JISEA Joint Institute for Strategic Energy Analysis

2023 JISEA Annual Meeting: JISEA Catalyzer Spotlight—Energy and Atmospheric Systems Catalyzer

Garvin Heath & Michael Martin

April 26, 2023

NREL Transforming ENERGY · Colorado School of Mines · Colorado State University · Howard University Office of Research · Massachusetts Institute of Technology · Stanford University · University of Colorado Boulder

JISEA Joint Institute for Strategic Energy Analysis

Energy and Atmospheric Systems Catalyzer Overview

Garvin Heath

April 26, 2023

NREL Transforming ENERGY
COLORADO SCHOOL OF MINES
COLORADO STATE UNIVERSITY
HOWARD UNIVERSITY Office of Research
Massachusetts Institute of Technology
Stanford University
University of Colorado Boulder

Energy and Atmospheric Systems Catalyzer

Model and quantify multidirectional relationships of climate, air quality, and energy systems

Co-PIs: Garvin Heath and Michael Martin

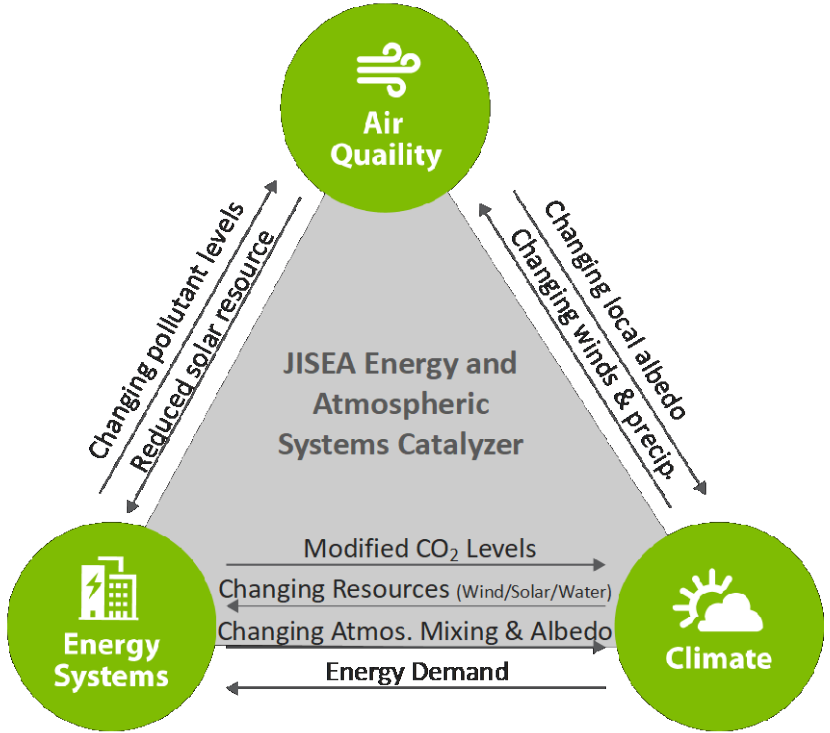
Climate and air quality are drivers of global transitions in power, transportation, industry, buildings, and product design.

The complex relationship between energy, climate and clean air *requires expertise in all three domains*

- *The answers impact renewable energy adoption, sustainability, and environmental justice.*

NREL research sponsors are asking some of these questions.

Goal of this catalyzer theme is to grow capability and ensure NREL/JISEA is a recognized leader.

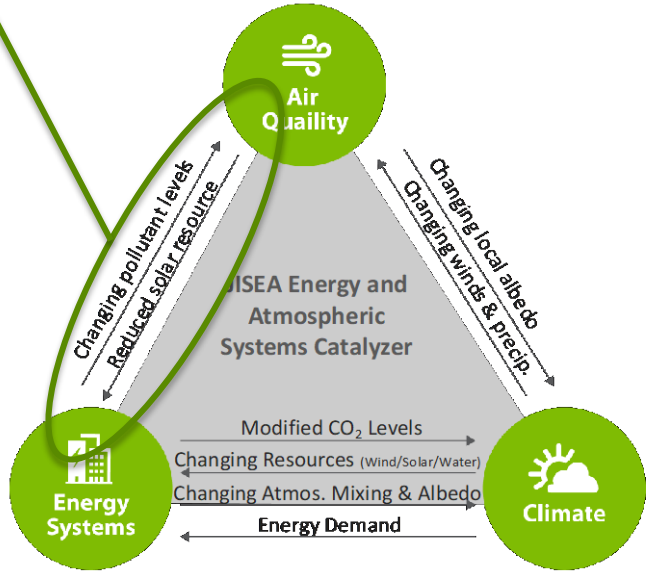


Overview: Energy Systems and Air Quality

Focus on effects in both directions and extensions to health and disparities

Sample questions

- How much could air quality improve with RE adoption? Could cities/nations come into compliance with health-protective standards? Will documented disparities of air pollutant exposure and health be reduced?
- How much does current air pollution reduce solar power output (US and int'l)? Can we forecast air pollution episodes (including wildfire) to increase grid reliability?
- How much will reduced non-GHG emissions benefit GHG mitigation and vice versa?



