FROM LEAST COST TO LOW-CONFLICT: USING GEOSPATIAL ANALYSIS TO IMPROVE CLEAN ENERGY PLANNING

Grace C. Wu, PhD
Assistant Professor
Environmental Studies Department

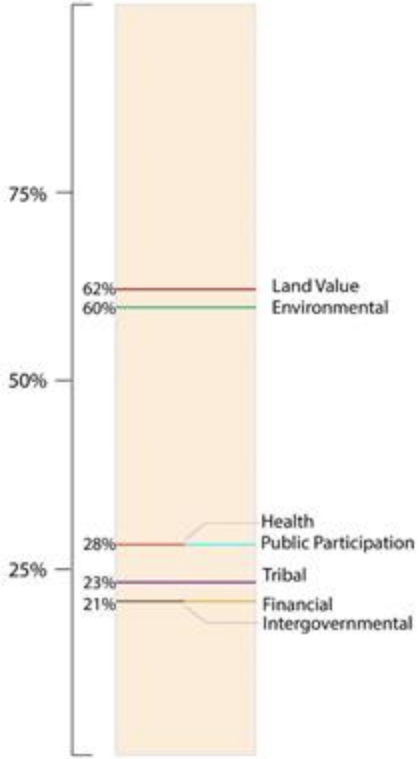
ESIG | June 15, 2026

Environmental Studies
FOR OUR SHARED FUTURE
UC SANTA BARBARA

UCSB

situated on the unceded lands and waters of the Indigenous Chumash people

SOURCES OF SITING CONFLICTS ARE NUMEROUS AND ON THE RISE



Sources of opposition to renewable energy projects in the US (Susskind 2022)

Conflicts escalate amid surge in WA solar farm proposals

June 13, 2022 at 6:00 am | *Updated June 13, 2022 at 11:47 am*

Hundreds of Michigan clean energy projects wait years to plug in. Most never do

Updated: Mar. 23, 2025, 6:01 a.m. | Published: Mar. 23, 2025, 6:00 a.m.

Green power runs up against desert conservation in California

By THE TIMES EDITORIAL BOARD MAR 11, 2019 | 4:10 AM

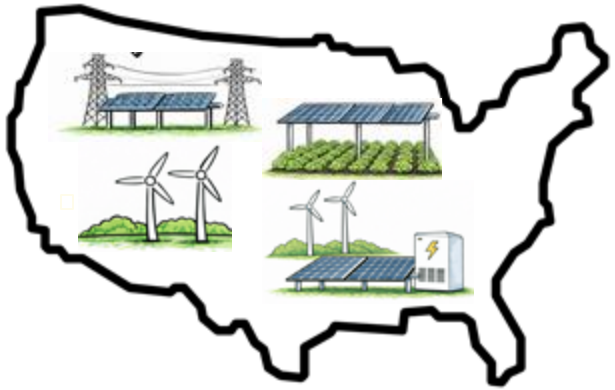
SCIENCE ENVIRONMENT

Oregon Restricts Solar Development On Prime Farmland

By Cassandra Profita (OPB)

Sherwood, Ore. May 23, 2019 4:45 p.m.

Projects



1. Power of Place

The Nature Conservancy

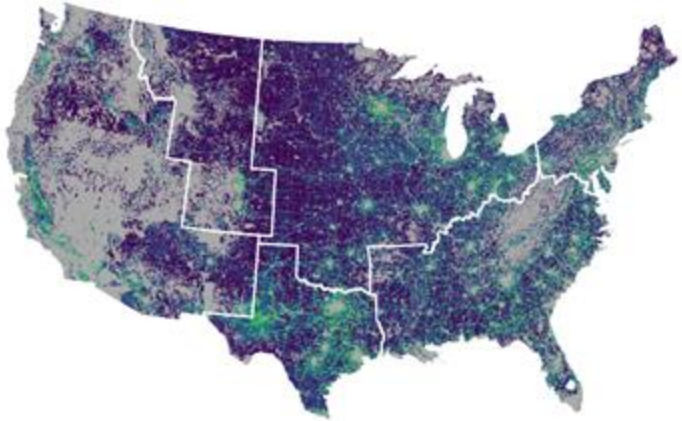
EVOLVED ENERGY RESEARCH

MONTARA MOUNTAIN ENERGY

Erica Brand, Sophie Parker, Brian Cohen, Joseph Fargione, Julia Prochnik, Maya Batres, Mary Gleason, Michael Schindel, Charlotte Stanley, Liz Kalies, Chris Hise, Christel Hiltibran, Nels Johnson, Jessica Wilkinson

Ryan Jones, Emily Leslie

James H Williams, Andrew Pascale, Rebecca Hernandez



2. Factors shaping wind and solar project siting in the US

UCSB

Yohan Min, Ranjit Deshmukh

Paloma Cartwright, Joseph DeCesaro, Daniel Kerstan, Desik Somasundaram and Henry Strecker

Power of Place

California

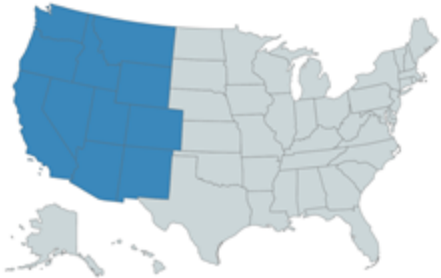
- "Low-impact land use pathways to deep decarbonization of electricity" (Wu et al., 2020, *Environmental Research Letters*)
- Environmental exclusions and environmental impact metrics

100% carbon-free and renewable electricity by 2050

West

- "Minimizing habitat conflicts in meeting net-zero energy targets in the western United States" (Wu et al. 2023, *Proceedings of the National Academy of Sciences*)
- Environmental exclusions and some social impact metrics

Net zero economy-wide emissions by 2050



National

- Journal paper(s) in prep
- Executive Summary
- Environmental AND social impact scoring system and expanded set of social impact metrics

Net zero economy-wide emissions by 2050

Research questions

What **role could land-sparing renewable energy siting approaches** play in reducing the land use requirements of the buildout needed to achieve net zero by 2050 in the US?

Clean energy needs

What is the composition of clean energy technologies needed by 2050?

Land area requirements

How much land area will be needed?

Impact to land

How do shifts in clean energy technologies impact natural areas and working lands?

Socio-environmental considerations

What are the infrastructure buildout differences of minimizing environmental and social impacts separately and in conjunction?

