Quantifying Risk to California's Energy Infrastructure from Projected Climate Change

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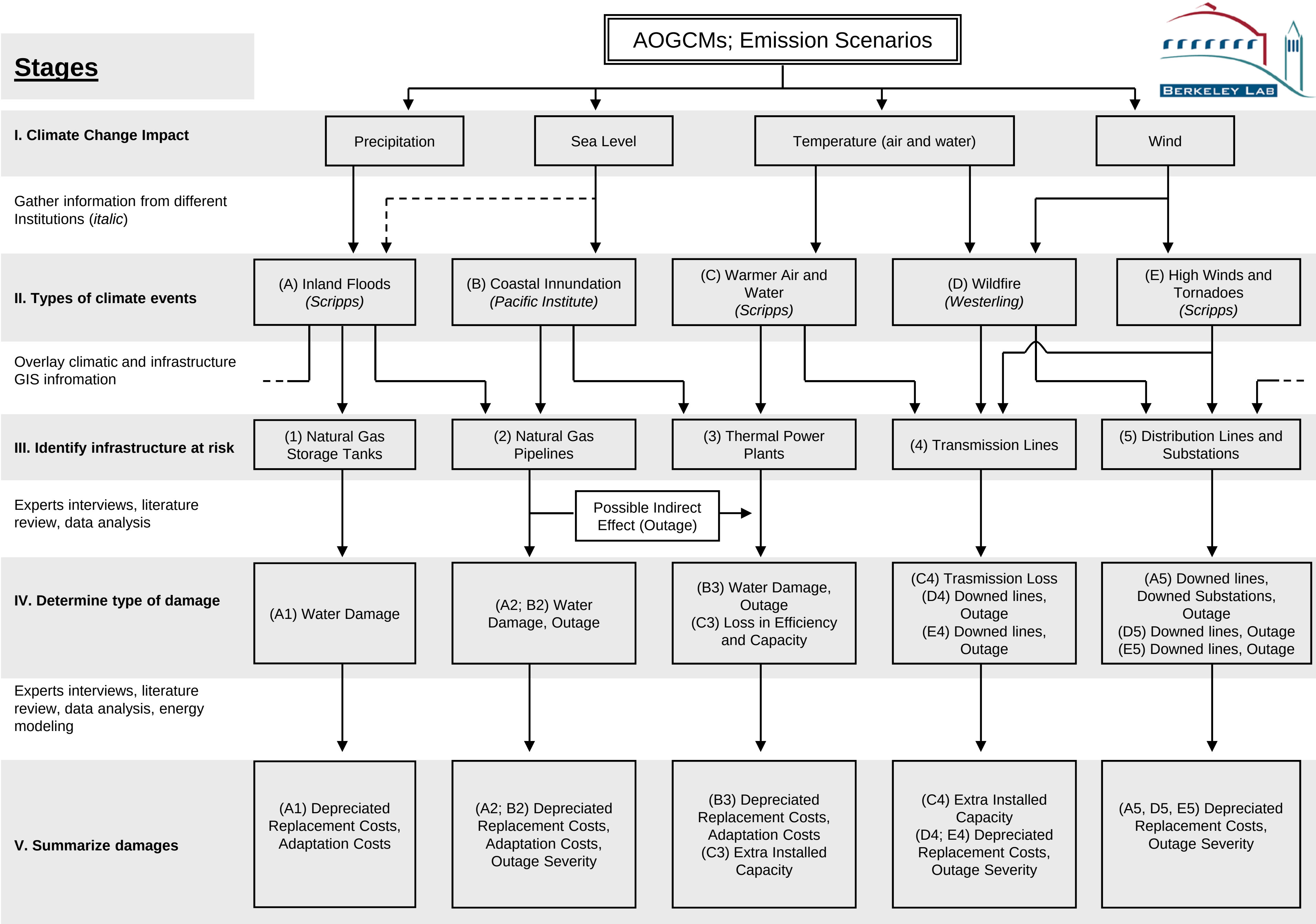
- Background to study
  - PIER studies focus on climate risks to the general economy
  - State's energy infrastructure also directly at risk
  - Study has not formally begun.
  - Deliverables to include white paper this summer and report early next year

- This presentation
  - Overview of the methodology (Larry Dale)
  - Example of the methodology (Andre Lucena)
  - Damage metrics and data needs (Pete Larsen)

