A Customer Benefit Study of Distribution Investment for the Georgia Power Company System

May 2022

EXECUTIVE SUMMARY

Electric utility customers expect and depend on high levels of service reliability at a reasonable cost. As such, when developing a reliability improvement plan, a diligent utility must carefully evaluate the costs and benefits that accrue to customers under such a plan. The purpose of this Distribution Investment Study for the Georgia Power Company ("GPC") system is to determine the range of investment in GPC's distribution system that is optimal from a customer perspective.

This study is an updated version of the Economic Benefit Analysis completed in 2019 and reviews a revised Distribution Investment Plan that reflects lessons learned over the last 3 years. This study analyzes the best set of investments to be made under the Grid Investment Plan starting in 2023. This study concludes that the revised 8-year investment plan in the amount of ~$3.4B is within the optimal range of investment.

As background, GPC conducted an Economic Benefit Analysis on its original Distribution Investment Plan in 2019 to ensure that the plan was within the optimal range of investment from a customer perspective. The original plan was a ~$4.9B, 11-year plan that sought to improve approximately 800 of GPC's worst-performing distribution feeder circuits (also referred to as "circuits") with a target end-state SAIDI of ~65 by 2031 (also referred to as "Original Plan").

GPC has updated the Original Plan based on lessons learned through the execution of the plan over the last 3 years. Changes from the Original Plan are primarily driven by:

(1) Revised investment criteria, which select circuits with sustained poor performance.

(2) Increased capital requirements by investment package due to increases in the scope and cost of work required to achieve expected reliability improvements.

(3) A refined optimization methodology which relaxes the investment package hierarchy used in 2019 and allows for a larger set of possible investments to be evaluated when determining the optimal set of investments for a given scenario.

The revised plan (also referred to as "Distribution Investment Plan" or "the Plan") is expected to invest ~$3.4B over the remaining 8 years and achieve an end-state overall company SAIDI of ~80 by 2031. By targeting GPC's worst-performing circuits, the plan strives to equalize the customer experience and improve overall company reliability.

To create the Distribution Investment Plan, 15 alternate investment plans were constructed targeting end-state system reliability scores ranging from ~155 SAIDI to ~30 SAIDI. The plan that resulted in the lowest total cost to the customer under the most sensible set of assumptions was selected as the go-forward Distribution Investment Plan (also referred to as the "Base Case").

Plans targeting end-state SAIDIs lower than ~80 represent higher levels of investment than the Base Case. Plans targeting end-state SAIDIs higher than ~80 represent lower levels of investment

than the Base Case. The "No Incremental-Investment" plan represents a scenario in which GPC does not invest any incremental capital in its distribution system above historical levels, leading to a forecasted decline in GPC reliability and an end-state SAIDI of ~155 by 2031. See III.A for further discussion of investment scenarios.

Consistent with findings from the Original Plan, the Base Case shows that higher levels of investment result in diminishing reliability improvement (see Figure 1). This is because circuits with the poorest reliability that represent the highest improvement opportunities are invested in first. Increasing capital investment means investing in circuits with relatively better reliability that represent lower improvement opportunities.

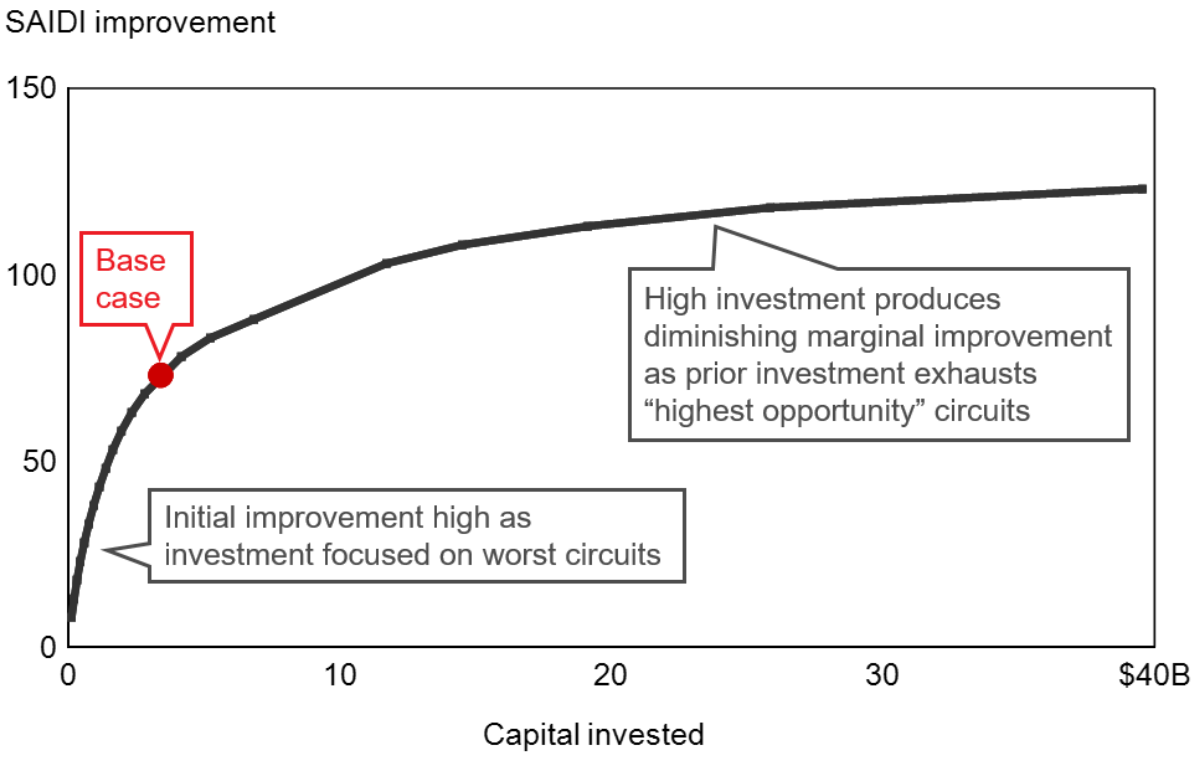

Figure 1. Diminishing Reliability Improvement

As illustrated in Figure 1, incremental customer benefit from distribution investment levels off after a certain amount of spending. The Base Case plan corresponds to the level of investment

that includes the highest opportunity investments but excludes investments that produce diminishing returns. See III.B for further discussion of diminishing reliability improvement.

To evaluate the Distribution Investment Plan from the customers' perspective, the present values of three types of costs were evaluated for each scenario. These include:

- **Capital Revenue Requirement:** Capital revenue requirement refers to the direct monetary cost customers incur as a result of GPC's capital investment. On a present value basis this is equal to the amount of capital GPC is required to spend under each scenario multiplied by GPC's distribution capital k-factor of 1.17[1]. See I.N for further discussion of capital revenue requirement assumptions and calculations.
- **Economic Cost:** Economic cost refers to the implicit costs customers incur as a result of outages. For the purposes of this study, economic cost strictly refers to the costs customers incur as a result of distribution outages in each scenario. See I.O for further discussion of economic cost assumptions and calculations.
- **Operations and Maintenance Expense ("O&M"):** In this study, O&M refers to outage repair-related and vegetation management O&M. Only these pieces of O&M are included, as investment in GPC's distribution system will not impact other components of O&M. See I.P for further discussion of O&M assumptions and calculations.

Because all of these costs are explicitly or implicitly borne by customers, an investment plan that minimizes the sum of these costs is considered to be within the optimal range of investment.

[1] GPC's k-factor is used to convert GPC's capital investment into a present value of revenue requirements to customers.

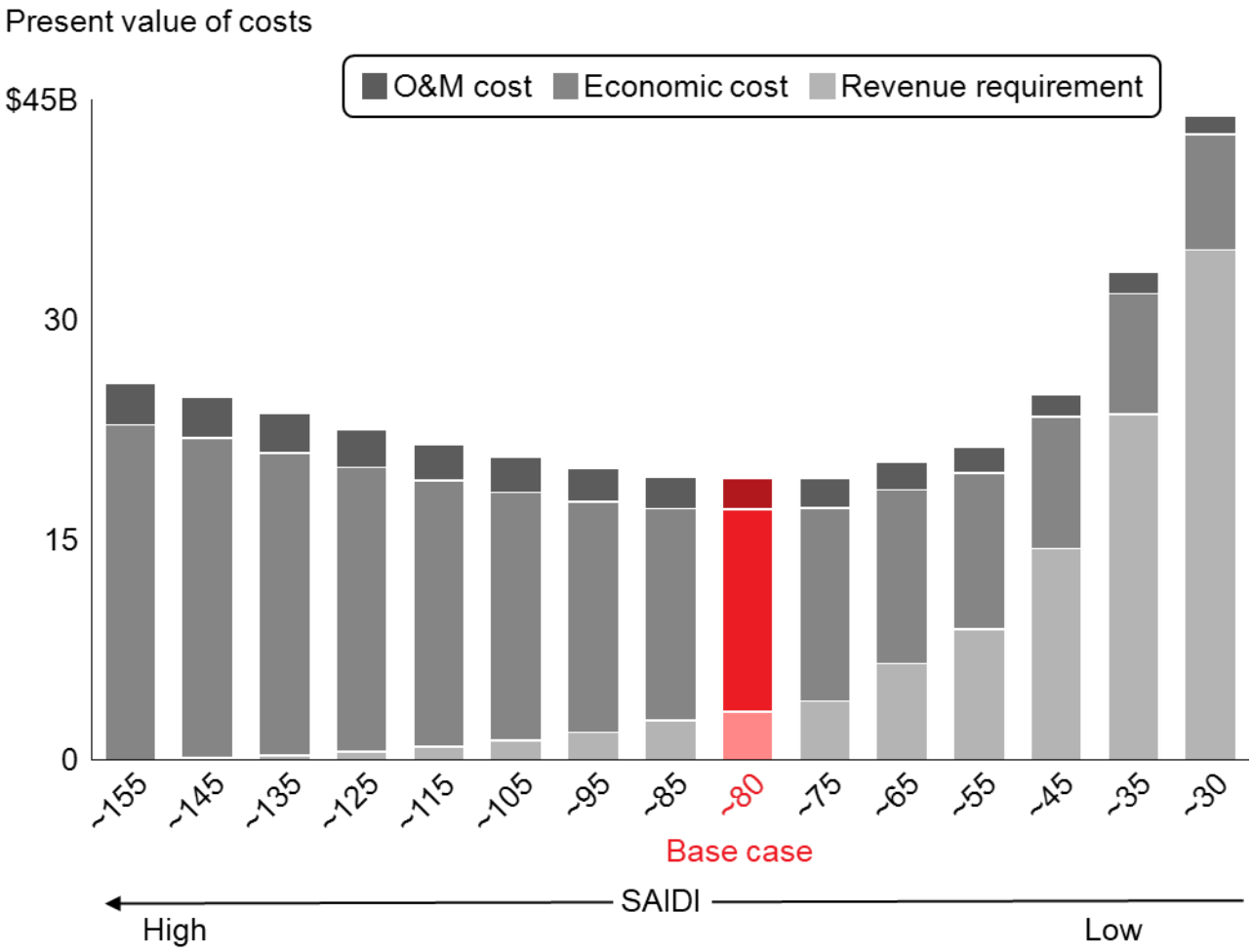

Figure 2. Present Value of Total Cost

Figure 2 demonstrates the total of these three costs (capital revenue requirement, economic cost, O&M) for each scenario. Moving from left to right along the chart's x-axis, capital revenue requirements increase as more aggressive reliability targets are achieved, while both economic costs and O&M costs decrease. Of the 15 scenarios evaluated, the Base Case scenario results in the minimum present value of costs and should thus be seen as the preferred option for customers.

Minimizing the present value of total customer cost is equivalent to maximizing the net present value of investment.

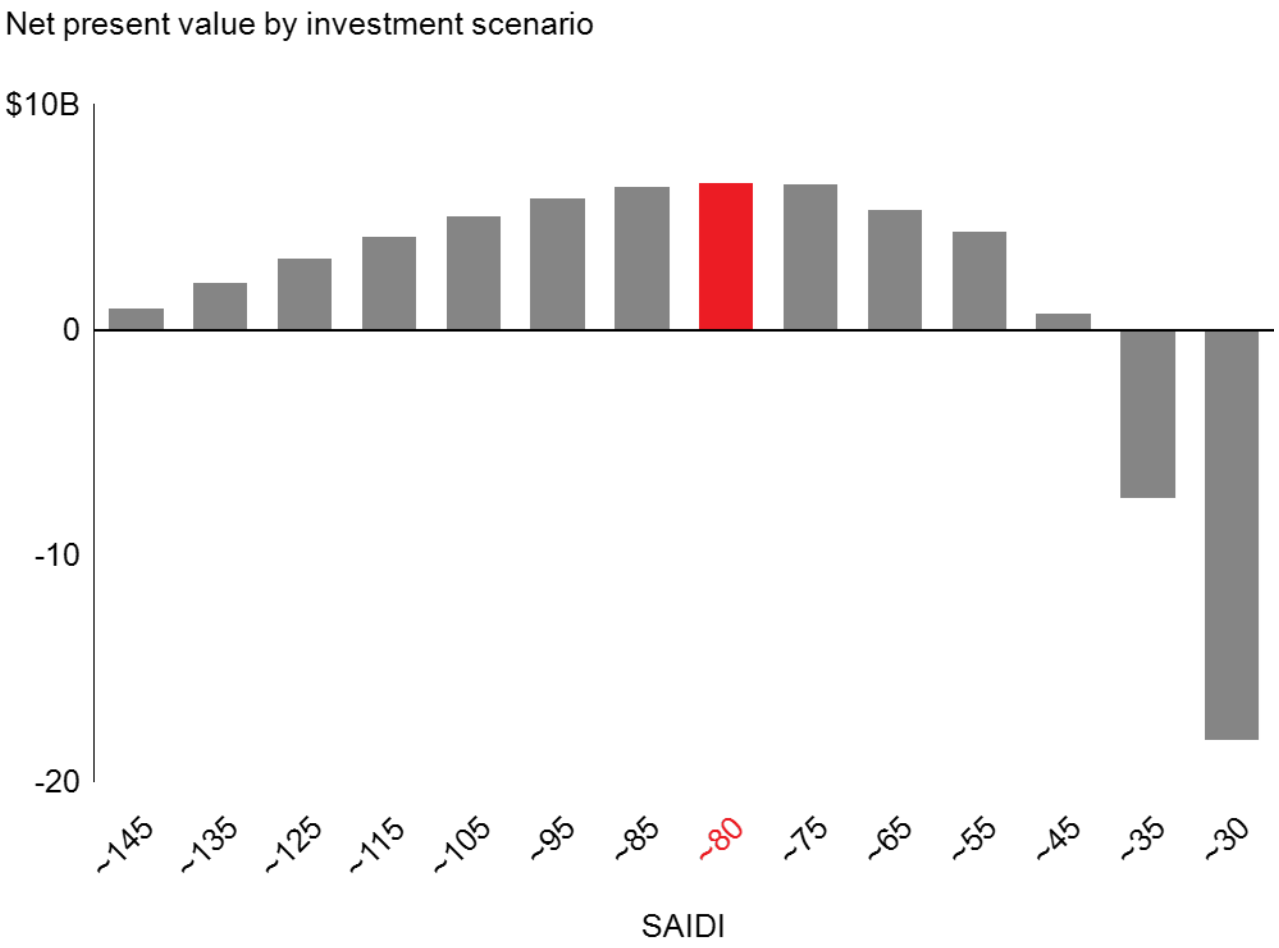

Figure 3. Net Present Value

Figure 3 shows the net present value ("NPV") of customer costs for each scenario. The NPV for any given scenario (for example, scenario "S") is calculated by taking the difference between the No Incremental-Investment scenario's present value of costs and scenario S's present value of costs. The Base Case scenario has the highest associated NPV of all scenarios and therefore creates more customer value than any other scenario analyzed. See Section III for a further discussion of scenario cost calculation.

In addition, seven sensitivity analyses on key inputs to the model were conducted. While the optimal scenario does move slightly (+/- 5 SAIDI) when key assumptions are adjusted, in the

majority of cases, the movement is from ~80 SAIDI to ~75 SAIDI when shifts in assumptions make it more favorable to spend additional capital (e.g., each investment costs less to return the same benefits, benefits from investing are higher than expected).

