Grounding Climate Risk Decisions: Physical Climate Risk Assessment Scientific Foundation and Guidance for Companies

Initial Key Company-Level Insights, Technical Principles, and Technical Issues

Introduction

The climate is changing and society needs to assess and plan for it. The world has warmed on average and some level of additional global average warming is unavoidable. Changes are observed locally as well, with more complex dynamics as both climate change and other factors contribute to the local changes observed and possible in the future. With a changing climate comes the potential for new physical conditions for society, with possible changes in weather variability, patterns, and extremes, and related conditions, such as sea-levels and stream flows.

Natural condition variability and extremes are nothing new for private and public decision-makers and planners. Technologies, systems, and markets are already designed to consider conditions such as extreme heat and cold, flooding, drought, wildfires, ice, and hurricanes. However, with a changing climate there is the potential for new natural physical conditions—with the possibility of changes to the intensity, frequency, duration, variability, and the geographic extent of the areas affected.

With the climate changing, it is prudent to assess the potential physical changes and the resulting implications, risk, and risk management options. However, this is a complex and challenging task that requires knowledge and utilization of different scientific disciplines, technical resources, and tools. It also requires development of new capabilities and advances in science to inform company- and system-level applications. For many who are interested in assessing the physical risks of climate change, this is a new topic and there is an overall lack of familiarity with, and common understanding of, the science, how to use it, and what is associated with appropriate physical climate risk assessment and management. This is especially true for assessing and managing the physical climate risks for individual companies, communities, and systems.

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EPRI has begun developing a technical resource and guidance for companies, communities, and stakeholders and for educating based on assessment of the science associated with understanding the relationship between physical climate change and a company, community, or system (Figure 1). This document is a summary of insights from our initial analysis. This publication shares our set of initial findings for discussion and to facilitate dialogue. This set of initial insights highlights important concepts and messages that are emerging from the study, with the full report expected to be published in early 2023.

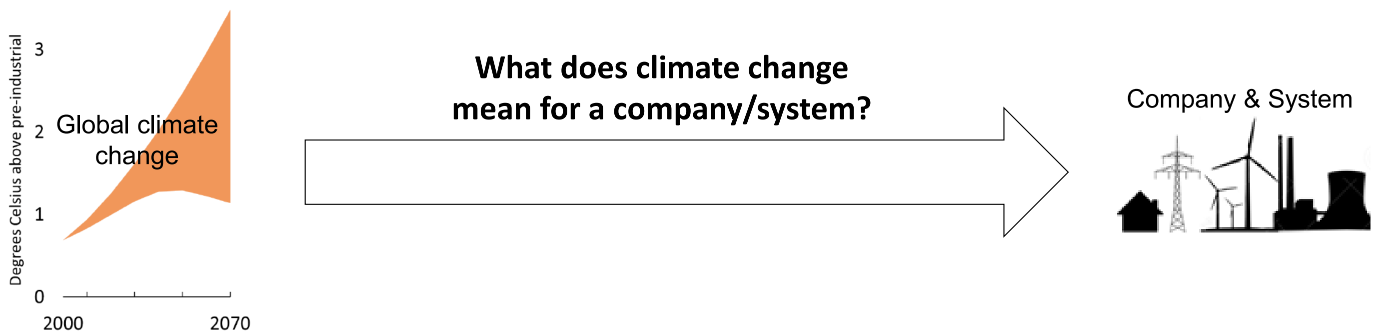

Figure 1. What do physical changes in the climate mean for a company or system?

The overall study's objective is to inform dialogue regarding the science and to provide conceptual guidance for the design of local physical climate risk assessments. The primary audiences for this study are stakeholders and companies, with the content designed to educate and facilitate informed external and internal dialogues.

The report is organized into eight sections—an introduction followed by analyses and discussions associated with the topics listed below.

- Section 2: Conceptual framing for physical climate risk assessment and decision-making
- Section 3: Defining information requirements
- Section 4: Assessing the climate change hazard
- Section 5: Assessing exposure to the hazard
- Section 6: Assessing vulnerability and response options – potential impacts from the hazard and exposure
- Section 7: Assessing risks and identifying robust and resilient risk management strategies
- Section 8: Metrics

For each of the topics, we are characterizing and assessing the relevant science and deriving key company-level insights and technical principles for physical climate risk assessment, and identifying technical issues that need to be considered (Figure 2):

- **Key company-level insights** are technical insights for company- and system-level decision-makers derived from the science related to each section. These represent important learnings that inform physical climate risk assessment and internal and external stakeholder expectations regarding appropriate physical risk assessment, management, and communications, as well as potential sources of differences in risks and strategies between companies and systems.
- **Technical principles** are technical guidance for company- and system-level physical climate risk assessments based on EPRI's technical observations and company insights derived from assessment of the science associated with each section. These represent technical considerations and steps that are essential for developing an appropriate and meaningful company physical climate risk assessment and risk management strategy and for informative and grounded company communications and disclosure.
- **Technical issues** are issues we have identified associated with using the information and science related to each section. It is important for companies to be aware of these issues and to consider them when designing and executing each assessment.

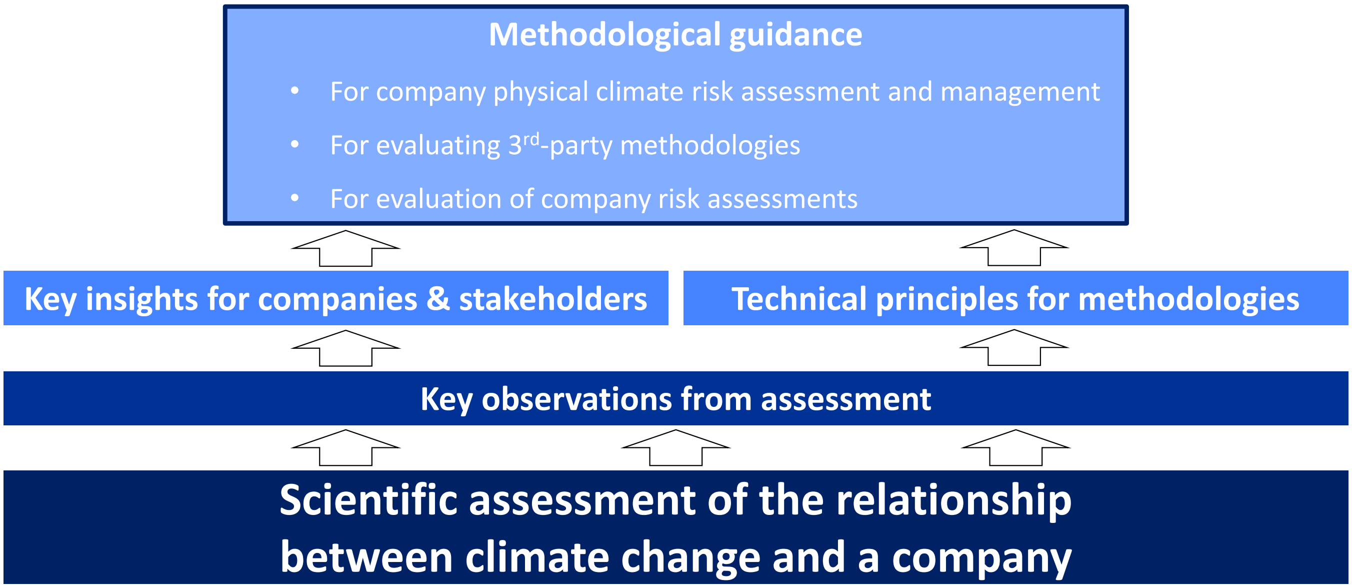

Figure 2. This study's approach starts from the "ground up"—deriving insights, technical principles, and methodological guidance from a foundation of scientific assessment

The full report will provide graphics (tables and figures) and examples to communicate assessment findings, illustrate issues and insights, and support the derived guidance. The result will be a technical foundation for company and system physical climate risk assessment grounded in scientific evaluation. The study's focus is assessing and translating the science for electric power physical climate risk assessment applications. However, many of the insights and guidance generalize and are applicable and transferable to other companies and systems (e.g., natural gas), other sectors (e.g., industry, finance), as well as local communities.