Example Catalyzer Projects: Air Quality

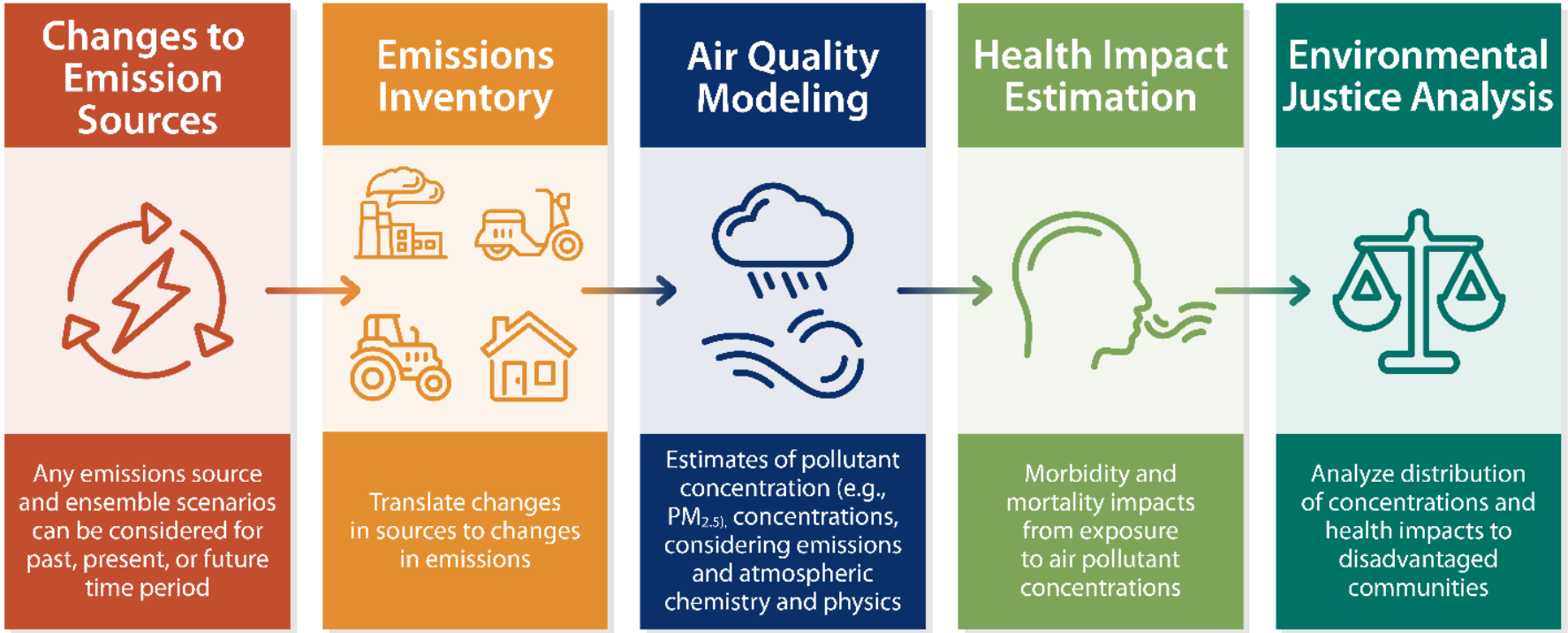
Anchor and Ongoing Projects

- **LA100** - Los Angeles 100% renewable energy study, including environmental justice, air quality, grid integration analysis
- **ExxonMobil** - Air quality analysis of biofuel supply chain (life cycle) (first funded project under the $100M CRADA)
- **DOE/BETO** - Air pollutant emissions from advanced biorefinery designs, support of Triennial Report to Congress on biofuel sustainability, etc.

Clients/Projects Won During Catalyzer

- **LA100-Equity Strategies** - Truck electrification benefits to AQ, health and EJ
- **LADWP Strategic Long Term Resource Plan** - Changes to NOx emissions from conversion of fleet to H_2 combustion, as ordered by LA City Council
- **DOE/SETO** - Effect of increased frequency and severity of wildfires on reduction in solar power output and resultant need for better planning of grid reserve margin
- **USAID** - Co-benefits of renewables integration into SE Asian power grid in terms of air quality and health

General Approach to Air Quality/EJ Studies



NREL's Experience in Air Quality/Health-related EJ Research

Regional air quality modeling (state-of-the-science and reduced-complexity models)		
Study/Topic	**Published/Ongoing**	**Sectors**
LA100	Air quality/health Environmental Justice	Conversion of power plants to H_2, amongst changes to many load sectors
Industrial Process Heat H_2 Substitution	Ongoing	Petroleum refining, cement and steelmaking
Near-source modeling (~10-100m ground-level resolution)		
Utility Long-Term Resource Planning	Ongoing	Conversion of gas turbines to H_2
LA100-Equity Strategies	Ongoing	Implementation-ready strategies for electrification of medium- and heavy-duty vehicles

