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Considering Climate Change Scenarios in Site Resilience Planning

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U.S. DEPARTMENT OF ENERGY

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Contents

Acknowledgments

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This paper was prepared in support of the U.S. Department of Energy's Federal Energy Management Program (FEMP). The paper serves as a resource for site-level personnel who are performing energy and water resilience planning at their sites and who need to identify and incorporate data that may help them assess risks to infrastructure and operations as a result of future climate change impacts. Specifically, the paper is a high-level look at available scenarios of future climate that can be incorporated into assessments based on U.S. regional models.

1.0 Introduction

As the world faces climate change, U.S. energy, water, and facility managers are confronted with the challenge of preparing their sites for associated stresses on infrastructure. The first step to increasing site climate resilience is to consider how climate change may impact the region in which the site is located. Climate models tend to be designed on a global or regional scale. Determining how the results of these models apply to a particular site is not always straightforward. By considering a range of scenarios[1], where lower greenhouse gas (GHG) emissions are likely to result in less dramatic climate impacts, and higher GHG emissions are likely to result in more extreme climate impacts[2], decision makers can survey the range of potential circumstances for which they may prepare. This approach allows decisions to be made considering both intermediate as well as more extreme[3] future climate scenarios. This report describes the state of science on future climate scenarios and how these can be incorporated into energy and water resilience planning. In particular, the report lays out multiple scenarios vetted by the U.S. Global Change Research Program (USGCRP).[4] By incorporating future climate scenarios into resilience planning, managers will be in a better position to protect their infrastructure and mission-critical operations from both current and future climate-related risks.

2.0 Overview of climate scenario resources

A scenario-based approach can support a comprehensive risk assessment related to climate change. This report focuses on the scenarios used by the National Climate Assessment (NCA) which the USGCRP oversees. The NCA is Federally mandated under the Global Change Research Act of 1990. To fulfill the Global Change Research Act, the NCA evaluates risks that climate and other interlinked global changes (e.g., changes in energy supply, delivery and demand and water quantity and quality) pose to the United

[1] In this paper, the term "scenario" refers to one possible climate future, consistent with how the term is used in the climate change literature. However, the term "scenario" generally has a different meaning in risk analysis, and as used in the Technical Resilience Navigator (TRN). There, it refers to one possible sequence of events with an adverse outcome. In the TRN, a scenario reflects the realization of a hazard and of a site vulnerability, resulting in the consequence of mission disruption. In both cases, "scenarios" offer a way to systematically identify possible outcomes for planning purposes.

[2] In addition to uncertainty related to not knowing which GHG emissions pathway best represents the future, uncertainty also arises from model uncertainty and natural system variability. The more complex the model, the more assumptions are used and the larger the uncertainty. However, most uncertainty found in projections of climate change impacts results from the intrinsic variability in the climate, economic, social, and environmental systems, and assumptions regarding human responses (e.g., mitigation, adaptation and decision making) to change (Wilby and Dessai 2010).

[3] These refer to scenarios with very high GHG concentration trajectories.

[4] The USGCRP is responsible for overseeing the development of the National Climate Assessment (NCA), a key report issued every four years that distills the scientific consensus on climate change patterns in the United States.

States. To evaluate these risks, USGCRP identified multiple scenarios representing different potential futures in the most recent NCA (NCA4; USGCRP 2017, 2018).[1] Specifically, the NCA identifies a suite of scenarios for the United States at subnational scales that consider the future extending through the 21st century (at a minimum). The scenarios span a range of plausible future changes in key environmental parameters such as weather and climate extremes, sea level, population, and land use. The suite of scenario products consists of documents, graphics, references to data sets, and other resources. These products depict a range of plausible future conditions against which risks and opportunities could be assessed at regional and national scales.

Though climate models do not provide this level of detail at a site/facility level, site managers can use these scenario products for general context-setting to illustrate a range of possible future outcomes in key drivers of risk and determinants of vulnerability. They can also apply them to bound the envelope of scientifically plausible future climate change in assessing regional or sectoral risks.