METHODS: Integrated land-energy modeling approach

1. Environmental & social data collection and processing

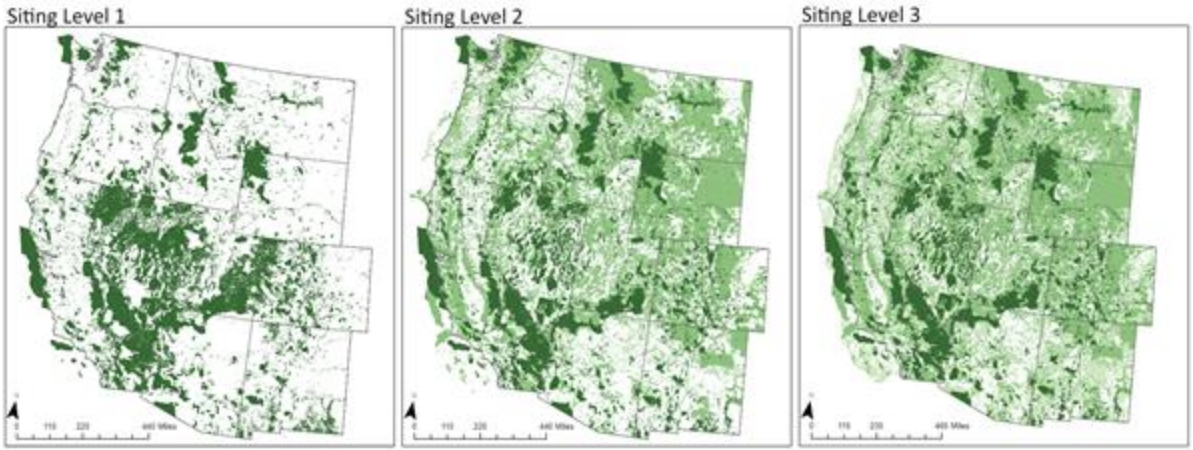
250+ datasets

2. Renewable resource mapping

MAP RE

Site suitability

ENVIRONMENTAL SITING LEVELS



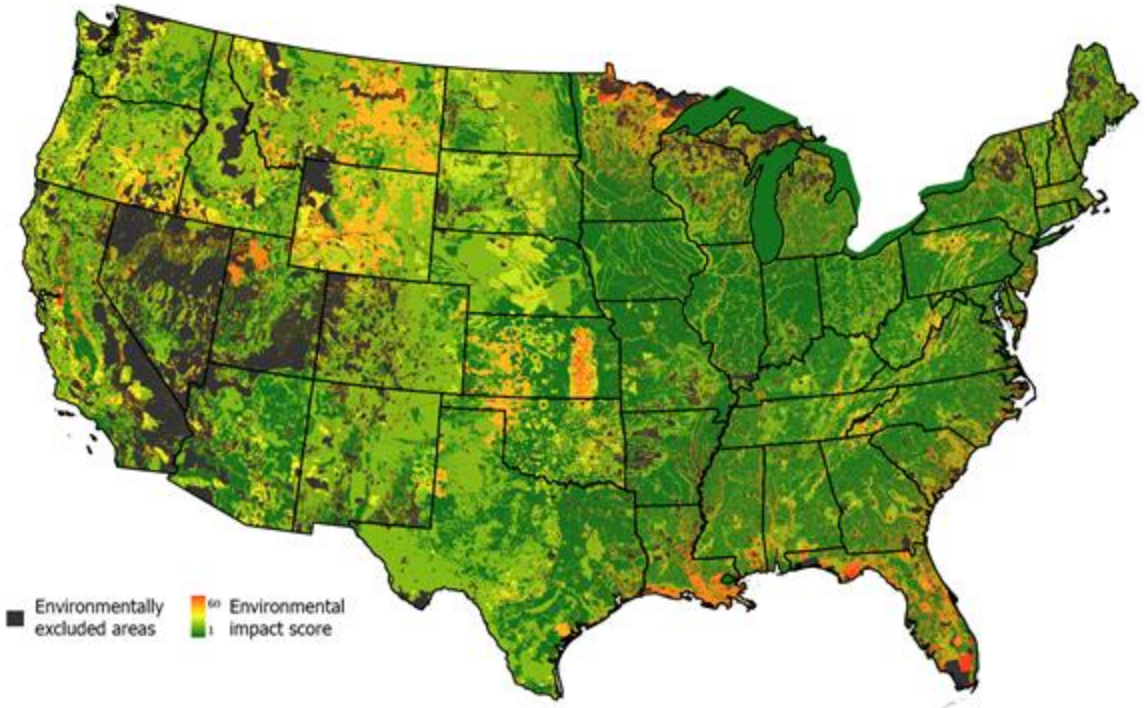
Power of Place - West

Categories	Definition of Category	Examples
Level 1	**Legally protected:** Areas with existing legal restrictions	**National Wildlife Refuges**, National Parks, Marine Sanctuaries, Military Training Areas
Level 2	**Administratively protected:** Level 1 + areas with existing administrative and legal designations requiring consultation or review; lands with conservation restrictions owned by NGOs.	**Critical Habitat for Threatened or Endangered Species**, Sage Grouse Priority Habitat Management Areas, vernal pools and wetlands, tribal lands
Level 3	**High conservation value:** Level 1 + Level 2 + areas with high conservation value per multi-state or ecoregional analysis (e.g., state, federal, academic, NGO) and lands with social, economic, or cultural value.	**Big game priority habitat and corridors**, Prime Farmland, Important Bird Areas, TNC Ecologically Core Areas, "Resilient and Connected Network"

METHODS: Environmental impact score - solar PV

Categories	Score	Solar Discount	Wind Discount
Wetlands	30	1	0.5^2
Managed areas	15	1	0.5
Threatened and Endangered species habitat and occurrences	10	1	0.5
Intact habitat	10	1	0.5
Focal bird habitat	10	1	1
Bat habitat	3	1	1

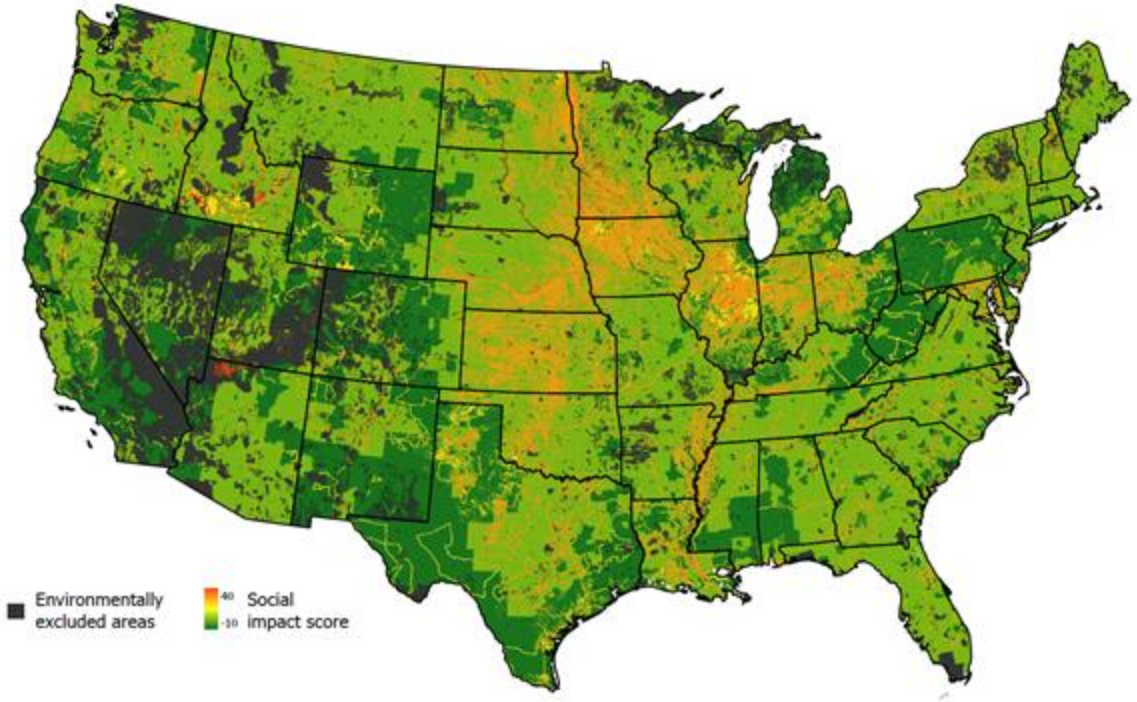
Download social and environmental data on Zenodo here: https://zenodo.org/record/7878144