Example Study: Hydrogen for Industrial Decarbonization

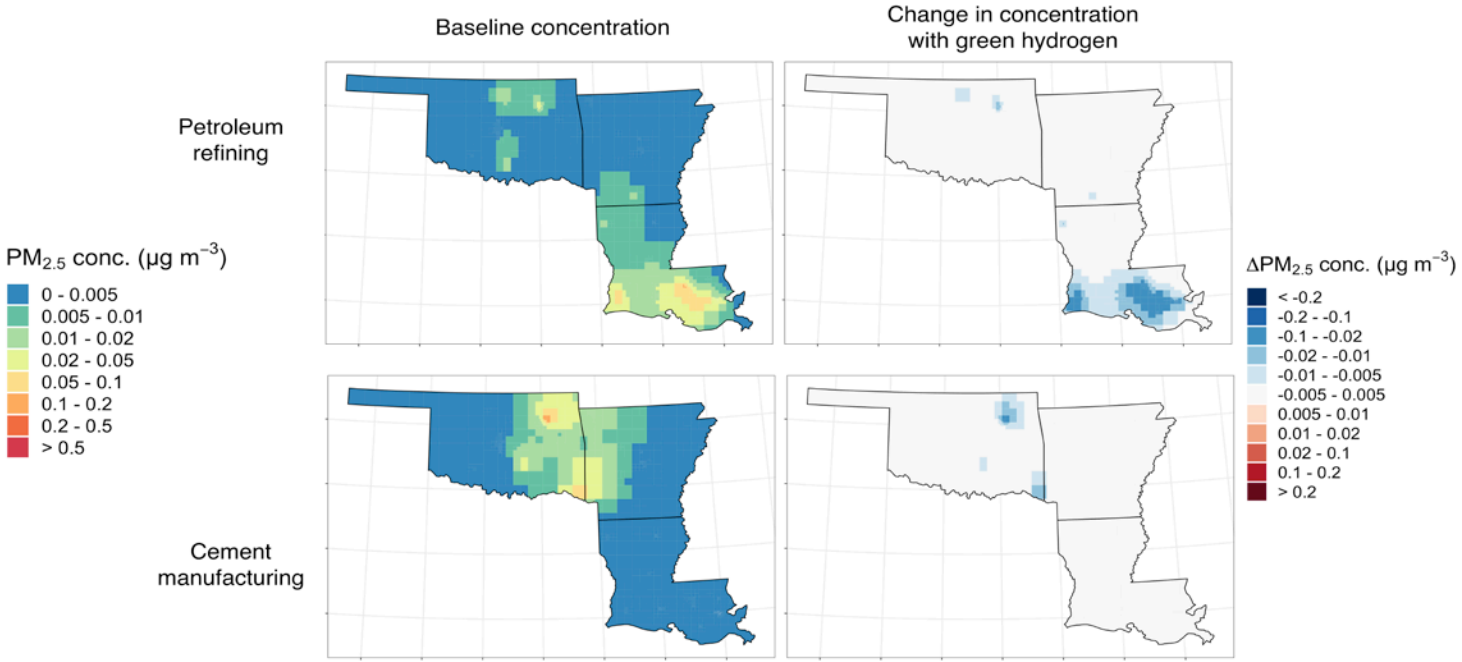
In preparation

Fuel Switching to Hydrogen

- Industrial process heat accounts for 20% of domestic CO_2 emissions and substantial air quality damages that disproportionately impact minority communities
  - Fuel switch to hydrogen is a viable decarbonization strategy with air quality benefits
- We estimated changes in $PM_{2.5}$ concentrations for fuel switch to gray, blue, and green hydrogen in
  - petroleum refining (in progress)
  - steelmaking, and
  - cement manufacturing

Air Pollutant Concentration Results: $PM_{2.5}$

Example Regional Analysis



Fuel Switching to Hydrogen for an Equitable Energy Transition in Industry

- Substitution with hydrogen in top three CO_2-emitting industries can reduce up to 280 air quality-related premature mortalities per year
- Substitution with green hydrogen leads to greater equity, reducing race/ethnic $PM_{2.5}$ exposure disparities and providing up to 38% of air quality benefits to DACs
- Our analysis, once complete, can identify industries where fuel switching yields optimized multi-criteria benefits to CO_2 emissions, deaths and equitable distribution of co-benefits

Example Study: Air Quality and Public Health Benefits of Decarbonization of Power Sector in Southeast Asia

Overview of Project

GOALS

To quantify air quality and health benefits of renewable energy integration to the ASEAN power grid

HOW

Apply a first-of-its-kind, user-friendly global air quality model to an example energy transition topic in Asia

WHY

To inform regional planning, policymaking, and regulatory decision making. Also, to raise awareness of the model's capability for future decision-relevant studies.

USAID FROM THE AMERICAN PEOPLE | NREL Transforming ENERGY | University of Minnesota Driven to Discover℠ | ASEAN Centre for Energy One Community for Sustainable Energy