EPRI is a non-advocacy, nonprofit, scientific research organization with a public benefit mandate. EPRI strives to advance knowledge and facilitate informed discussion and decision-making. EPRI has over five decades of recognized expertise in, among other things, climate scenarios, climate-related risk assessment, energy and societal transitions, climate impacts, policy evaluation, energy supply, delivery, end use technologies, and sustainability. This includes EPRI's research community leadership and participation in related activities, such as research community studies, the Intergovernmental Panel on Climate Change (IPCC), U.S. National Climate Assessment (NCA), the Task Force on Climate-Related Financial Disclosures (TCFD) Advisory Group for Scenario Guidance, and the National Academies of Sciences, Engineering and Medicine. Furthermore, EPRI's climate-related risk research and technical resources and guidance to date have already been informing and educating companies and stakeholders (e.g., Alliant Energy, 2022; WEC Energy, 2022; Taber and Rose, 2022; EPRI, 2022; OG&E, 2021; Ameren, 2021; Duke Energy, 2020; Allete, 2020; Entergy, 2019; WEC Energy, 2019; FirstEnergy, 2019; Xcel, 2019; EPRI, 2020; TCFD, 2020).

This work complements EPRI's previous climate-related low carbon transition risk and greenhouse gas goal setting technical resources and guidance, which similarly derived company insights and technical principles and guidance from assessing the relevant science (e.g., Rose and Scott, 2018, 2020). It also motivates, informs, and provides a conceptual foundation for the research and coordination needed to develop the detailed data and analyses capabilities and guidance for on-the-ground physical climate risk assessment, which is the goal of EPRI's Climate Resilience and Adaptation Initiative (Climate READi). Finally, this study informs future climate-related risk conversations, methodologies, assessments, reports, communications, and disclosure guidance and rulemakings.

Before presenting company key insights, technical principles, and technical issues, we present a conceptual framing for physical climate risk assessment and decision-making.

Conceptual framing for physical climate risk assessment and decision-making

It is helpful to begin with a very basic question: What is the relationship between physical climate change and a company (Figure 1)? While the question is simple, it is complex to answer. Not only do we need to define what we mean by climate change and understand if and how the climate is changing, we need to evaluate if, how, and when those changes might matter for the company and what the company might do about it.

Physical climate risk assessment is much more than simply knowing whether the climate is changing or could change. A set of assessments—information needs, hazard, exposure, vulnerability and response, and risk and risk management—is required to assess risk and develop risk management strategies (Figure 3). A hazard assessment evaluates whether the physical climate (hazard) is changing. An exposure assessment identifies what might be in harm's way and exposed to those physical changes. A vulnerability and response assessment evaluates the implications and whether the exposure to the physical changes matters and identifies options for managing the implications. And a risk and risk management assessment evaluates if the risks are large, considering likelihood and the magnitude of the implications, and identifies a robust and resilient risk management strategy. It all begins, however, with defining application information requirements—variables and metrics defined by decision objectives and thresholds.

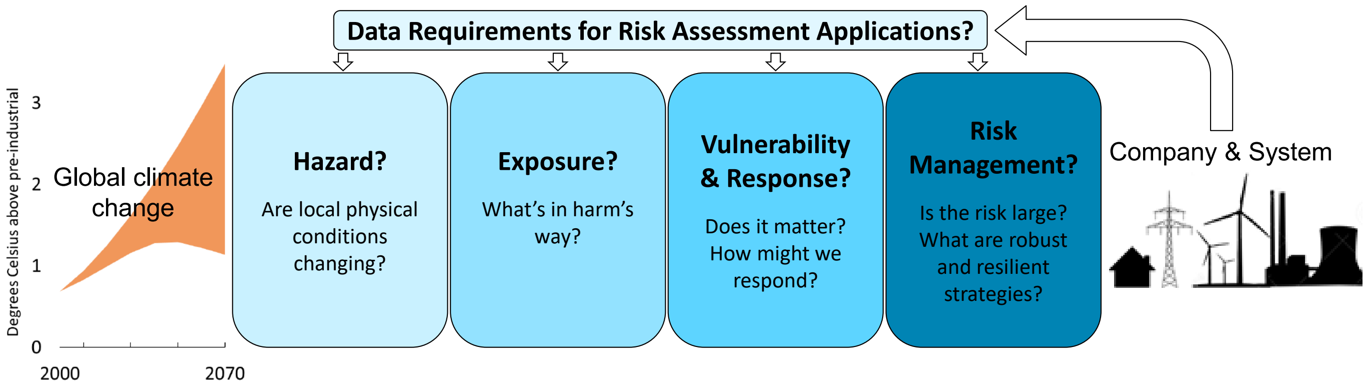

Figure 3. The set of assessments needed to evaluate the risk of physical climate change for a company or system

Thus, before starting hazard discussions and assessment, it is necessary to define the scope of the applications, input data requirements, and meaningful output metrics. Fit for purpose information and metrics are needed based on requirements and capabilities. Given the different types of assessments associated with assessing physical climate risk, different categories of metrics are needed: physical (for example, temperature, precipitation, extreme weather, and extreme events), operational (outages, performance), power and natural gas market, and financial.

Physical climate risk assessment is often misunderstood as a simple hazard evaluation of whether the climate has or could change and/or exposure evaluation of what is affected. Risk, however, requires there to be implications—an expected consequence of the exposure. All five assessments are necessary for identifying whether there is risk, developing a strategy for managing the risk, and communicating the robustness of that strategy. Not until the risk and risk management assessment is completed do companies know whether current operations, designs, and strategies are sufficient for a changing climate or need to be revised. Together, the assessments identify potential climates, societies, markets, systems, system elements, responses, and risks to consider. From there, an assessment also identifies a set of risk management options. The assessments need not be a linear sequence as shown in Figure 3. Depending on circumstances, such as where a company is in its current processes, there could be a different entry point. Nonetheless, each of the assessments will be needed in some form. Furthermore, in practice, the assessments are iterative in nature with each informing the others—with potential inputs, or other motivations for revisions.

Uncertainty is what makes this a risk issue. If we know with certainty what will happen, we can plan for it without any risk of being wrong. However, when we do not know what will happen, we must contend with the possibility of being wrong and manage the risk. Risk, by definition, entails considering uncertainty and the consequences and probabilities of potential outcomes. Risk assessment, therefore, is an evaluation of the implications and likelihood of uncertain conditions and potential responses, while risk management is a strategy for managing the risk of being wrong that takes into account risk preferences and objectives. A strategy for today is robust if it is appropriate given the future possibilities and regardless of the outcome revealed. Meanwhile, a resilient strategy is one that can successfully respond in all possible futures.

A formal physical climate risk assessment is a substantial undertaking. It entails development and assessment of high-resolution, comprehensive, tailored hazard and exposure data as well as execution of individual system element and energy system modeling for vulnerability and response analyses.

Each assessment has its own questions, science, data, modeling, constraints, and metrics, and must consider historical, current, and potential future conditions. Planning horizon is also an important factor, with companies needing to choose a horizon relevant to their investment decisions today.

Also, tiers of risk assessment analyses can be valuable—from individual system element (e.g., equipment components, assets, service demands), to system, service territory, and beyond service territory (e.g., market, water shed) assessments (Figure 4). Each tier has to implement the set of Figure 3 assessments but with different scope: each with its own objectives and data requirements, and each identifying different levels and types of potential risks and response options. For example, an asset assessment would identify potential performance and failure risks and risk management opportunities for an individual system element, while a system assessment would identify systemwide reliability or resilience risks and risk management opportunities across assets that could help manage operational risk and asset level performance and failure risks.

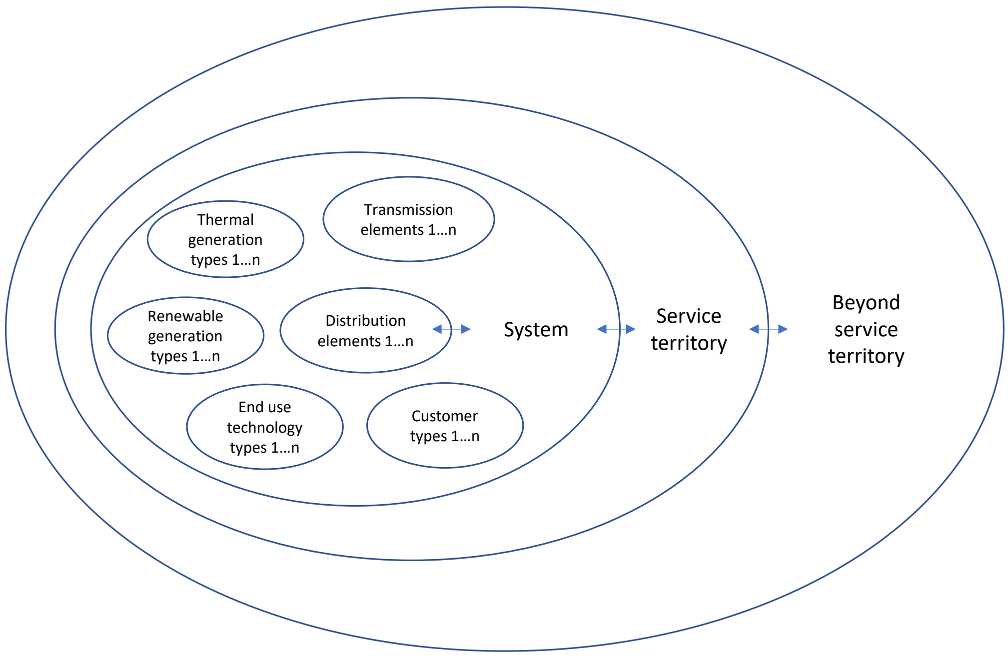

Figure 4. Tiers of potential physical climate change risk assessment

Initial key company-level insights, technical principles, and technical issues

Below we have collated and summarized the key company-level insights, technical principles, and technical issues derived from our initial assessment of the relevant science associated with each topic.