As an example, Figure 4 shows a sensitivity on this study's capital investment cost assumptions. To capture potential deviations from current investment cost estimates, cost assumptions were flexed up and down 10% to determine the impact on the optimal investment range. When costs are assumed to be 10% higher, the Base Case remains in the optimal range. When costs are assumed to 10% lower, the optimal scenario shifts to the ~75 SAIDI scenario, which invests significantly higher capital. Therefore, it is more conservative to use the Base Case as the basis for the Distribution Investment Plan as this plan invests less capital than the ~75 SAIDI scenario and is within the optimal range for a greater range of conditions. See Section IV for a further discussion of sensitivity analyses.

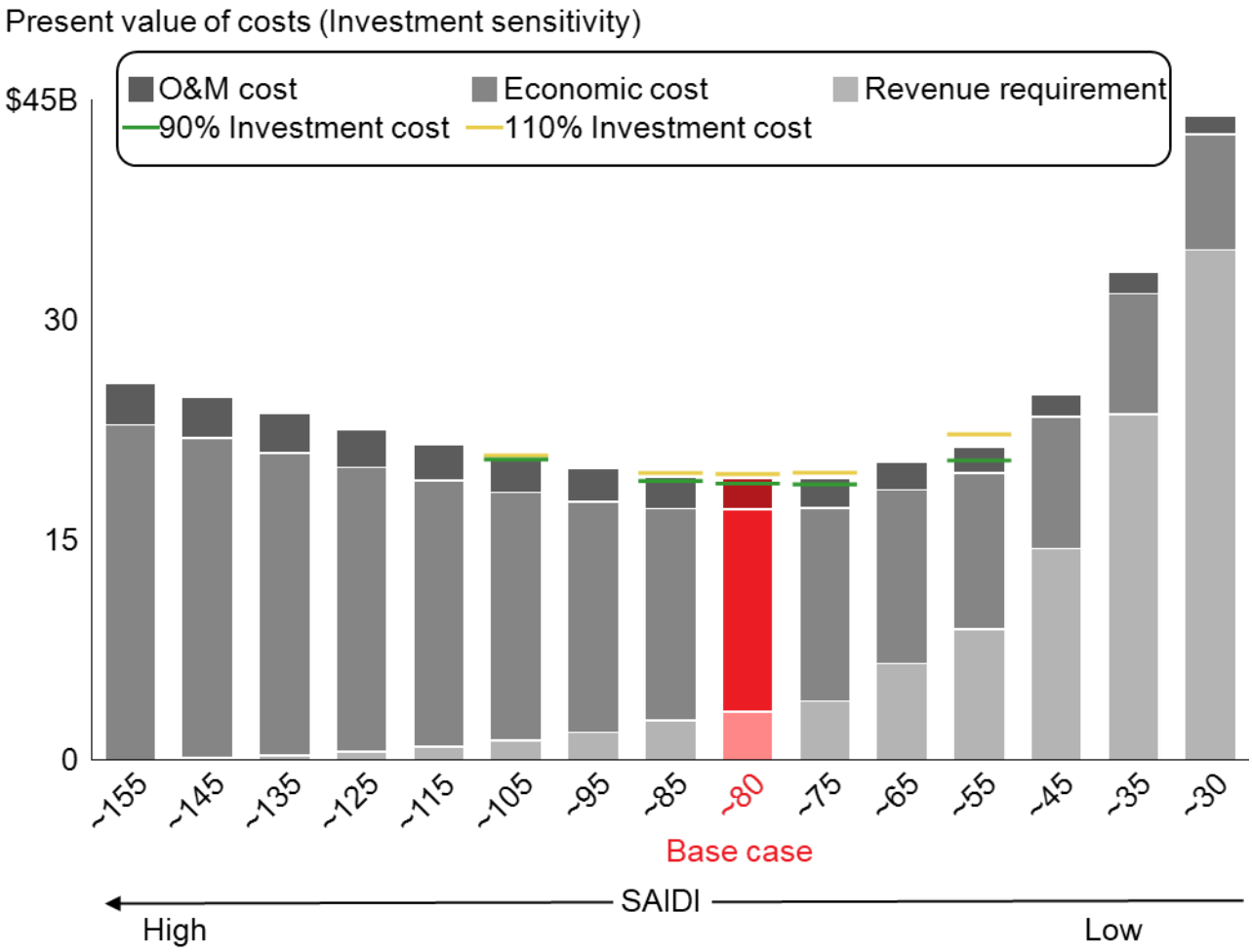

Figure 4. Investment Cost Sensitivity

While these sensitivities result in increases or decreases to the overall cost bars, the Base Case investment plan remains in the *optimal range* of investment across all sensitivities. As such, the Base Case investment plan should be considered the preferred option for GPC customers.

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I. ASSUMPTIONS

The following sections of this report provide detailed discussions related to the input assumptions associated with the 2022 Distribution Investment Plan.

A. Explanation of Investment Packages

The Distribution Investment Plan assumes that GPC distribution circuits can receive any one (or multiple) of 6 different "investment packages." The menu of circuit investment packages was developed by GPC distribution engineers based on prior investments that GPC has successfully implemented in its distribution system. Packages are listed in Table I.1 below:

Table I. 1. Description of Investment Packages

Number	Name	Description
1	Add sectionalizing, DA devices	• Install additional intelligent line devices on overhead line to achieve segmentation
2	Add / strengthen ties	For circuits without a tie: • Add new tie(s) to other circuit(s) For circuits with existing tie(s): • Increase capacity of tie points that offer increased ability to restore load • In some cases, create a new tie on a radial branch of the circuit
3	Circuit hardening (BIL)	• Replace wooden and steel pole arms with fiberglass brackets • Add wildlife protective equipment
4	Break feeder	• Introduce a new source (e.g., new breaker at existing substation) to split an existing circuit into two smaller circuits while applying segmentation
5	Relocate feeder; bring to road	• Identify inaccessible lines and rebuild on private property along accessible roadway
6	Underground the feeder	• Underground 100% of multiphase overhead lines

B. Criteria for Package Investment

To determine which (if any) investment package(s) should be applied to each circuit, specific criteria are set for each package. Criteria for each package are chosen to tailor package choice to each circuit based on that circuit's specific characteristics. A circuit must meet ALL criteria

thresholds in order to qualify for an investment package. The criteria thresholds used in the Base Case scenario are listed below in Table I.2:

Table I. 2. List of Package Investment Criteria

Number	Name	Criteria for Investment
1	Add sectionalizing, DA devices	• [redacted] • [redacted] • [redacted]
2	Add / strengthen ties	• [redacted] • [redacted] • [redacted]
3	Circuit hardening (BIL)	• [redacted] • [redacted] • [redacted]
4	Break feeder	• [redacted] • [redacted] • [redacted]
5	Relocate feeder; bring to road	• [redacted] • [redacted] • [redacted]
6	Underground the feeder	• [redacted] • [redacted] • [redacted]

The criteria above were determined in collaboration with GPC distribution engineers and subject matter experts to isolate circuits with "systemic issues" that are in most need of investment and most likely to experience further reliability decline in the absence of investment. For the

purposes of this study, circuits with "systemic issues" are those with poor reliability stemming from topographical conditions (e.g., vegetation growth), unaddressed customer or load growth, or legacy design specifications. The criteria above have been updated slightly from 2019 based on lessons learned over the last 3 years. A key difference from the Original Plan is the transition to utilizing 5 years of reliability data to determine which circuits qualify for investment. Utilizing the average reliability performance across 5 years allows GPC to better identify circuits with consistently poor reliability.

Data from ~2300 distribution circuits were analyzed against these criteria to determine if circuits were 'qualified' for each investment package. In many cases, circuits qualify for just a single investment package. In cases where a circuit qualifies for multiple packages, the following logic is applied to determine the set of investments the model can select from:

[redacted]

After all qualified investment packages are identified, the model evaluates combinations of potential investments to determine the optimal subset of investments to achieve the lowest total cost to the customer for a given SAIDI (details on the selection approach are described in section I.F below).

Each subset of investments selected represents a single scenario and each scenario is identified by the end-state SAIDI achieved. As part of this study, 15 scenarios were ultimately created for SAIDIs ranging from ~155 to ~30.

To create investment scenarios with SAIDIs below 60, certain of the above criteria are flexed to be more permissive, allowing more circuits to qualify for, and receive, investment. This change in criteria is necessary to reach the lowest SAIDIs.

C. Package Investment Cost Drivers

Estimated capital required for each circuit investment is determined based on the cost driver(s) of the package(s) the circuit receives. Cost drivers and unit costs for each package were

determined by GPC engineers based on analysis of test projects and were then updated based on the first 3 years of implementation experience. In addition, over the last three years, the Company has determined that additional work is required to complete certain investments. Therefore, a scope multiplier has been added to the sectionalizing, circuit hardening, and undergrounding investments. See Table I.3 for the list of drivers, scope multipliers, and unit costs.

Table I. 3. List of Package Cost Drivers and Unit Costs

Number	Name	[redacted]	[redacted]
1	Add sectionalizing, DA devices	[redacted]	[redacted]
2	Add / strengthen ties	[redacted]	[redacted]
3	Circuit hardening (BIL)	[redacted]	[redacted]
4	Break feeder	[redacted]	[redacted]
5	Relocate feeder; bring to road	[redacted]	[redacted]
6	Underground the feeder	[redacted]	[redacted]

D. Expected Investment Package Reliability Benefit

Expected SAIDI and SAIFI improvement for each circuit receiving an investment is determined based on the package(s) it receives. Expected SAIDI and SAIFI improvements for each package

are based on past GPC projects.[2] While initial investments from the first 3 years of the Grid Investment Plan have resulted in positive reliability benefits, GPC has not updated the expected benefits due to the small sample size of investments that have been completed for a full calendar year and desire to remain conservative in estimating potential benefits.

The scope of the Distribution Investment Study only extends to forecasting SAIDI and SAIFI values scrubbed of major weather events for each circuit. See Table I.4 for a list of expected package reliability improvements.

Table I. 4. Estimated Reliability Improvements for Package Investment

Number	Name	SAIDI Reduction	SAIFI Reduction
1	Add sectionalizing, DA devices	[redacted]	[redacted]
2	Add / strengthen ties	[redacted]	[redacted]
3	Circuit hardening (BIL)	[redacted]	[redacted]
4	Break feeder	[redacted]	[redacted]
5	Relocate feeder; bring to road	[redacted]	[redacted]
6	Underground the feeder	[redacted]	[redacted]

2 [redacted]

E. Expected Package Investment Benefit Length

All package benefits are forecasted to last 25 years past the investment period of 2020 to 2030 (i.e., to 2055). This reflects a conservative estimate of the average useful life of package improvements[3] and is in line with historical GPC experience.

F. Investment Selection

Once it is determined which package(s) a circuit qualifies for, a projection for the cost and benefit of each possible investment occurring in each possible year is made in the optimization model. An optimization model then evaluates possible combinations of investments to determine which subset of investments generates the greatest benefits for the customer (in terms of reduced O&M and reduced economic cost of outages) for each invested dollar. The optimal subset of investments selected produces the lowest total cost to the customer for a given SAIDI score.

Using this approach, 15 different scenarios were created, each targeting an end-state system reliability score ranging from ~155 SAIDI to ~30 SAIDI. The 15 scenarios were compared to determine which scenario produced the lowest overall total cost to the customer. This overall lowest total cost to the customer scenario corresponds to the Base Case and go-forward Distribution Investment Plan.

G. Investment Sequencing

Circuit investments are sequenced for execution over the remaining 8-year investment horizon (2023-2030). Exact investment sequencing is determined based on several factors:

- **Annual spend:** Fluctuation in annual overhead and underground investment cost is minimized from year to year as spikes in either overhead or underground spend and labor requirements would be difficult to manage from an operational and supply chain perspective.
- **Region-by-region approach:** The region by region sequencing established in 2019 was maintained with 2 exceptions: The South region was shifted forward 1 position to start in advance of the West region and the Northeast region was shifted forward 1 position to start in advance of the Metro North region. These switches were made in order to balance

[3] Brown (2009) states underground and overhead T&D infrastructure have 40 and 60 year lifespans, respectively. See section IV.E for a sensitivity analysis on this assumption.

the amount of overhead and underground spend and labor required from year to year given the new set of investments selected for the revised Distribution Plan. In keeping with the 2019 plan, all circuits selected for investment in a particular region are addressed in sequence, such that once investment in a region begins, that region is invested in every year until investment in that region is completed.

- **Annual regional spend:** Year over year fluctuation in total investment per region is minimized to ensure that no one region is oversaturated with investment in one particular year, as concentrated construction may pose operational difficulties and negatively impact customer experience.
- **Circuit ordering:** Within the constraints described above, circuits in each region which present the worst reliability are prioritized for investment. In order to minimize travel, disruption, and switching costs, investments within a single substation were grouped where possible.

H. Reliability Decline

Without continued maintenance or investment, certain circuits are expected to experience reliability decline over the long term[4]. To reflect this, the roughly 1000 circuits identified as having systemic issues (as discussed in I.B) and hence qualifying for investment are projected to experience a modest yearly reliability decline across the investment period[5] or until invested in.

[4] Because of the multitude of factors impacting circuit reliability in a given year (e.g., weather, traffic incidents, wildlife incidents) reliability cannot be forecasted accurately on a yearly basis. That said, over a longer period (e.g., 10 years) reliability can be expected to follow a forecasted trend.

[5]Note that reliability decline is capped after the investment benefit period. In other words, no circuit is projected to decline past 2031.