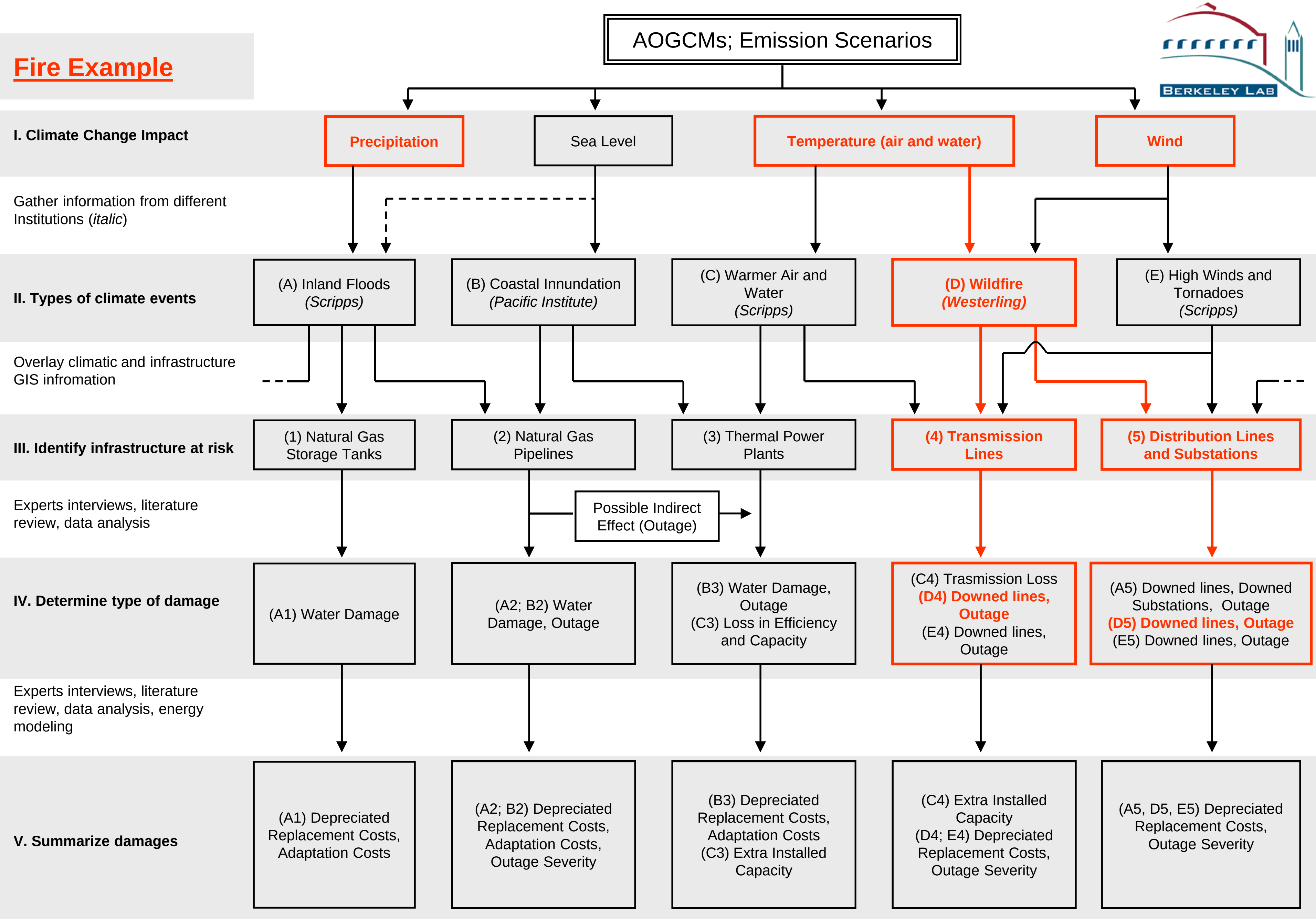
Methodology Overview

1. What's covered?
   - Types of climate events
   - Energy infrastructure at risk
   - Time period
2. How to identify infrastructure at risk?
   - GIS mapping of climate and infrastructure.
   - Previous studies of some risks (fire and ocean level)
3. How to determine damage to infrastructure?
   - Energy and utility expert interviews
   - Data collection, analysis
   - Review of past studies
4. How to summarize damages?
   - Costs, Discounting, and Uncertainty
   - Outages?/Energy Output Measures
   - Adaptation Assumptions?
5. Principle data and analysis gaps
   - Data gaps--location and severity of extreme wind and flood events
   - Assembling expert panel

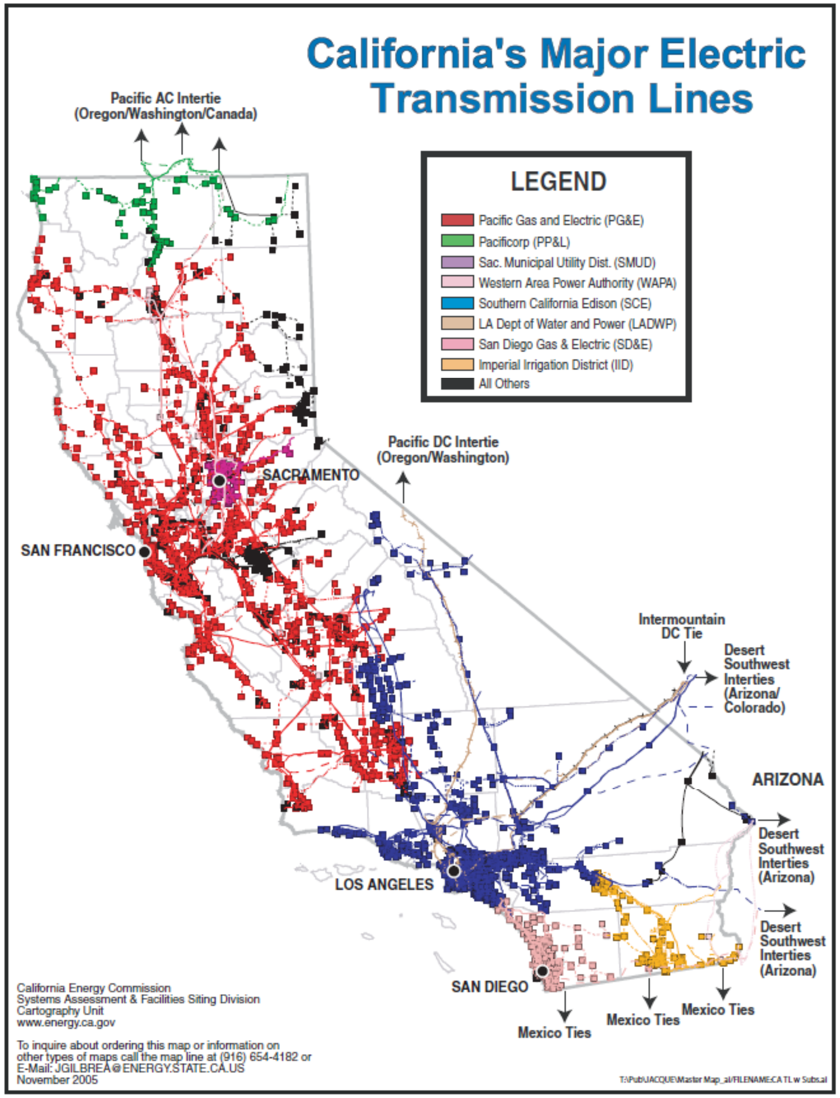

Stages
AOGCMs; Emission Scenarios
I. Climate Change Impact
Precipitation
Sea Level
Temperature (air and water)
Wind
Gather information from different Institutions (italic)
II. Types of climate events
(A) Inland Floods (Scripps)
(B) Coastal Innundation (Pacific Institute)
(C) Warmer Air and Water (Scripps)
(D) Wildfire (Westerling)
(E) High Winds and Tornadoes (Scripps)
Overlay climatic and infrastructure GIS infromation
III. Identify infrastructure at risk
(1) Natural Gas Storage Tanks
(2) Natural Gas Pipelines
(3) Thermal Power Plants
(4) Transmission Lines
(5) Distribution Lines and Substations
Experts interviews, literature review, data analysis
Possible Indirect Effect (Outage)
IV. Determine type of damage
(A1) Water Damage
(A2; B2) Water Damage, Outage
(B3) Water Damage, Outage
(C3) Loss in Efficiency and Capacity
(C4) Trasmission Loss
(D4) Downed lines, Outage
(E4) Downed lines, Outage
(A5) Downed lines, Downed Substations, Outage
(D5) Downed lines, Outage
(E5) Downed lines, Outage
Experts interviews, literature review, data analysis, energy modeling
V. Summarize damages
(A1) Depreciated Replacement Costs, Adaptation Costs
(A2; B2) Depreciated Replacement Costs, Adaptation Costs, Outage Severity
(B3) Depreciated Replacement Costs, Adaptation Costs
(C3) Extra Installed Capacity
(C4) Extra Installed Capacity
(D4; E4) Depreciated Replacement Costs, Outage Severity
(A5, D5, E5) Depreciated Replacement Costs, Outage Severity

