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# Black Swan Energy - A Story of Enhanced Climate Resilience

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**SUMMARY**

Significant adverse weather events are increasing in both frequency and intensity, raising the cost of resilience for utility infrastructure at an accelerated pace. Utilities must make decisions today on the resilience of those assets based on their multi-decade lifespan, while also considering the changing frequency and intensity of extreme weather events over these time-periods. While climate risk disclosures are a foundational step in addressing corporate climate responsibility, most fall short of quantifying the current and future risks to their assets posed by physical climate impacts. As climate science improves and higher-resolution data becomes more accessible to utilities, it is now possible to provide more locational-specific estimations of risk. Such data allows utilities to better target their resilience investments. Quantification of physical climate risks provides an addressable baseline against which to measure the value of the investments required to mitigate them. This is critical for cost-effective climate adaptive actions and in new infrastructure design. With our hypothetical utility, Black Swan Energy, we can illustrate how to quantify resilience risk and define adaptive actions that improve resilience.

**KEYWORDS**

Infrastructure Resilience, Microgrids, Resilience Quantification, Big Data for Resilience, Resilience Planning, Aging Infrastructure & Asset Management

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**Increasing Climate and Extreme Weather damage in the power sector**

Hurricane Ida hit Louisiana in 2021 causing $95 billion in damages. The infamous winter storm Uri, which led to the Texas blackout in 2021 and 11 million customers experiencing sustained outages, caused an estimated $195 billion in damages. These damages were made much more severe due to infrastructure that was not built to withstand the meteorological extremes of the 21st century. The recently passed Bipartisan Infrastructure Law in the US is dedicating $5B in grants to utilities to focus on fixing this exact issue.

Both chronic climate trends and extreme weather events pose an increased risk for utility infrastructure damage, power outages, increased operations & maintenance (O&M) costs, and siting implications. Changing air temperatures can alter the useful life of assets, where we see aging of a device as a function of temperature changes. High wind events (e.g., hurricanes) can damage towers and lines. Flooding damage to coastal substations and other equipment during extreme precipitation events can be compounded by sea level rise and storm surge.

**Predicting Extreme Resilience Events**

Predicting when extreme events will occur is extremely challenging given their variability and infrequency. However, when utilities invest, most of their assets have useful lives that span decades: a distribution utility pole lasts 45 years, a transmission lattice tower lasts 100 years, a natural gas power plant lasts 30 years. As such, utilities must make decisions today on the resilience of those assets based on their multi-decade lifespan, while also taking into account the changing frequency and intensity of extreme weather events over these time-periods.

For an asset that has 45 years of useful life, the likelihood it experiences a once in a one-hundred-year event that exceeds its design threshold and causes failure during its useful life is 36%. However, if the same design threshold is exceeded once every 50-year in the future due impacts from climate change, the likelihood rises to a 60% probability of failure. Said differently, there is a three in five chance the asset will unexpectedly fail before it is replaced at the end of its useful life.

**Moving from Climate Risk Disclosure to Quantifying Physical Climate Impacts**

Many utilities are currently leveraging climate risk disclosure frameworks to acknowledge these risks and identify potential mitigations of GHG emissions and adaptive actions to physical climate risks. While climate risk disclosures are a foundational step in addressing corporate climate responsibility, most fall short of quantifying the current and future risks to their assets posed by physical climate impacts.

Critical for cost-effective climate adaptive actions in new infrastructure design, quantification of physical climate risks provides an addressable baseline against which to measure the value of the investments required to mitigate them. Without quantification of physical climate impacts, utilities are unable to convert those adaptive actions into a rate-based asset investment plan.

In this paper, we present a framework for utilities to measure physical climate risks downscaled to specific asset locations against IPCC global climate scenarios. Quantification of the financial value of these risks allows utilities to substantiate and prioritize today's investments to protect against this risk tomorrow.

## 1. Resilience Risk Assessment Approach

### Methodology Of Physical Risk Assessment

To illustrate this methodology, we will look at the hypothetical utility Black Swan Energy which serves two million customers with operations in coastal states. The concentration of coastal assets exposes Black Swan Energy to hurricanes and flooding (due to sea level rise), causing them to seek additional clarity on its level of exposure to climate threats, how it impacts asset vulnerabilities, and subsequent risk to climate change.