Conceptual framing for physical climate risk assessment and decision-making (Section 2)

Key company-level insights

The following are technical insights related to overall assessment framing and design:

- Physical climate risk assessment requires a set of assessments – Physical climate risk assessment is much more than knowing whether the climate is changing or could be changing. A set of assessments is required—assessing company information requirements, changes in the physical climate hazard, exposure to the hazard, vulnerability and response options for the exposure, and risks and risk management for the vulnerability.
- Each assessment has different analytical needs – Each assessment in the sequence has its own analytical needs – data and modeling for evaluating historical changes, current conditions and trends, future changes, and risk management options.
- Tiers of physical risk assessment analyses are valuable – Undertaking physical climate risk assessments at different scales is valuable for identifying different potential risks and response and risk management options, with system element (components, assets, and end-use), system, service territory, and beyond service territory assessments possible and helpful. Like assessment types, each tier, as well as category and subcategory (e.g., nuclear generation as a category with different types of nuclear generators or different components of a nuclear power plant as subcategories) within a tier, has its own operational and risk management objectives and data and modeling analysis requirements.

- Assessment begins with identifying company information requirements – To develop a company-relevant assessment, company-specific information requirements need to be articulated, including inventorying assessment applications (tiers and categories); and, for each, defining decision objectives, identifying decision-relevant climate variables and thresholds, and determining meaningful input data and output metrics for each company. Company data requirements can vary between companies due to differences in, among other things, location, assets, systems, markets, local policies, business models, and risk criteria.
- Meaningful, fit for purpose, metrics needed – Meaningful physical climate risk assessment requires metrics tailored to company decision-making information requirements, with different metrics appropriate for each type, tier, and category of assessment. Existing climate and other data do not automatically provide the information needed by individual companies and systems. Meaningful metrics must also reflect current analytical capability, considering the strengths and weakness of available data and modeling for the different types of data and variables.

Technical principles

The following are technical principles and guidance for overall assessment:

- Develop a climate risk assessment culture and capability internally to facilitate discussion, engagement, assessment, and risk management.
- Educate internal and external stakeholders for informed and scientifically grounded dialogue, assessment, and risk management.
- Plan for the set of assessments—information requirements, hazard, exposure, vulnerability and response, risk and risk management—and tiers of assessments.
- Initiate a process, first developing foundational technical resources (e.g., framework, data, qualitative insights) that facilitate more detailed analyses and a roadmap for working through the set of assessments, progressively building knowledge and capability within and across assessments, and providing constructive insights along the way.

Defining information requirements (Section 3)

Key company-level insights

The following are technical insights related to defining information requirements for physical climate risk assessment:

- Climate data is needed to evaluate physical risk for most power system elements (components, assets, and end-use):
  - Climate change—changes in average trends and extreme weather—can impact many system elements of a company's business, e.g., generation assets, transmission and distribution assets, demand, and fuel supply (Table 1).
  - Some climate hazards could impact multiple elements simultaneously.
  - Individual elements and systems can be affected by multiple hazards simultaneously or sequentially.
  - Potential adaptation responses are specific to each combination of climate hazard and system element. Adaptation responses can have impacts on elements other than those to which they are applied.
- System and other broader climate data application requirements are informed by system element information assessment and integrated systems information assessment:
  - System element or individual asset information requirements and types of impacts for assessment can be aggregated to help identify system, service territory, and beyond service territory physical climate touch points, impacts analysis scope, and data requirements (Table 1).
  - Integrated system-level analysis applications (e.g., load forecasting, resource adequacy, capacity planning, transmission planning, service territory, energy system, market) help identify a broader set of potential simultaneous impacts, linkages, and adaptation strategies and their information requirements.
- Tailored data is needed:
  - There is a need to identify specific decision-relevant metrics for each company. Typically, this is not the type of information published, for example, by the Intergovernmental Panel on Climate Change, national assessments, or sub-national assessments. However, much of the information and metrics needed can be custom developed from available climate data (historical and projected), keeping in mind data limitations (e.g., data quality, spatial and temporal resolution, modeling skill).
  - Developing the required data entails working through the identified technical issues—recognizing the many physical environment touch points, specifying climate input data requirements by developing an application inventory, including tiers and categories of applications (Figure 4) that differentiate today from the future, and that defines impact/vulnerability metrics per application.

Table 1. High-level example of system element and overall system applications and relationships to climate variable categories. Source: EPRI.

	Average air temp.	Extreme heat	Extreme cold	Air humidity	Average precip.	Extreme precip.	Floods	Surface water temp.	Stream flow	Drought	Average wind speed	Severe wind storms	Severe ice storms	Wildfires	Sea level rise
Thermal power	X	X	X	X		X	X	X	X	X	X	X		X	X
Wind power		X	X								X	X	X	X	
Solar power	X	X				X	X					X		X	X
Hydro power	X	X			X	X	X		X	X		X		X	
Battery storage	X	X	X	X		X	X					X		X	X
Electrolysis		X	X			X	X	X	X	X		X		X	X
Electricity demand	X	X	X	X											
Transmission Towers and Lines	X	X									X	X	X	X	
Transmission Substations		X					X					X	X	X	X
Distribution Substations		X				X	X					X	X	X	X
Distribution Poles & conductors		X		X	X	X	X					X	X	X	X
Distribution Transformers		X		X	X	X	X					X	X	X	X
System Planning & Operation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Technical principles

The following are technical principles and guidance for defining information requirements:

- Identify information requirements independent and irrespective of data availability to inform data development and the identification of research gaps.
- Identify information requirements for current and potential future applications.
- Consider defining different tiers, categories, and subcategories of applications (e.g., Figure 4).
- For each application, identify decision relevant environment and other variables and specific metrics.
- As possible, develop the data required for the metrics needed, evaluate and recognize data limitations, including whether and how uncertainty is captured.
- Ensure that the implications of any data limitations, uncertainties, or gaps are understood in the context of resulting decisions.

Technical Issues

The following are important technical issues when assessing climate data information requirements:

- Many physical environment touch points – System design and climate impacts analyses reveal that there are many climate change touch points on the power sector and broader energy system (Table 1). These are direct points of contact between the physical environment and individual power and energy system supply or demand elements. As such, each of these touch points represents avenues by which climate change could affect power and energy system operations and costs; and, therefore, they represent points of potential physical climate risk to assess.
- Climate data requirements – It is important for companies to identify the specific climate data needed for physical risk assessments independent from the data that are currently available. Doing so will define company data requirements that will guide the development of metrics tailored to company need and fit for purpose. Defining company data requirements includes accounting for decision-making objectives, decision thresholds (e.g., extreme heat temperature), and probabilistic information needs. Identifying company climate data requirements will also facilitate identification of data gaps and research priorities.

- Developing an application inventory – Developing an inventory of assessment applications is a tractable approach for identifying climate data requirements. In doing so, the following are important considerations:
  - Defining applications: Deciding how to define and differentiate types of individual applications affected by natural conditions, such as types of power supply assets (generation resource types, elements of transmission, elements of distribution), types of power system modeling assessments (e.g., load forecasting, resource adequacy, capacity expansion), and types of electricity demand elements (e.g., hourly load, end-use technologies).
  - Facilitating tiers of analyses (Figure 4): There are potential tiers of analyses of interest, each with different data requirements—from asset level analysis, to system, service territory, and beyond the service territory analyses (e.g., input and output markets, watersheds, communities), and different operational/production perspectives (e.g., unit versus service outage).
  - Differentiating today from the future: For each application type, it is helpful to differentiate today from the future, identifying data requirements for current electricity system assets, systems, and markets separate from requirements for potential future assets, systems, and markets.
  - Facilitating end point and climate event assessment perspectives: It is helpful to develop an application inventory structure that recognizes assessment and data needs in terms of (1) potential affected system element end points, such as power supply assets or demand elements, as well as (2) physical climate events, such as potential drought or storm impacts on power system elements and operations.
- Defining impact/vulnerability metrics – The process of developing an application inventory and identifying data requirements can also yield information regarding meaningful climate impact, or vulnerability, metrics for each application, including vulnerability metrics for individual asset climate risk assessments to larger applications, such as supporting integration infrastructure, system, or market climate risk assessments.