2.1 What do the National Climate Assessment (NCA) scenarios represent?

The NCA is grounded in an analysis of the widely-used radiative forcing scenarios termed the Representative Concentration Pathways (RCPs) that form the foundation for the majority of recently coordinated global climate model experiments.[2] The RCPs are numbered as follows according to changes in projected radiative forcing[3] in 2100 relative to preindustrial conditions: +2.6 (very low), +4.5 (lower), +6.0 (mid-high) and +8.5 (higher) watts per square meter (W/m^2). Starting from these radiative forcing values, scientists use integrated assessment models to work backwards to derive a range of GHG emissions trajectories and corresponding policies and technological strategies for each RCP that would achieve the same impact on radiative forcing (IPCC 2014; USGCRP 2017). An RCP with a higher number represents a future scenario with more significant climate change impacts with higher GHG emissions, higher GHG concentrations, and a larger temperature increase. The 2018 NCA focused primarily on RCP 8.5 (higher radiative forcing) and RCP 4.5 (lower radiative forcing) for framing purposes, but also considered other scenario information where appropriate. The RCPs represent changes in the mean and extreme values of key climate variables such as temperature and precipitation. For example, under RCP 4.5 and RCP 8.5, significant temperature increases are projected late century: 2.3° to 6.7°F (1.3°–3.7°C) in the case of RCP 4.5, and 5.4° to 11.0°F (3.0°–6.1°C) under RCP 8.5 (Hayhoe et al. 2018). In addition to the RCPs, the NCA also used scenarios of future sea level rise and associated coastal flood hazard

[1] The latest NCA (2018) is available at the following site: https://nca2018.globalchange.gov. Development of the Fifth NCA is currently underway, with anticipated delivery in 2023.

[2] The RCPs and associated model results from the Climate Model Intercomparison Project Phase 5 (CMIP5) are used to support the NCA. CMIP is a standard experimental framework for studying and comparing the output of coupled atmosphere-ocean general circulation models. CMIP5 was, at the time of the NCA, the most current and extensive of the CMIPs. Since then, a new phase was organized, CMIP6 (Eyring et al., 2016), and a new set of future projections have been produced under *ScenarioMIP* (O'Neill et al., 2016, Tebaldi et al., 2021). Similar to the RCPs, CMIP model results have become standard reference inputs for virtually all work in the United States and internationally concerning climate change science, impacts, vulnerability, adaptation, and mitigation.

[3] Radiative forcing is a measure of the influence that a factor, such as GHG emissions, has in changing the global balance of incoming and outgoing energy.

scenarios and tools for the entire U.S. coastline.[1] These scenarios are available for the period 2000–2100 at 10-year intervals and from 2100–2200 at a coarser temporal resolution.

2.2 Importance of climate scenarios to site-level planning

The NCA's use of scenarios underscores the importance of considering low-probability and high-consequence climate futures. In the past, the focus has been on average changes (e.g., in temperatures and precipitation) relative to a base year; however, it is the lower-probability outcomes (orange "very unlikely" areas in Figure 1) that often generate the largest impacts and can drive risk (Ackerman et al. 2010; USGCRP 2015). Thus, the NCA frames its findings by considering the most probable (blue "likely" areas in Figure 1), as well as more extreme future climate scenarios, and assesses the degree to which the available literature addresses both.

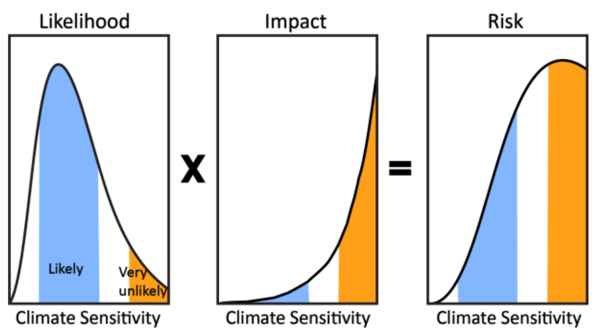

Figure 1. Schema of climate-related risk, showing the differences in likelihood and impact of different climate scenarios for a range of climate sensitivity. Event likelihood multiplied by Impact produces Risk. Lower likelihood events (orange) can have the highest risk if the corresponding impact is high enough. After Spratt and Dunlop 2019.