Advanced Energy Partnership for Asia

Audience

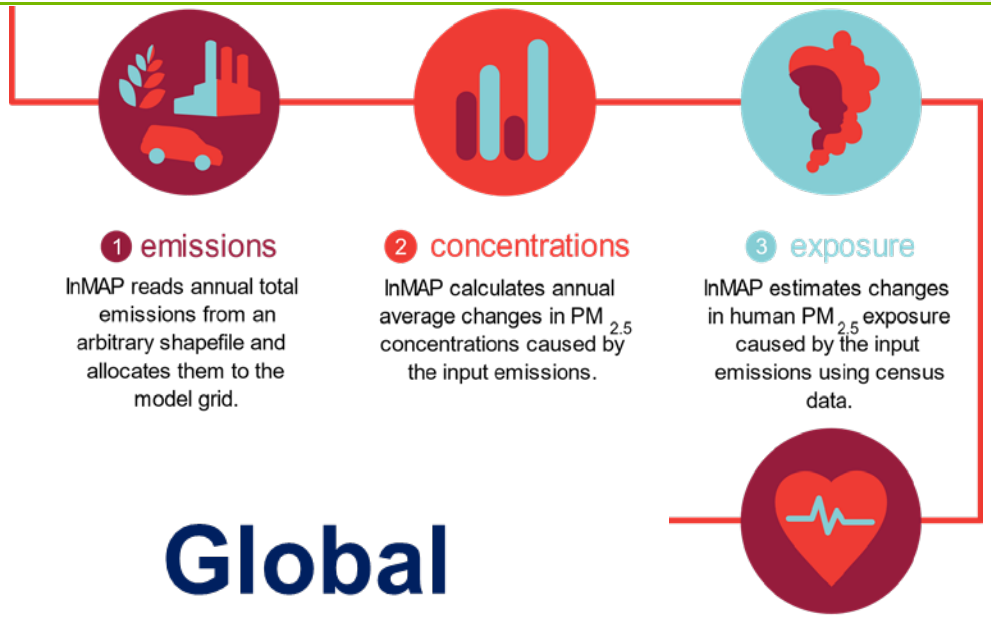
- ACE research staff
- Renewable Energy-Sub Sector Networks (RE-SSN) and Regional Energy Policy and Planning-Sub Sector Networks (REPP-SSN)
- Members of Heads of ASEAN Power Utilities (HAPUA)
- Other interested energy and air quality stakeholders within ASEAN Member States (AMS)

Deliverables

- Training activities and materials – delivered March 2022
- Technical report – October 2022

Air Quality Model: Global InMAP

- **Global InMAP** (Intervention Model for Air Pollution)
  - Global version of a model first developed for the United States
  - Expansion to health was collaboration with University of Minnesota
- One goal:
  - Democratize capability of in-country experts to consider air quality and citizen health in decision making
- Details: *Plos One* article



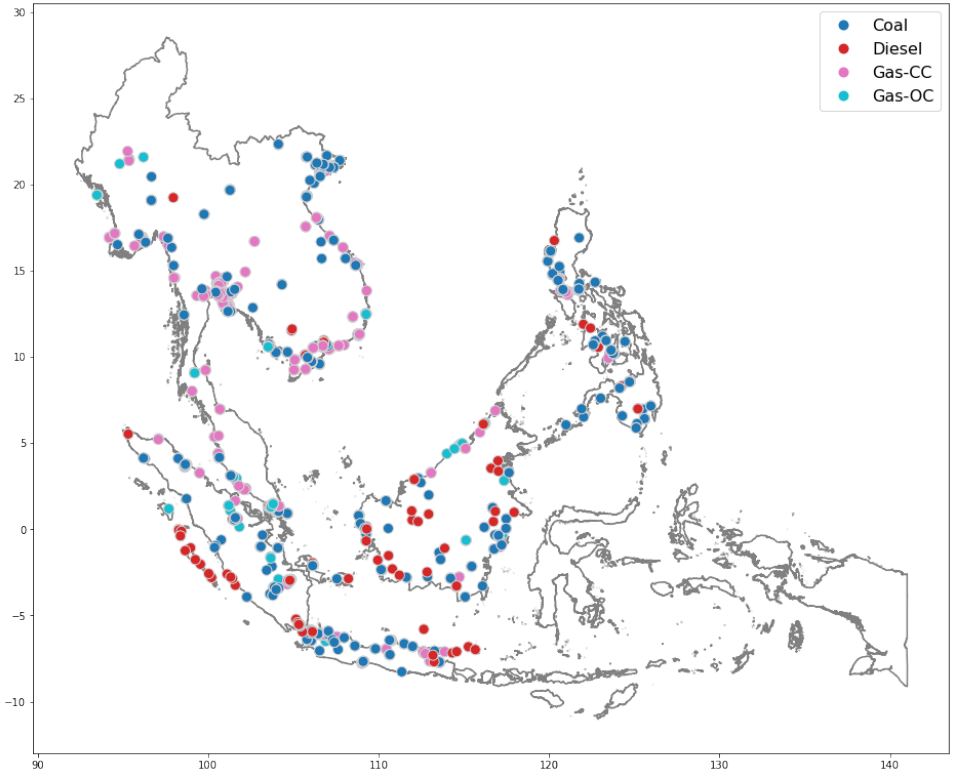
USAID FROM THE AMERICAN PEOPLE · NREL Transforming ENERGY · University of Minnesota Driven to Discover · ASEAN Centre for Energy One Community for Sustainable Energy

Advanced Energy Partnership for Asia

Components of Emissions Inventory

Emissions of air pollutants relevant to formation of fine particulate matter ($PM_{2.5}$)

A. **WHO** emits → AIMS III scenarios tell us generation by fuel type in each ASEAN country
B. **WHEN** emissions occur → AIMS III modeling for generation mixes in 2025, 2030, and 2040
C. **WHERE** emissions occur → locations of specific coal, gas, and oil power plants based on AIMS III and other data sources, as well as height of their smokestacks
D. **HOW MUCH** is emitted → emission rates based on regulations compiled by ACE with contributions from ASEAN Member States

