MIT Climate & Sustainability Consortium

# Toolkit for Assessing the Vulnerability of Industry Infrastructure Siting to Climate Change

## Project Overview

**How can we improve the siting process for renewable energy infrastructure, making it more strategic and proactive?**

Michael Howland

Liying Qiu

The siting of renewable energy infrastructure in markets such as the United States has historically been driven by private interests, with less coordination at the system level. However, with the growing penetration of weather-dependent renewables and the increasing shifts in the frequency and intensity of extreme weather events, this uncoordinated siting approach may be insufficient to ensure long-term energy resilience and reliability.

To address this challenge, this team, led by Professor Michael Howland and postdoctoral associate Liying Qiu (Civil and Environmental Engineering), has developed a climate-informed energy infrastructure siting framework. This framework leverages high-resolution meteorological and energy system modeling tools and data to identify optimal siting strategies that minimize costs and enhance resilience under both current and future climate conditions.

The framework has broad applicability, from large-scale national power systems to more localized infrastructure deployments, such as siting for data centers, microgrids, and manufacturing facilities for specific industries that consume power. By integrating physics-based understanding with energy system optimization tools, this approach aims to proactively guide energy infrastructure investments in ways that are robust to long-term climate risks.

The project aligns closely with the MCSC's Value Chain Resilience pathway.

The team's work was featured in MIT News.

## Findings & Outcomes

**The team's work has provided guidance on regionally tailored siting strategies for utility-scale renewable energy infrastructure and has linked spatial siting to improved system-wide performance.**

***Journal Publication: Cell Reports Sustainability (Cover Article)***

The team's research was published as a cover article in *Cell Reports Sustainability*, titled *"Decarbonized energy system planning with high-resolution spatial representation of renewables lowers cost."* This study demonstrates that spatially optimized renewable energy siting – using the team's high-resolution climate-energy modeling framework – can reduce total system costs by up to 40% compared to current approaches that maximize the energy production for each renewable energy plant individually. It also uncovers the geophysical drivers behind these cost savings across three diverse grid regions: New England, Texas, and California.

Key outcomes:

- Provided guidance on regionally tailored siting strategies for utility-scale renewable energy infrastructure. For example, the team demonstrated that onshore wind in New England and California is most valuable when sited in areas with strong diurnal complementarity to both regional demand peaks and solar generation. Solar deployment is most cost-effective when geographically dispersed east–west, capturing broader temporal diversity in irradiance. And in Texas, prioritizing geographically complementary wind siting – rather than clustering in the highest-capacity-factor "hot spots" – lowers system-wide balancing costs by reducing correlated variability.
- Linked spatial siting to improved system-wide performance and quantified the value of high-resolution energy infrastructure siting based on reliable, high-resolution meteorological modeling.