Assessing the climate change hazard (Section 4)

Key company-level insights

The following are technical insights related to assessing physical climate changes:

- Global climate change has occurred, is occurring, and more is to be expected.
- The human contribution to climate change is evident at aggregate scales—global and continental. At higher resolutions, the climate signal is less prominent due to local dynamics and non-climate factors.
- There are different types of climate data, with different strengths and weaknesses, that present different physical climate risk assessment opportunities (Table 2).
- There are different types of physical changes associated with climate change—changes in trends, frequency, duration, intensity, seasonality, variability, and the extent of area affected.
- Understanding of climate change and climate change projection capability varies by variable, location, resolution, and time dimension.
- Climate and non-climate factors are drivers in observed local physical environment changes (e.g., wildfires, flooding).
- There are different kinds of physical climate uncertainty and only a portion is currently being captured and characterized:
  - Projected global climates are not equally likely and some are implausible (Figure 5). Assessment of global emissions scenarios finds that some are implausible (e.g., RCP8.5, SSPx-8.5, RCP2.6, SSPx-2.6, SSPx-1.9) and planning for global average temperatures greater than 2°C and less than 4°C is pragmatic.
  - Not all climate change response uncertainty for a given future global emissions pathway is being captured by current global climate projections information and what is available may not be what is sought for company assessments.
  - Given the nature of climate projections data, medians and ranges—minimum and maximum values—from multiple models (i.e., ensembles) or variants from a single model are appropriate when utilizing multiple global climate projections..
- The physical climate change hazard is company-specific, varying by location and company requirements. To effectively inform company decision-objectives and exposure, vulnerability and response, and risk and risk management analyses, as well as communications, each company will need to make hazard assessment choices regarding types of climate data, global climate projections, climate models, climate variables and metrics, data resolution, and specific assessment locations.

Table 2. Key sources for historical and projected climate data. Source: EPRI.

	Historical			Future				
Data	Direct observations (e.g., in situ and satellite observations)	Gridded reanalysis	Historical climate model simulations	Weather forecasts	Climate forecasts	Extrapolated historical trends	Global climate projections	Downscaled climate projections
Sources	NOAA / National Weather Service	e.g., MERRA2, ERA5, ERA5-Land	CMIP6 e.g., ISI-MIP bias-corrected historical runs	NOAA / National Weather Service, private companies	e.g., NOAA Climate Forecast System (CFS), ECMWF S5	Any historical dataset with long enough records	CMIP6 model projections from Earth System Grid Federation (ESGF), AWS registry of open data, NASA Earth Exchange, etc.	e.g., LOCA, LOCA2, NA-CORDEX, cal-adapt.org
Spatial Coverage	Global. Best coverage in Europe and North America.	Global	Global	Global, regional (Europe), & country level (US)	Global	Where historical data is available	Global	Regional, local
Spatial Resolution	Point location	9 km – 54 km grid cell	11 km – 110 km grid cell	Point location	54 km – 110 km grid cell	Resolution of historical data	~50 km grid cell	~6 – 9 km grid cell
Temporal Coverage	1880s – present (satellites since 1980)	1950 – present	1851 – Present	Present – ~2 weeks	~2 weeks – 3 months	Fills gap between seasonal forecasts and climate projections (up to 10 years)	Present – 2100	Present – 2100
Temporal Resolution	Hourly/Daily	Hourly/Daily	Daily	15-Minute to Daily	Weekly/ Monthly	Daily to Yearly	Daily	Daily

** Multi-decadal averages are appropriate to compute and use to capture climate related dynamics (see text discussion).*

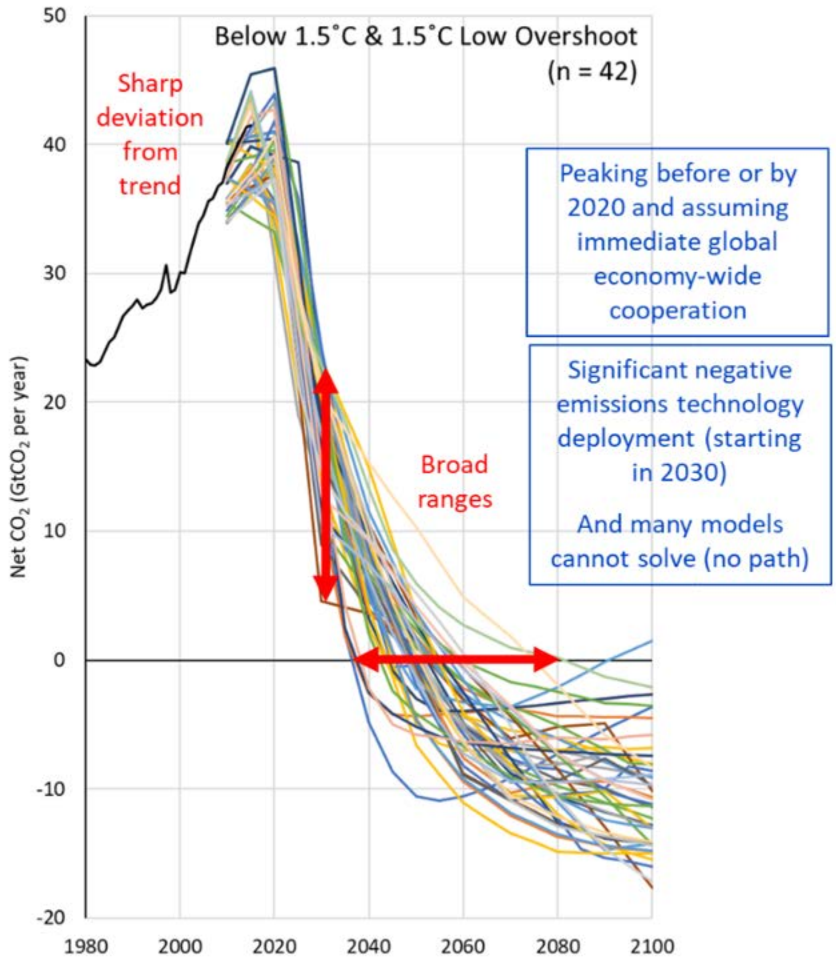

Figure 5. 1.5˚C global CO_2 emissions pathways, including SSPx-1.9, found to be implausible as they assume immediate global economy-wide policies and cooperation to reduce emissions and global net and energy CO_2 emissions peaking before or by 2020. Furthermore, many models cannot solve, and for those that can, the pathways assume highly optimistic energy system transformations and technology deployments. Similar plausibility issues are found with 2˚C global emissions pathways, including RCP2.6 and SSPx-2.6. Source: Rose and Scott (2018, 2020)

Technical principles

The following are technical principles and guidance for assessing physical climate changes:

- Hazard assessment needs to be company-specific – recognizing company context (current and future) and decision criteria.
- Companies need to know what data they require and hazard information objectives.
- Evaluate whether a climate variable has or will change, not whether an asset is at risk. The latter is evaluated in subsequent assessments (Section 5).
- Know your climate data options – there is more than one type and can be more than one option per a type (Table 2).
- Evaluate data relative to application needs and objectives – consider data type, variables and metrics, location, resolution, time horizon and periods, and uncertainty representation.
- Develop the data needed and possible – make data choices based on company applications, recognizing the identified technical issues and company insights, understanding the uncertainty captured and limitations (e.g., scientific understanding and modeling skill, the role of non-climate factors).
- Use the data appropriately recognizing uncertainty representation and limitations.
- Communicate on the data to educate stakeholders and to justify data choices and how data are being used.