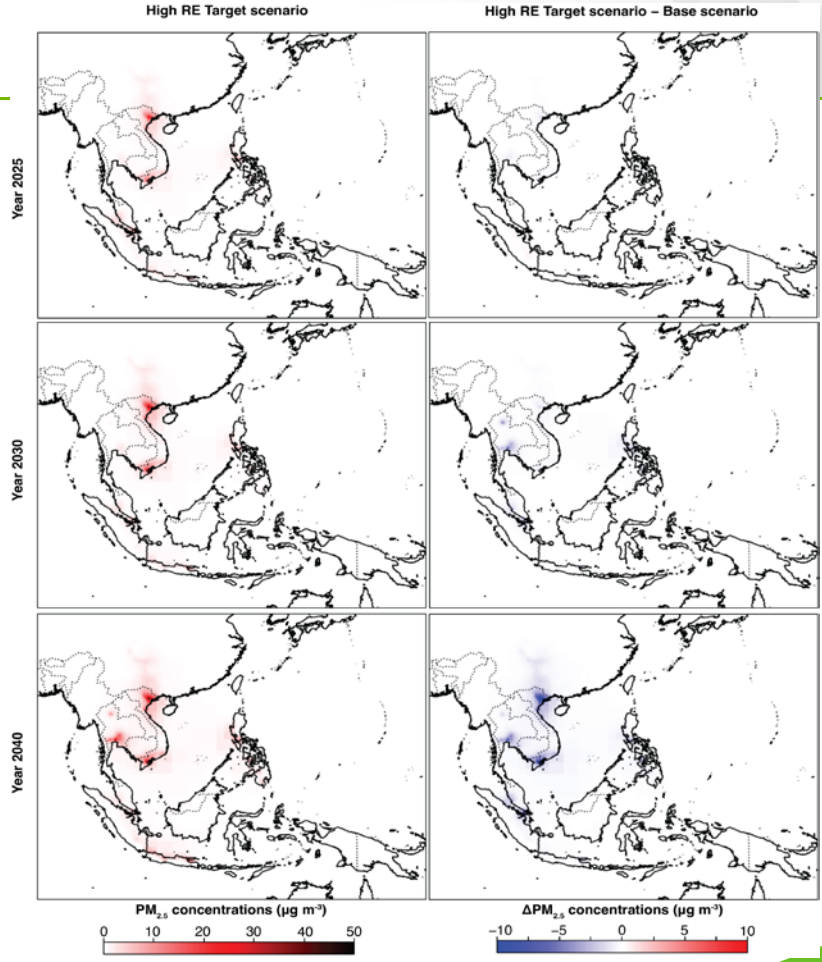


Results: Concentration Changes

$PM_{2.5}$ concentration

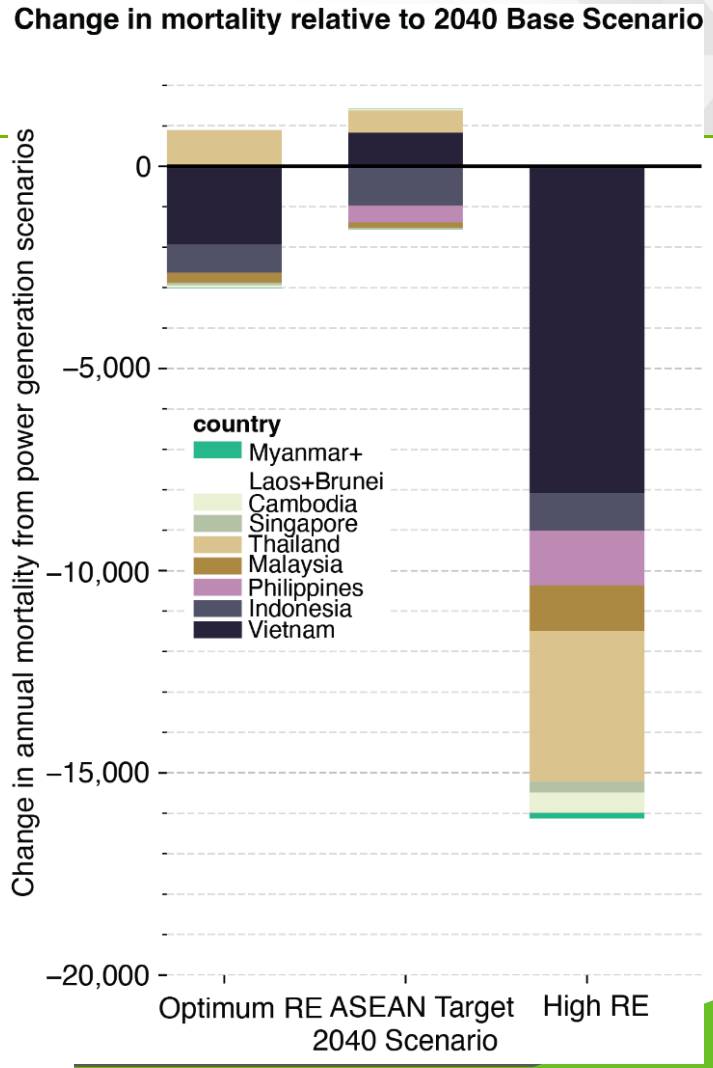
- All scenarios lead to increase in $PM_{2.5}$ concentration because of increased generation, especially coal/gas
- In Optimum RE and High RE Target scenarios, the majority of citizens in ASEAN countries would breathe cleaner air compared to concentrations resulting from the Base Scenario