In this study, the impact of climate change is analyzed for 100,000 distribution poles, 50,000 transmission structures, and 1,000 substations. This study specifically focuses on the impacts of flooding, wind, and heat on Black Swan Energy, though a comprehensive analysis could include other climate hazards (e.g., drought, cold, wildfires) across electric transmission and distribution, generation, and natural gas assets.

| Black Swan Energy Key Energy Facts | |
|---|---|
| • Number of customers: 2 million<br>• Location: Gulf Coast<br>• Key risks: Hurricanes; flooding | • 100,000 distribution poles<br>• 50,000 transmission structures<br>• 1,000 substations |

The approach to quantifying and mitigating physical risk is very similar the traditional asset investment planning performed by utilities today. For reliability-focused investments, utilities gather data about their assets' condition and forecast when failures may occur. They then bundle the assets requiring replacement or refurbishment based on the forecasted declining condition into asset investments. The investment action results in some value, in this case, avoided risk. Investments are scored based on their ratio of value to cost and prioritized in a portfolio against financial constraints. The result is a portfolio that avoids the most risk per dollar given the budget the utility may spend.

With physical risk from climate change, asset investment planning is largely unchanged, except now the measure of value is avoided resilience risk. Figure 2 below illustrates the core elements of the framework to establish a baseline for this risk against which the value of the investments is measured.

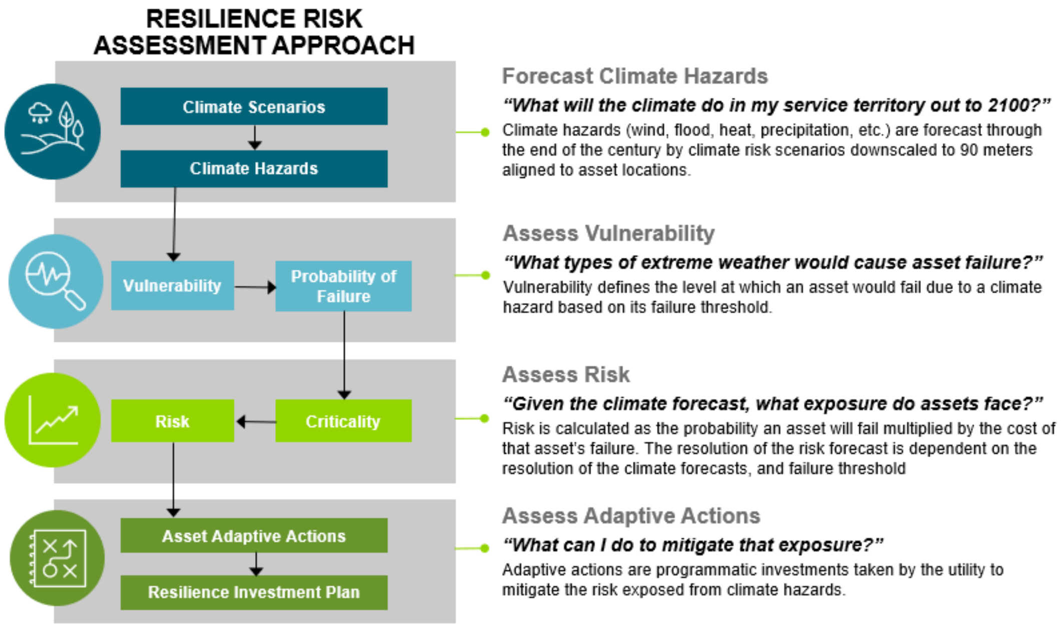


**Figure 1: Resilience Risk Assessment Approach**

## 2. Forecast Climate Hazards

### Importance for Electric Sector Planning

For utilities to better prepare for the increasing frequency, intensity, and variability of these events, it is important to model resilience risk across many climate hazards. Future projections of location-specific climate hazards are the foundation of a climate risk model. Projections of annual average temperatures – in particular, the extremes – can provide a clearer line of site of future peak capacity and conditions that could increase derating. Flood projections can identify where storm hardening and investments in the distribution system are needed to ensure reliability. Projections of wind including higher sustained and extreme wind gusts can help determine future infrastructure designs of overhead assets.