NCA authors applied the framing of a lower radiative forcing scenario (RCP 4.5) and higher radiative forcing scenario (RCP 8.5) to provide a range of future scenarios to illustrate possible climate change impacts across different sectors and U.S. regions. Site energy and water managers can use these findings to identify key climate hazards for their region. In the northeastern United States, for example, the NCA reports that the largest threats are from precipitation and flooding. Figure 2 shows the projected change in the number of days with heavy precipitation for Charleston, South Carolina under RCP 4.5 and RCP 8.5.

[1] These scenarios were developed by the Federal Interagency Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Task Force, a joint task force of the National Ocean Council and USGCRP, to support coastal preparedness planning and risk management processes. For more information, please see: https://scenarios.globalchange.gov/sea-level-rise.

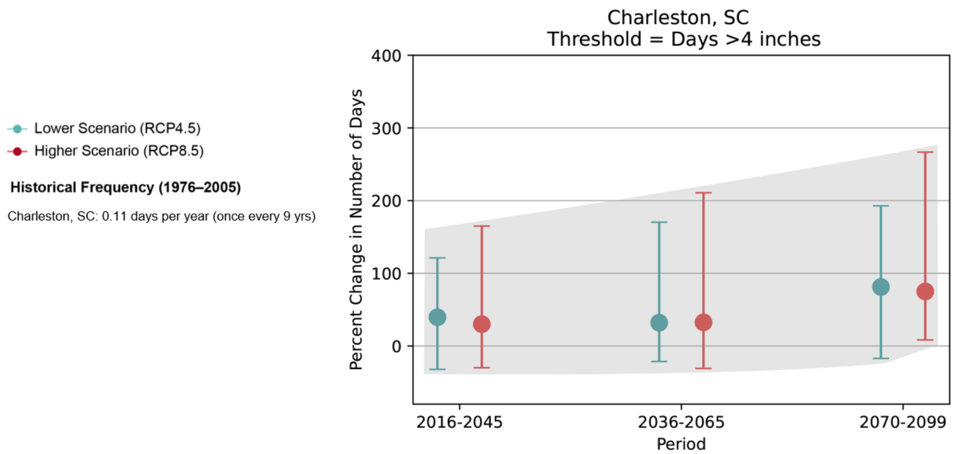

Figure 2. Climate change scenarios can help bound potential future climate exposures. This example from Charleston, South Carolina shows the change in the projected number of days with heavy precipitation. After NCA 2018.

3.0 Incorporating climate change into resilience planning

Incorporating these scenarios into site-level plans involves considering hazards that a site is exposed to as well as how those hazards may impact a site. These two considerations can help to drive decisions about the appropriate resilience measures to implement. These decisions can be supported by following a risk-informed resilience planning process.

3.1 Risk-informed resilience planning

Risk-informed resilience planning processes incorporate elements of risk analysis to help facilities identify 1) hazards that are likely to impact their site, 2) vulnerabilities that could prevent the site from performing its mission(s) in the event of a realized hazard, and 3) consequences that the site will bear if the hazard occurs and existing or proposed mitigation measures are unsuccessful. To assess potential impacts of climate change, it is important to incorporate scenarios as described above into risk-informed resilience planning.

Risk-informed resilience planning processes, such as FEMP's Technical Resilience Navigator (TRN), require hazard data to be included as a quantified annual frequency in order to include the likelihood of the natural hazard occurring at a site's location. Hazards are often quantified using historical data to estimate annual frequencies because this is the most reliable data source on a relatively local scale. However, climate change is expected to continue producing higher average temperatures as well as changes in precipitation in most of the United States. These changes, as well as other factors, are likely to change historical patterns of some natural hazards (Table 1). Therefore, climate change could change the frequencies of natural hazards in the future, potentially leading to overestimates or underestimates of the risk for analyses relying on historical hazard data. Thus, while risk analysis often incorporates hazard information based on historical patterns, incorporation of climate change into the analysis requires the use of future projections. However, it is important to keep in mind that projections cannot be used to predict the precise occurrence in space and time of individual events impacted by climate change.