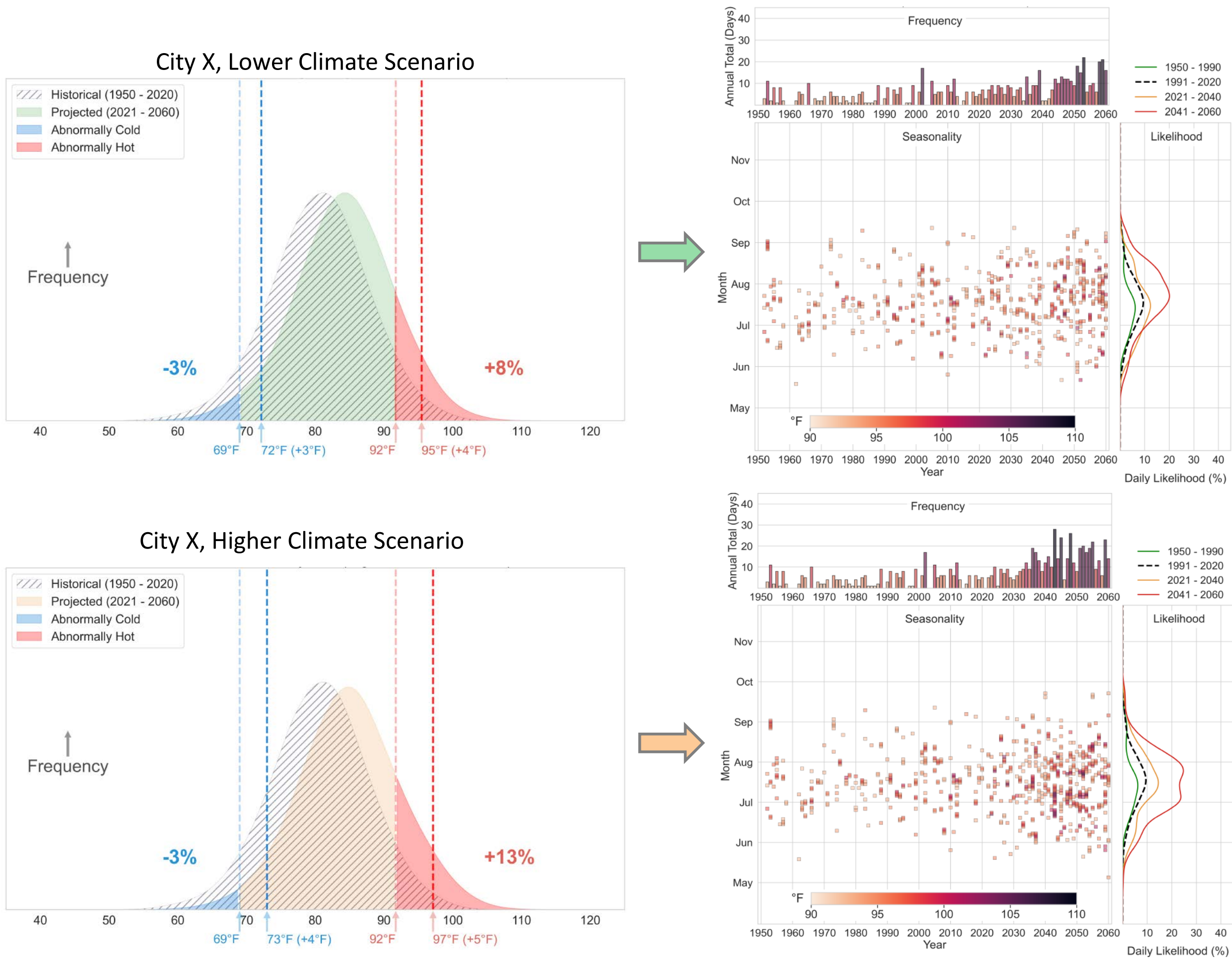

Figure 6. Left panels: An example real city's temperature distributions for the periods 1950-2020 and 2021-2060 for lower and higher projected climate change. Changes in extremes (5th and 95th percentiles) highlighted with blue (5th) and red (95th) shading. Right panels: frequency of extreme heat (top) from 1950 – 2060, the seasonality of extreme heat (main), and the likelihood of extreme heat by day of the year (right). Extreme heat defined in this example as 92 °F, which is the historical 95th percentile daily maximum value for this location. Source: Developed from EPRI's Climate Data Repository.

Technical issues

The following are important technical issues related to assessing physical climate changes:

- Different climate data – Climate data consist of more than global climate model projections (Table 2). Climate data include data for historical and future periods, with different kinds of data available for each. Historical data include direct observations, satellite reanalysis, and simulated historical climates, while future data include weather forecasts, climate forecasts, extrapolated historical trends, global climate projections, regional climate projections, and downscaled climate projections. The different kinds of data have different strengths and limitations, and data choice should be determined by application needs, including decision time horizon, which could suggest utilizing more than one kind of data.
- Different types of physical change – There are different types of potential physical changes and metrics to consider that could occur with climate change—with potential changes in trends, frequency, duration, intensity, seasonality, variability, and extent of area affected relevant to decision-making. See Figure 6 for an example for a city. Climate variable metrics can be designed to capture each and tailored for company purpose to company decision criteria.
- Decision-making data needs – Decision-making application needs, such as scope and objective, will impact the needed climate data types, specific metrics (e.g., extreme heat threshold), global emissions projections, climate model selection, and climate projection ensembles.
- Characterizing historical climate change – The ability to characterize historical climate change, for instance current versus past climates, will depend on data availability for the resolution sought and the type of data available (e.g., observations, reanalysis combining observations and short-run

forecast modeling, and/or historical simulation by climate models). Furthermore, understanding observed physical changes (e.g., wildfires, heavy precipitation, droughts) will also require understanding the role of non-climate versus climate drivers of change, where the former could be the primary driver of the observed physical changes but both are important information for managing current and future risks.

- Characterizing potential future climate change – There are a variety of technical considerations in developing and using localized climate data to evaluate future change:
  - Data options: Identifying and evaluating alternatives appropriate for needs.
  - Historical trends vs. projections: Historical trends, which can include observed climate change to date, can be more reliable for informing near-term decisions (e.g., 5 to 20-year horizons), while projections can be more reliable for longer time horizons. However, the historical time period used to compute a trend needs to be thoughtfully selected.
  - Multi-decadal annual averages: Climate change is a gradual and long-run dynamic and multi-decadal average results (e.g., 30- or 20-year averages) are effective for capturing climate-related physical changes over time.
  - Average projected results: Global circulation models (GCMs), sometimes referred to as global climate or earth system models, are designed to get global trends right on average, but not necessarily to get weather correct on a given day/year or location. Recent examples include the 2021 Pacific Northwest heat dome and the 2022 United Kingdom heat wave which had not been "projected" in the climate model archives to happen in the early 2020s. Some practical steps to overcome this can include putting larger spatial and temporal windows on the assessment of hazard (e.g., using average results from a 30-year window and/or treating events in neighboring regions as representative).
  - Global climate projection scenario selection: The likelihood of global climate projections is a function of the likelihood of the input global emissions scenarios as well as the climate response to an emissions scenario, and there is uncertainty associated with both.
    - Regarding the likelihood of input global emissions scenarios, some have been found to be implausible (RCP8.5, SSPx-8.5, RCP2.6, SSPx-2.6, SSPx-1.9), due to, for instance, inconsistency with observations and long-run dynamics and constraints or implausible assumptions (e.g., Rose and Scott, 2018, 2020; EPRI, 2021; Hausfather & Peters, 2020). See Figure 5 for an example. Decision-makers will need to decide which categories of global climate projections to use.
    - The climate change response to any given global emissions scenario is also uncertain due to uncertainty about short- and long-run global system dynamics (e.g., uncertainty regarding carbon cycle feedbacks), as well as sub-global dynamics, but they should be weighted by the likelihood of the emissions scenario. There are valid reasons to consider more extreme climate projections ranging from data availability to the desire to evaluate "worst-case" outcomes; however, the upper end of the range would be constrained by the likelihood of the emissions projections.
- Climate model and model variant (ensemble member) selection: Different models produce different results, and there are different results from the same model for different assumption variants. Need to consider (1) using results from alternative models to capture climate system response uncertainty due to modeling structure, (2) using results variants from individual climate models based on different parameter and input assumptions, and (3) the implications of model and variant selection on insights and communications. Data availability will constrain what is possible in terms of capturing physical climate change uncertainty. The objective, therefore, is to take advantage of the data available to capture the uncertainty as well as possible.
- Uncertainty represented and not: Currently available results only partially capture uncertainty. Need to understand the uncertainty captured and not captured by results from different models and different model variants, as well as different emissions futures.
- Distributional interpretation: Currently available global projection results are not random samples and represent limited variability. Within the databases, there is disproportionate representation of the models, with some models providing far more results than others, and limited and uncontrolled parameter uncertainty represented in the variants represented from individual models and across models. As a result, distributional shapes of outcomes cannot be inferred; and, results do not support statistical interpretations, such as identification of means, standard deviations, and percentiles. Ideally, models would be run probabilistically with uncertain inputs to generate climate change distributions. However, the computationally intensity of the complex climate models precludes this kind of analysis. Due to these constraints, we cannot readily identify more and less likely climate responses (i.e., distribution tails, outliers) and therefore need to consider the range of possibilities.
- Robustness of information: Need to identify results that are robust to alternative assumptions by assembling results from alternative models, parameters, and inputs.
- Model performance and accuracy: Models vary in their ability to simulate different metrics and locations and therefore it is important to evaluate model skill to simulate the historical record for the metrics and locations of interest.
- Other lines of evidence: As noted, projections are but one type of climate information. The different types of climate data represent other lines of evidence regarding climate change dynamics and can be utilized to evaluate and constrain projections. For instance, historical observations and modeling can be used to help constrain projected climate possibilities.
- Temporal and spatial resolution: To identify the appropriate resolution for metrics, need to consider how alternative resolutions (temporal and spatial) can impact results (e.g., wind averaging across larger spatial areas can decrease the perceived likelihood of low wind events at point locations).