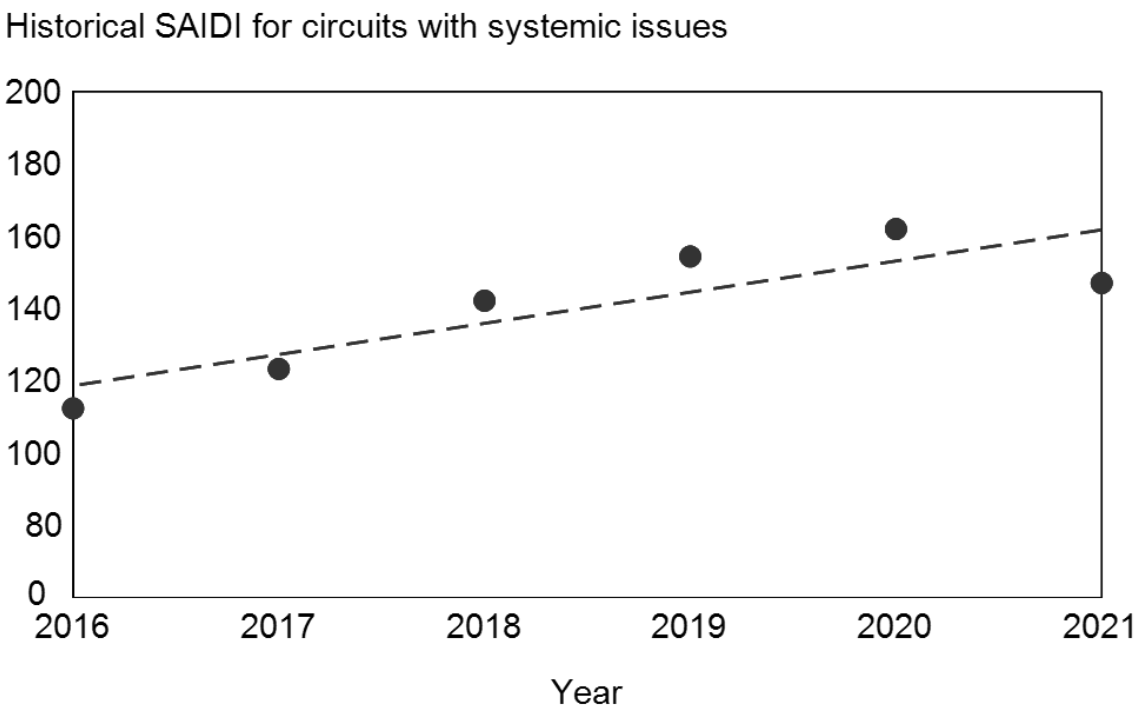

Figure I. 1. Historical SAIDI of Circuits with Systemic Issues

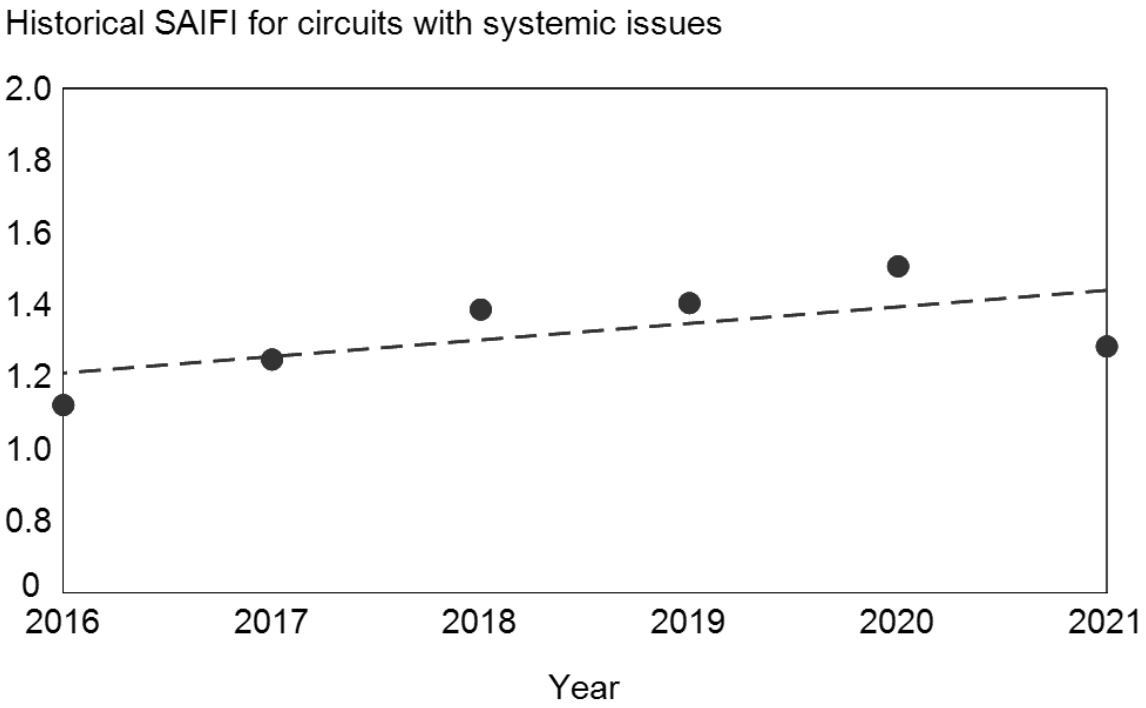

Figure I. 2. Historical SAIFI of Circuits with Systemic Issues

Figures I. 1 and I. 2 show the historical SAIDI and SAIFI, respectively, of roughly 1000 circuits identified as having systemic issues. Within the last six years, these circuits have experienced an average of ~6% SAIDI and ~3% SAIFI increase per year. To be conservative, SAIDI is projected to decline 4% for these circuits. SAIFI is projected to decline at 3%, in line with historical trends and the previous study.

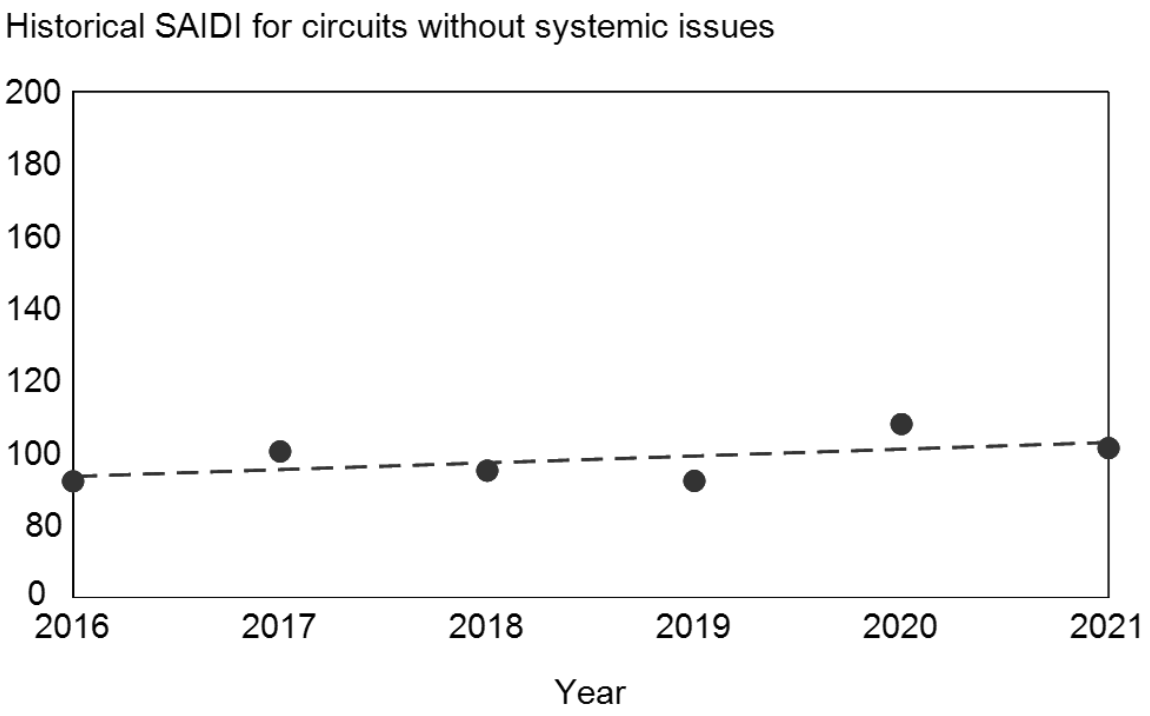

Figure I. 3. Historical SAIDI of Circuits without Systemic Issues

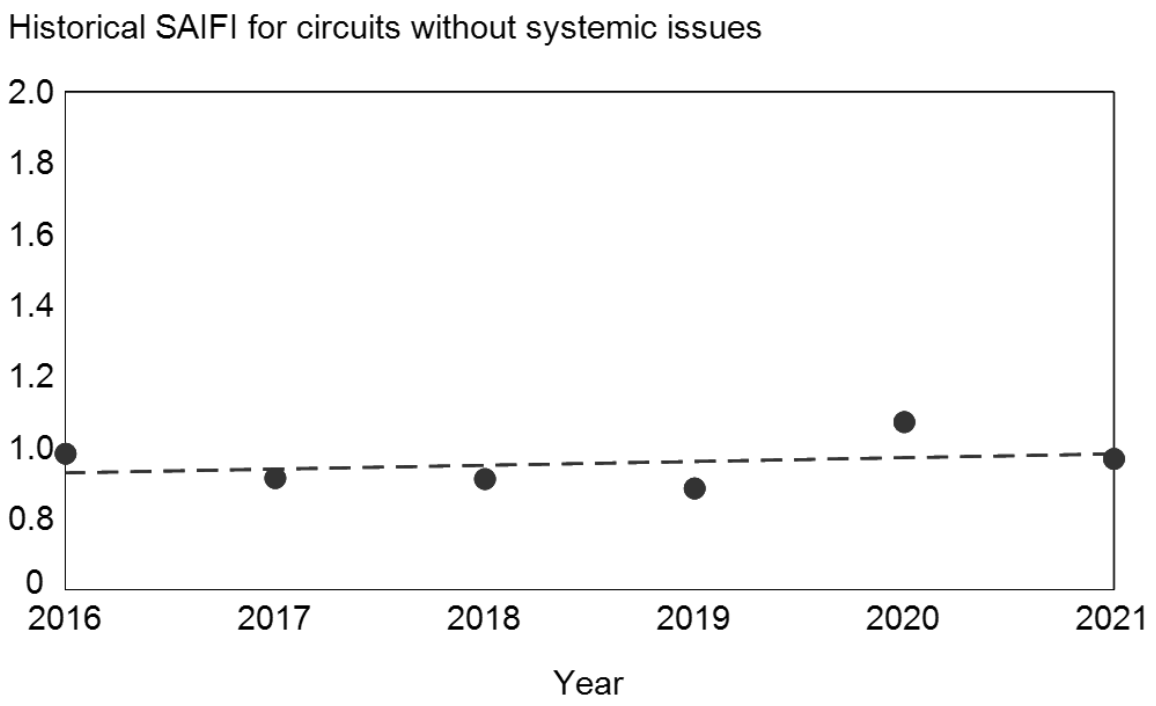

Figure I. 4. Historical SAIFI of Circuits without Systemic Issues

Figures I. 3 and I. 4 show the historical SAIDI and SAIFI trends, respectively, of the remaining ~1300 GPC circuits that were not identified as having systemic issues. In the last six years, reliability for these circuits has been flat to improving. As such, this study assumes each of these circuits will experience no reliability increases or decreases over the course of the investment period and these circuits do not qualify for investment as part of the GIP.

I. Package Investment Benefit Timing

To reflect variations in the timing of circuit investment completions, for packages 1-5, only 1/3 of expected reliability benefit is realized during investment. The remaining 2/3 of benefit is realized in the year following completion.

For package 6 specifically, as no benefit can be realized until investment is complete and customers transitioned to the new line, no benefit is realized during investment. Instead, 100% of the reliability benefit is achieved in the year following completion.

J. Population Growth

GPC's customer base is assumed to grow at an annual rate of [redacted]% between 2023 and 2055, based on GPC subject matter expert projections.

K. System Load Growth

Customer power usage (measured in MWh) is assumed to decline at an annual rate of [redacted]% between 2023 and the end of the investment period, based on GPC subject matter expert projections.

L. Weighted Average Cost of Capital

GPC's corporate WACC (Weighted Average Cost of Capital) of [redacted]% is used for all discounting.

M. Historical Inflation Rate

An inflation rate of [redacted]% is used to correct historical dollar figures to 2022 values, to discount projected costs, and to estimate expected investment cost increases over time. This figure is used for consistency with other GPC studies and reports[6].

N. Capital Revenue Requirement

Capital revenue requirement refers to the direct monetary cost customers incur as a result of GPC's capital investment on a present value basis. This is equal to the amount of capital GPC is required to spend under each scenario multiplied by GPC's distribution capital k-factor of [redacted][7].

Investment values in each year are multiplied by GPC's distribution capital k-factor of [redacted] to achieve a revenue requirement number for each year. Revenue requirement numbers for each

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6 [redacted]

7 GPC's k-factor is used to convert GPC's capital investment into a present value of revenue requirement to customers.

year's expenditures are then discounted back to 2022 values to achieve the present value of capital revenue requirement for a given investment plan.

O. Economic Cost

Economic cost refers to the implicit costs customers incur as a result of outages. Economic costs in the utility setting are often measured in terms of willingness to pay to avoid an outage or lost production as a result of an outage. For the purposes of this study, economic cost strictly refers to the costs customers incur as a result of distribution outages[8] in each scenario.

To facilitate estimating the economic cost of outages, Freeman, Sullivan & Company conducted a Cost of Expected Unserved Energy (EUE) survey of GPC and Mississippi Power Company (MPC) in 2011. This survey was conducted among the following four customer classes:

- Residential
- Commercial (below 1 MW average demand)
- Industrial (below 1 MW average demand)
- Large Business (commercial and industrial customers above 1 MW average demand)

The cost of EUE (in 2022 dollars) for these four customer classes is shown in Table I. 5.

Table I. 5. Cost of Expected Unserved Energy by Customer Class[9]

Customer Class	Cost per Unserved KWh (2022)
Residential	[redacted]
Commercial	[redacted]

[8] A "distribution outage" is defined as an outage that originates on a distribution circuit (as opposed to originating from, for example, a transmission substation).

[9] Values are an average of summer and winter dollar amounts from the survey. Values are adjusted to 2022 dollars.

Industrial	[redacted]
Large Business	[redacted]

The yearly economic cost of distribution-related outages on a system level is calculated using the following formula:

*Economic cost for system = SAIDI * Average KWh Usage per Minute * Cost per Unserved KWh*

Where:
Economic cost for system = Nominal economic cost of unserved power for customers on the system;
SAIDI = System Average Interruption Duration Index in minutes;
Average KWh Usage per Minute = Amount of energy used in the average minute for customers on the system; and
Cost per Unserved KWh = weighted average EUE cost survey value for customers across the system

System nominal economic costs for each year are discounted back to 2022 dollars and summed together to calculate the present value of economic cost.

Implicit in these formulas is that system economic cost (a) declines as reliability of the system improves and (b) declines as system load decreases. Since package investment is sequenced across the investment period of 2023-2030 and full reliability benefit for each circuit is only realized after investments are completed, an investment plan targeting an end-state reliability figure will see a gradual improvement of economic cost until end-state reliability is reached in 2031.

P. Operations and Maintenance Expense Impacted by Investment

In this study, Operations and Maintenance Expense ("O&M") refers only to portions of GPC O&M that could be impacted by the circuit investments analyzed in this study. Specifically, this study forecasts two pieces of O&M:

- **Outage Repair-Related O&M:** Costs that are related to the restoration of power when outages occur. When reliability improves and the frequency and duration of outages decreases, these O&M costs are expected to decline.
- **Vegetation Management O&M:** Costs associated with the trimming of plant foliage and removal of trees adjacent to distribution lines and within GPC's right-of-way. Vegetation management costs are incurred to ensure that plant foliage and trees do not interfere with overhead distribution circuits. For distribution circuits receiving package 6 (undergrounding) vegetation management is expected to decline.

These two pieces of O&M are assumed to grow or decline with the following:

- **Outage Repair-Related O&M:** Increases or decreases with SAIFI
- **Vegetation Management O&M:** Increases at historical CAGR of ~2.2%, decreases with proportion of overhead 2&3-phase line miles undergrounded

As such, outage repair-related O&M decreases with investment as system reliability improves. Vegetation management O&M also decreases to a lesser degree with investment as 2&3-phase line miles are undergrounded.

Outage repair-related O&M is projected using the prior year's system outage O&M spend, disaggregated to the circuit level based on a circuit's contribution to system level SAIFI. Vegetation management O&M is projected using a historical 3-year average[10] of system total vegetation spend, disaggregated to the circuit level based on a circuit's proportion of 2 and 3 phase overhead line miles.

As with capital revenue requirement and economic cost, O&M is forecasted out for each year in the investment period in nominal terms and then discounted back to 2022 dollars to obtain a present value of O&M.

[10] GPC uses a three-year vegetation management cycle for most circuits.

Q. Optimal Investment Range Determination

Customers directly or indirectly incur capital revenue requirement costs, O&M costs, and economic costs. As such, customers prefer investment plans that offer a lower present value of capital revenue requirement, O&M, and economic costs over plans that offer a higher present value of these costs. Thus, an investment plan that minimizes the present value of the sum of these three costs is considered optimal from the customer's perspective. Because only a finite number of investment plans can be tested, for the purposes of this study, the investment plan that minimizes the present value of costs is assumed to be in the optimal investment *range* (as opposed to the exact optimal investment plan).

II. SIMULATION PROCEDURE

The following sections of this report provide detailed discussions related to the steps taken to generate each investment scenario and arrive at total costs (including capital revenue requirement costs, economic costs, and O&M costs) for that scenario.

A. Application of Investment Criteria and Selection of Investments

Circuit data are evaluated against investment criteria for each investment package (see Table I. 2 for a list of criteria and baseline values) to determine which investment package(s) each circuit qualifies for.

As described in I.F above, a projection is then created to determine the cost and benefit of undertaking every qualified investment using the cost drivers and benefit estimates described in I.C and I.D respectively. An optimization model then evaluates possible combinations of these investments to determine which subset produces the lowest total cost to the customer for a given SAIDI.

B. Sequencing of Investments

After investments are selected, circuits are sequenced according to the procedure outlined in I.G. This places each circuit investment into a specific investment year within the 2023-2030 investment window.

C. Forecasting Circuit Reliability

GPC circuit reliability scores are then projected out for each year in the investment horizon. The projection takes the following variables as inputs:

- 5-year average (2017-2021) SAIDI and SAIFI for each circuit
- For circuits that are part of the investment plan for the scenario in question: Selected package(s), timing of investment, and expected reliability improvement
- For circuits with systemic issues: Assumed reliability decline in the absence of, or until, investment

D. Forecasting Circuit CMI and Customer Interruptions[11]

By using the circuit-level forecasted reliability figures from II.C, customer counts for each circuit, and the GPC compound annual growth rate to forecast customer counts for each circuit for each year in the investment horizon, we forecast each circuit's CMI and customer interruptions for each year in the investment horizon.

