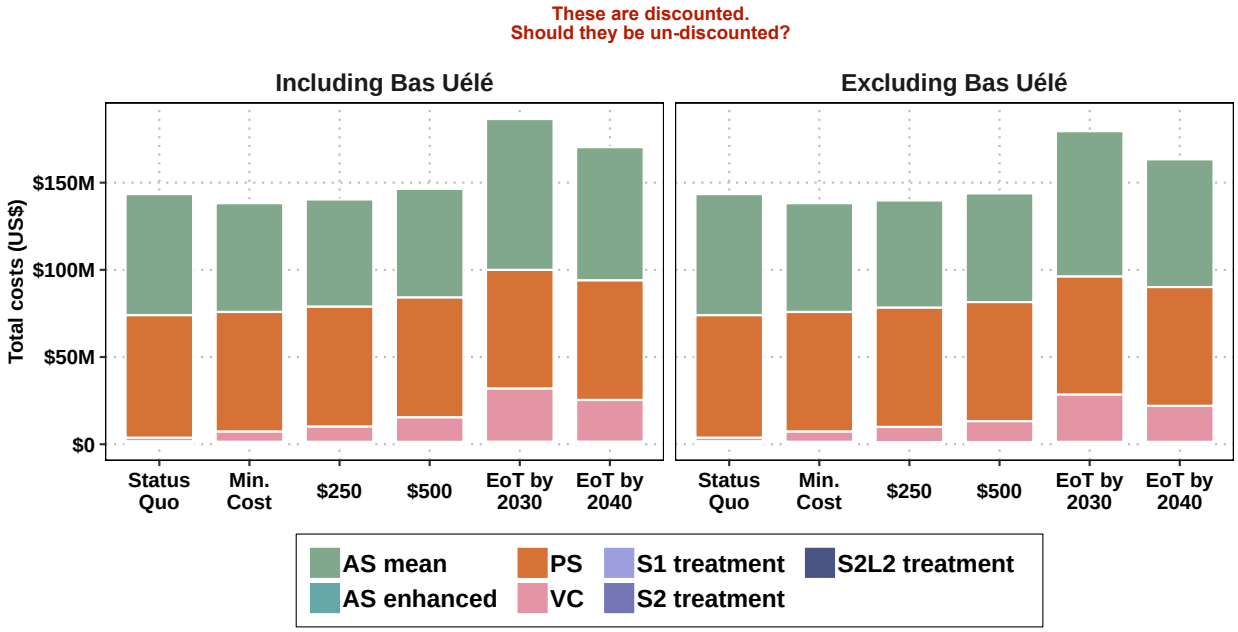


Figure E17: **Costs allocated to different activities across different levels of investment.**