METHODS: Social impact score - solar PV

Categories	Score	Solar Discount	Wind Discount
Productive and valuable farmland (prime farmland)	15	1	0
Scenic areas	15	1	0.5
Recreational Areas	10	1	0.5
Populated areas	3-5	0	1
Marginal farmland	-5	1	1
Energy communities	-5	1	0.1

Download social and environmental data on Zenodo here: https://zenodo.org/record/7878144



METHODS: Integrated land-energy modeling approach

1. Environmental & social data collection and processing

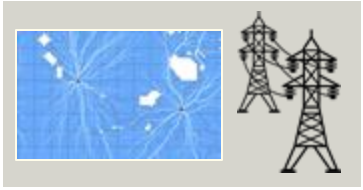
250+ datasets

2. Renewable resource mapping

MAP RE

Site suitability

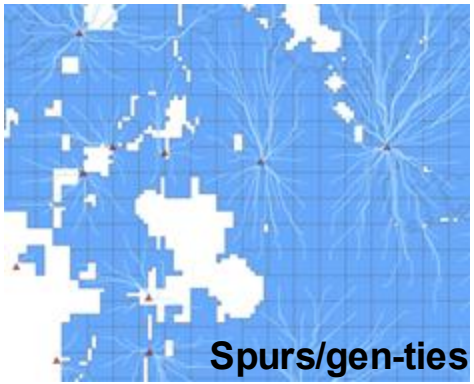
3. Power line routing and costing



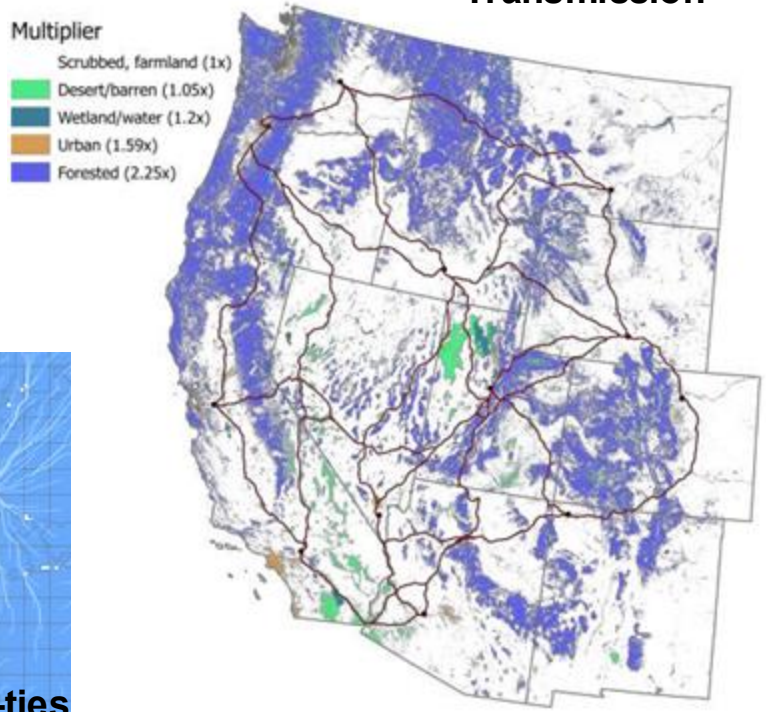
Least cost path modeling

METHODS: Routing and costing for power line modeling

1. Develop cost and routing surfaces using multipliers
2. Route spur lines using routing surface
3. Estimate line costs using costing surface



Interzonal Transmission



Criteria	Value[1]
Forested	2.25
Urban	1.59
Wetlands (and water)[5]	1.20
Desert/barren	1.05
Scrubbed/Farmland/(& other)[5]	1.00
mountain (greater than 4 degrees)	1.75
rolling hills (between 1 and 4 degrees)	1.40
flat (less than 1 degree)	1.00
Category 1	100 (TNC)[3]
Category 2	20 (TNC)
Category 3	15 (TNC)
No Category	1 (TNC)
< 5km from either	100 (32)
New builds + in existing ROW	9 (TNC)[7]
Co-locate + outside existing ROW >= 230 kV	9 (TNC)[7]
230 kV reconductor + outside existing ROW = 230 kV	2.22[9]
345 kV reconductor + outside existing ROW = 345 kV	1.82[9]
500 kV reconductor + outside existing ROW = 500 kV	1.54[9]
230 kV + population density > 100 people/square mile	1.1
345 kV + population density > 100 people/square mile	1.3
500 kV + population density > 100 people/square mile	1.5
risk scaled[6]	1 to 5 (TNC)[2]