E. Calculating Aggregate Reliability Scores

System-wide SAIDI is calculated by summing together each circuit's forecasted CMI and dividing by the projected number of GPC customers in each year. System-wide SAIFI is calculated by summing together each circuit's forecasted customer interruptions and dividing by the projected number of GPC customers in each year.

F. Forecasting Capital Revenue Requirement

Capital revenue requirement for each year is calculated by summing the investment costs of circuits that will be invested in a given year and multiplying by the k-factor of [redacted], as discussed in I.N.

[11] Annual "customer interruptions" for a circuit is the sum of the number of customers impacted by an outage across each of a circuit's outages in a given year. Customer Interruptions = SAIFI * Total Number of Customers.

G. Forecasting Economic Cost

The economic cost of outages across GPC for each year is determined by summing up the economic costs (calculated using methods described in I.O) of all distribution circuits.

H. Forecasting Operations and Maintenance Expense

Outage repair-related O&M is forecasted on an aggregate level for 2020-2031 in proportion to system SAIFI projections (see I.P).

Vegetation management O&M is forecasted at a circuit level using the 3-year average of spend. As mentioned (see I.P), vegetation management O&M increases at historical rates and decreases with the proportion of overhead 3-phase line miles undergrounded.

I. Discounting Projected Costs

Using GPC's WACC (see I.L) and the assumed inflation rate (see I.M), projected capital revenue requirement, economic cost of outages, and O&M for each year in the investment horizon are discounted back to 2022 dollars.

J. Calculating Terminal Value of Costs

Since benefits of investment are expected to last well beyond 2031 (see I.E), the present value of costs beyond the investment horizon is calculated using a bounded terminal value. Economic and O&M costs are estimated to continue to grow at a terminal growth rate equal to the estimated population growth (see I.J). Since traditional terminal value calculation assumes an infinite time horizon, a bounded terminal value is calculated using the following formula:

$$TV_{2033\text{-}2055} = TV_{2033} - TV_{2056}$$

Where:

$TV_{2033\text{-}2055}$ = Present value of costs from 2033 to 2055;

TV_{2033} = Present value of costs from 2033 onward; and

TV_{2056} = Present value of costs from 2056 onward

This figure is discounted back to 2022 dollars to calculate the present value of 2033-2055 economic and O&M costs.

K. Calculating Present Value of Costs

Summing the present value of 2023-2032 costs and 2033-2055 costs yields a total present value of costs for a given investment plan.

III. SCENARIO RESULTS

A. Summary of Scenarios and Selection of Base Case

For this analysis, 15 alternative investment scenarios were evaluated. Each scenario was created by determining the optimal subset of potential investments that delivers the lowest total cost to the customer for a given SAIDI score ranging from ~155 to ~30. The results of these scenarios were then compared to determine which of the scenarios produced the overall lowest total cost to the customer. This scenario was then selected as the 'Base Case'.

Under the Base Case, roughly 870 circuits are marked for investment for the remainder of the plan. The set of circuits and associated investment packages in the Base Case scenario make up GPC's proposed Distribution Investment Plan[12]. The Base Case set of investments is projected to cost ~$3.4B over the remaining 8 years (using the cost estimates discussed in I.C). Under the Base Case scenario, GPC reliability is projected to reach ~80 SAIDI by 2031 (using reliability improvement estimates outlined in I.D).

As noted in section I.B, to achieve end-state SAIDI below 60 requires significant undergrounding and so the undergrounding investment criteria were relaxed to allow more circuits to qualify for undergrounding investments in all scenarios with SAIDIs below 60.

The worst reliability scenario (the "No Incremental-Investment" scenario) results in an end state of ~155 SAIDI, based on the assumption that GPC does not invest any incremental capital in its distribution system between 2023 and 2030 and that circuits with systemic issues continue to

[12] Exact set of circuits and investment timing in Base Case scenario will closely mirror final proposed Distribution Investment Plan; however, slight updates to the Distribution Investment Plan may be made after this study is published. As such, the Base Case scenario in this study may differ slightly from GPC's final Distribution Investment Plan.

decline during this period. The best reliability scenario targets an end state of ~30 SAIDI, which is the lowest feasible end-state SAIDI target under current input assumptions. To reach this scenario's end-state would require a very large increase in total capital spend (roughly 11x as much capital as required in the Base Case) and number of circuits invested in (roughly 2x as many circuits as are included in the Base Case). In addition, reaching an end state of ~30 SAIDI would require undergrounding far more circuits than are undergrounded in the Base Case[13] (roughly 35x).

B. Diminishing Reliability Improvements with Investment

Moving from the worst reliability scenario, in which no incremental investments are made, to each successive reliability scenario, which target better customer reliability experience and lower end-state SAIDI, requires adding circuits to the investment plan. As more circuits receive investment, a better end-state SAIDI is expected.

The circuits with the worst reliability tend to be the circuits that, when invested in, are expected to produce the largest reliability improvement. As a result, higher investments (i.e. investment scenarios targeting more circuits and better end-state reliability) result in diminishing reliability improvements. This is because the worst circuits presenting the highest reliability improvement opportunity have already been added to the investment plan and incremental circuits added to the plan present lower reliability improvement opportunity. As a result, reliability benefit per invested dollar diminishes as investment scope increases. In Figure III. 1 one can see a visualization of this process.

[13] This is due to the fact that the undergrounding package generally results in the lowest reliability end-state compared to any other investment package.

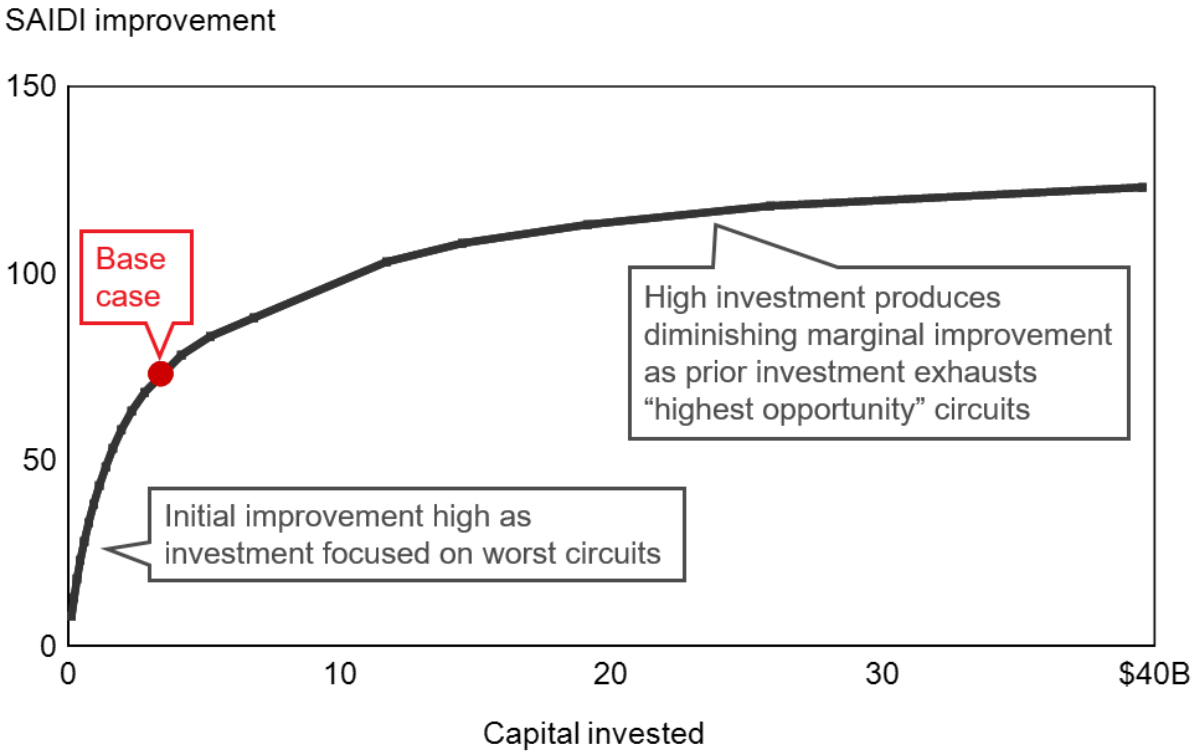

Figure III. 1. Diminishing Reliability Improvement[14]

The slope of the curve is initially high as investment focuses on the worst circuits. As successive incremental investment is restricted to better and better circuits, however, reliability improvement per dollar falls and the slope tapers off. Investment past the Base Case (i.e. targeting end-state GPC SAIDI values lower than ~80) requires investing in circuits with relatively better reliability and shows a pronounced decline in reliability improvement per dollar invested.

C. Introduction and Discussion of U-Curve

As discussed in I.Q, the optimal range of investment from a customer perspective is that which minimizes the summed present values of capital revenue requirement, economic cost, and O&M. Taking the identified scenarios as the domain of investment plans, the optimal range of investment can be identified by calculating the present value of each of these costs for each investment plan.

[14] "SAIDI improvement" is the difference between a scenario's end-state SAIDI and the No Incremental-Investment end-state SAIDI; each point represents a scenario.

i. Present value of capital revenue requirement

The present value of capital revenue requirement for each scenario is shown below in Figure III. 2:

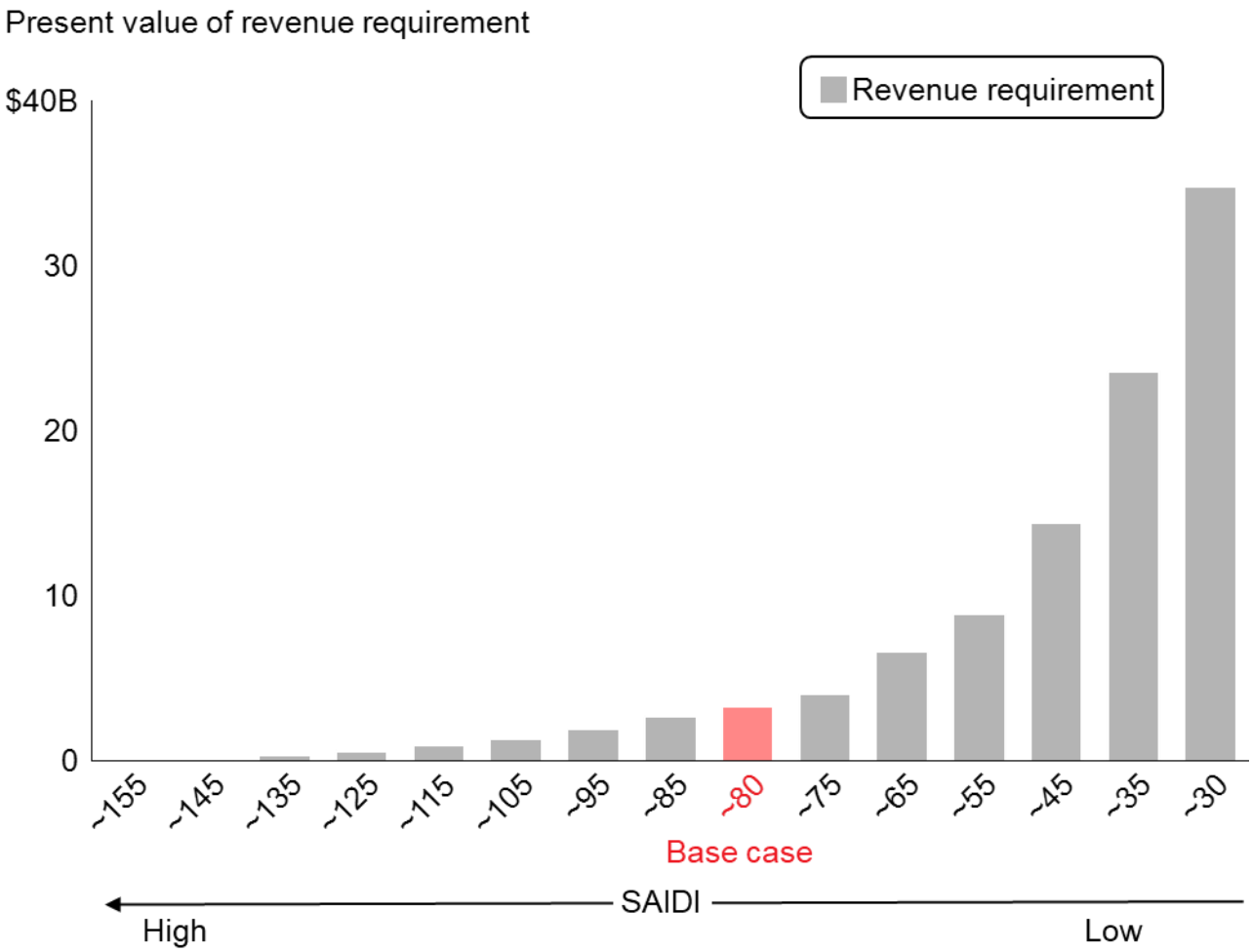

Figure III. 2. Present Value of Capital Revenue Requirement

As mentioned above, the worst reliability scenario with end state ~155 SAIDI assumes that no incremental investment is made in the distribution system during the investment period and thus has a present value of capital revenue requirement equal to $0. Moving right along the axis, the slope of the curve increases as equal reliability improvements can only be attained via higher and

higher levels of capital investment in the distribution system which results in higher and higher revenue requirements. This is due to diminishing reliability improvement, as discussed in Section III.B. The right most scenarios targeting the most aggressive end-state reliability scores require increasingly large investment amounts as incremental investment is restricted to relatively better circuits with lower reliability improvement opportunity.

ii. Present value of outage economic cost

The present value of outage economic cost for each scenario is shown below in Figure III. 3:

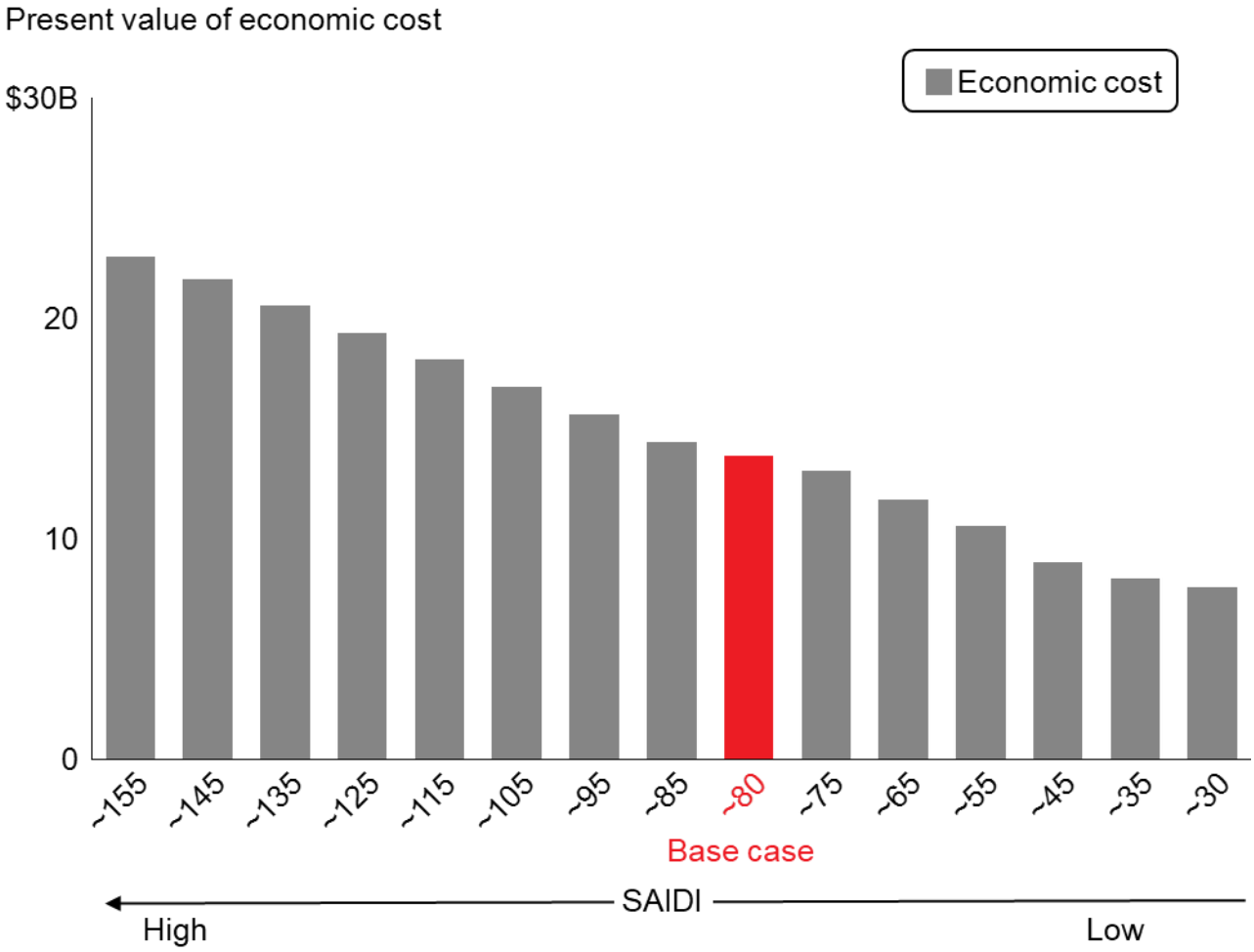

Figure III. 3. Present Value of Economic Cost from Outages

The present value of economic cost decreases moving from left to right along the x-axis. As end-state reliability improves, customers face less outage time and incur less economic cost as a result.