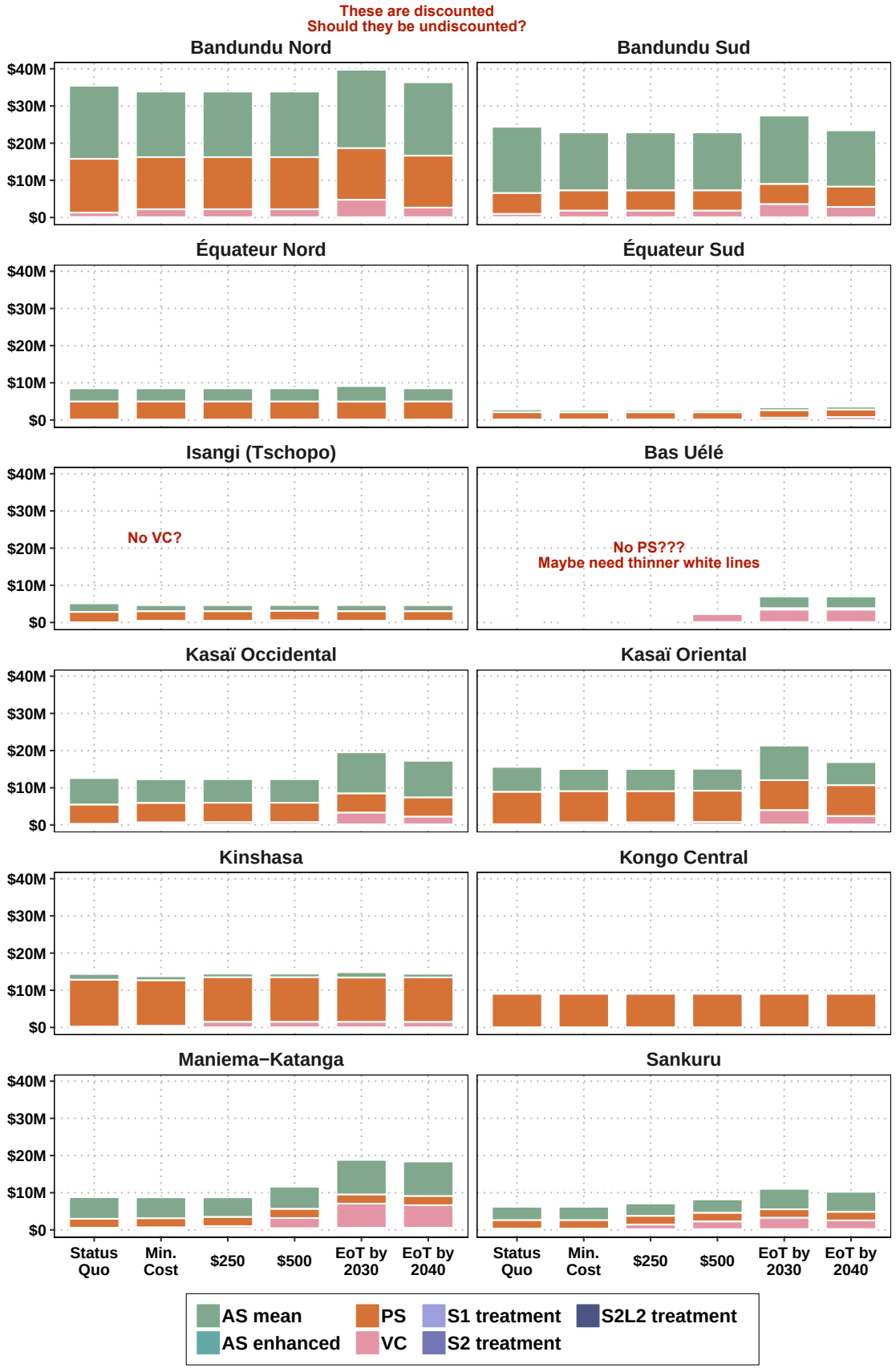


Figure E18: **Costs allocated to different activities across different levels of investment by coordination.**