METHODS: Integrated land-energy modeling approach

1. Environmental & social data collection and processing

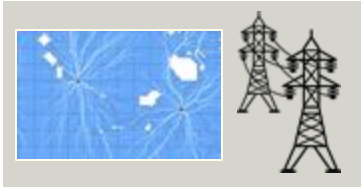
250+ datasets

2. Renewable resource mapping

MAP RE

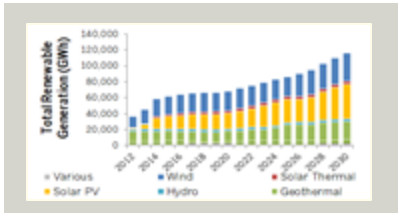
Site suitability

3. Power line routing and costing



Least cost path modeling

4. Capacity expansion optimization



ENERGY PATHWAYS

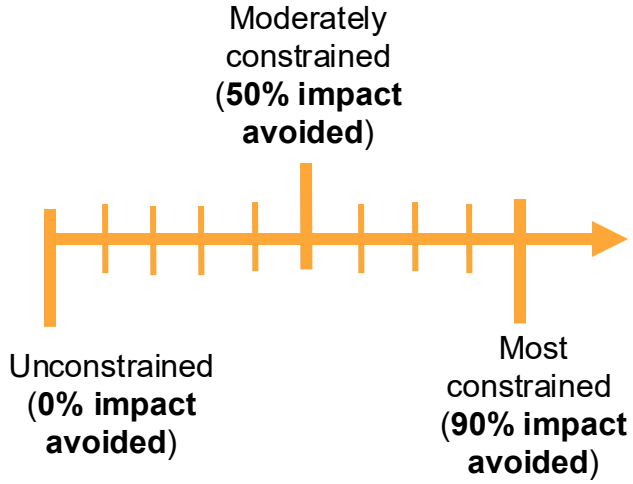
RIO

1. Run RIO without any social or environmental constraints

2. Calculate the total impact

3. Ratchet down unconstrained total impact in 10% increments

4. Run RIO



METHODS: Integrated land-energy modeling approach

1. Environmental & social data collection and processing

250+ datasets

2. Renewable resource mapping

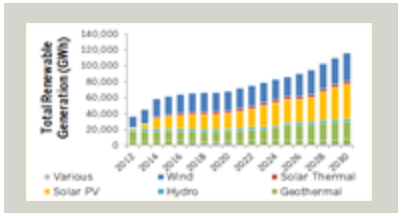
MAP RE

Site suitability

3. Power line routing and costing

Least cost path modeling

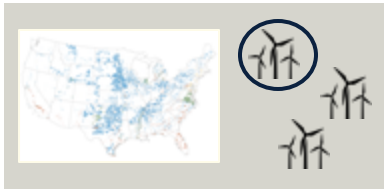
4. Capacity expansion optimization



ENERGY PATHWAYS

RIO

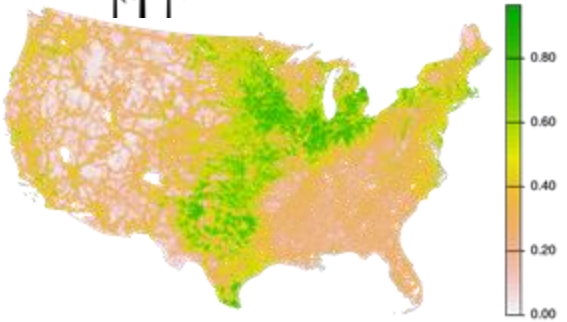
5. Site selection



Statistical approaches using historic data

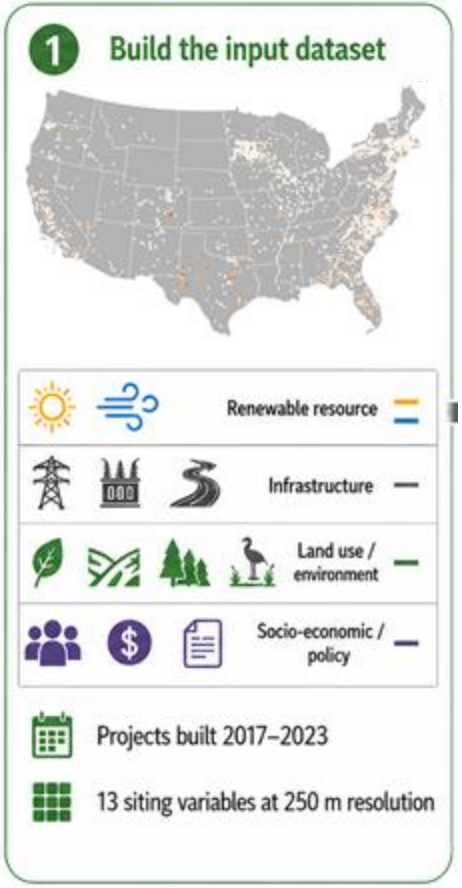