The concave nature of the curve pictured is due to two factors:

- **Gradual reliability improvement:** As discussed in Section I.O, end-state reliability for a given investment plan is only reached in 2031. Between 2023 and 2031, reliability benefit accrues gradually as GPC invests in more circuits. As such, the differences between scenarios is less pronounced in earlier years.
- **Discounting:** Due to the compounded discounting of economic costs, the economic costs of the investment period's early years (when scenarios' reliability differences are less pronounced) are given more weight than later years (when scenarios' reliability differences are more pronounced).

iii. Present value of O&M

The present value of O&M cost for each scenario is shown below in Figure III. 4:

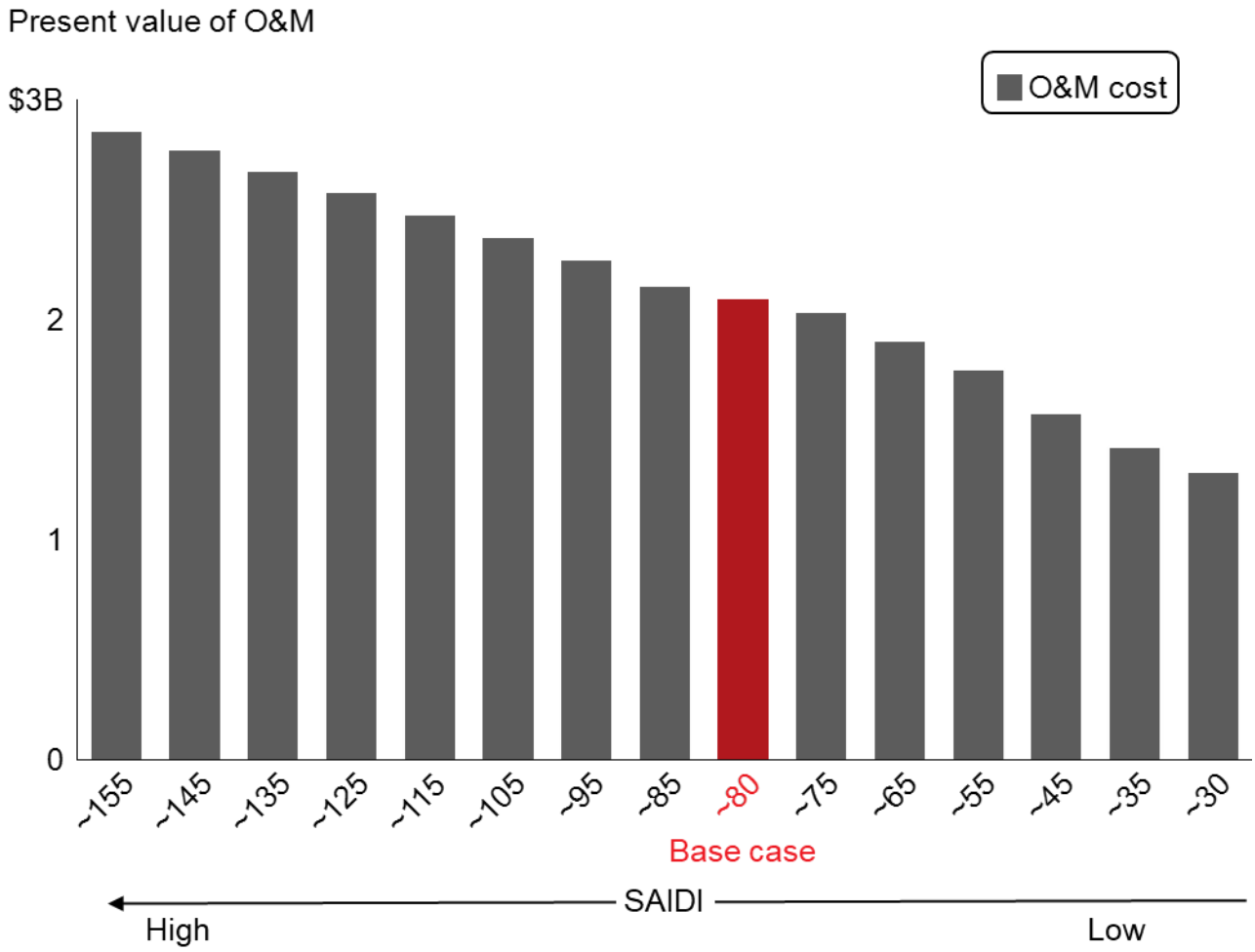

Figure III. 4. Present Value of O&M

The present value of O&M steadily decreases as lower SAIDI end-states are targeted. This is due to declining system SAIFI (resulting in lower outage restoration costs) and increased undergrounding (resulting in lower vegetation management costs). Notably, O&M represents a much smaller portion of total cost than economic costs and capital costs. Again, the concave nature of the pictured function is due to gradual reliability improvement and discounting, similar to economic cost.

iv. Present value of total cost

The present value of all costs for each scenario is shown below in Figure III. 5:

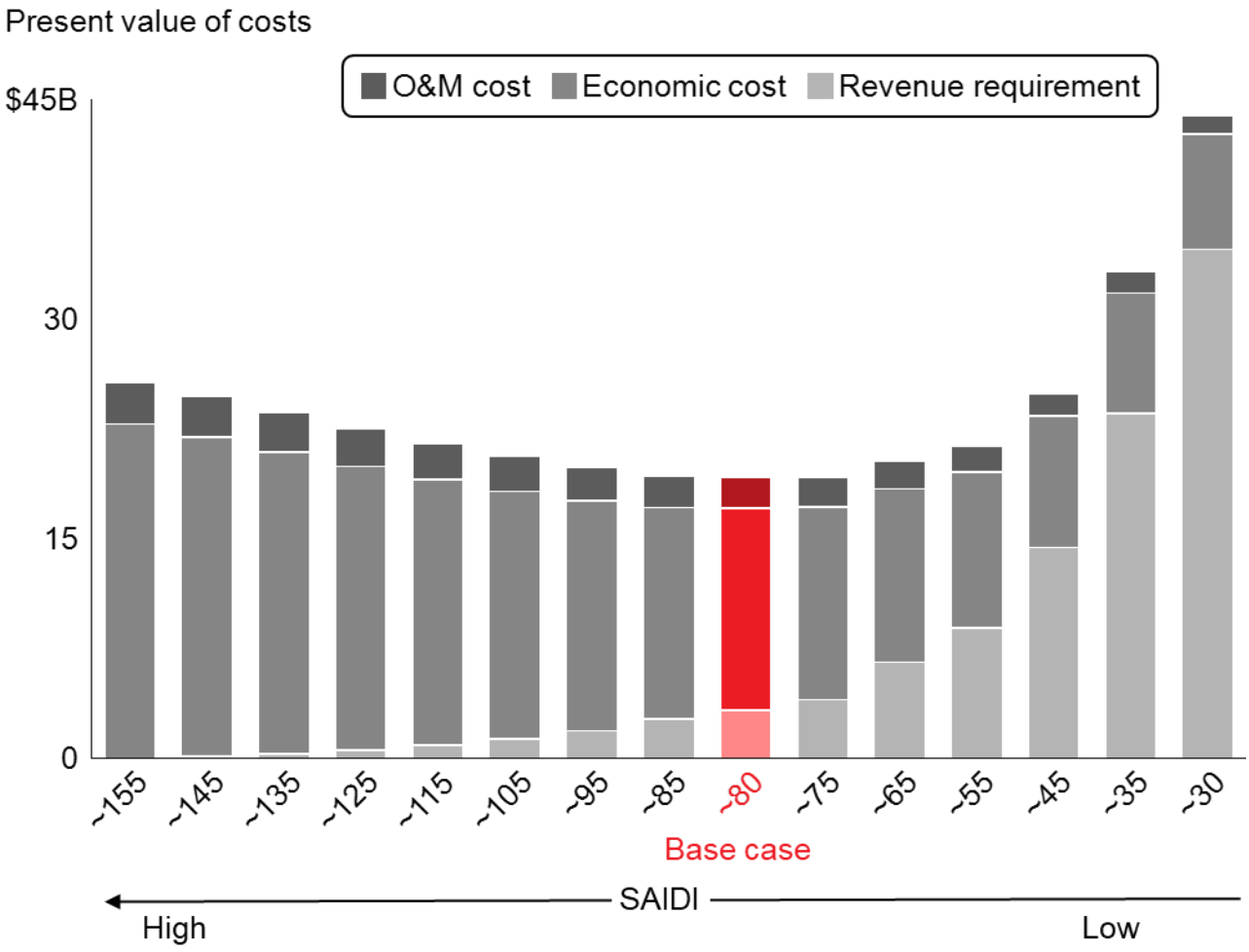

Figure III. 5. Present Value of Total Cost

Moving from left to right along the x-axis, capital revenue requirement increases for each successive scenario while O&M and economic cost decrease. The Base Case scenario lies at the minimum of the U-curve and is therefore the plan that minimizes customer costs under default assumptions.

D. Net Present Value of Investment Scenarios

The net present value (NPV) of an investment scenario S is the measure of its benefit compared to investing $0 incrementally and is calculated using the following formula:

$$NPV_S = PVC_{NI} - PVC_S$$

Where:
NPV_S = Net present value of scenario S;
PVC_{NI} = Present value of costs for the No Incremental-Investment scenario; and
PVC_S = Present value of costs for scenario S

When the NPV of a scenario is positive, that scenario's investment plan represents a net benefit for customers, with a present value equal to the NPV. When the NPV of a scenario is negative, that scenario's investment plan represents a net loss for customers, with a present value equal to the NPV. If scenario S' has a higher NPV than scenario S, S' represents a higher benefit for customers and should be preferred for investment. The "optimal range" is represented by the scenario with the highest NPV.

The net present value for each scenario is shown below in Figure III. 6:

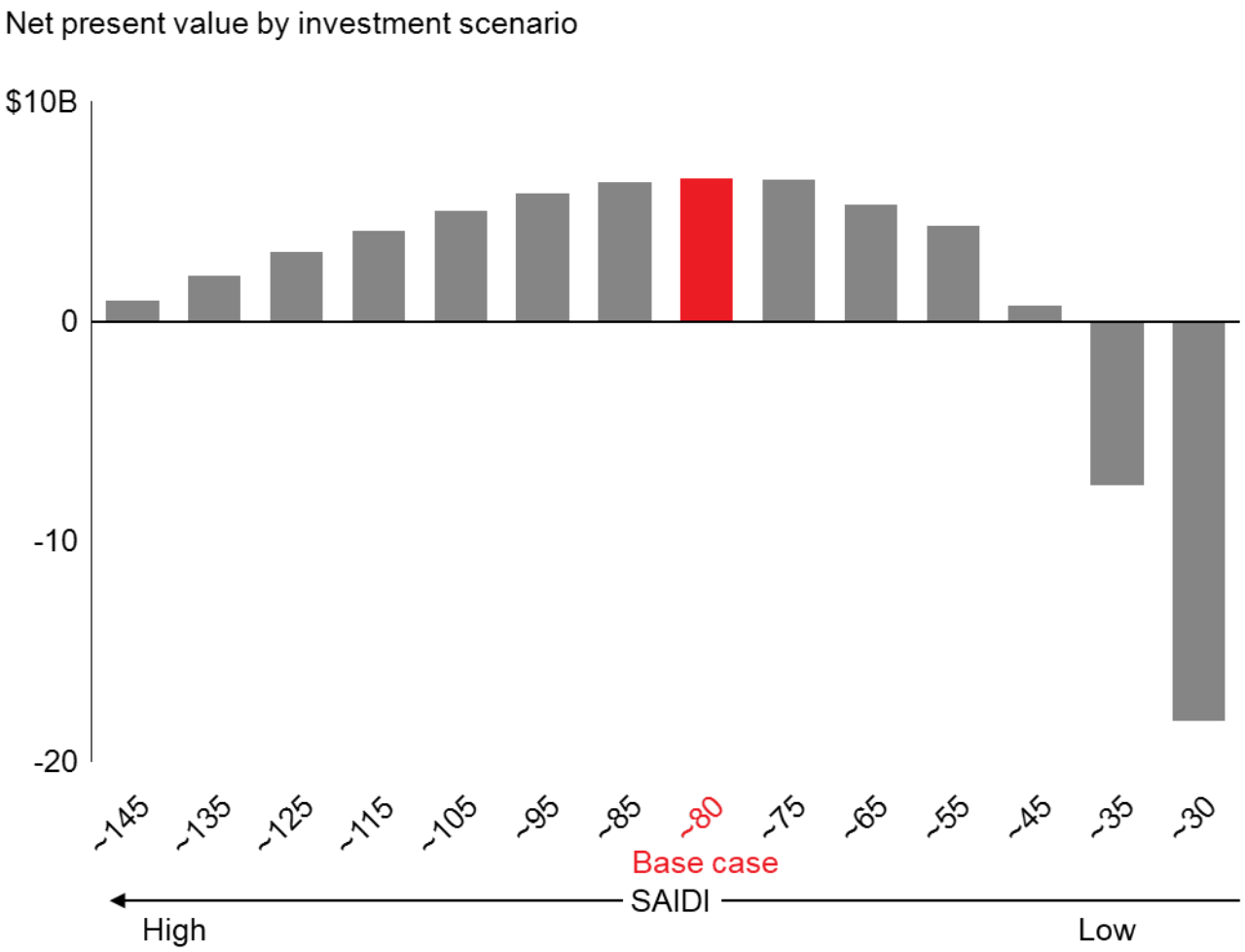

Figure III. 6. Net Present Value

Of note is that Figure III. 6 is a derivative of Figure III. 5's present value U-curve. The NPV for each scenario (for example, scenario "S") is calculated by taking the *difference* between the No Incremental-Investment scenario's present value of costs (the left-most bar) and scenario S's present value of costs. Hence, the NPV of the No Incremental-Investment scenario is $0 and is therefore not pictured in this figure.

As shown in Figure III. 6, the Base Case scenario represents the optimal investment plan with an NPV of ~$6.5B. Each investment scenario, with the exception of the 2 scenarios targeting ~35 and ~30 SAIDI end-state, is NPV positive, indicating that investment is strictly more beneficial to

customers than non-investment. Moving from left to right along the x-axis, NPV begins falling after reaching the Base Case scenario. This is because incremental investment is restricted to the highest performing circuits. Reaching ~35 or below SAIDI as an end-state would result in a net detriment to customers as increased capital revenue requirement would outweigh any reduction in economic costs and O&M.

E. Marginal Benefit of Grid Investment

As mentioned in III.B, reliability improvement per invested dollar declines as investment increases. This relationship can also be analyzed by calculating *marginal benefit per invested dollar* (MBID)[15], where marginal benefit is calculated using the following formula:

$$MBID = -1 * \Delta \text{ Benefit} / \Delta \text{ Capital Revenue Requirement}$$

Where:

MBID = Customer value gained per dollar of investment, moving from S to S', where S and S' are adjacent scenarios

Δ Benefit = $PV_{S'}$(Economic cost) – PV_S(Economic cost) + $PV_{S'}$(O&M) – PV_S(O&M)

Δ Revenue Requirement = $PV_{S'}$(Capital revenue requirement) – PV_S(Capital revenue requirement)

When MBID is greater than $1, additional investment benefits customers more than it costs customers. This is because the additional reliability improvement grants customers greater savings in economic cost and O&M than it costs them in capital revenue requirement. When MBID is less than $1, additional investment costs customers more than it benefits them. This is because the additional reliability improvement costs customers more in capital revenue requirement than it saves them in economic cost and O&M. Thus, an MBID of $1 represents an "efficiency cutoff" for investment.