Impacts: Methodology Examples

Fire Example

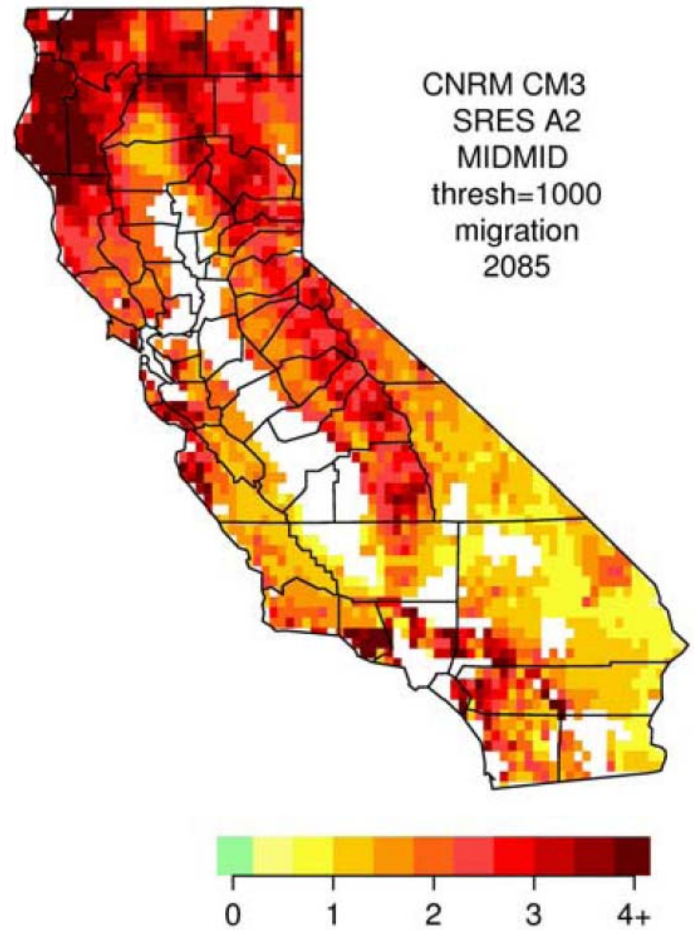


GIS Crossing – Example: Wildfire

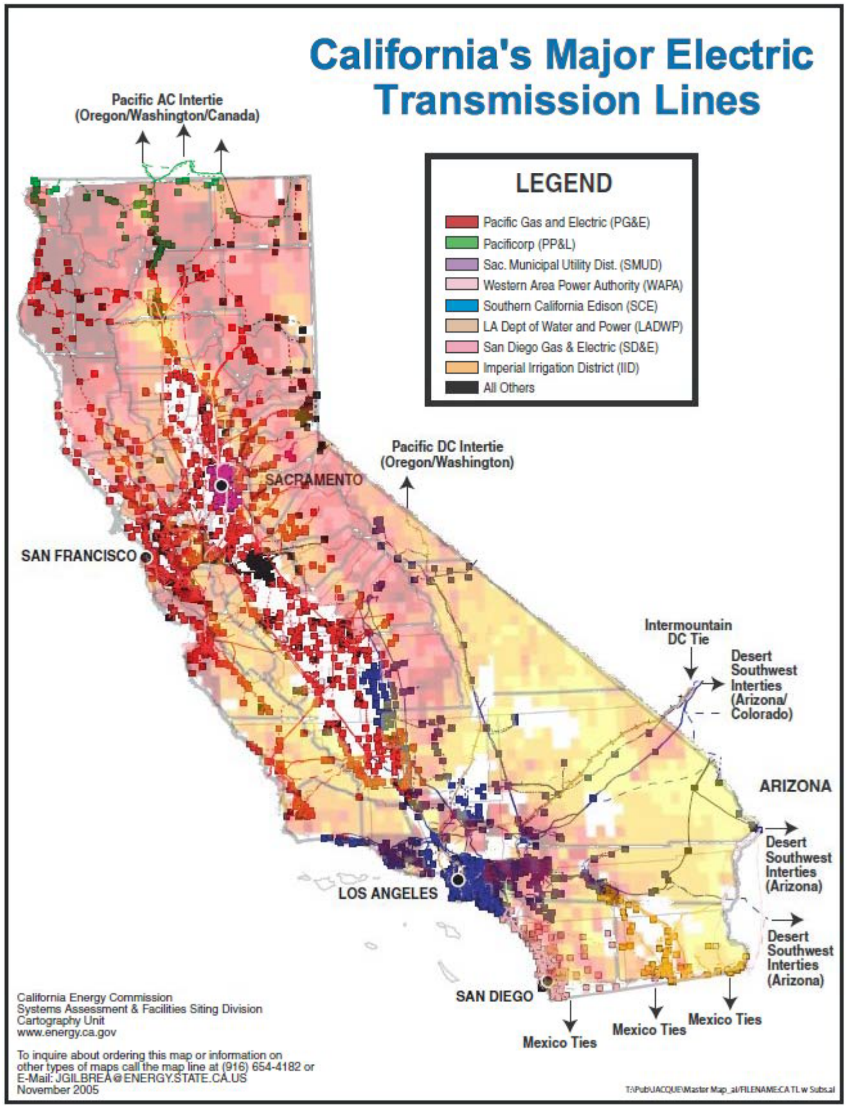


2085 Predicted Burned Areas (multiple of reference period)

Source: Westerling et al. (2009)