**Climate Hazards**

The climate forecasts for acute climate hazards are provided at six return periods: 10-year, 20-year, 50-year, 100-year, 200-year, and 500-year. Return periods are an estimated average time between events and are used to conceptualize the frequency of acute risks. Note, experiencing a 100-year event one year does not change its probability in the following year as these events are independent. There is still a 1-in-100 chance of it occurring again. Each of these return periods equate to an annual probability, which is the inverse of the return period. For example, a 100-year return period would equal a 1% annual probability and a 200-year return period would equal a 0.5% annual probability. The results from the climate forecast show the maximum flood depth at each return period. For example, a 2-foot flood depth at the 100-year return period would mean that there is 1% chance in that year there will be 2 feet or more of flooding.

**Case Application:** This analysis for Black Swan Energy utilizes a 90-meter resolution which helps identify targeted areas of resilience risk. Figure 3 illustrates the probability (or likelihood) of projected flooding and wind speeds for substations, transmission structures, and distribution poles from 2020 to 2070.

**For Black Swan Energy's assets**, substations were analyzed for their exposure to flooding and heat, while transmission structures and distribution poles were analyzed for their exposure to extreme wind. Due to Black Swan Energy's coastal location, it has exposure to hurricane force winds and extreme flooding including fluvial flooding from rivers, lakes, and streams, storm surge, and sea-level rise. Substations have a 10% likelihood of being exposed to at least 2 feet of flooding in 2020; by 2070, that same likelihood results in 2.5 feet of flooding. In a more extreme scenario (i.e., high-impact, low-probability event), there is a 0.2% probability of substations experiencing flood depths greater than 3 feet in 2020. By 2070, the likelihood of substations experiencing 3 feet flood depths grows to 1% (as compared to 0.2% in 2020), a 5x increase in 50 years.

**For transmission structures and distribution poles**, exposure to damaging winds is not forecasted to change substantially because extreme wind does not have as strong of a climate signal as flooding. For transmission structures, wind speeds reach a maximum of 150 mph (equivalent to a Category 4 hurricane). They have a 2% chance of experiencing a Category 2 equivalent wind speed of over 100 mph. Distribution poles, which are more geographically dispersed and closer to the coast, are exposed to even higher maximum wind speeds of up to 175 mph, equivalent to a Category 5 hurricane. There is a 10% chance these assets will experience Category 1 hurricane wind speeds or greater in a given year.

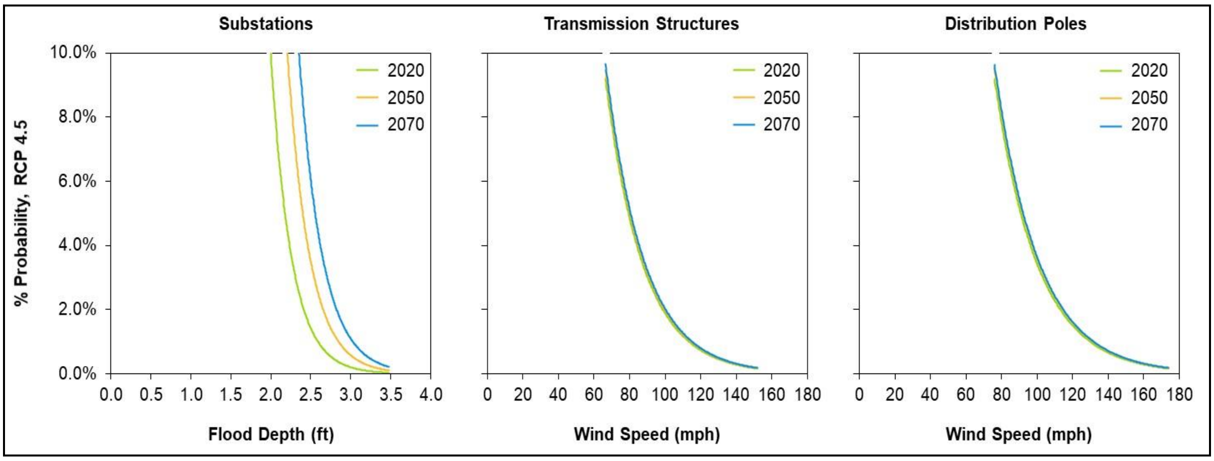


**Figure 2: Probability of Climate Hazards Occurring from 2020-2070 (RCP 4.5) for Substations, Transmission Structures, and Distribution Poles**

By 2050, substations experience almost the same heat exposure across all scenarios at about 5 days/year with temperatures greater than 104°F. After 2050, results diverge with annual days reaching an average of 22 days/year by 2100 for RCP 8.5. The maximum and minimum values within the asset class, represented by the error bars in Figure 4, show a wide breadth of exposure to substations, indicating a large variation of heat exposure across the asset class.