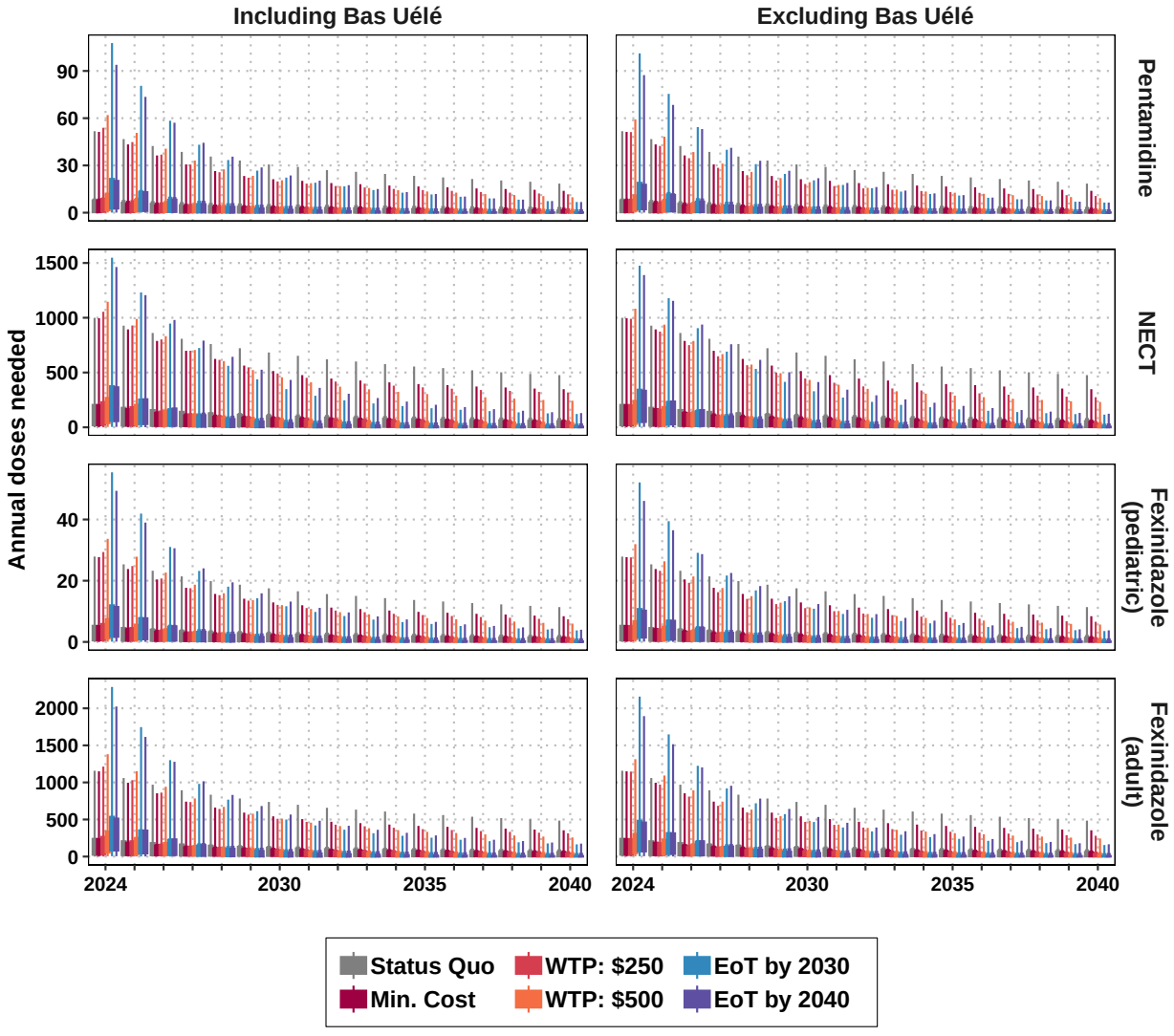


Figure E19: **Drugs used by year from 2024-2040 across different levels of investment.**

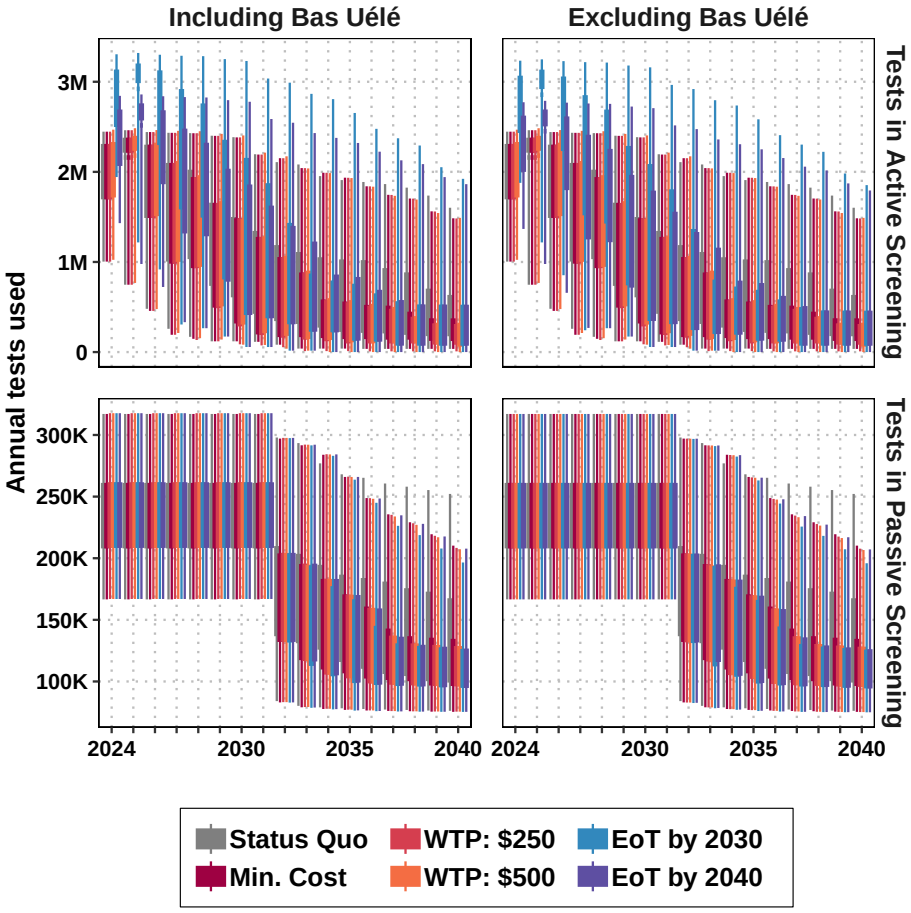


Figure E20: **Tests used by year from 2024-2040 across different levels of investment.**