- Time horizon and differentiating futures: The need to consider alternative climate scenario futures (e.g., RCPs, SSPs) is less important for shorter assessment time horizons (e.g., decades) because the climate system responds slowly to emissions changes, as well as the multi-decadal nature of climate system dynamics.
- Other possible futures: Climate scenario futures (e.g., RCPs, SSPs) are a finite set of climate futures driven by particular emissions and other forcing projections. There are many other plausible possibilities.
- Localizing the information that is available: Developing the climate data needed for assessing higher-resolution potential local changes requires considering additional modeling that downscales lower resolution results. This modeling comes with its own strengths, weaknesses, and uncertainty. In addition, utilizing other types of data should also be considered (e.g., observations, reanalysis, historical trends).
- Potential societal condition: Different possible societies, as represented by different populations, economies, and emissions, can be consistent with any potential future climate, which factors into local conditions and the assessments of exposure, vulnerability and responses, and risk and risk management.

Assessing exposure to the hazard (Section 5)

Key company-level insights

The following are technical insights related to assessing exposure to climate change:

- Exposure is not risk – Exposure assessment is an input to risk assessment, identifying where there may be a risk and further assessment is required. Treating exposure as risk can be very misleading (e.g., Moody's, SEC proposed rule). For instance, an asset or system exposed to natural disasters or to changes in extreme events due to climate change may already have a design or plan able to accommodate or otherwise address the change.
- Exposure is company-specific – Companies will have different exposure to a changing climate due to differences in local climate change, assets, systems connecting assets, markets, policies, and future possibilities.
- There are many types of potential exposure:
  - With many physical environment touch points and types of physical changes in the climate, there are many types of potential exposure to climate change.
  - There are exposure tiers and categories within tiers. Exposure to climate change can occur at system element, system, service territory, and beyond service territory (upstream input markets, downstream output markets, water shed, etc.) levels, as well as for different categories within levels, such as different types of generation and transmission assets.
  - It is helpful to separate exposure assessment into assessments of current and future exposure.
  - For assessment of future exposure, there are uncertainties to consider. In addition to climate change uncertainty, there is uncertainty about future policy and non-policy conditions, specific asset types, locations of assets and activity, and descriptions of assets (e.g., capacity). A company-specific scenario design that accounts for climate, policy, and non-policy uncertainties can be a helpful approach for characterizing future exposure.

Technical principles

The following are technical principles and guidance for assessing exposure to climate change:

- Exposure assessment needs to be company-specific – recognizing company context (current and future) and decision criteria.
- Companies need to identify climate change information requirements and relevant physical changes in climate.
- Evaluate exposure of current assets, systems, and markets.
- Evaluate exposure of future assets, systems, and markets:
  - Use a scenario analysis to evaluate plausible alternative potential exposures given uncertainties – a well-constructed company-specific scenario design can inform exposure assessment, as well as vulnerability and response, and risk characterization and management assessments.
    - Consider different future time periods,
    - Define types of company uncertainties and specify their representation,
    - Develop and analyze a company-tailored scenario design and consider company plans, and
    - Account for asset lifetimes and retirement schedules.

Technical issues

The following are important technical issues related to assessing exposure to physical climate change:

- Many touch points – As revealed by the information requirements assessment (Section 3), there are many points of contact between the natural environment and energy systems today and in the future. These represent the points of current and potential future exposure to a changing physical climate and therefore are essential to inventory and define.
- Climate information requirements – The process of identifying climate data requirements is crucial in determining current and future exposure, i.e., what might be in harm's way of climate change today and in the future. The data requirements process defines current and future applications and their relationship to climate variables and by doing so determines the applications exposed.
- Exposure assessment structure – There are concentric tiers of potential current and future exposure—asset, system, service territory, and beyond service territory. Characterizing tiers, as well as categories and sub-categories within tiers, provides a tractable and meaningful structure for evaluating exposure, as well as a framework for subsequent assessments of vulnerability and responses, and risk and risk management. The specific details of the tiers (e.g., technology categories, specific technology sub-categories, markets) could vary with current versus future perspectives.
- Characterizing potential future societal conditions – Future exposure will be a function of societal development, which is uncertain. Uncertain climate policy (e.g., stringency and design) and non-policy (e.g., technology, resources, markets) factors create uncertainty regarding future assets and their locations, the size and operation of future systems, future characteristics of customers, future markets, and future integration of systems and markets. Transition scenarios considering policy and non-policy uncertainties will be valuable in identifying potential future exposure possibilities, as well as subsequent vulnerabilities and responses, and risk and risk management strategies.
- Characterizing and communicating exposure – Care is needed when characterizing and communicating exposure insights because exposure does not equate to risk and it would be misleading to draw that conclusion. The implications of exposure should not be inferred. An asset, for instance, can be exposed to changes in hurricane intensity, but there may be no implications due to the asset's design. Exposure only indicates that something is or will be touched by a changing climate. The implications of exposure need to be evaluated in terms of vulnerability, response strategy, and risk and risk management.

Assessing vulnerability and response options – potential impacts from the hazard and exposure (Section 6)

Key company-level insights

The following are technical insights related to assessing vulnerability of exposure to climate change:

- Vulnerability is not risk – Vulnerability assessment is an input to risk assessment, identifying the potential implications of exposure and the effects of responses which inform risk evaluation and the risk management strategy that ultimately determines the resulting risk. Treating vulnerability as risk can be very misleading because it fails to consider the likelihood of potential outcomes and risk management effects on risk. For instance, an asset or system vulnerable to increased natural disaster outages due to climate-related changes in extreme events may have a low likelihood, modest implications, and/or the implications are addressed by risk management plans related to system operations and resource recovery.
- Vulnerability is company-specific – Even for the same hazard and exposure, vulnerability will vary by company due to operational, value, strategy, and beyond service territory (e.g., independent or regional system operator) company differences.
- Company vulnerability is determined by more than climate change and exposure – Vulnerability depends on designs (technology, system, and market), operational conditions, value, strategy (preventive and restorative), and beyond service territory factors, as well as assessment tier, metrics considered, and vulnerability type and responses.
  - Assessing different types of vulnerability—reference vulnerability, vulnerability with autonomous (instinctive or automatic) adaptation, and vulnerability with planned climate-resilient strategies—provides unique insights into the potential implications of climate change, possible responses, and the benefits and costs of responses (Figure 7).
  - It is helpful to separate vulnerability assessment into assessments of existing and future vulnerability.
  - For assessment of future vulnerability, there are uncertainties to consider. In addition to climate change uncertainty, there is uncertainty about future policy and non-policy conditions, specific asset types, locations of assets and activity, and descriptions of assets (e.g., capacity). A company-specific scenario design that accounts for climate, policy, and non-policy uncertainties can be a helpful approach for characterizing future vulnerability. Future vulnerability will also depend upon company strategy, which will shape the implications of potential future conditions.
  - There are many possible responses to the potential implications of exposure to climate change. Response types include responses that are autonomous or automatic behavioral or market responses to climate change, as well as the development and adoption of additional climate-resilience response strategies.

- At the asset level, potential adaptation responses should be evaluated within the context of expected asset lifetime and the asset's role within the broader system.
- Integrated system modeling can help identify response portfolios that are cost-effective for a given risk management objective.