Prediction surfaces

Onshore wind

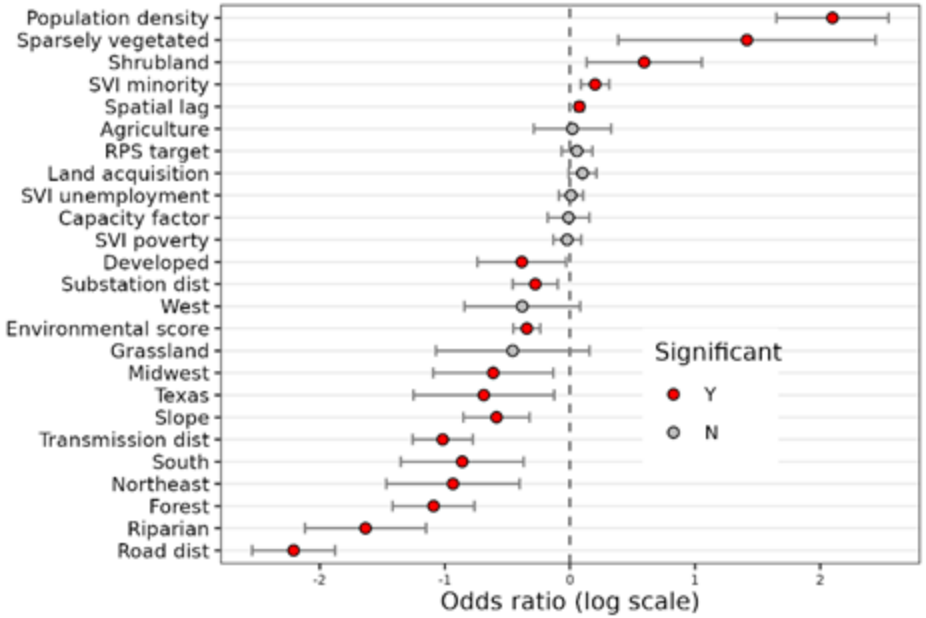


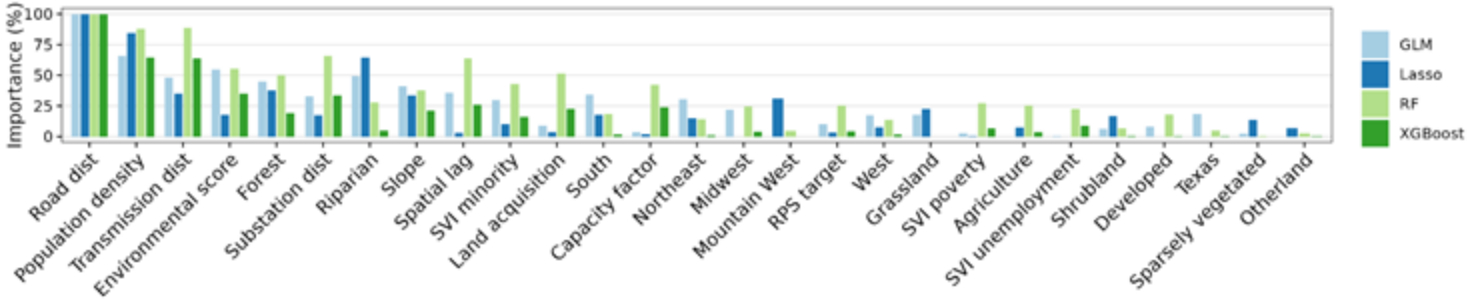
Utility-scale PV

Approach

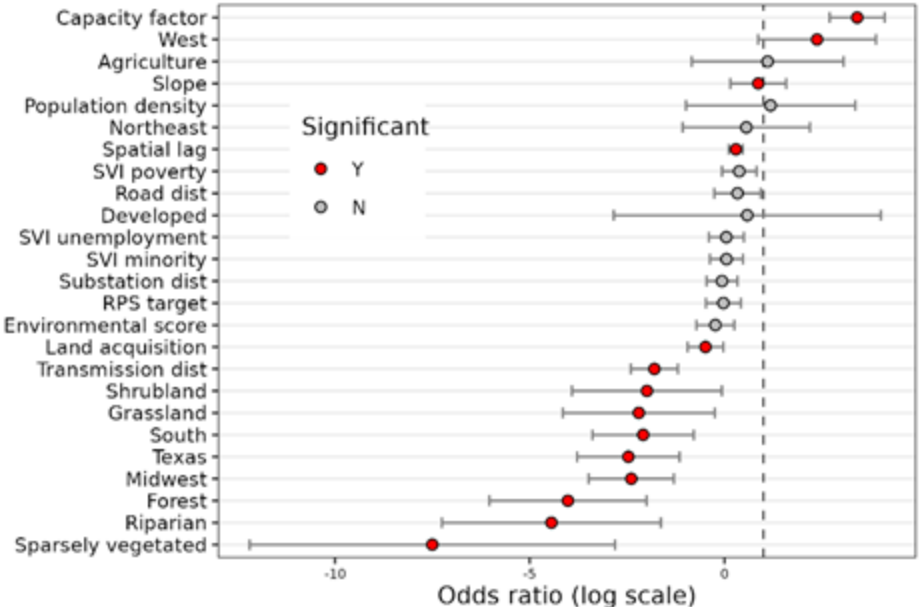

1
Build the input dataset
Renewable resource
Infrastructure
Land use / environment
Socio-economic / policy
Projects built 2017–2023
13 siting variables at 250 m resolution

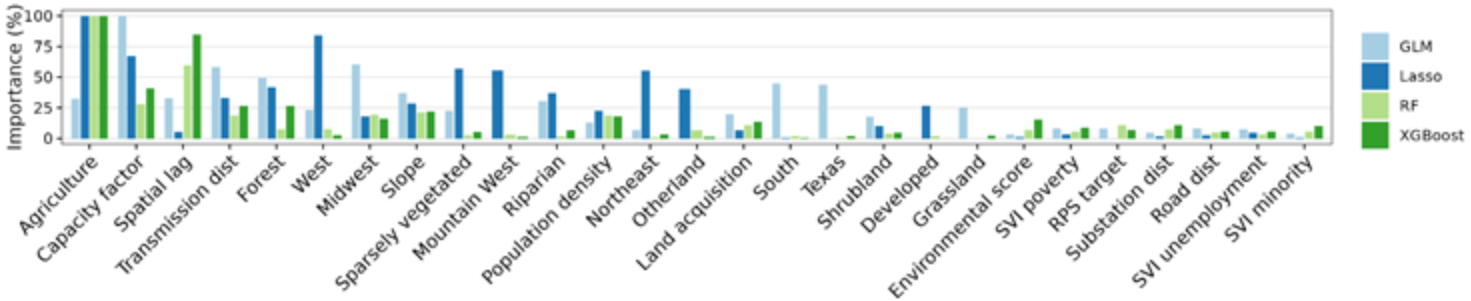
Solar variables of high importance





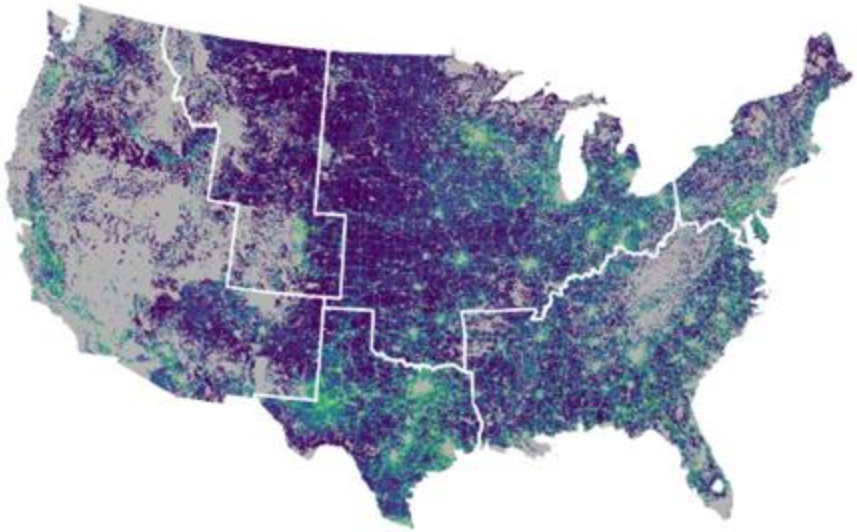
Wind variables of high importance



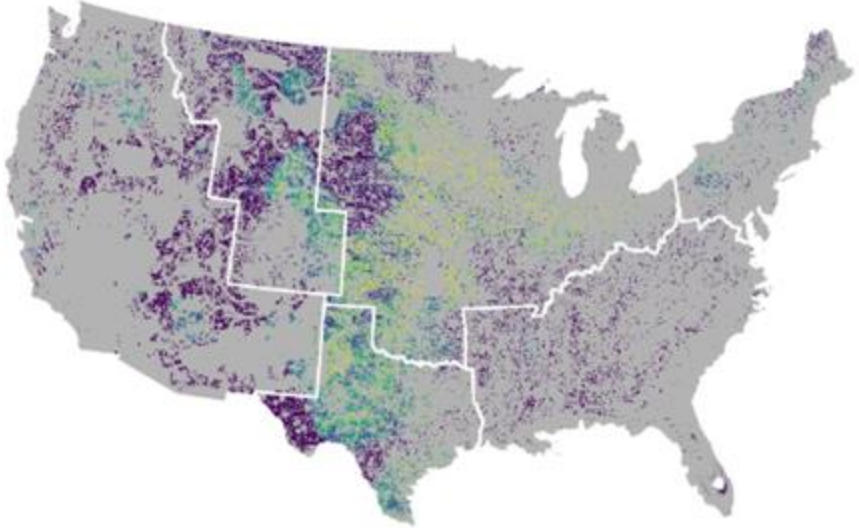


Prediction surfaces

Utility-scale solar (random forest)



Onshore wind (random forest)



METHODS: Integrated land-energy modeling approach

1. Environmental & social data collection and processing

250+ datasets

2. Renewable resource mapping

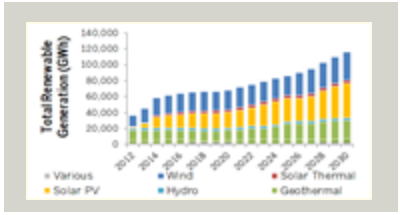
MAP RE

Site suitability

3. Power line routing and costing

Least cost path modeling

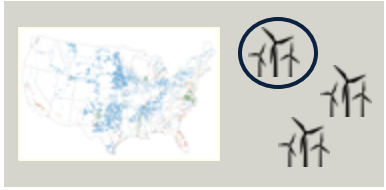
4. Capacity expansion optimization



ENERGY PATHWAYS

RIO

5. Site selection



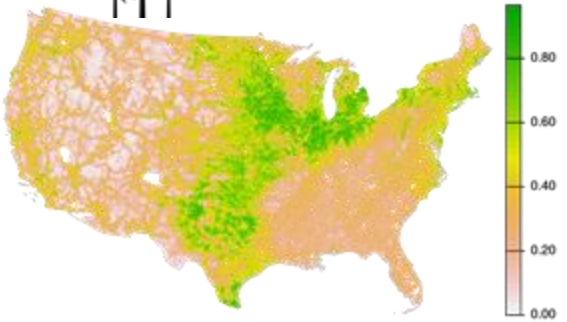
Statistical approaches using historic data