There is significant uncertainty associated with how climate change will impact hazard occurrence. This is a result of uncertainty about which RCP best represents the future, inherent variability of the climate system, and uncertainty in the models used to understand future climate change. The impacts of climate change are best incorporated into a risk analysis by conducting multiple analyses incorporating different climate scenarios to test the sensitivity of the resulting risk to different possible futures.

Table 1. Observed and projected impacts of climate change on natural hazards based on the NCA 4. Specific impacts vary across regions of the United States and these regional impacts should be considered when incorporating climate change considerations into a resilience planning process. Note that, though hazards such as strong winds, lightning, and ice storms may change in the future as a result of climate change, current global and regional climate models do not have the required resolution to reliably project these changes. The confidence level associated with each hazard indicates the degree of confidence in these projections. The confidence level describes "the validity of a finding based on the type, amount, quality, strength, and consistency of evidence (such as mechanistic understanding, theory, data, models, and expert judgment); the skill, range, and consistency of model projections; and the degree of agreement within the body of literature" (NCA 4, Volume I).

Natural Hazard	Changes in Climate Phenomena	Confidence Level
Coastal flooding	Current trend of increasing frequency, flood depth, and extent expected to continue in locations that are projected to experience significant sea level rise	Very high
Cold wave	Projected to become less intense	Very high
Drought	Increasing temperature and changes in snowfall patterns likely to cause greater frequencies and magnitudes of drought	Very high
Hail	Observed increase in number of days per year with hail likely to continue	Low
Heat wave	Projected to become more intense	Very high
Hurricane	Minimal change in frequency of hurricanes that make landfall projected, though intensity and precipitation rate expected to increase for most severe hurricanes (i.e. Category 4–5 hurricanes expected to become more extreme)	Medium
Riverine flooding	Regions with increased precipitation likely to have increased flooding, though exact frequency and magnitude patterns vary regionally.	Medium
Tornado	Observed decrease in number of days per year with tornadoes, but an increase in number of tornadoes on those days	Medium
Wildfire	Observed increase in large fires in 7 out of 10 ecoregions in the western U.S.	Medium
Winter weather	Observed trends in winter weather vary regionally. Frequency of large snowfall years has decreased in the southern U.S. and Pacific NW, but increased in the northern U.S.	Low

Due to locally variable weather and climate patterns, it is important to consider anticipated trends in hazards on a regional scale, such as that discussed in the NCA. However, attempts to analyze changes at these finer geographic scales (e.g., in regional climate models) lead to projections with additional uncertainty. In spite of these challenges, it is important to consider climate change at the scale most relevant to a site (i.e., regional; Figure 3) because this is the scale relevant for designing and implementing resilience measures. One way to consider the uncertainty of regional climate models in site-level resilience planning is to conduct the analysis based upon a range of climate scenarios as described above.

3.2 Implementing climate scenarios in resilience sensitivity analysis

One approach for incorporating potential climate change-related impacts on natural hazards into a resilience analysis is to conduct a sensitivity analysis (i.e., comparing results from multiple analyses based on different assumptions about climate impacts in the future). For a risk-informed process, the sensitivity analysis can involve conducting a preliminary risk analysis with best estimate hazard values based on historical data. This analysis can then be compared with subsequent analyses that use hazard values based on different potential climate change scenarios. For an approach like the TRN, which is focused on energy and water resilience, climate change impacts to natural hazards can be captured by adjusting the impact that might be caused by the hazard (outage duration is used to quantify impact in the TRN) and/or the frequency of the hazard. Note that changes in projected intensity and frequency of natural hazards can vary significantly across regions of the United States. Changes to hazard characterization should, therefore, be driven by regional projections of hazard characteristics under different climate scenarios. Insights from comparing results of risk analyses based on different climate scenarios may lead to a range of possible adaptation measures that address a spectrum of potential futures. Some of these solutions that are targeted towards more extreme climate scenarios may be more expensive and difficult to implement. Adaptive planning allows decision makers to address the most probable future scenarios while remaining flexible and capable of updating solutions as additional information is gained (Marchau et al. 2019). In order to implement this approach, adaptation plans should involve monitoring programs with planned decision points which allow for updates based on observations that further constrain trends in the hazards to which a site is exposed.