The MBID for each reliability end-state is shown below in Figure III. 7:

[15] Denominator is expressed in terms of capital revenue requirement because this is the cost of investment from the customer's perspective.

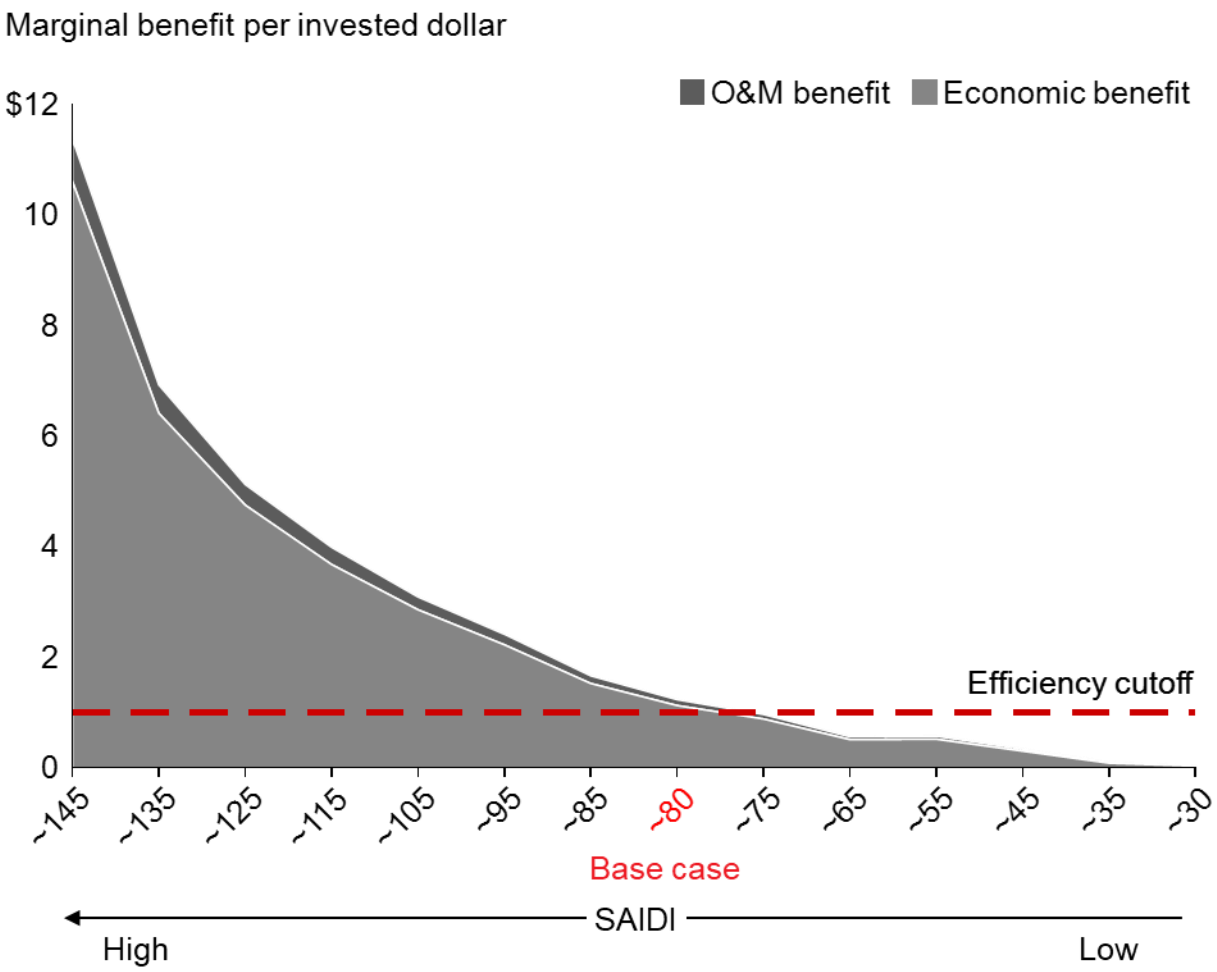

Figure III. 7. Marginal Benefit per Invested Dollar[16]

MBID is initially high as investment focuses on the worst circuits but declines as target SAIDI end-states get lower. Continued investment is above the efficiency cutoff, and therefore beneficial to customers, until reliability end-state passes ~80 SAIDI, after which point continued investment is no longer sensible.

[16] Curve represents the best-fitting exponential line.

IV. SENSITIVITY ANALYSES

The following sensitivities were run to determine the optimal ranges of investment under varying model conditions, and whether optimality shifts when assumptions are adjusted. For each sensitivity, excluding IV.A, two sets of analysis were run for each sensitivity, one in which the assumptions were flexed up above the baseline assumption and one in which the assumptions were flexed down below the baseline assumption. Note that all sensitivities were conducted on only a subset of investment scenarios above and below the Base Case. This approach was taken to balance thoroughness and efficiency.

A. Publicly Available Cost of EUE

The first sensitivity run uses publicly available EUE data to replace internal EUE survey data. Specifically, this sensitivity uses the Interruption Cost Estimate Calculator[17], developed by Nexant and funded by Lawrence Berkeley National Laboratory and the Department of Energy, to estimate the present value of the economic cost of outages for each scenario.

The ICE calculator differs from this study's default economic cost methodology in several ways:

- EUE values are estimated based off proprietary Nexant surveys
- Economic cost calculation incorporates SAIFI in addition to SAIDI
- ICE incorporates household income, the distribution of outages over the course of the day, industry breakdown among business customers, and prevalence of backup generation as additional factors

The present value of costs U-curve using the ICE calculator to estimate the economic cost of outages is below in Figure IV. 1:

[17] The ICE calculator is available for use at http://icecalculator.com

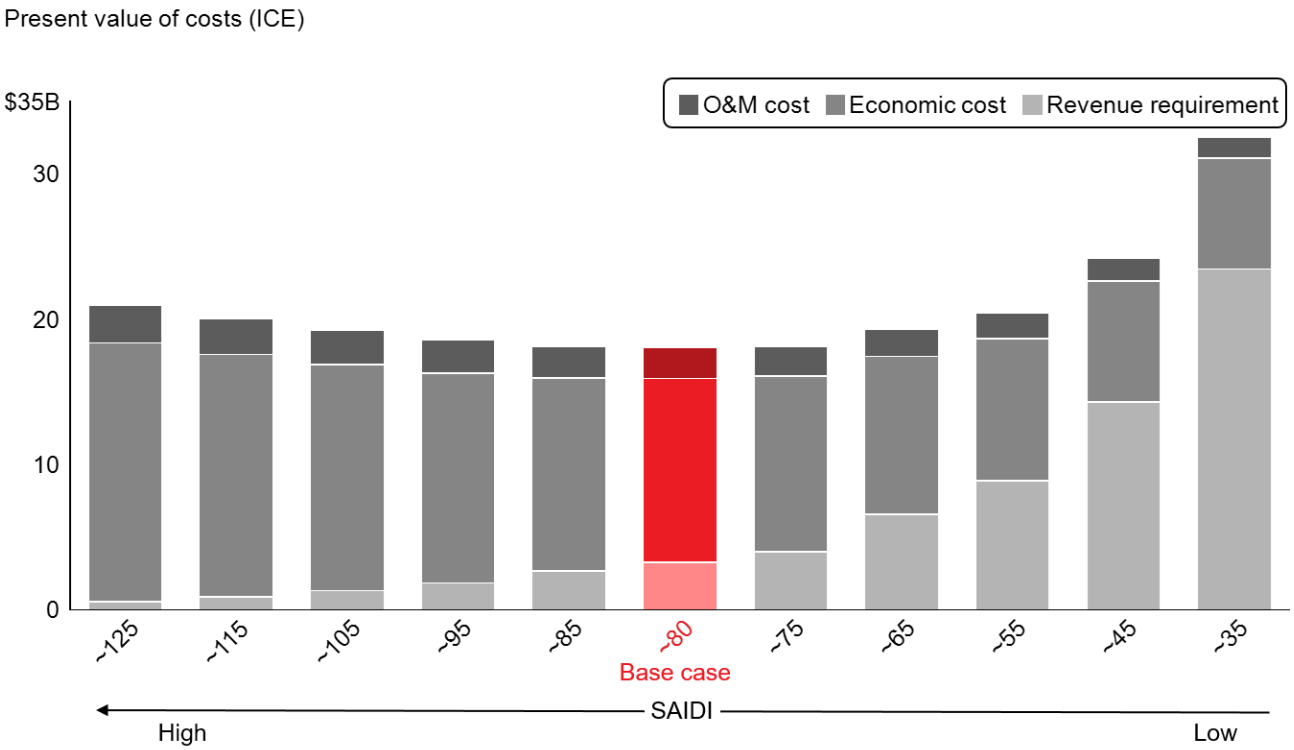

Figure IV. 1. Present Value of U-Curve with ICE Economic Costs

Compared to the Base Case EUE calculation in Figure III. 5, the economic cost of outages is slightly lower for each scenario. This has the effect of flattening the curve and therefore compressing the gap between scenarios. O&M and capital revenue requirement remain the same for each scenario. This is because the calculation of economic cost has no influence on either. The Base Case remains in the optimal investment range, targeting an end-state of ~80 SAIDI.

B. Internal EUE Estimates

Since customer electricity reliability expectations may change during the investment period, EUE cost estimates were flexed up and down by 10% to determine the impact on economic cost calculations and the optimal investment range. Flexing EUE cost estimates impacts the economic cost bar only, as capital revenue requirement and O&M cost bars are not affected by this variable. Figure IV. 2 shows the sensitivity calculations for the Base Case and four points around the Base Case.

The Base Case remains the optimal investment under the 90% of default EUE cost assumptions. In the 110% of default EUE cost assumption, the optimal point moves to the ~75 SAIDI scenario. The 110% EUE cost scenario is a more lenient assumption as it assumes that the value of the benefits to customers of reducing outages is higher than expected (and therefore investing more capital to improve reliability is more favorable) and so the optimal point shifts to ~75 SAIDI where more capital is spent to achieve improved reliability. It is more conservative to assume that the EUE costs do not rise and so the Base Case should still be considered to be within the optimal range.

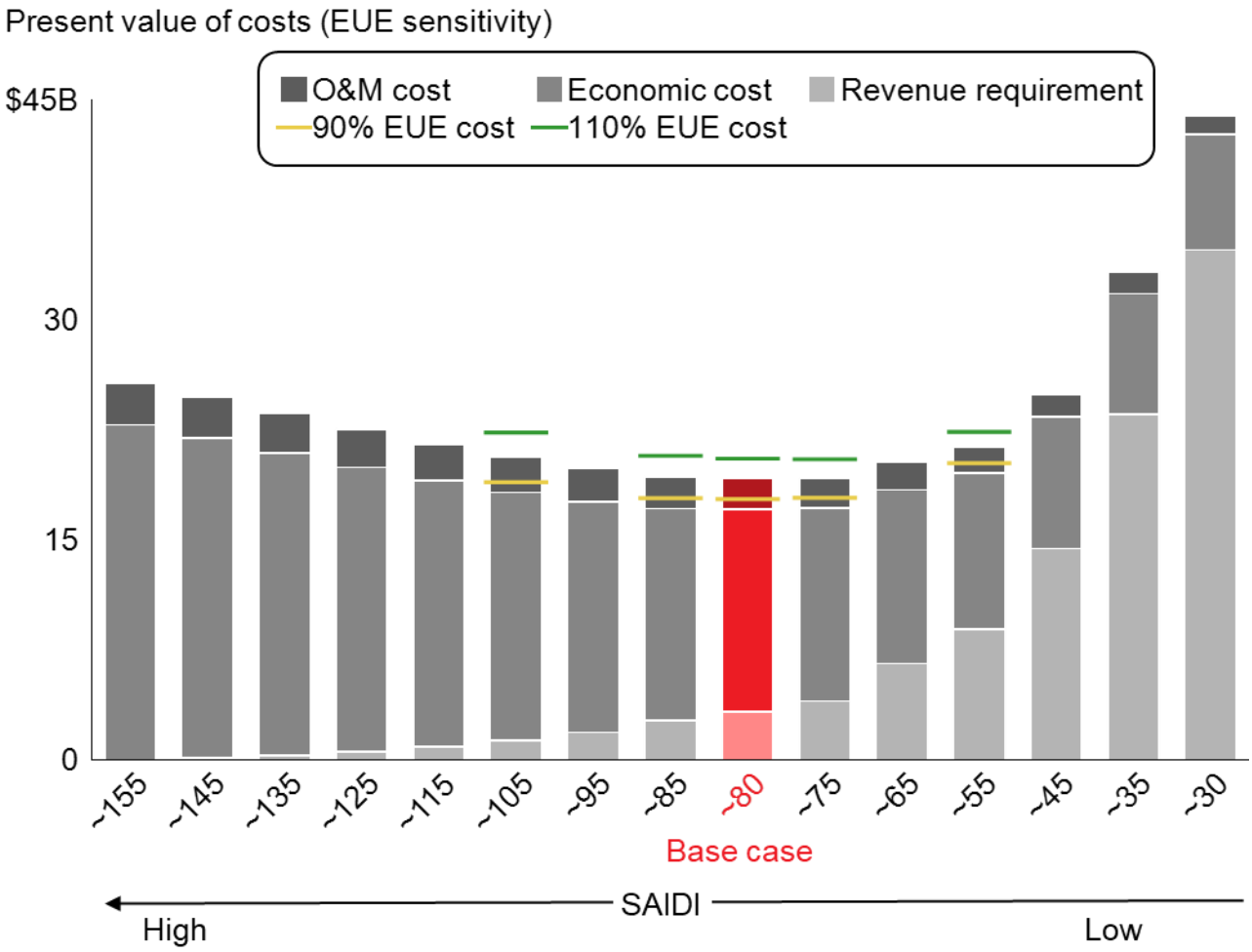

Figure IV. 2. Internal EUE Estimate Sensitivity

C. Investment Cost

To capture potential deviations from current investment cost estimates, investment cost assumptions were flexed up and down 10% to determine the impact on capital revenue requirement and the optimal investment range. Flexing investment cost assumptions only affects the capital revenue requirement cost bar as economic cost and O&M are unaffected by investment cost. Figure IV. 3 shows the sensitivity calculations for the Base Case and four points about the Base Case.

The Base Case remains in the optimal investment range under the 110% of default investment cost assumptions. In the 90% of default investment cost assumption the optimal scenario moves to the ~75 SAIDI scenario, as this change reduces the cost of each investment to achieve the same benefit and therefore encourages the spend of additional capital. It is more conservative to assume that investment costs will not decline and so the Base Case should still be considered to be within the optimal range.