6. Impact assessment

GIS overlays with environmental and social data

Prediction surfaces

Onshore wind



Utility-scale PV

METHODS: Characterizing land sparing technologies and siting strategies

Crop-based agrivoltaics

Crops suitable for agrivoltaics:

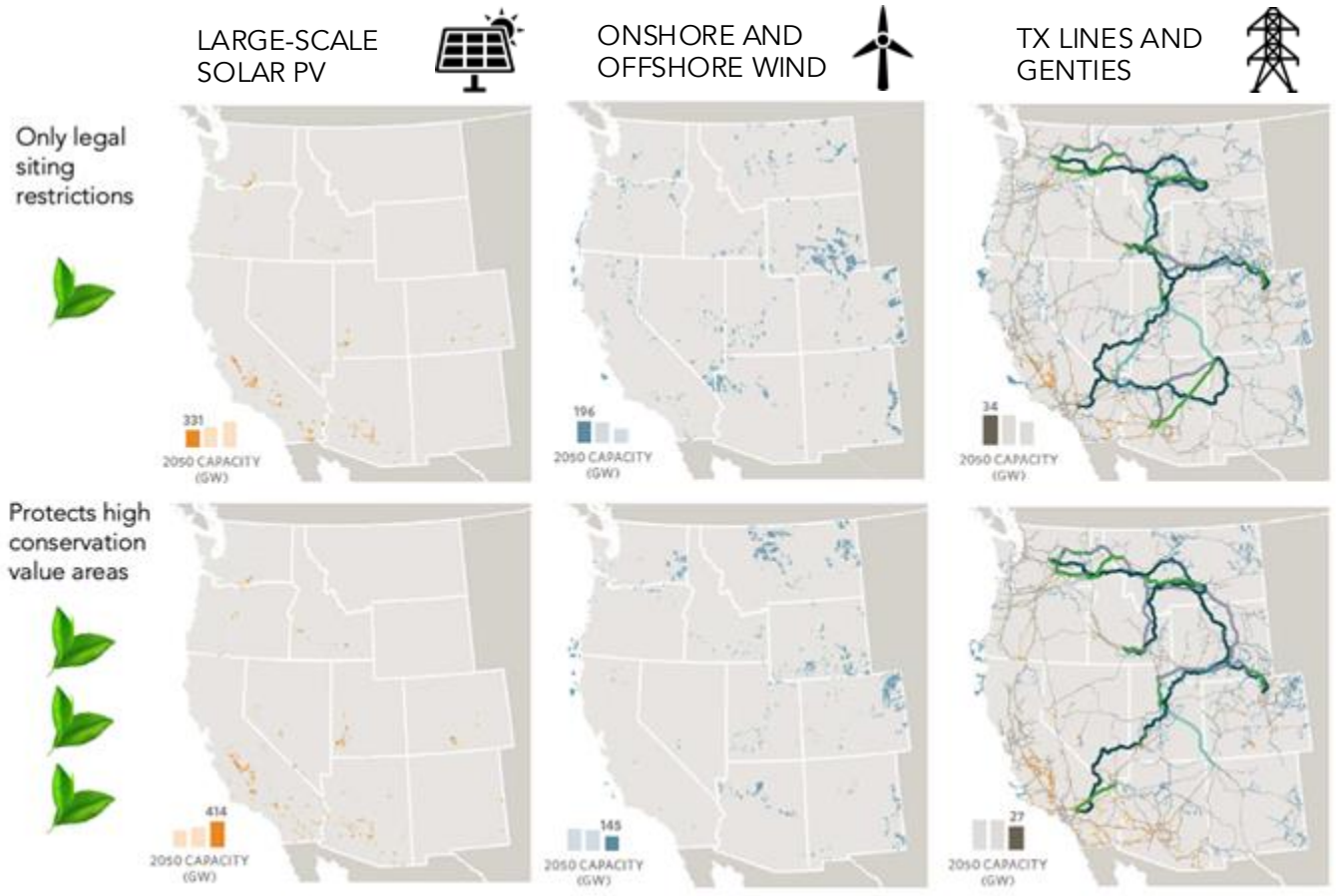
- Misc Vegs & Fruits
- Cucumbers
- Tomatoes
- Grapes
- Broccoli
- Peppers
- Lettuce
- Cabbage
- Cauliflower

Wind-solar co-location

Co-location of renewables leads to 'significant cost savings'