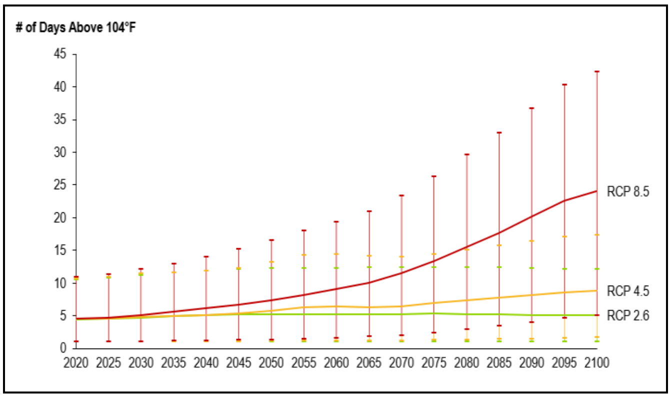


**Figure 3: Number of Days Above 104°F from 2020-2100 for Substations, by Scenario (Error Bars Indicate Maximum and Minimum Values)**

## 3. Assess Vulnerability

After calculating the expected climate forecasts, we look at Black Swan Energy's asset vulnerabilities. The vulnerability assessment involves mapping Black Swan Energy's assets to climate hazards by defining the failure modes and failure thresholds for each. Shown in Figure 5 below are the failure modes for the three asset classes we are evaluating: transmission structures, substations, and distribution poles.

| | Transmission Structures | Substations | Distribution Poles |
|---|---|---|---|
| Flood | Minimal impact: Rapidly moving water could cause washout at the base of structures. | Flooding can cause shorting, corrosion and debris damage and can stop access to equipment causing batteries to lose charge and all equipment to lose power. Key assets impacted are switchgear and control houses, and risk of oil leakage from transformers. | Minimal impact: Fast moving flood water could cause erosion and impact pole foundations. |
| Wind | Extreme wind can cause the structure to fall over or break either directly or from nearby vegetation. | No impact | Extreme wind can cause the pole to fall over or break either directly or from nearby vegetation. |
| Heat | No impact | Prolonged exposure to high heat can cause accelerated degradation of the asset and earlier than expected retirement. | No impact |

**Figure 4: Vulnerability Assessment for Transmission Structures, Substations, and Distribution Poles**

Each asset class has a unique failure threshold for the different climate hazards. The failure threshold is the value at which the asset experiences loss of operation or damage that prohibits safe operation and typically results in customer interruptions. These values are used to calculate the probability of failure.

## 4. Assess Risk

The second part of the risk equation is criticality. For Black Swan Energy's poles, substations, and transmission structures the cost of failure is comprised of asset repair/replacement costs and the value of lost load to the customer.

Looking at Black Swan Energy's assets, overall risk grows by a CAGR of 0.2% for substations (flooding), 7% for substations (heat), 0.2% for transmission structures, and 0.1% for distribution poles through the end of the century. As the probability of substations failure increases due to changes in flood likelihood, so does the financial risk to Black Swan Energy, growing from $58 million in 2020 to $70 million through 2100. While there are 100x more distribution poles compared to substations, the cost of failure for the poles is just 61% of the substations. Despite having near-equal average failure probabilities, the differences in asset count and failure cost bring the risk in dollars of the respective asset types much closer to each other. Distribution poles failures grow from $37 million in 2020 to $40 million in 2100. Heat risk to substations represents the most dramatic change, with risk materializing in 2040 at the lowest value within that year ($1.7 million) to nearly $100 million by 2100. These results highlight how we can disaggregate which element of the risk equation is the primary driver of total risk comparatively – failure likelihood, cost of failure, and asset count. Based on the resilience risk forecast, Black Swan Energy can now identify which asset types and specific locations would benefit the most from resilience investments.