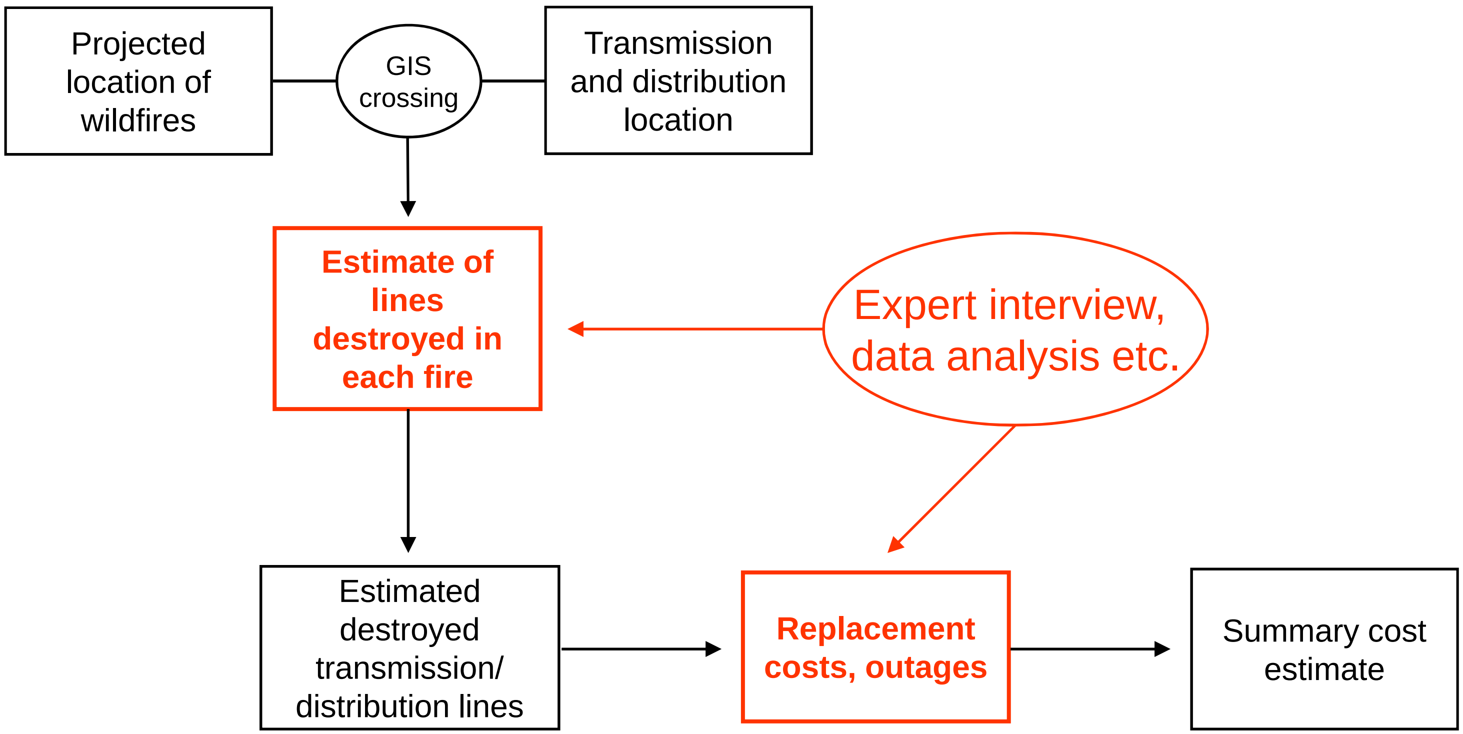


GIS Crossing
Example: Wildfire vs. Transmission Lines

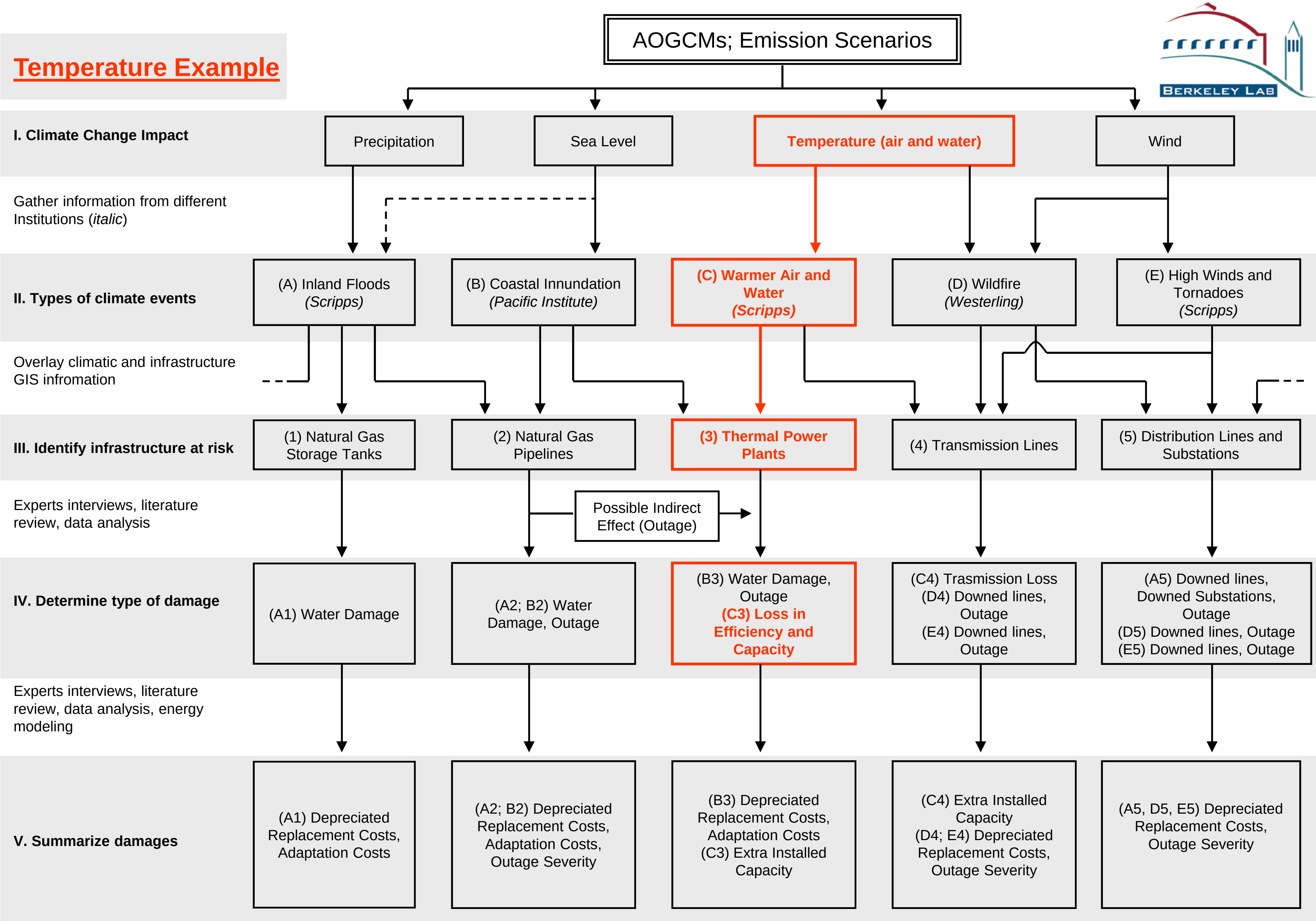


Impacts of Increased Wildfire Activity on Transmission and Distribution Lines

- Similar methodology to Westerling and Bryant (2008)
  - Analyzed property damages due to wildfire