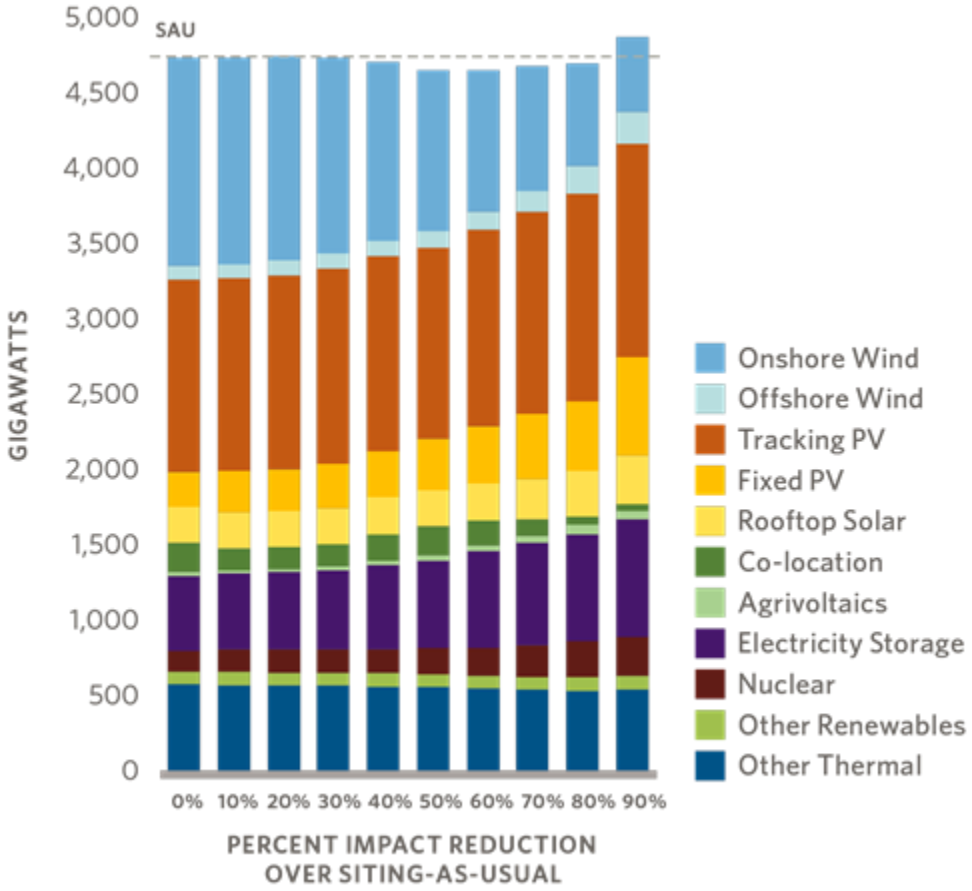
Fixed-tilt vs. tracking PV

RESULTS: Western buildout of wind, solar, tx by 2050

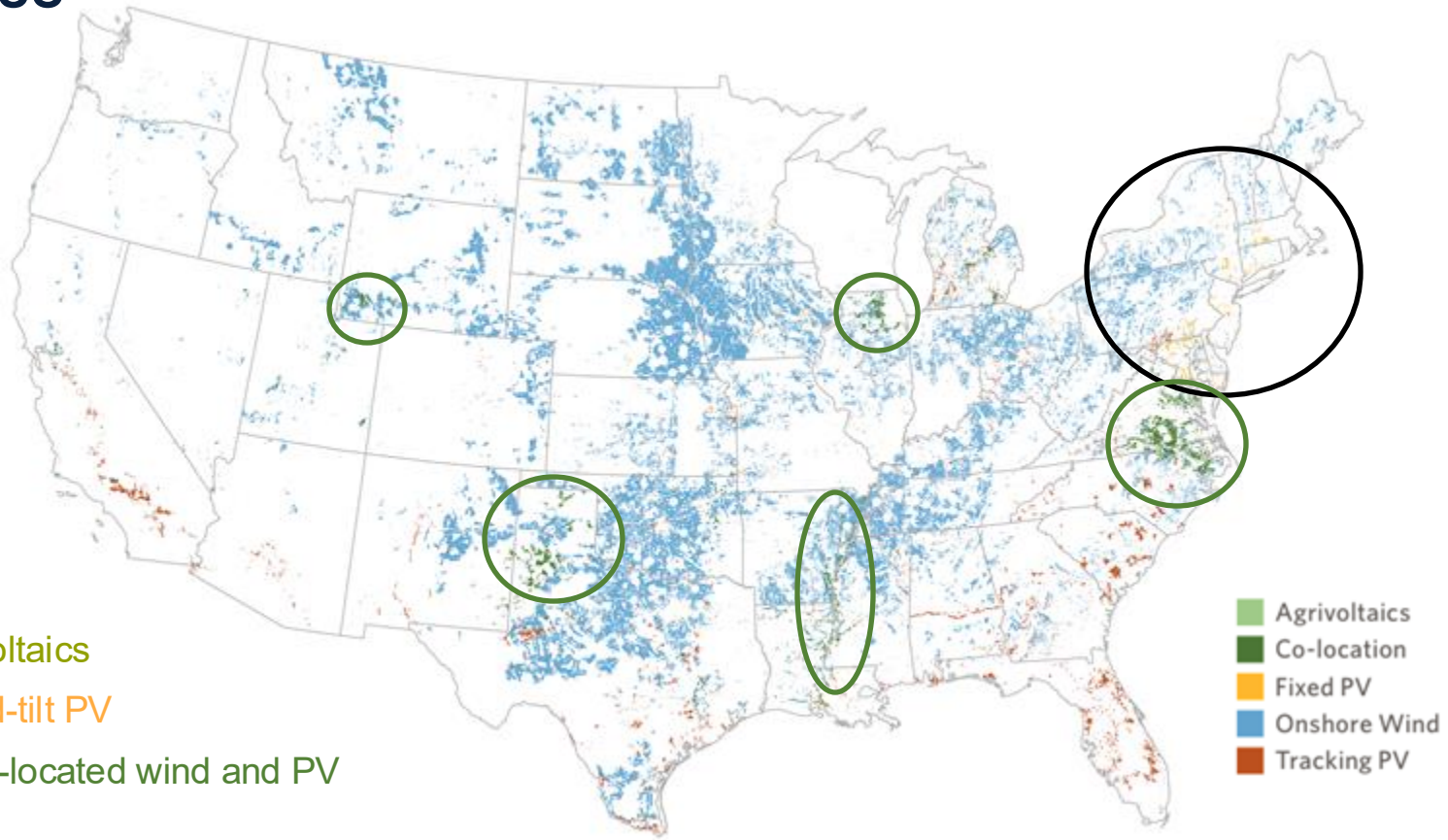


Build-outs differ in response to different levels of land/ocean use protections, most notably for transmission and wind