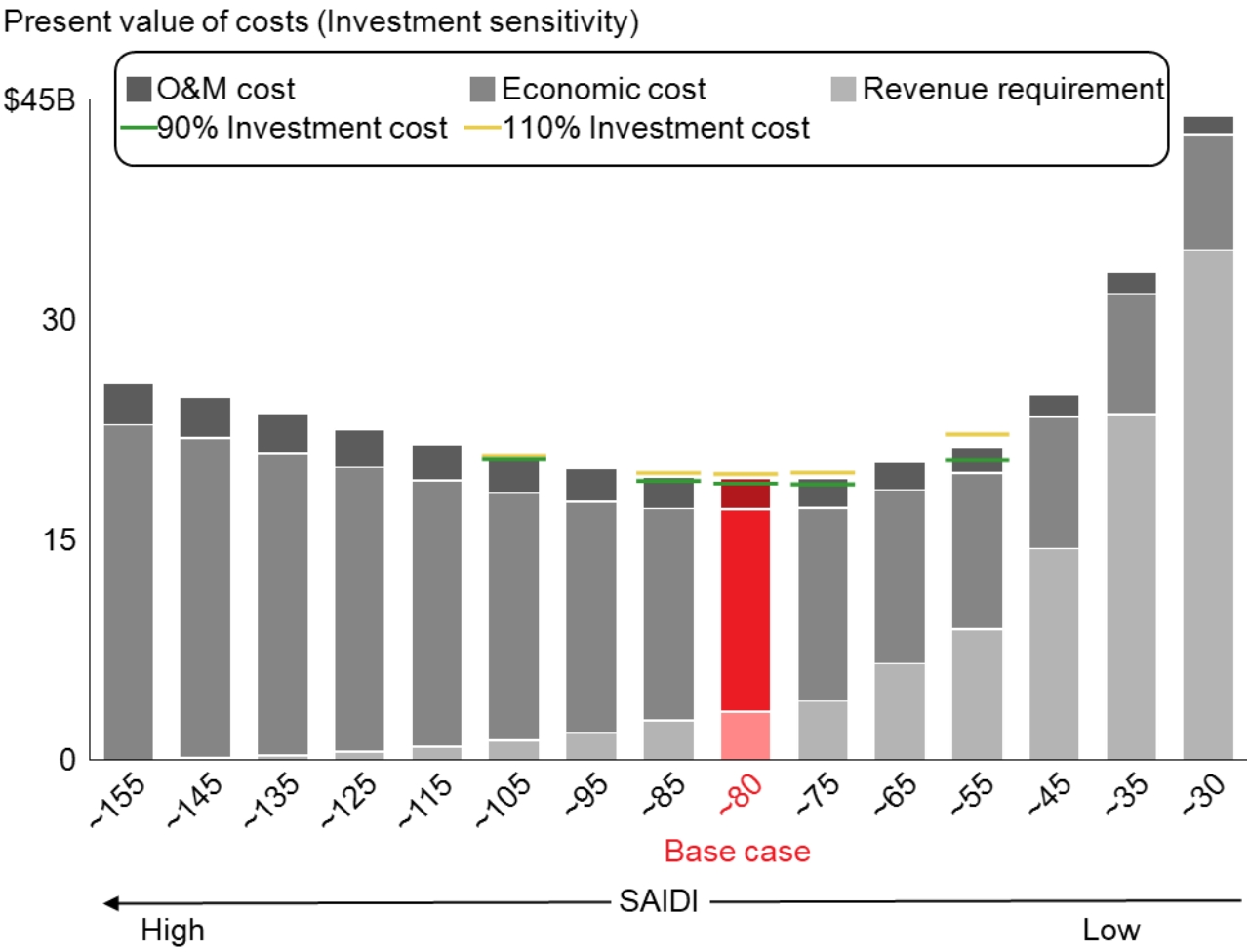

Figure IV. 3. Investment Cost Sensitivity

D. Load Growth

As discussed in I.K, default assumptions, electricity demand per customer is projected to decline [redacted]% annually over the course of the investment period. To capture possible load growth changes, estimated load growth was flexed up and down by 1 percentage point to determine the impact on economic cost and the optimal investment range. Flexing load growth assumptions affects the economic cost bar by changing the volume of unused energy during loss of service. Capital revenue requirement and O&M are unaffected by flexing load growth assumptions. Figure IV. 4 shows the sensitivity calculations for the Base Case and four points about the Base Case.

The Base Case remains in the optimal investment range under the [redacted]% load growth assumption. The optimal point shifts to ~75 SAIDI under the [redacted]% load growth assumption as this assumes that there is more load on the system and therefore that the benefits of reducing outage minutes is higher. It is more conservative to assume that load will not rise and so the Base Case should still be considered to be within the optimal range.

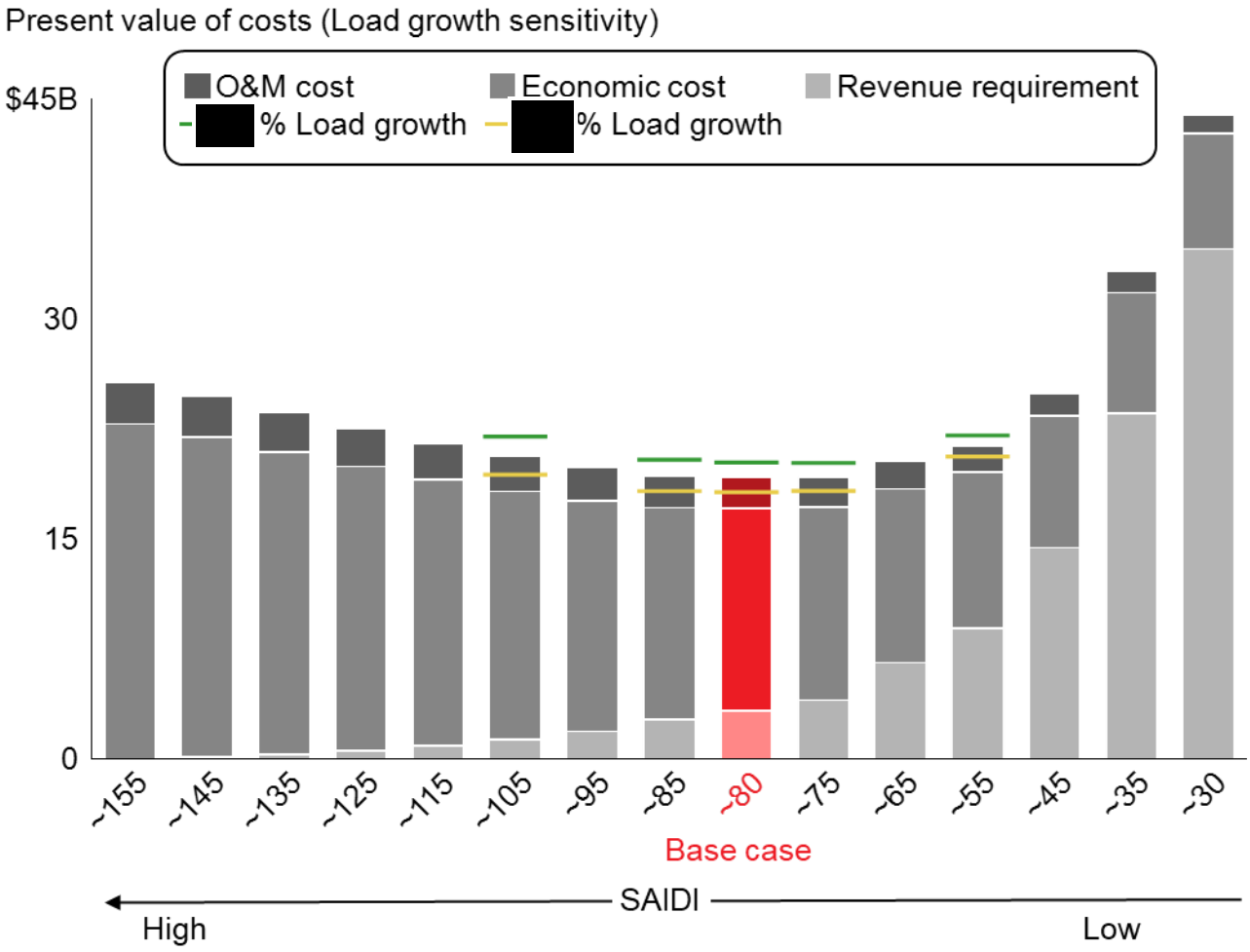

Figure IV. 4. Load Growth Sensitivity

E. Benefit Length

As discussed in I.E, under default assumptions package investment benefit is expected to last until 2055, 25 years past the end of the investment period of 2023-2030. To capture variation in

realized benefit length, estimated benefit length was flexed up and down by 10 years on a system level to determine the impact on economic cost and the optimal investment range. Flexing benefit length assumptions affects both the economic cost and O&M bars by extending the valuation horizon. Capital revenue requirement is unaffected by changes to the assumed benefit length. Figure IV. 5 shows the sensitivity calculations for the Base Case and four points about the Base Case.

Under a 15-year benefit assumption, the optimal point shifts to the ~85 SAIDI scenario and using the 35-year benefit assumption, the optimal point decreases to ~75 SAIDI. However, in both scenarios, the Base Case SAIDI remains in the optimal investment range.

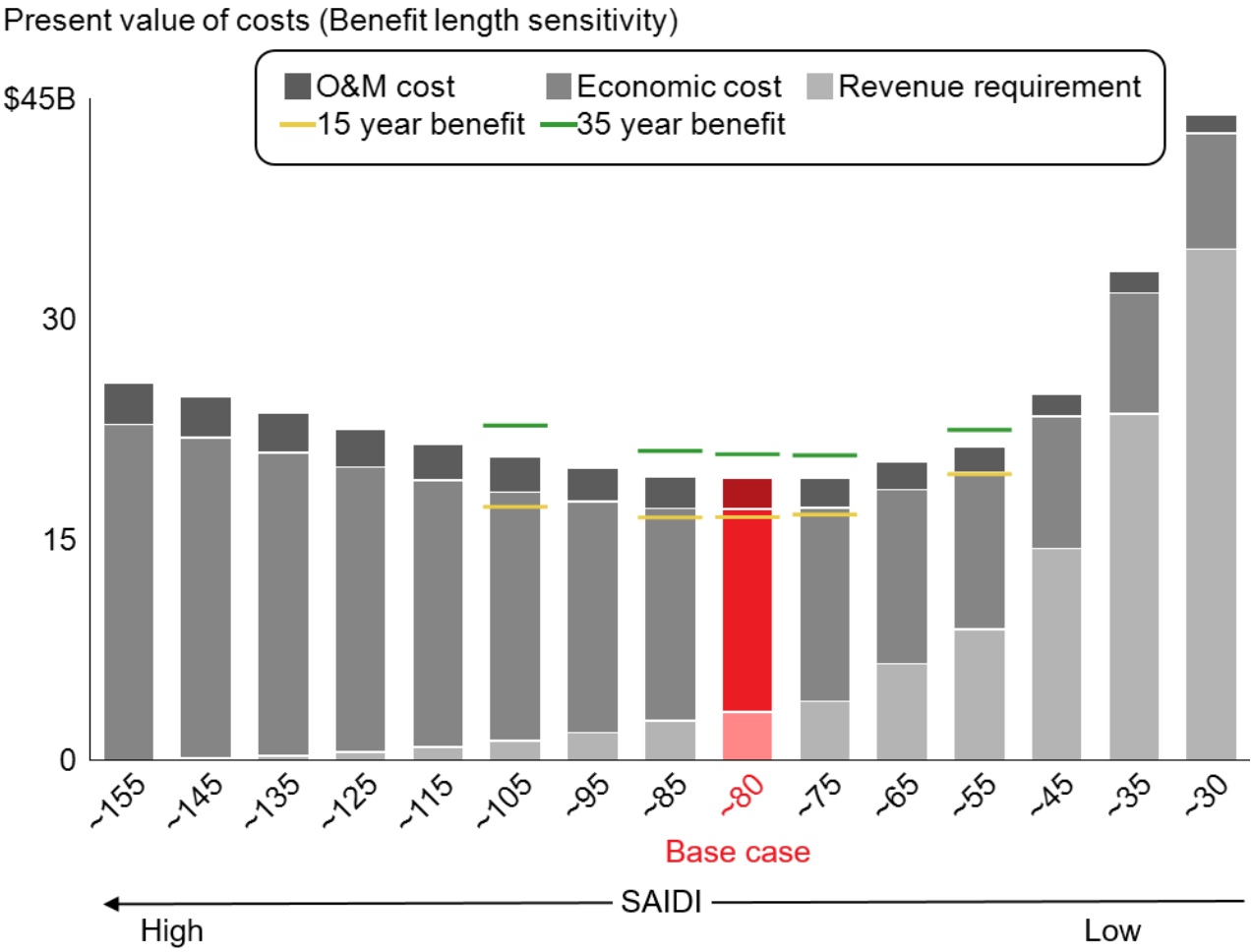

Figure IV. 5. Benefit Length Sensitivity

F. Load Growth / Benefit Length Interaction

Load growth and benefit length are unique among the study's assumptions in that they interact with one another. High load growth can strain circuit infrastructure, decreasing the expected benefit length of circuit investment. Low load growth can increase benefit length by extending circuit infrastructure useful life. To capture this variation, two separate model variants were run: (1) [redacted]% load growth and 35 year benefit, and (2) [redacted]% load growth and 15 year benefit. Both variants affect the economic cost and O&M bars, while capital revenue requirement remains unchanged. Figure IV. 6 shows the sensitivity calculations for the Base Case and four points about the Base Case. The Base Case remains in the optimal investment range under the 15-year benefit

and [redacted]% load growth assumption. Under the [redacted]% load growth and 35-year benefit assumption, the optimal point shifts to the ~75 SAIDI scenario.

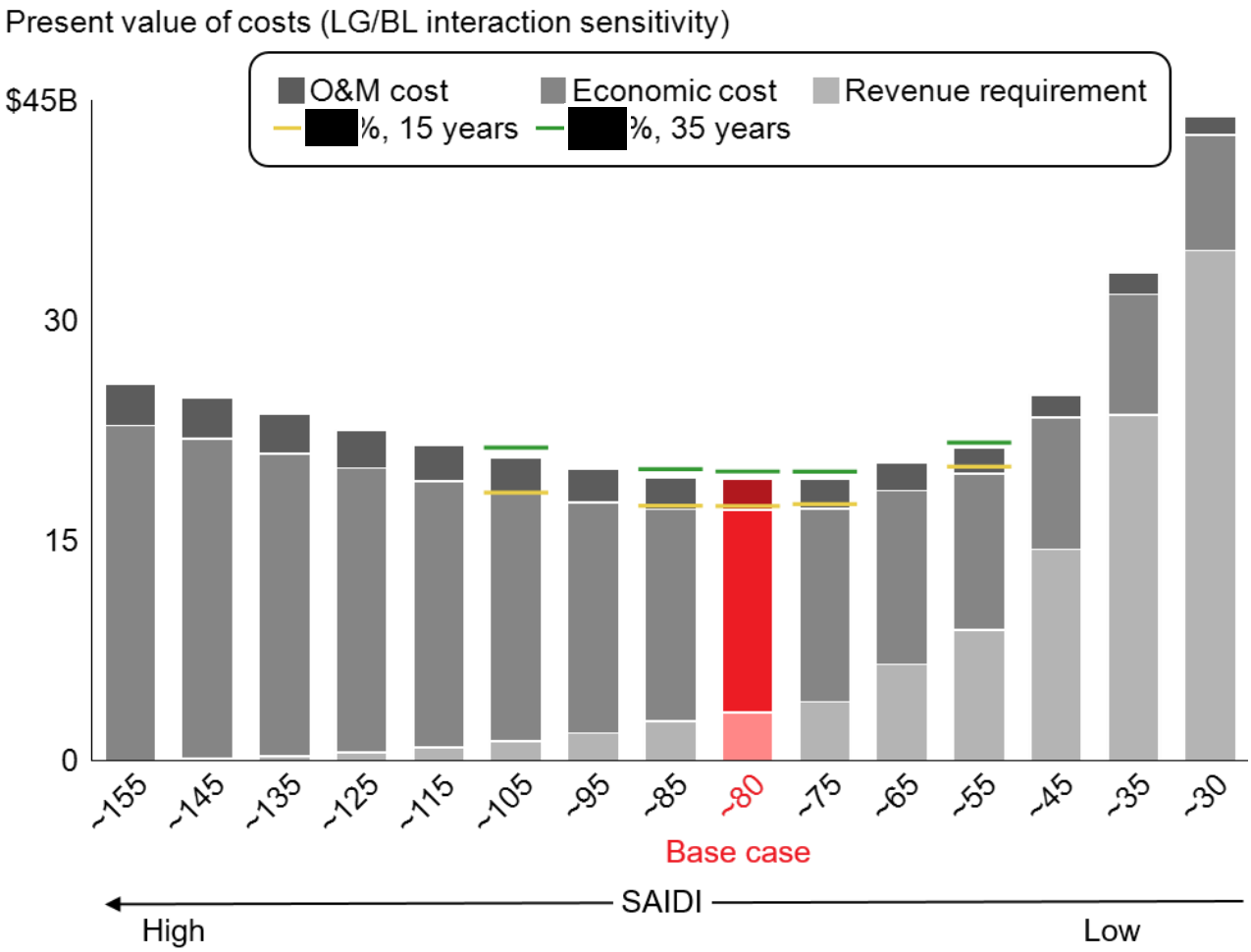

Figure IV. 6. Load Growth / Benefit Length Interaction Sensitivity

G. Rate of Reliability Decline

As discussed in I.H, the roughly 1000 circuits identified as having systemic reliability issues are projected to continue to experience reliability decline at conservative annual SAIDI and SAIFI rates of ~4% and ~3%, respectively, for each year in the investment horizon or until invested in. Given that reliability can vary year-by-year due to factors such as weather patterns, traffic, and wildlife events, possible reliability decline differences were captured by varying SAIDI and SAIFI

decline rates up or down by 2 percentage points. Figure IV. 7 shows the sensitivity calculations for the Base Case and four points about the Base case. The Base Case is the optimal investment under the low reliability decline assumption but under the high reliability decline assumption the optimal SAIDI moves to ~75. It is more conservative to assume that reliability will not decline faster than expected (and therefore that the benefits to improving reliability are greater) and so the Base Case should still be considered to be within the optimal range.