Temperature Example

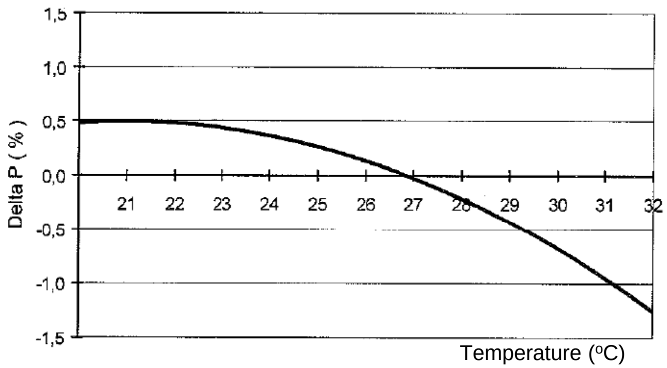


Warmer Air and Water Impacts on Power Plant Efficiency and Capacity

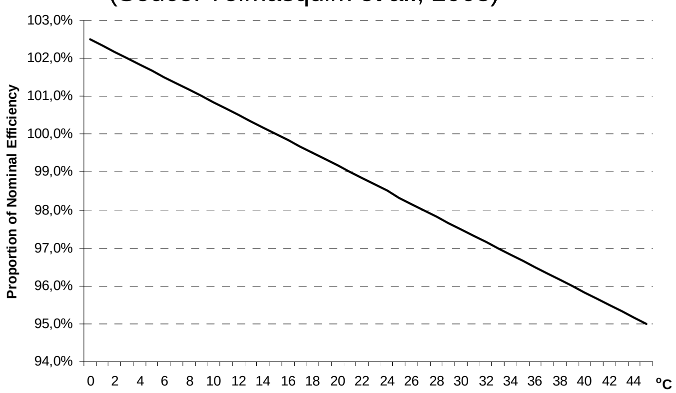
- GIS crossing: power plants location vs. projected temperature *variation*
- Finding a representative relationship between Air/Water temperature and thermal power plants conversion efficiency and capacity:
  - Information from utilities
  - Types/models of turbines
  - Level of aggregation (more than 300 natural gas power plants)
- RESULTS:
  - Loss in efficiency – lower electricity generation (MWh)
  - Loss in capacity – lower installed generating capacity (MW)

Warmer Air and Water Impacts on Power Plant Efficiency and Capacity

Change in power as function of sea temperature at the Angra 2 Nuclear Power Plant (Source: Eletronuclear)



Influence of atmospheric temperature on the efficiency of gas turbines (Souce: Tolmasquim et al., 2003)



Change in Power as function of temperature (Source: CEC-500-2006-034)

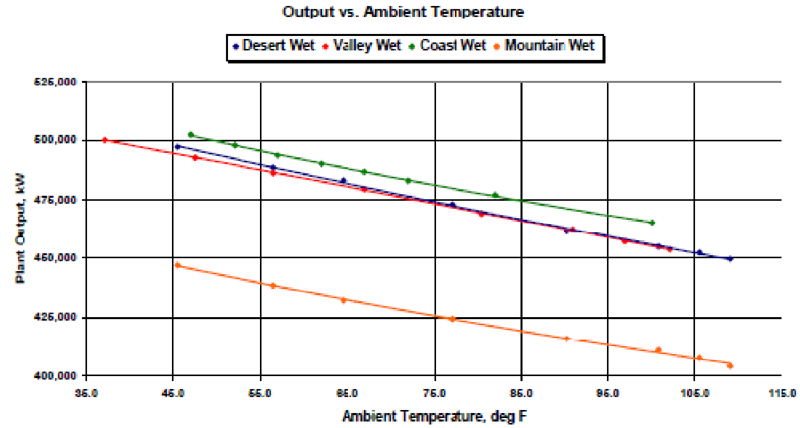


Figure 7. Output vs. ambient temperature—wet-cooled plants

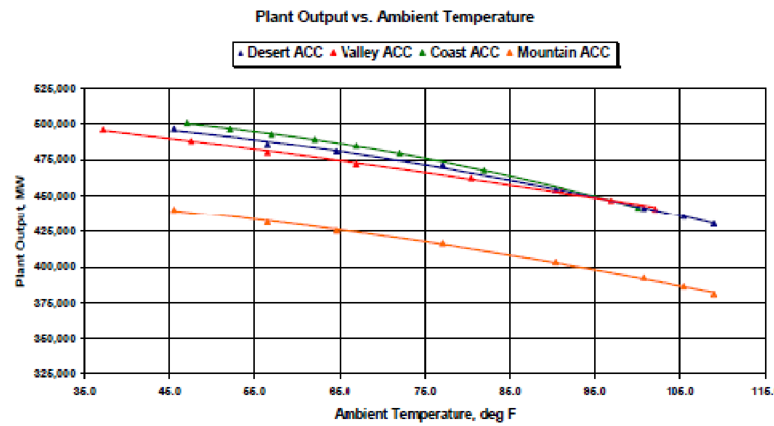
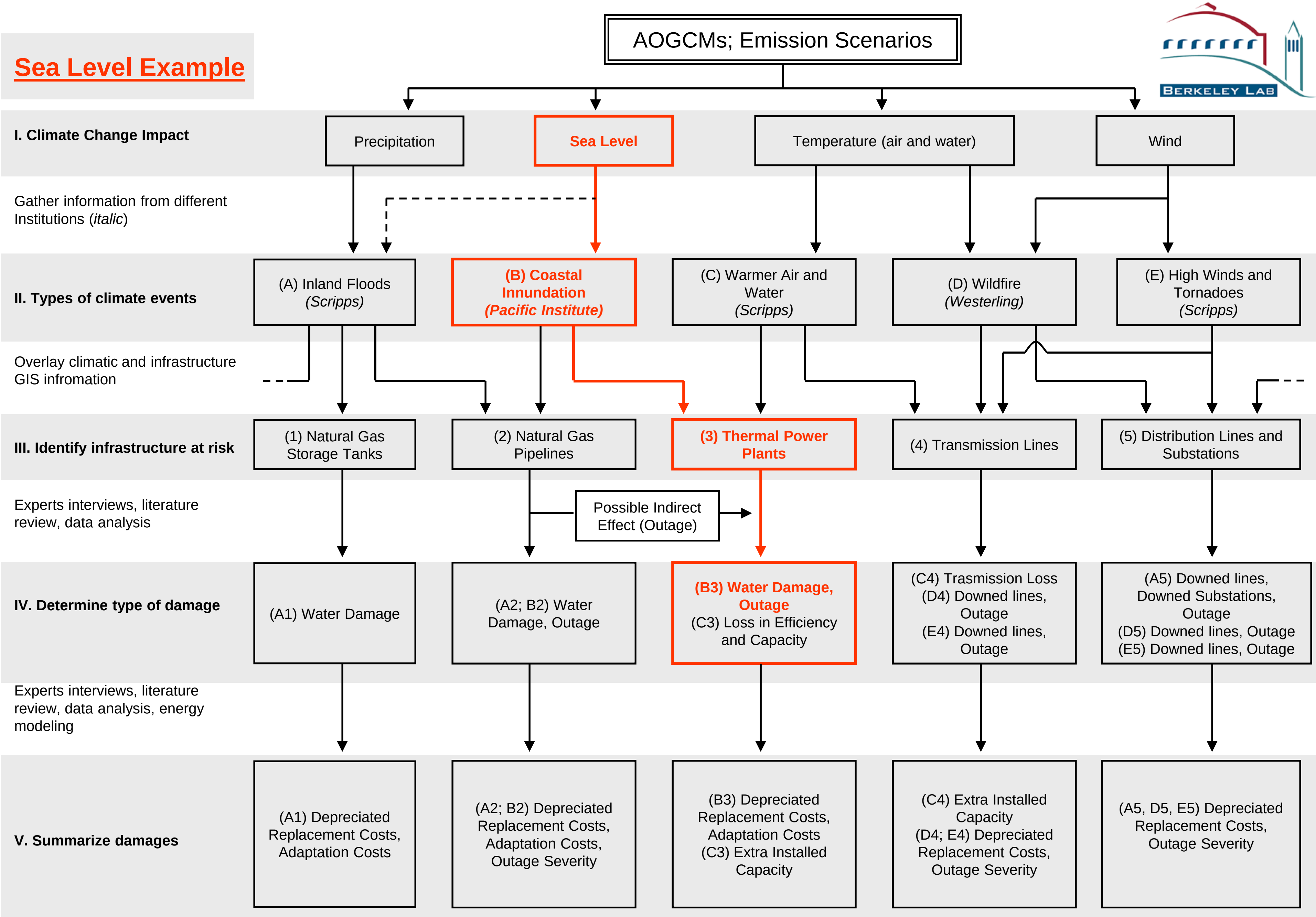