RESULTS: Electricity portfolio

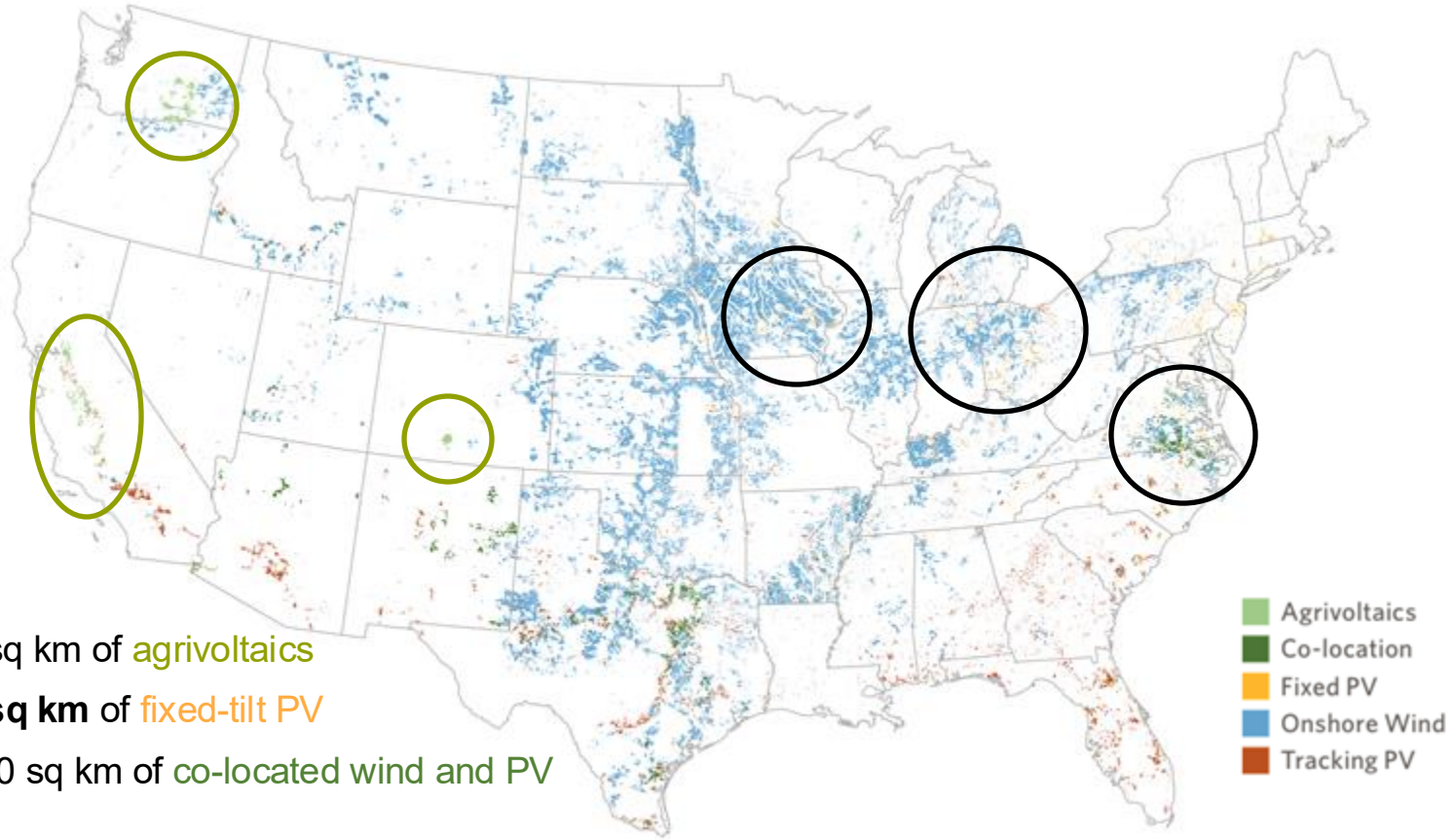


RESULTS: Wind and PV build-out, 0% Impact Avoided (Siting-As-Usual) in 2050



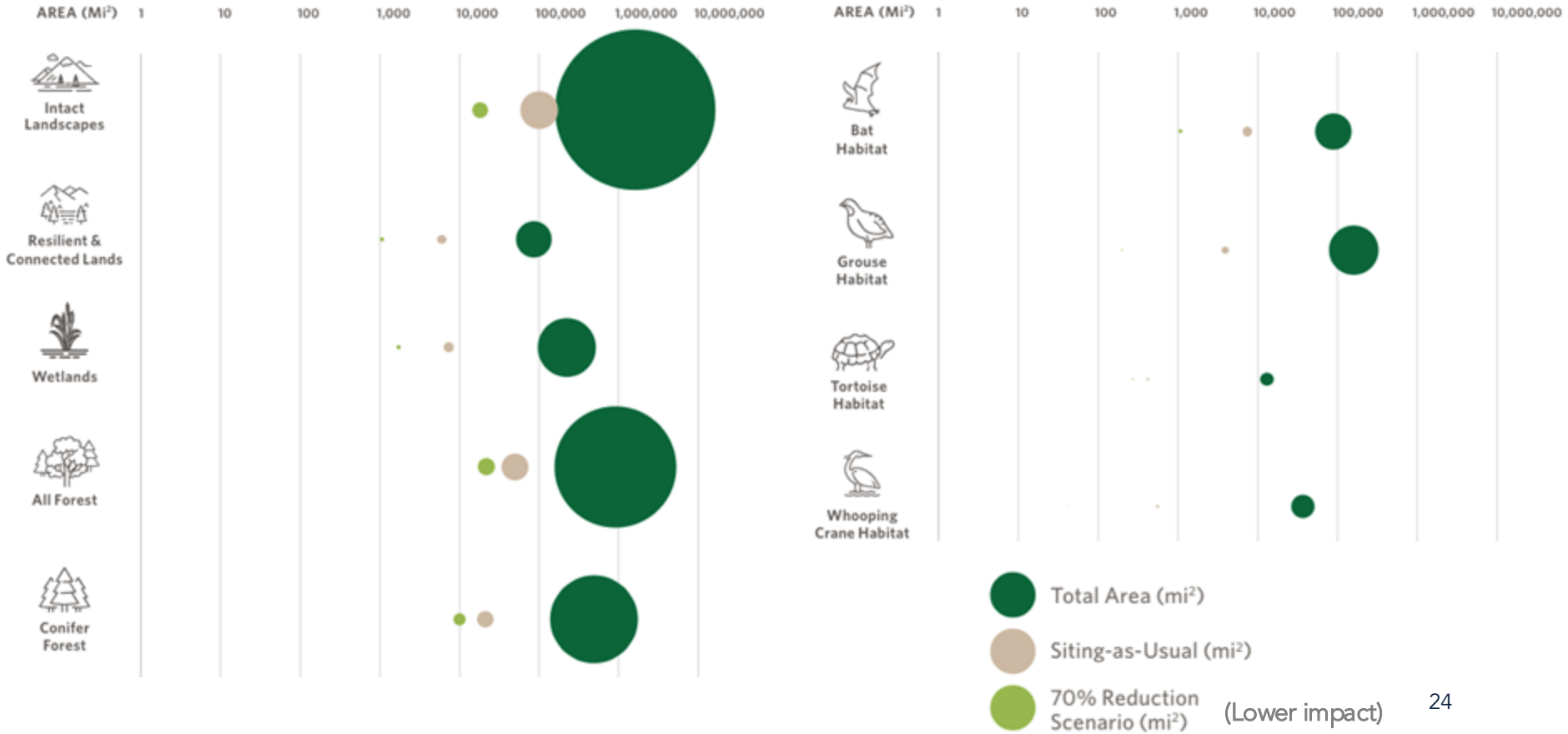
- 550 sq km of agrivoltaics
- 3200 sq km of fixed-tilt PV
- 24,000 sq km of co-located wind and PV

RESULTS: Wind and PV build-out, 70% Impact avoided in 2050



- **Increase to 1550** sq km of agrivoltaics
- **Increase to 5900 sq km** of fixed-tilt PV
- **Decrease** to 15,000 sq km of co-located wind and PV

RESULTS: <2% of land cover and habitat types are converted in the 70% impact scenario



CONCLUSIONS

Environmental and social land constraints:

- Change the renewables landscape by shifting from wind to solar, but the overall potential for renewable development remains the same
- Increase the economic competitiveness of agrivoltaic and fixed-tilt PV systems
- Reduce co-location opportunities, likely due to reduction in overall onshore wind capacity
- Reduce total project area by 33% and direct land conversion by 8%

Relevance for policy, planning, and practice

- Maps used in TNC's Site Renewables Right tool
- Regional and state chapters of TNC have used this as a blueprint for identifying state level optimal sites
- Maps have been or are being used by some solar developers for siting
- Multiple transmission planning studies have used Power of Place - West as scenarios for future build-out
    - California Public Utilities Commission and California Independent System Operator's Transmission Planning Process Busbar mapping
    - GridLab's Connected West study
    - Western Transmission Expansion Coalition (WestTEC)'s 10 year study

Opportunity areas and next steps

- Project scale, agrivoltaic vs. non-agrivoltaic projects
- Dynamic database of projects and siting criteria
- Integration of social (particularly, case study, interview, survey) data with environmental, techno-economic
- Siting outcomes reflect interconnection queue bottlenecks, yet interconnection data are not considered in predictive models
- Comprehensive national ordinance dataset

THANK YOU

EXTRA SLIDES