Year	Change in $PM_{2.5}$ Concentration Relative to Base Scenario ($\mu g\ m^{-3}$)	% of Population Breathing Cleaner Air (Relative to Base scenario)
2040	-0.08	91%
2040	-0.01	34%
2040	-0.50	99%



Results: Mortality Changes

- All alternative AIMS III scenarios lead to decrease in regional, net $PM_{2.5}$-caused annual mortality relative to the Base scenario in 2040
- For the High RE Target scenario, all countries benefit
- A few countries experience increases in $PM_{2.5}$-related excess mortality under the Optimum RE (Thailand) and ASEAN RE Target (Thailand and Vietnam) scenarios



USAID FROM THE AMERICAN PEOPLE | NREL Transforming ENERGY | University of Minnesota Driven to Discover | ASEAN Centre for Energy One Community for Sustainable Energy

Advanced Energy Partnership for Asia

Capability as a Result of Catalyzer

- Air quality has been a driver for decarbonization efforts and is a critical co-benefit with high monetized value, salience to community lived experience and contributor to environmental justice/disparity
- NREL's use of and development of emissions and air quality models is enabling broader use within flagship studies
- JISEA Catalyzer has allowed concentrated effort to expand and elevate capability for both domestic and international clients applicable to any energy sector

Supplemental Slides

Catalyzer: New GHG-related Projects

Water Power Program

Life cycle GHG emissions from modern, domestic pumped hydropower storage

Geothermal Technology Office

Life cycle GHG emissions from low temperature geothermal district heating

National Petroleum Council

Supporting Secretary Granholm-ordered study of life cycle GHG emissions from natural gas for LNG

JISEA Joint Institute for Strategic Energy Analysis

Beyond CO_2 Reduction: Understanding the Interaction Between Climate & Renewable Energy

Michael James Martin

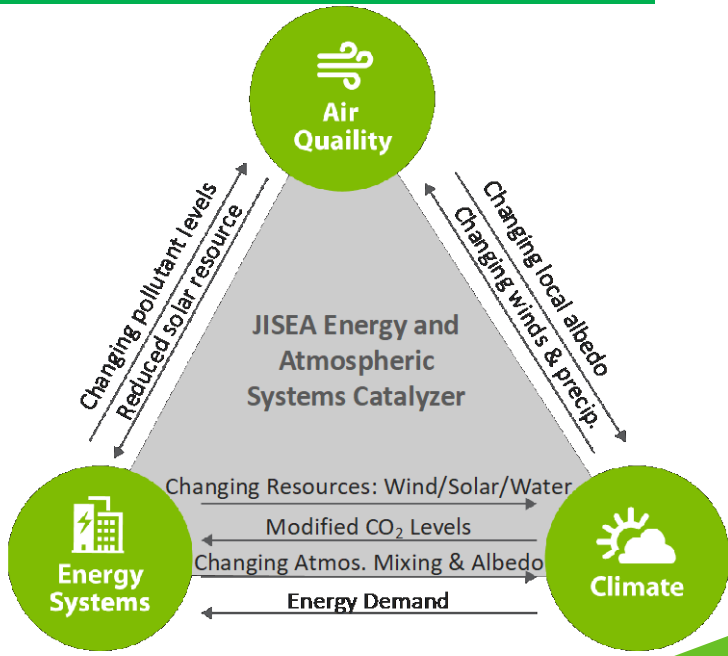
April 26, 2023

NREL Transforming ENERGY · Colorado School of Mines · Colorado State University · Howard University Office of Research · Massachusetts Institute of Technology · Stanford University · University of Colorado Boulder

Renewable Energy and Climate Interactions

The relationship between renewable energy and climate is more complex than simply reducing greenhouse gas emissions.

- Renewable energy resources will be impacted by climate change, often *within the lifetime of systems being currently deployed.*
- Renewable energy has direct feedbacks into the climate, as solar panels change surface albedos and wind farms cause mixing within the atmospheric boundary layer.
- If geoengineering is used for mitigation, renewable resources will be impacted.



Impacts of Climate Change on Renewable Energy

Climate change doesn't just lead to an increase in temperatures, it leads to changes in weather and ecosystems.

Climate Impact		Technology Impacted
Shifting agricultural productivity	→	Biofuels
Changing precipitation patterns	→	Water power
Increased/decreased cloud cover	→	Solar
Changes in local wind patterns	→	Wind Energy

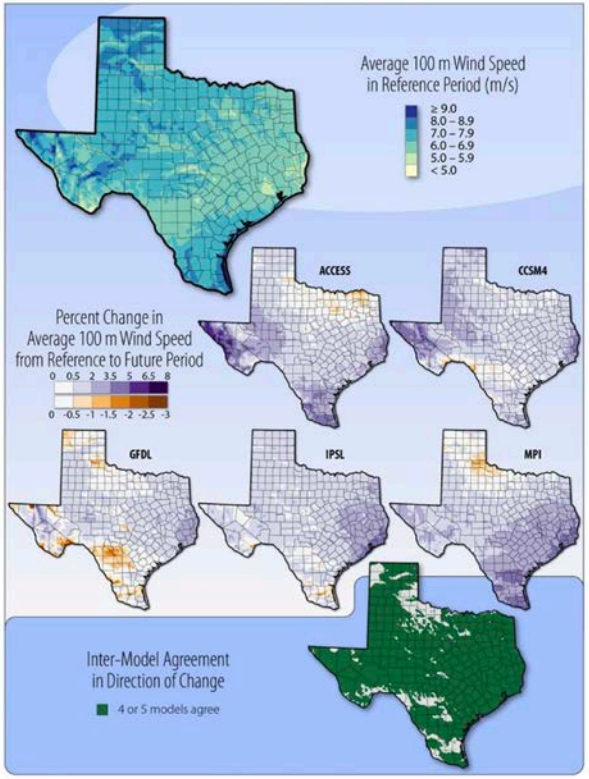
The challenge is *quantifying* impacts.