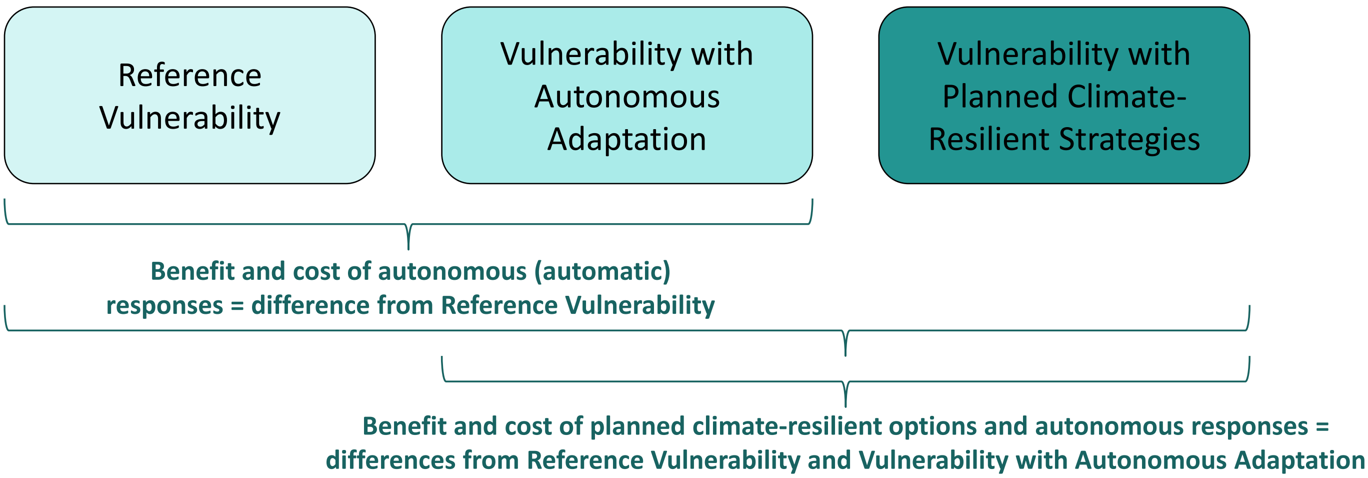

Figure 7. Characterizing vulnerability and response benefits and costs. Source: EPRI.

Technical principles

The following are technical principles and guidance for assessing vulnerability of exposure to climate change:

- Vulnerability assessment needs to be company-specific – recognizing company context (current and future) and decision criteria.
- Need to know your relevant changes in climate and exposure of current assets, systems, and markets.
- Evaluate vulnerability of current assets, systems, and markets.
- Evaluate vulnerability of future assets, systems, and markets:
  - Use company-tailored scenario analysis to evaluate future vulnerability for different future time periods under different plausible conditions based on the exposure scenario design.
- Evaluate different types of current and future vulnerability
  - Identify current and future adaptation response options for evaluation – autonomous and planned additional climate-resilient responses.
  - Evaluate Reference Vulnerability by assessing the implications of climate change exposure when decisions do not consider climate change.
  - Evaluate Vulnerability with Autonomous Adaptation by assessing the implications of climate change exposure with autonomous (automatic) behavioral or market adaptation responses to climate change.
  - Evaluate Vulnerability with Planned Climate-resilient Strategies by assessing the implications of climate change exposure given autonomous adaptation and the possibility of developing and adopting additional climate-resilience adaptation response strategies.
  - Consider uncertainty in potential adaptation responses.
  - Valuate the benefits and costs of autonomous and additional planned climate-resilient responses – using the differences between vulnerability types.
- Assess vulnerability by tiers to fully identify vulnerabilities and response alternatives.
- In designing scenarios and choosing analytical methods, consider strengths and limitations with respect to scope (spatial, temporal, tiers) and capability.
- Identify and evaluate the potential for maladaptation

Technical issues

The following are important technical issues related to assessing vulnerability to climate change and response options:

- Different types of vulnerability – There are different types of vulnerability to climate change that can be evaluated. Assessing and comparing the different types yields valuable insights. For instance, we define Reference Vulnerability, Vulnerability with Autonomous Adaptation, and Vulnerability with Planned Climate-resilient Strategies (Figure 7). Reference Vulnerability assesses the implications of climate change exposure when decisions do not consider climate change. Vulnerability with Autonomous Adaptation assesses the implications of climate change exposure with autonomous or automatic behavioral or market responses to climate change (e.g., increased cooling demand, relative changes in market prices and production) given current and projected knowledge, technology, and processes without additional climate change. Vulnerability with Planned Climate-resilient Strategies assesses the implications of climate change exposure given autonomous adaptation and the possibility of developing and adopting additional climate-resilience response strategies. Assessing each provides unique insights into the potential implications of climate change, possible responses, and the benefits and costs of autonomous and additional climate-resilient responses.
- Tiers of analysis – The tiers of applications also imply tiers of vulnerability analyses to consider and potentially undertake, identifying the potential implications of climate exposure within and across tiers, as well as asset to system to service territory to market response options for addressing implications.
- Current versus future vulnerability – Like with exposure assessment, differentiating current from future vulnerability with separate analyses is helpful to identifying vulnerabilities and response options, as well as climate risk communications; and, it can make assessment more analytically tractable.
- Characterizing potential future societal conditions – In addition to hazard and exposure uncertainty, future vulnerability, as well as response options, will be a function of societal development, which is uncertain. Uncertain climate policy and non-policy (e.g., technology, resources, markets) factors create uncertainty regarding future assets, their locations, and operations, the size of future systems, future markets, and future integration of systems and markets. Transition scenarios considering policy and non-policy uncertainties will be valuable in identifying potential future vulnerability possibilities.
- Assessing adaptation response options – An important issue in assessing the implications of exposure to climate change is assessing potential adaptation responses to changing climate conditions. Some types of adaptation are autonomous or automatic responses to new conditions based on current and projected knowledge and options, while others require additional decisions to develop and adopt new knowledge, technologies, and processes specifically for climate resilience. Defining individual (current and future) adaptation response options is an essential initial step, followed by evaluation with appropriate analytical tools.
- Vulnerability analysis tools – There are different tools available for evaluating vulnerability and response options. The appropriate tool will depend on the application—tier, category, subcategory, and objectives. Having the right tool for the analysis and information required is critical. In identifying tools, it is important to consider the scope (spatial and temporal), objectives, and strengths and weaknesses of alternatives, as well as the types of physical changes needing evaluation—from single climate variable changes to extreme events, to concurrent physical changes and interactions, and sequential physical changes and interactions.
- Potential maladaptation – Adaptation actions can have unintended consequences that actually create more vulnerability. It is important to be aware of and evaluate the possibility of maladaptation.
- Characterizing and communicating vulnerability – While closer to risk information, vulnerability insights, presented in isolation, can mislead audiences. Like exposure, care is needed when characterizing and communicating vulnerability insights. Vulnerability does not equate to risk. The risk associated with vulnerability should not be inferred. An asset, for instance, can be vulnerable to changes in extreme heat, but the risk depends on the likelihood and magnitude of the potential implications and the risk management strategy. Furthermore, it is crucial to characterize and communicate the type(s) of vulnerability(ies) evaluated. For example, reference vulnerability ignores climate responses and therefore overestimates implications, while autonomous vulnerability only partially captures the potential for adaptation. Vulnerability metrics go beyond exposure indicators that identify what is in harm's way. Vulnerability metrics estimate the potential implications, such as related to potential performance, reliability, value, cost, and customer/societal impacts of exposure to climate change.

Assessing risks and identifying robust and resilient risk management strategies (Section 7)

Key company-level insights

The following are technical insights related to assessing climate risk and risk management options:

- Characterization of risk will depend on many factors – decision criteria, risk metric, climate and non-climate uncertainties, assigned likelihoods, and the magnitude of the potential implications (i.e., the assessed vulnerability).
- Risk and risk management are company-specific – Physical climate risk and risk management will vary by company due to differences in hazard, exposure, vulnerability, and the risk interpretation of these, which accounts for each company's business composition, decision criteria, risk metric, climate and non-climate uncertainties, and assigned likelihoods. As a result, physical risk planning needs will vary by company.
- Strategy robustness and resilience evaluation could be valuable – Assessing the robustness of a strategy to different plausible alternative assumptions, such as assumed likelihoods, and strategy resilience to the different plausible future conditions that could unfold over time can be valuable to effective company climate risk management strategy design.
- Risk management strategy prioritization requires the analytical capability to evaluate multiple risks, alternative sets of strategies, and trade-offs.
- Important to consider the relative risk of climate change – Climate is but one of several factors and uncertainties driving change in the electric power sector. Physical climate risk, therefore, needs to be evaluated and managed relative to other risks and as part of a broader risk management strategy.
- Effective risk and risk management communications are valuable – Communicating the physical climate risks identified for a company and the management of those risks can properly inform stakeholders on risks and their management, including strategy robustness and resilience, consideration of alternative responses, and justification for climate risk management investments.

Technical principles

The following are technical principles and guidance for assessing climate risk and risk management options:

- Risk assessment needs to be company-specific – recognizing company context (current and future) and decision criteria.
- Decision criteria needs to be articulated – this includes risk preferences and risk management objective.
- Need to identify appropriate risk metric(s) given decision criteria.
- As needed, given decision criteria, consider potential likelihood of vulnerability outcomes for climate and non-climate uncertainties.
- Identify a robust and resilient strategy and communicate robustness and resiliency of the strategy:
  - Evaluate robustness and resilience of potential strategies,
  - Identify no regrets strategies by evaluating potential conditions and responses to elucidate responses in common under all conditions,
  - Communicate strategy robustness and resilience using appropriate metrics.
- Use tiers of analyses and integrated analyses to identify risk management strategy portfolios.
- Evaluate relative risk of climate change.