Incorporating Climate Change in the TRN

In the TRN, hazards are characterized based on their frequency and the duration of an outage that the hazard could cause to energy and water systems. For a best estimate risk assessment, these characteristics can be estimated based on historical data.

To incorporate a climate scenario into a TRN analysis, the climate change impact can be incorporated through sensitivity analysis using either hazard characteristic (frequency or outage duration). For example, if the site expects to see an increase in the frequency of riverine floods, but not more intense floods, it could change only the frequency value associated with the riverine flooding hazard. Alternatively, if the site is considering hurricane hazards and expects to experience more intense hurricanes yet expects to experience a similar overall frequency of hurricanes, it could change only the outage durations associated with the hurricane hazard. Note that in some cases, it may be appropriate to change both variables: frequency and outage duration.

The risk calculated in the sensitivity analysis based on the climate scenario can then be compared to the best estimate risk and to any other climate scenarios.

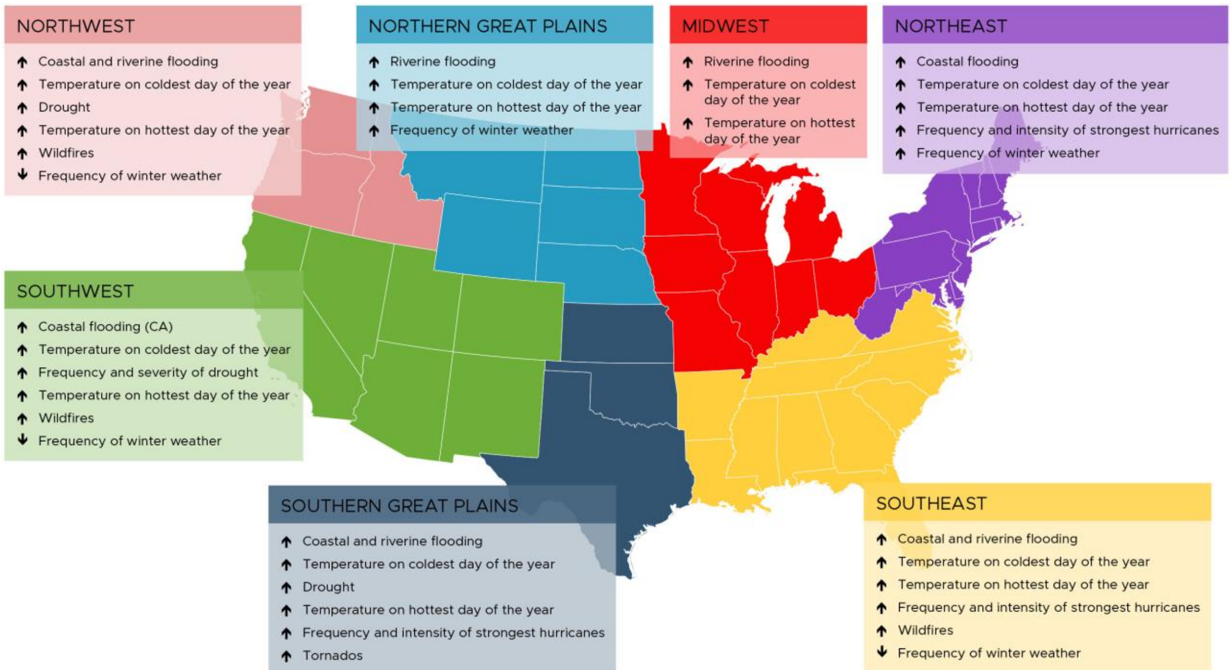

Figure 3. Map of the contiguous United States with projected regional climate change hazards, based on analysis in the NCA 2018. The NCA also provides projected climate change hazards for Alaska and Arctic and Hawaii and the Pacific Islands.

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