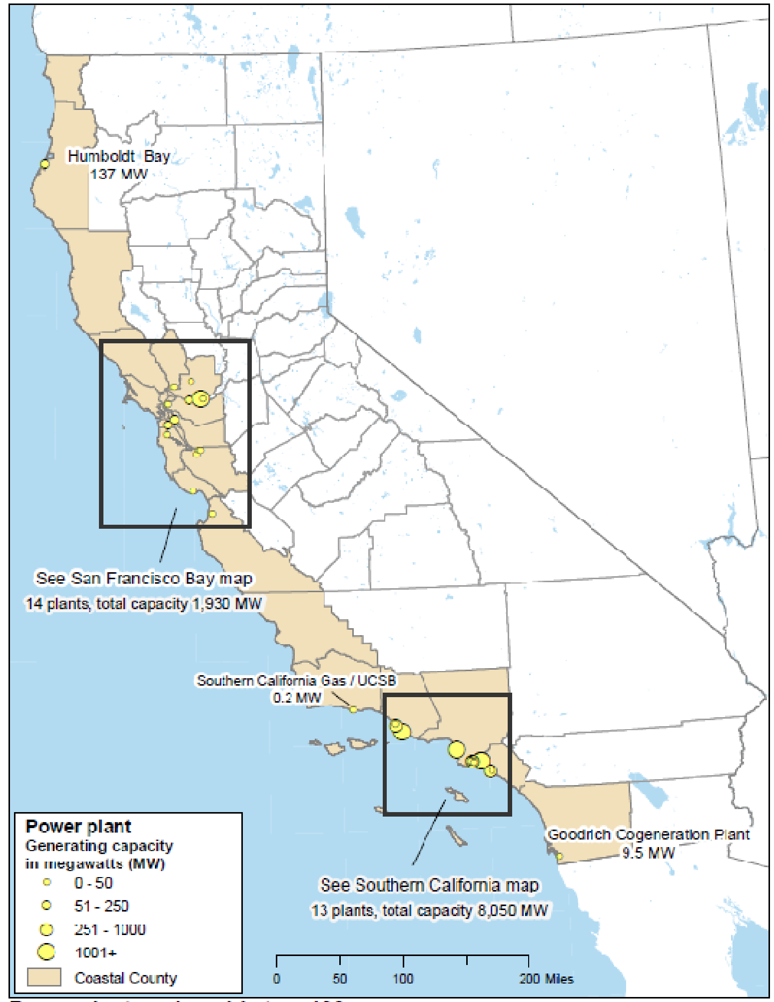
Figure 8. Output vs. ambient temperature—dry-cooled plants

Sea Level Example



Sea Level Rise Impacts on Coastal Power Plants

- 30 Power Plants totaling over 10,000 MW vulnerable to a 100-year coastal flood with a 1.4 meter sea level rise.
- In some cases whole piece of infrastructure is at risk, whereas in other cases, only portions of structure are at risk (e.g., intake or other peripheral structures are exposed to flood risk).
- Information gathering:
  - What are the consequences (and costs) to each specific power plant that might be impacted?
  - What is the expected useful life span of each specific power plant?
  - Are there adaptation measures being taken (or proposed) to prevent (or reduce) damages from projected flooding? At what costs?



Power plants vulnerable to a 100-year coastal flood with a 1.4 meter sea-level rise

Data sources: USGS/Scripps Institution of Oceanography, California Energy Commission, CaSIL, ESRI
http://www.pacinst.org/reports/sea_level_rise

(Source: Pacific Institute – http://www.pacinst.org/reports/sea_level_rise/maps/)

Misc. Thoughts on Damage Metrics and Data Needs

Useful Metrics to Evaluate Second-Order Climate Risk to Energy Infrastructure

I. Overlaid GIS Visualizations
- LBNL deliverable for this project.

II. Direct Risk to Energy *Capacity* (MW or universal measure) or Energy *Output* (MWh or universal measure)
- LBNL deliverable for this project.

III. Direct Risk to Infrastructure *Operational* and *Capital* Costs
- LBNL deliverable for this project? (pending data and other constraints)

IV. Indirect Risk to Other Economic Activity (e.g., Outages?)
- Interesting future research topic?

EXAMPLE: Financial Risk to Physical Capital (i.e. Lifecycle Cost Method)

Consider Catastrophic Sea-level Rise/Storm Surge Scenario for Vulnerable Infrastructure

Step 1: Estimate Baseline Present Value Replacement Costs

$$BCRC = \sum_{j=1}^{5,000} \sum_{i=2010}^{2050} \left(\frac{\Theta_{ij}}{(1+r)^{i-2010}} \right) \text{ where } \Theta_{ij} = \frac{BASERC_{ij}}{BASELIFE_{ij}}$$

Step 2: Estimate Climate-Related Present Value Replacement Costs

$$ADJRC = \sum_{j=1}^{5,000} \sum_{i=2010}^{2050} \left(\frac{\Delta_{ij}}{(1+r)^{i-2010}} \right) \text{ where } \Delta_{ij} = \frac{BASERC_{ij}}{ADJLIFE_{ij}}$$

Step 3: Determine Infrastructure Capital at Risk (no adaptation assumed)

AIC = ADJRC-BCRC

Step 4: Assume Some Level of Structural Adaptation?