Modeling Climate Change Impacts on Energy Resources

The methods that can be used to predict renewable energy resources in the existing climate can be adapted to look at future climates.

Climate models operate at length scales *O(100 km)* while wind energy models resource models operate at *O(1 km).*

Using climate simulations to set boundaries for regional simulations work…but results can be very sensitive to climate models!



Predicted change in wind energy resource

I Losada Carreño, *et al. Climatic Change* **163**, 745, 2020.

Modeling Climate Change Impacts of Renewable Energy

Discussion shaped by two high-profile journal papers.

Climate model shows large-scale wind and solar farms in the Sahara increase rain and vegetation

YAN LI, EUGENIA KALNAY, SAFA MOTESHARREI, JORGE RIVAS, FRED KUCHARSKI, DANIEL KIRK-DAVIDOFF, EVIATAR BACH, AND NING ZENG Authors Info & Affiliations

SCIENCE · 7 Sep 2018 · Vol 361, Issue 6406 · pp. 1019-1022 · DOI: 10.1126/science.aar5629

More energy, more rain

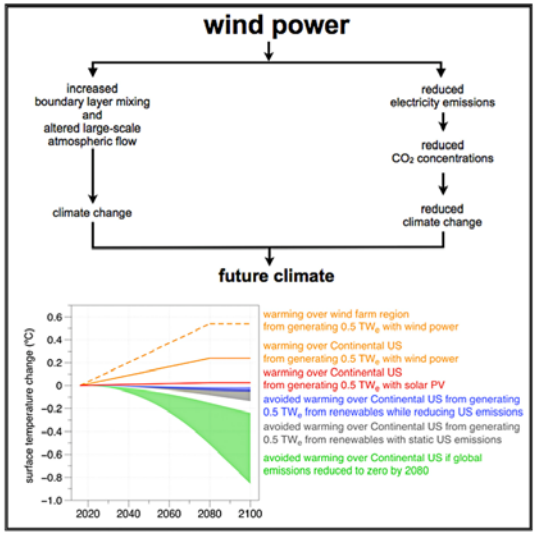
Energy generation by wind and solar farms could reduce carbon emissions and thus mitigate anthropogenic climate change. But is this its only benefit? Li *et al.* conducted experiments using a climate model to show that the installation of large-scale wind and solar power generation facilities in the Sahara could cause more local rainfall, particularly in the neighboring Sahel region. This effect, caused by a combination of increased surface drag and reduced albedo, could increase coverage by vegetation, creating a positive feedback that would further increase rainfall.

Science, this issue p. 1019

Y Li, *et al. Science* **361**, 1019, 2018.

Article

Climatic Impacts of Wind Power



Lee M. Miller, David W. Keith

lmiller@seas.harvard.edu (L.M.M.)
david_keith@harvard.edu (D.W.K.)

HIGHLIGHTS

Wind power reduces emissions while causing climatic impacts such as warmer temperatures

Warming effect strongest at night when temperatures increase with height

Nighttime warming effect observed at 28 operational US wind farms

Wind's warming can exceed avoided warming from reduced emissions for a century

LM Miller, *et al. Joule* **2**, 2618, 2018.

Modeling Climate Change Impacts of Renewable Energy

So who is right? Neither paper. Both of these high-profile papers used unrealistic deployment scenarios and flawed physical models to reach their conclusions. An NREL review showed dozens of related studies:

7 studies of solar energy impacts using *changes in surface albedo* to estimate the effect of deployments ranging from local to continental-scale.

6 studies of wind energy impacts using *changes in surface roughness* to estimate the effects of deployments at scales ranging from regional to global-scale.

18 studies of wind energy impacts using *parameterized wind turbine models* to estimate the impacts of deployments at scales ranging from local to continental.

1 study modeling continental-scale deployments of wind and solar using changes in surface albedo and surface roughness.

Modeling Climate Change Impacts of Renewable Energy

These studies showed a broad range of impacts:

Cases are often physically unrealistic boundary cases (generating several times global energy production in the Sahara) that should be seen as thought-experiments.

Solar impacts for *realistic* cases had regional impacts of +/- 0.5°C, local impacts of +/- 1.0°C

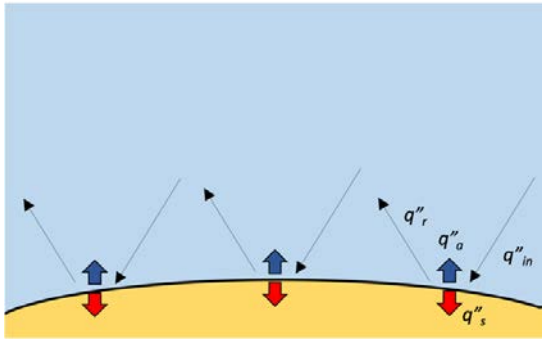
Wind energy impacts for *realistic* cases typically had regional impacts of + 0.1-1.0°C.