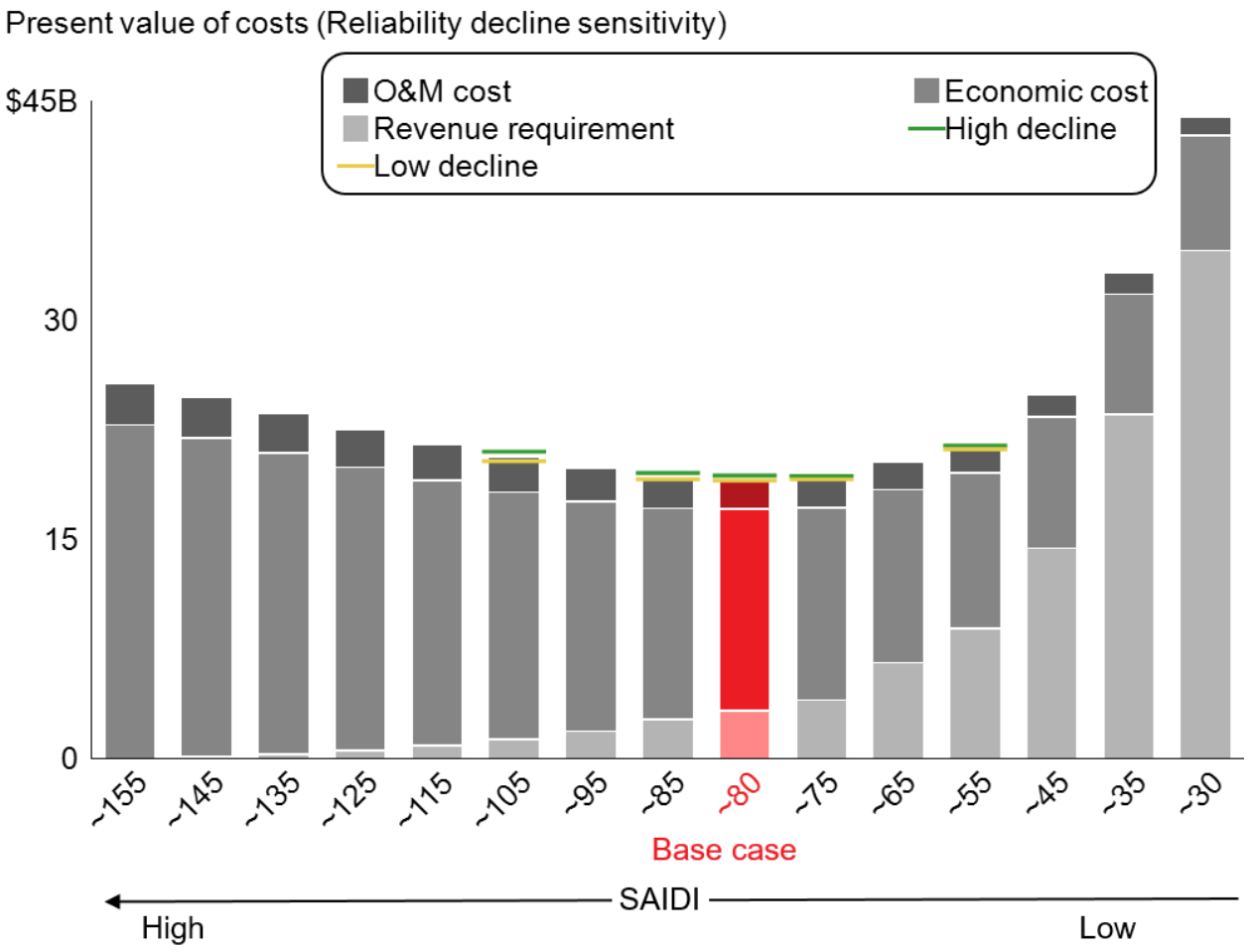

Figure IV. 7. Reliability Decline Sensitivity

V. CONCLUSION

The 2022 Distribution Investment Study is aimed at determining the optimal investment range for GPC's proposed Distribution Investment Plan by comparing the costs and benefits across various investment scenarios. As shown in Figure III. 1 (reproduced below) investment scenarios targeting more circuits and better end-state reliability result in diminishing reliability improvements. As noted, this is because the "highest opportunity circuits" are the first to be invested in. The Base Case plan corresponds to the level of investment that includes the highest opportunity investments but excludes investments that produce diminishing returns.

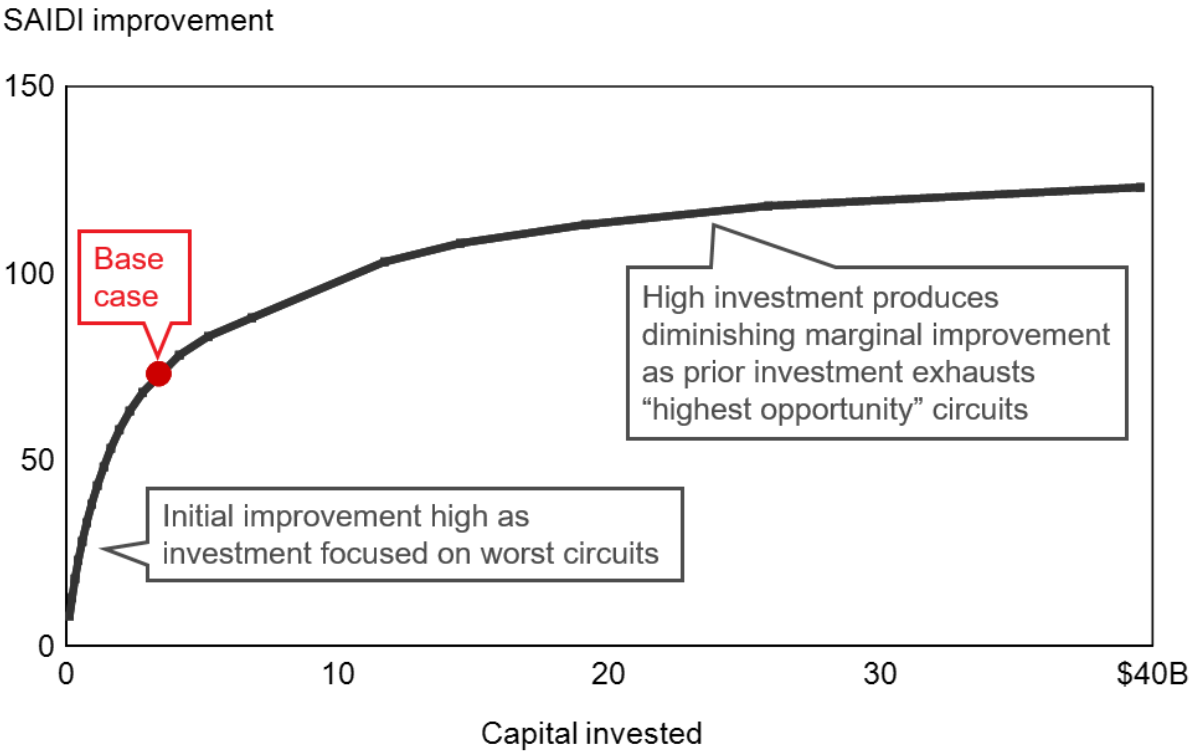

Figure III. 1. Diminishing Reliability Improvement

As discussed above in I.Q, the investment scenario that minimizes capital revenue requirements, economic costs, and O&M can be seen as optimal from the customer's perspective. This is because all of these costs are either directly or indirectly borne by customers. As shown in Figure III. 5 (reproduced below), of the 15 scenarios run, the Base Case scenario results in the minimum cost and should therefore be seen as the preferred option for customers.

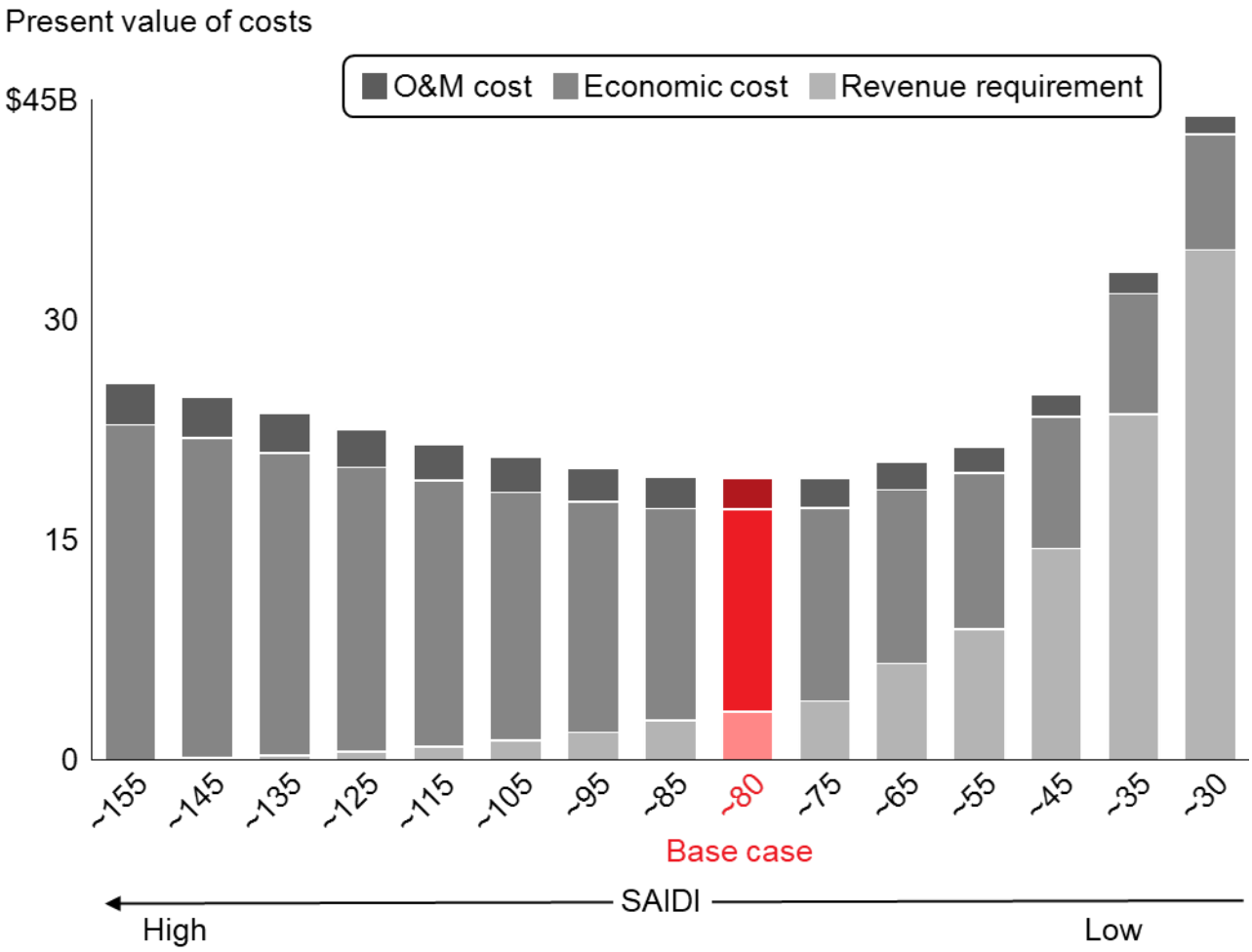

Figure III. 5. Present Value of Total Cost

Minimizing total customer cost is equivalent to maximizing the net present value of investment.

Figure III. 6, reproduced below, shows NPV of each scenario.

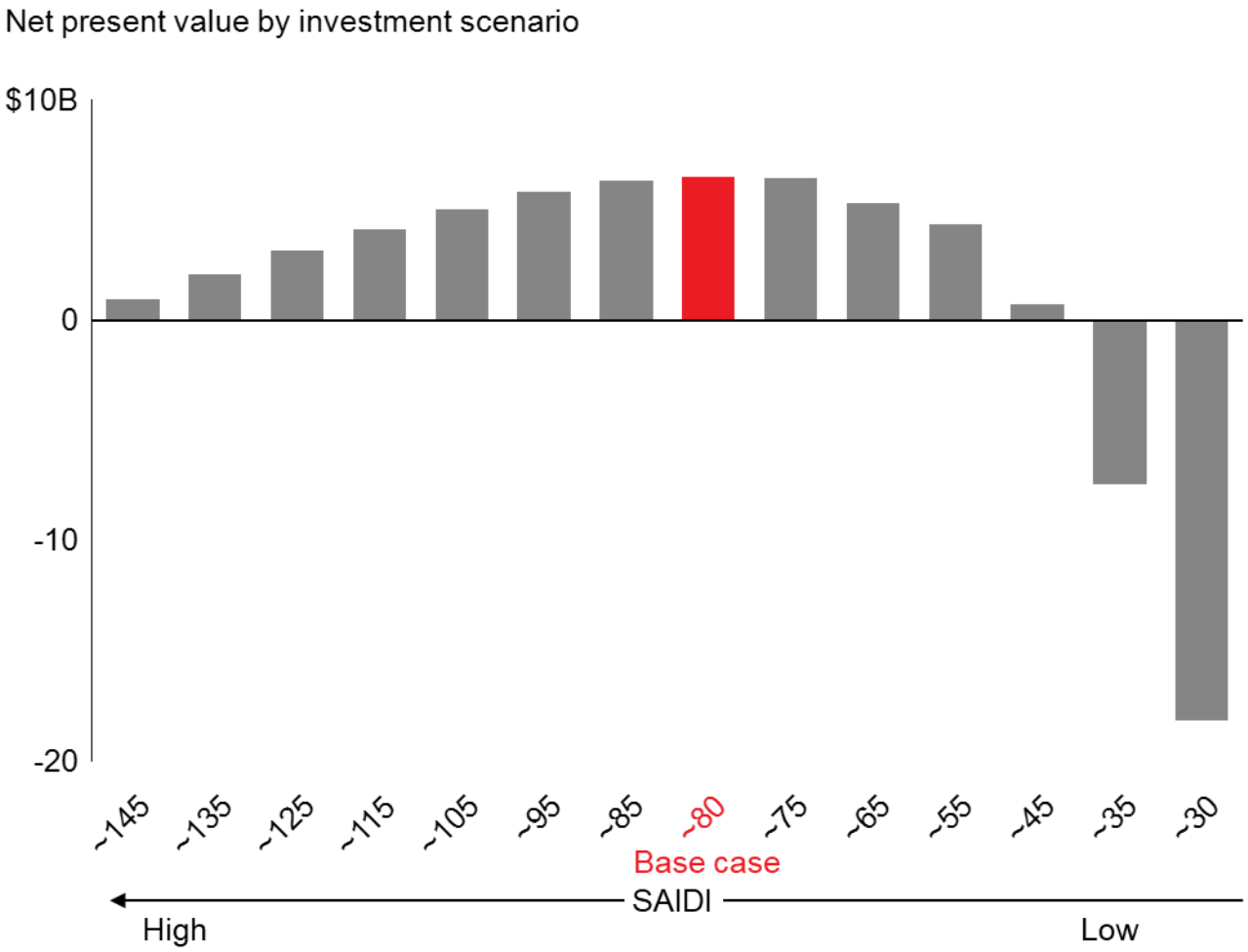

Figure III. 6. Net Present Value

Lastly, seven sensitivity analyses on key inputs to the Distribution Plan have been conducted. While these sensitivities result in increases or decreases to the overall cost bars, the Base Case investment plan remains in the *optimal range* of investment across all sensitivities. While the optimal point occasionally shifts slightly, the shift is primarily due to changes in assumptions that make it more favorable to spend additional capital. Given that the capital spent on investments directly increases the rates paid by customers, it is thus the conclusion of this report that the Base Case investment plan (the "Distribution Investment Plan") is the more conservative option and should be the preferred solution from the customer's perspective.