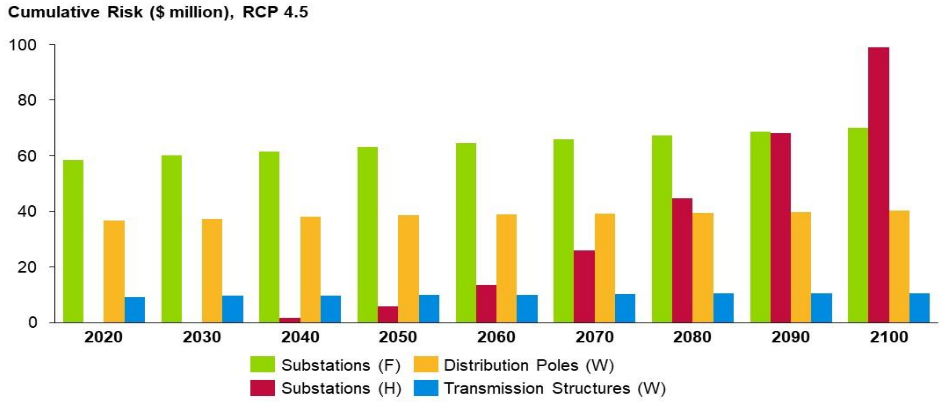


Figure 10. Cumulative Risk from 2020-2100 for Each Asset Class-Hazard Pair, RCP 4.5
*W = Wind, F = Flood, H = Heat*

## 5. Adaptive Actions

After completing the respective vulnerability and risk assessments, adaptive actions are introduced to provide an actionable path forward for utilities to manage their exposure to resilience risk. Depending on the investment horizon, the resolution of the recommendations can range from programmatic investments for multi-decade plans down to specific resilience investments at the asset-level for multi-year plans. Sample adaptive actions for Black Swan Energy's assets are listed below.

| | Transmission Structures | Substations | Distribution Poles |
|---|---|---|---|
| Flood | • Design new assets with steel foundations<br>• Avoid building new structures in flood zones<br>• Mount vulnerable equipment above expected flood levels<br>• Evaluate moving existing line structures from areas expecting increased flooding | • Install substation flood protection<br>• Elevate substations<br>• Install new substations that are submersible<br>• Evaluate moving existing equipment from areas expecting increased flooding | • Avoid installing new poles in flood zones<br>• Evaluate relocating poles out of potential flood areas |
| Wind | • Evaluate undergrounding critical equipment<br>• Modify design standards to meet or exceed new wind speed expectations<br>• Evaluate vegetation management specifications<br>• Use lidar to monitor vegetation growth rates and clearance violations<br>• Strengthen structures to higher class materials | No action required | • Evaluate vegetation management specifications<br>• Evaluate pole loading programs to understand potential vulnerable points<br>• Evaluate undergrounding feeder lines<br>• Truss or restore the pole to improve design standard<br>• Replace the pole with a higher-class material |
| Heat | No action required | • Develop new design specifications and operating guidelines to ensure proper operation at high temperatures<br>• Work with equipment manufacturers to modify designs to operate at higher temperatures | No action required |

**Figure 11: Adaptive Actions for Transmission Structures, Substations, and Distribution Poles**

The recommendations also may impact the existing engineering standards and operating procedures. These actions call for utility partners to evaluate their design standards for assets to further prevent the exposure from climate hazards when new assets are installed. A like-for-like replacement simply improves the condition of the asset but does nothing to mitigate the climate risk in the long-term.

## 4. Conclusion

Utilities have historically invested heavily in reliability to improve the condition of their assets and keep the lights on. While these investments do mitigate some resilience risk, existing design standards do not account for the increasing frequency and severity of extreme climate events. Extreme events by their very nature are high-consequence, low-probability events and are challenging to forecast, particularly in a changing climate. As a result, resilience risk has not been explicitly measured or incorporated into asset investment plans.

Many utilities have relied extensively on historic weather data to assess risk for their assets. Although an important benchmark, using historic climate data to project future risk will result in significant underestimations of asset risk from climate extremes. The error is especially pronounced for tropical cyclones, as many stretches of coastline have gotten extraordinarily lucky and unlucky over our limited historical record. Furthermore, as climate science improves and higher-resolution data becomes more accessible to utilities, it is now possible to provide more locational-specific estimations of risk. Such data, applied carefully, allows utilities to better target their resilience investments.

Black Swan Energy was able to identify that flooding to substations posed the greatest risk prior to 2050, followed by wind risk to distribution poles. They are now able to identify investments and build the business case to address their resilience risk. In our next paper, we’ll illustrate how Black Swan Energy develops an optimized resilience investment plan using the adaptive actions noted above and how Black Swan Energy measures the realization of the benefits when they make it through their first resilience event.