Technical issues

The following are important technical issues related to assessing climate risk and risk management strategies:

- Decision criteria – Defining risk management objectives and risk preferences will impact the set of candidate risk management options, as well as the information needed for identifying risks and potential risk management strategies.
- Physical climate risk metrics – In addition to defining decision criteria, there is the need to specify how physical climate risk is measured/estimated, where the risk metrics need to be consistent with the risk management objectives and capture the likelihood of potential vulnerability implications (e.g., minimizing the likelihood of increased outages).
- Likelihoods and expected outcomes – Depending on the risk management objective, a company may need to assign likelihoods to vulnerability implications by considering the information available and judgements regarding the likelihood of uncertain potential climate and non-climate conditions. In some decision contexts, assigning likelihoods may be unnecessary because the company's focus is on identifying, evaluating, and planning for plausible extreme climate and non-climate conditions. Companies might also consider a hybrid approach that, for instance, considers plausible extreme climates and non-climate condition likelihoods.

- Identifying a robust and resilient strategy – Because of climate and non-climate uncertainties, and hard to assess probabilities, robust and resilient strategies are valuable. A strategy is robust if it is practical under different plausible alternative assumptions, such as different reasonable alternative assumed likelihoods, and a strategy is resilient if it is able to adjust successfully to the different plausible conditions that could unfold over time. Identifying a robust and resilient strategy requires evaluation of alternative potential strategies for robustness and resiliency. Such an evaluation can help identify no regrets options that are practical regardless of the future and likelihoods. Of course, the quality of these strategies relies heavily on the ability to create and evaluate a realistic set of scenarios, and this can be a large undertaking on its own.
- Risk management strategy prioritization – With the possibility of multiple physical climate risks—for instance, with a specific climate event, like a drought, or with multiple simultaneous climate-related changes affecting an asset or system, there may be the need to prioritize risk management strategies and have the capability to evaluate multiple risks, alternative sets of strategies, and trade-offs.
- Characterizing and communicating risks and risk management – Characterizing and communicating the risks identified for a company and the management of those risks is critical to informing stakeholders and justifying climate risk management investments. However, it is its own technical challenge, drawing on all the prior assessments—information requirements, hazard, exposure, vulnerability and response—and translating those results into risk and risk management terms.

Metrics (Section 8)

Key company-level insights

The following are technical insights related to physical climate risk assessment metrics:

- Many different metrics needed – Many different types of metrics will be needed across and within the different assessments associated with physical climate risk assessment.
- Not all metrics are risk metrics – There are risk and non-risk metrics. Care with communications is needed, including providing definitions, being explicit about risk and non-risk information, and communicating risk management, risk reduction benefits, and remaining risk.
- Strategy robustness and resilience metrics could be helpful – Estimating and communicating the robustness of a strategy and strategy resilience can be valuable to strategy development and communications with the appropriate metrics.
- Validation is challenging, but important – Given the wide range of metrics proposed by researchers and practitioners, it is important to choose metrics that are known to be validated or that a company can validate themselves using data and models available to them. The wrong choice or application of metrics can result in distorted risk assessments and resulting decisions.

Technical principles

The following are technical principles and guidance for physical climate risk metrics:

- Develop metrics fit for purpose – tailored for company need.
- Work to validate any metrics chosen with applications designed around the intended purpose and company need.
- Recognize, consider, and communicate technical issues associated with hazard, exposure, vulnerability, and risk assessments, as well as information availability and limitations relative to requirements.
- Differentiate risk and non-risk metrics and clearly identify those best capturing company risk and risk management for climate risk communications and disclosure.
- Similarly, identify robustness and resilience metrics best representing company risk management and strategy robustness and resilience for climate risk communications and disclosure.

Technical issues

The following are important technical issues to consider related to physical climate risk metrics:

- Many different types of metrics – Each of the assessments—hazard, exposure, vulnerability and response, risk and risk management—produces their own type of information. Therefore, different metrics are associated with communicating the insights from each. Furthermore, there are many variables and different potential metrics within each assessment; and, metrics are often designed to work with specific types of data products or specific modeling approaches, and they may not be consistently applied when working across these spaces. Finally, with each company having different decision objectives and thresholds, as well as locations, and current and future assets, systems, markets, and opportunities, the set of meaningful metrics can vary from one company to the next.
- Not all metrics are risk metrics – Many metrics are not indicators of risk. For instance, physical climate change hazard metrics only indicate whether the climate has changed, while exposure metrics indicate whether something is exposed to those changes, and vulnerability indicates whether there

might be implications due to exposure. Risk metrices, on the other hand, capture expected consequences, taking into account the probability and magnitude of potential implications, as well as accounting for decision criteria, risk management, and its risk reduction effects.

- Not all metrics can be calculated – Oftentimes a proposed metric cannot be easily populated or calculated with the data used in existing models or currently collected within companies. It is important to assess which metrics are likely to drive decisions before investing time and resources into the use of metrics that may not be relevant to risk assessments.

References

Allete, 2020. *2020 Corporate Sustainability Report*.

Alliant Energy, 2022. *2022 Climate Report*.

Ameren, 2021. *Committed to Clean: Transformational Changes Toward Net-Zero*.

Duke Energy, 2020. *Achieving a Net Zero Carbon Future*. Duke Energy 2020 Climate Report.

Entergy, 2019. *Climate Scenario Analysis and Evaluation of Risks and Opportunities*.

EPRI, 2022. *Public Comments on the Federal Acquisition Regulation: Minimizing the Risk of Climate Change in Federal Acquisitions Advanced Notice of Proposed Rulemaking*. FAR Case 2021–016. EPRI, Palo Alto, CA:2022. 3002023465.

EPRI, 2021. *Repairing the Social Cost of Carbon: Immediate Steps for Scientifically Reliable Estimates and Use*. EPRI, Palo Alto, CA: 2021. 3002020523.

EPRI, 2020. *EPRI Comments on Moody's "Proposed framework to assess carbon transition risks for electric power companies."* EPRI, Palo Alto, CA: 2020. 3002020282.

FirstEnergy, 2019. *Climate Report: Energy for a Brighter Future*.

Hausfather, Z and G.P. Peters, 2020. Emissions – the 'business as usual' story is misleading. *Nature* 577: 618-620. doi: https://doi.org/10.1038/d41586-020-00177-3.

OG&E, 2021. *Power to Grow: 2021 Climate Analysis*.

Rose, S. and M. Scott, 2018. *Grounding Decisions: A Scientific Foundation for Companies Considering Global Climate Scenarios and Greenhouse Gas Goals*. EPRI, Palo Alto, CA: 2018. 3002014510.

Rose, S. and M. Scott, 2020. *Review of 1.5°C and Other Newer Global Emissions Scenarios: Insights for Company and Financial Climate Low-Carbon Transition Risk Assessment and Greenhouse Gas Goal Setting*. EPRI, Palo Alto, CA: 2020. 3002018053.

Taber, J and S Rose, 2022. *Opportunities for Decarbonizing Minnesota's Economy: Energy System Supply and Demand Assessment*. EPRI, Palo Alto, CA: 2022. 3002019333.

TCFD, 2020. *Task Force on Climate-Related Financial Disclosures Guidance on Scenario Analysis for Non-Financial Companies*.

Xcel Energy, 2019. *Xcel Energy Low Carbon Scenario Analysis*. Xcel Energy Carbon Report.

WEC Energy Group, 2022. *Pathway to a Clean Energy Future: 2022 Climate Report*.

WEC Energy Group, 2019. *Pathway to a Cleaner Future*. WEC Energy Group Climate Report.

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EPRI Resources

Steven Rose, *Technical Executive*
202.293.6183, srose@epri.com

Laura Fischer, *Technical Leader*
202.293.6349, lfischer@epri.com

Delavane Diaz, *Principal Project Manager*
650.319.5244, ddiaz@epri.com

Francisco Ralston Fonseca, *Engineer/Scientist III*
704.595.2224, fralstonfonseca@epri.com

Jonathan Lala, *Engineer/Scientist II*
650.855.1048, jlala@epri.com

Erik Smith, *Engineer/Scientist III*
202.293.6188, smith@epri.com

Ridwan Siddique, *Engineer/Scientist III*
972.556.6564, rsiddique@epri.com

Andrea Staid, *Senior Technical Leader*
202.951.4462, astaid@epri.com

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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com