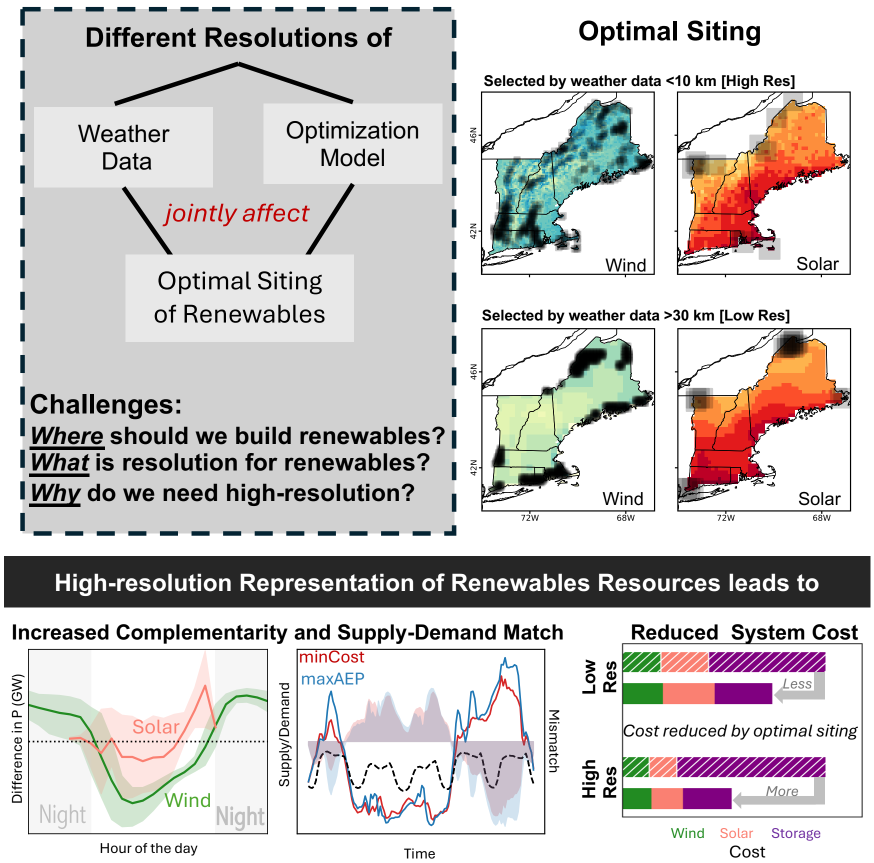


**Figure 1:** Key findings on the importance and rationale for using high-resolution representation of renewables to inform siting decisions. Upper right maps are the optimal siting of wind and solar selected using high- and low-resolution weather data. The bottom panel shows how high-resolution representation of renewables benefits the system design. Adapted from Qiu *et al. Cell Reports Sustainability* (2024).

### *Paper in Review*

In follow-up work, *"Climate change reshapes optimal renewable energy siting by concurrently altering wind, solar, and electricity demand,"* currently under peer review, the team explores how climate change alters the optimal siting of renewable infrastructure. This study integrates high-resolution climate projections into future-facing system planning to assess how shifts in temperature, wind and irradiance patterns, and electricity demand profiles affect the risk of resource adequacy failure (i.e., the ability to meet electricity demand at all times).

Major findings:

- Energy infrastructure and renewable energy siting affects the alignment between energy supply and demand in future climates. The siting locations for renewables significantly shapes how well renewable supply matches evolving demands, where both supply and demand will change under climate change-driven shifts in meteorological patterns.
- Climate-informed siting boosts power system resilience: Future-facing siting strategies mitigate system vulnerabilities by strategically shifting generation to better match future weather and energy consumption patterns. For example, rising summer electricity demand, particularly at

night due to increased air conditioning loads, makes sites with strong summer nighttime wind especially valuable in a warming climate.

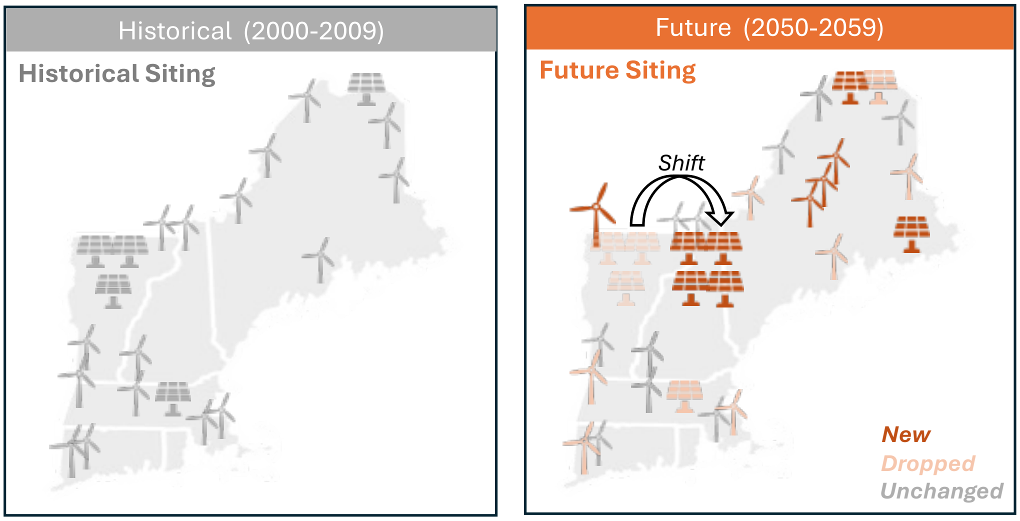


**Figure 2:** The schematic illustrates how integrating future climate conditions alter optimal renewable infrastructure siting in ISO-New England.

## Opportunities for Implementation

This work offers a toolkit and framework that can inform both research and real-world implementation across various sectors:

***Research***

- **Regional system planning**: Tailoring siting strategies to specific regions (meteorology, climate, and geographical characteristics) and regionally-specific energy demand profiles using detailed renewable, climate, and land-use data.
- **Infrastructure risk assessment:** Evaluating how siting decisions affect the power grid and also interconnected systems such as supply chains, data centers, water systems, and insurance-relevant infrastructure.

***Implementation***

- **Electricity procurement and siting strategy** for tech companies, manufacturing, and data centers looking to secure reliable, clean power under uncertain climate futures. Two specific applications include:
  - Identification and evaluation of the cost and risk of renewable energy power purchase agreements (PPAs) based on regionally-tailored climate and energy system modeling
  - Quantification of risk to the resource adequacy of power grid regions where large-scale energy consuming infrastructure is planned
- **Utility and ISO planning tools** to support integrated resource plans.
- **Government and policymaking** to understand needs and opportunities for investment in climate-resilient renewable energy infrastructure.