Step 5: Conduct Scenario/Monte-Carlo Simulations Varying the Inputs

Estimation Caveats and Other Important Considerations

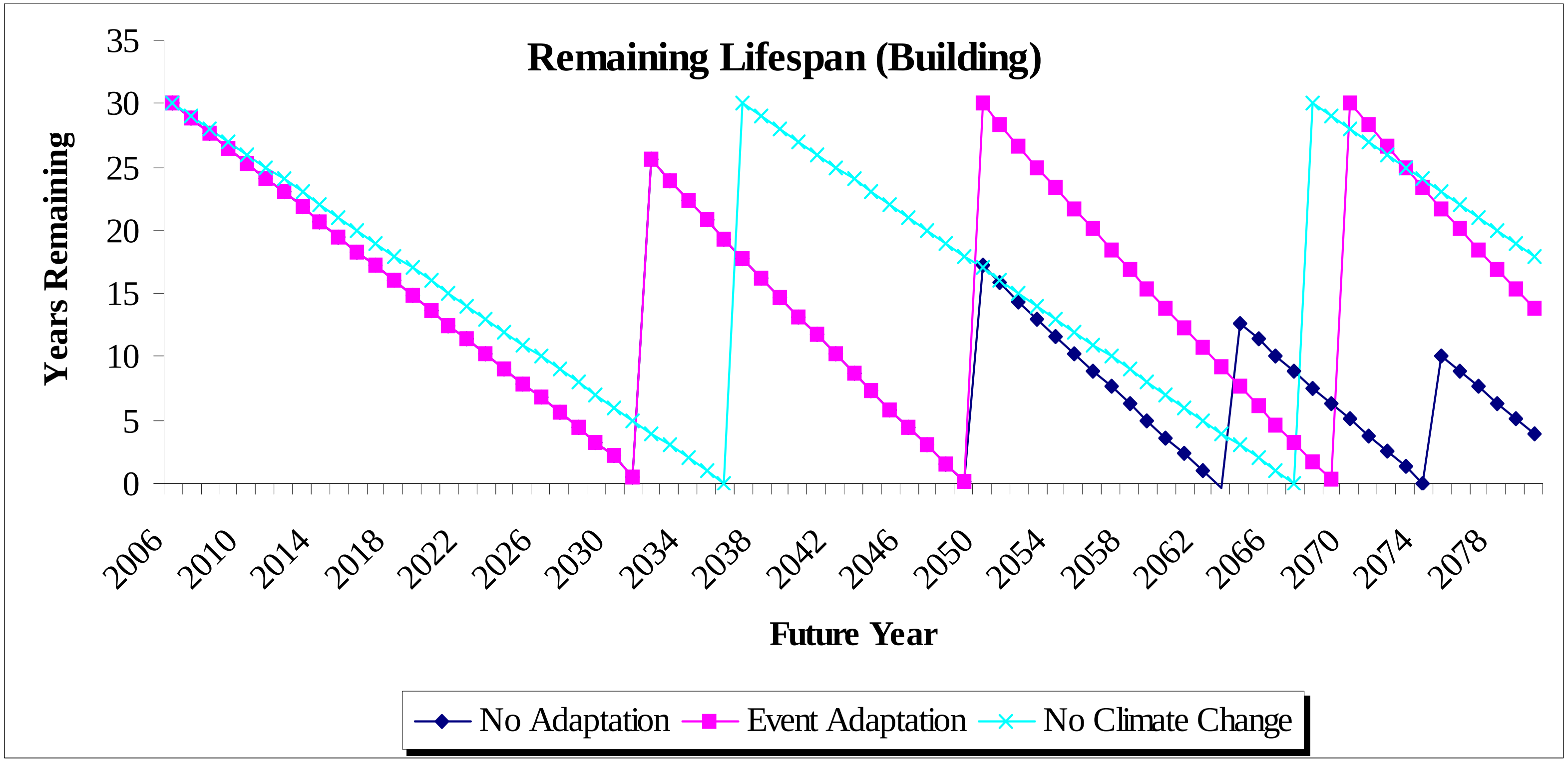
I. Scaling and Aggregation Issues
   A. Structure-by-structure?
   B. County or regional aggregation?
   C. Structure class (e.g., natural gas pipelines, power plant, etc.)?

II. Uncertainty and Discounting Future Economic Risk
   A. Communicating coupled modeling statistical uncertainty…
   B. "Structural" uncertainty of impacts outweighs influence of discount rate choice (see Weitzman 2008).
   C. Discount rate choice is still very critical in determining present value of climate impacts.

III. Modeling Assumptions about Adaptation (see Perez 2009)
   A. Energy Efficiency Standards (e.g., reducing water consumption)
   B. Siting, building codes, and relicensing
   C. Energy management and planning (e.g., optimally managing reservoirs)

IV. Period of Analysis
   A. Weak impacts signals in first few decades
   B. Impacts signals become exponentially (or non-linear) stronger further out
   C. Greater perceived risk influences forward-thinking adaptation decisions in earlier years

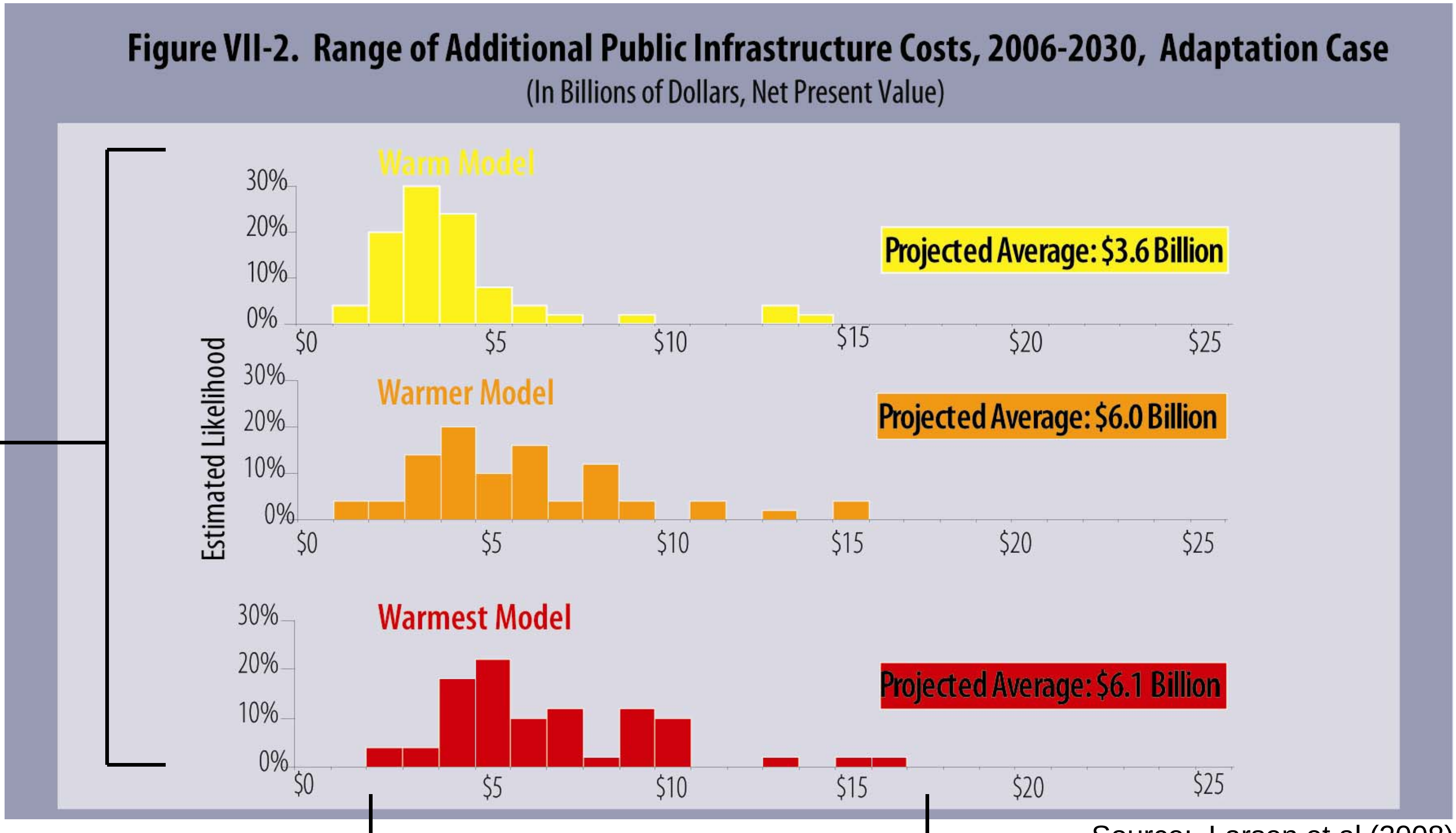
AK EXAMPLE: Modeling Infrastructure Lifespans (with adaptation)



Example Adaptation Scenario:

The Alaska model was programmed to rebuild/relocate structure at X% greater cost than average at point in time when Y% of structure's value is negatively impacted by climate change.

AK EXAMPLE: Communicating Multiple Forms of Model Input Uncertainty



Source: Larsen et al (2008)

Three different AOGCMs

Monte-carlo Simulation (varied inputs)

General Information Needs

I. Climate and Impact Variables

II. Energy Infrastructure Variables

III. Dispatch/Power Simulation Modeling Output?

IV. Constructive Feedback from Technical Advisory Committee (TAC)

Climate and Impact Variable Needs

Variable	Units	Timescale	Spatial Resolution
Monthly Ambient Temperature (high, low and average)	F or C	Current (AOGCM baseline)	1/8 of Degree
	F or C	Historical data	1/8 of Degree
	F or C	Projected (2050)	1/8 of Degree
Monthly Coastal Water Temperature (high, low and average)	F or C	Current (AOGCM baseline)	1/8 of Degree
	F or C	Historical data	1/8 of Degree
	F or C	Projected (2050)	1/8 of Degree
Monthly Freshwater Temperature (high, low and average)	F or C	Current (AOGCM baseline)	1/8 of Degree
	F or C	Historical data	1/8 of Degree
	F or C	Projected (2050)	1/8 of Degree
Wildfire Risk / Wildfire occurence	lat/lon	Current (AOGCM baseline)	1/8 of Degree
	lat/lon	Historical data	1/8 of Degree
	lat/lon	Projected (2050)	1/8 of Degree
Wind Velocities (high, low and average)	m/s	Current (AOGCM baseline)	1/8 of Degree
	m/s	Historical data	1/8 of Degree
	m/s	Projected (2050)	1/8 of Degree
Local Sea-level (high, low and average)	lat/lon	Current (AOGCM baseline)	Lat/Lon (continuous)
	lat/lon	Historical data	Lat/Lon (continuous)
	lat/lon	Projected (2050)	Lat/Lon (continuous)
Monthly maximum storm surge level	lat/lon	Current	Lat/Lon (continuous)
	lat/lon	Historical data	Lat/Lon (continuous)
	lat/lon	Projected (2050)	Lat/Lon (continuous)

Source: Sathaye et al (2009)

Energy Infrastructure Information Needs

Variable	Units	Timescale	Spatial Resolution
Power Generator Location, Type, and Basic Engineering	varies	Current	Lat/Lon (point)
Historical Production of electricity / power plant	energy	Historical Time series	power plant
Historical Fuel consumption / power plant	energy	Historical Time series	power plant
Quantitative relationship between air temperature and efficiency in each power plant, if possible, or aggregated by plant type - % / C or F			
Quantitative relationship between air temperature and capacity in each power plant, if possible, or aggregated by plant type - kW / C or F			
Quantitative relationship between cooling water temperature and efficiency in each power plant, if possible, or aggregated by plant type (for the case of wet coolir			
Quantitative relationship between cooling water temperature and capacity in each power plant, if possible, or aggregated by plant type (for the case of wet coolin			
Average Annual Maintenance Costs (aggregated by plant type?)	Dollars	Current	power plant
Power Plant Replacement Cost (aggregated by plant type?)	Dollars	Current	power plant
Powerplant age and useful lifespan	Years	Current	power plant
Transmission Line Location, Type, and Basic Engineering	varies	Current	Lat/Lon (continuous)
Heat dissipation (loss) due to conducstor's resistance	%	historical average	system
Material's temperature coeficient of resistivity	Ω.m/K	constant	system
Impacts of Fire on transmission lines	?		Lat/Long (ontinuous)
Average Annual Maintenance Costs (aggregated by line type?)	Dollars	Current	transmission line
Line Replacement Cost (aggregated by line type?)	Dollars	Current	transmission line
Trans. line age and useful lifespan	Years	Current	transmission line
Distribution Line Location, Type, and Basic Engineering	varies	Current	Lat/Lon (continuous)
Impacts of Fire on distribution lines	?		Lat/Long (ontinuous)
Average Annual Maintenance Costs (aggregated by line type?)	Dollars	Current	distribution line
Line Replacement Cost (aggregated by line type?)	Dollars	Current	distribution line
Dist. line age and useful lifespan	Years	Current	distribution line
Pipeline Location, Type, and Basic Engineering	varies	Current	Lat/Lon (continuous)
Average Annual Maintenance Costs (aggregated by line type?)	Dollars	Current	pipeline
Line Replacement Cost (aggregated by line type?)	Dollars	Current	pipeline
Pipeline age and useful lifespan	Years	Current	pipeline
Fuel Storage Location, Type, and Basic Engineering	varies	Current	Lat/Lon (point)
Average Annual Maintenance Costs (aggregated by storage type?)	Dollars	Current	storage facility
Facility Replacement Cost (aggregated by storage type?)	Dollars	Current	storage facility
Fuel storage facility age and useful lifespan	Years	Current	storage facility

Source: Sathaye et al (2009)

Other Information Needs…

III. Dispatch/Power Simulation Modeling Output?

- Would the CEC be able to provide power dispatch modeling output, if given agreed upon vulnerability scenarios?

IV. Constructive Feedback from Technical Advisory Committee (TAC)

- What is the most effective way to consolidate information from utility planners and engineers in order to determine the vulnerability of specific (or classes of) energy infrastructure?

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