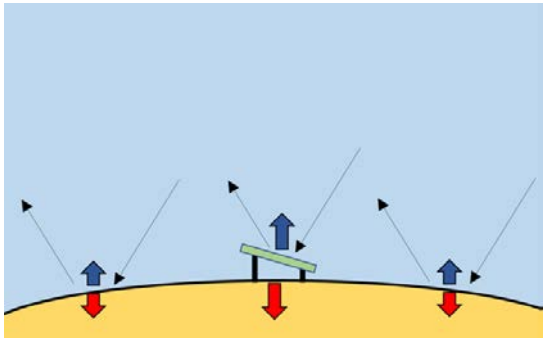
Thought-experiments often led to changes on the order of 1.0-2.0°C.

In general, better physical models, more finely resolved meshes, and more realistic deployment scenarios led to lower impact: but the impacts are real.

Modeling Climate Change Impacts of Renewable Energy

Even “simple” cases like the impact of solar become challenging to sort out.

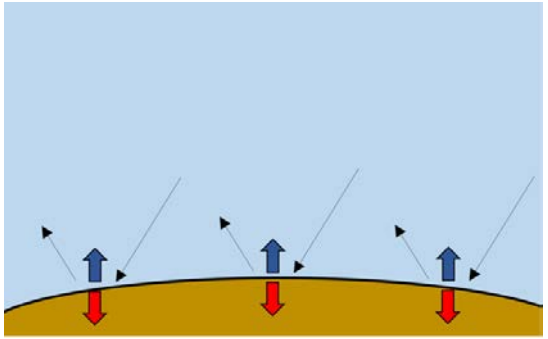


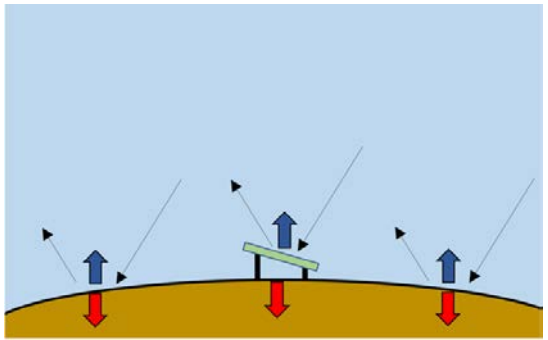


High albedo environment, without and with solar panels.

Adding solar panels to a “high albedo” environment, such as the desert, increase heat absorbed and temperature.

Adding the solar panel to a “low albedo” environment, such as an urban setting, has the opposite effect.





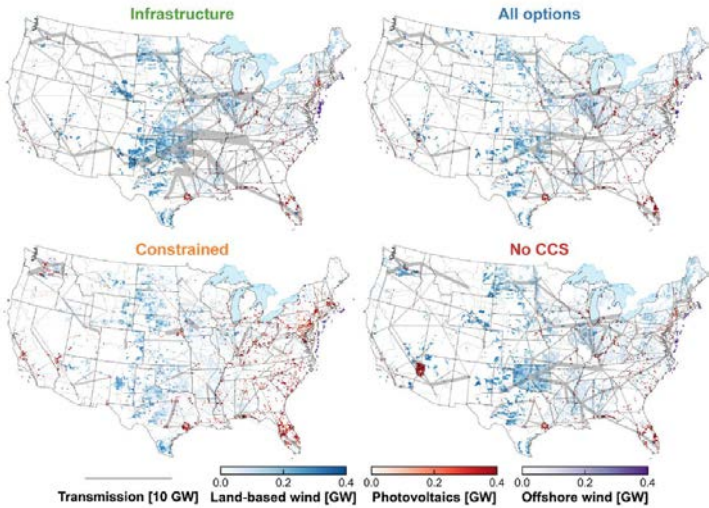
Low albedo environment, without and with solar panels.

Modeling Climate Change Impacts of Renewable Energy

Nothing in the literature predicts the impact of a 100% renewable system would be. What is missing?

- Realistic deployment scenarios that incorporate future demand, technology changes, and policy decisions through capacity modeling approaches.
- Impact of a changing climate.
- Improving the fidelity of physical models for renewables: possible to reach high-fidelity in atmospheric simulations, but difficult in Earth Systems Models.

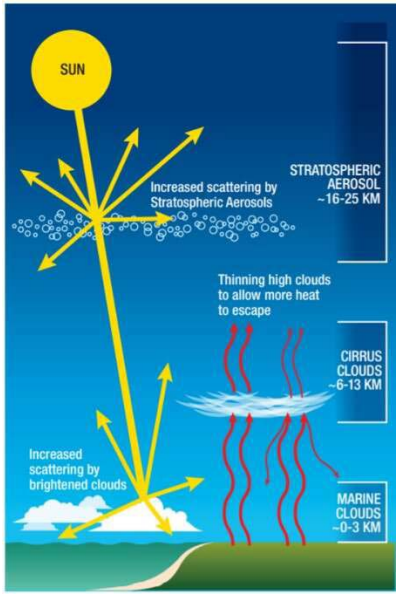
We also need to consider that this is an *energy equity* and *environmental justice* challenge.

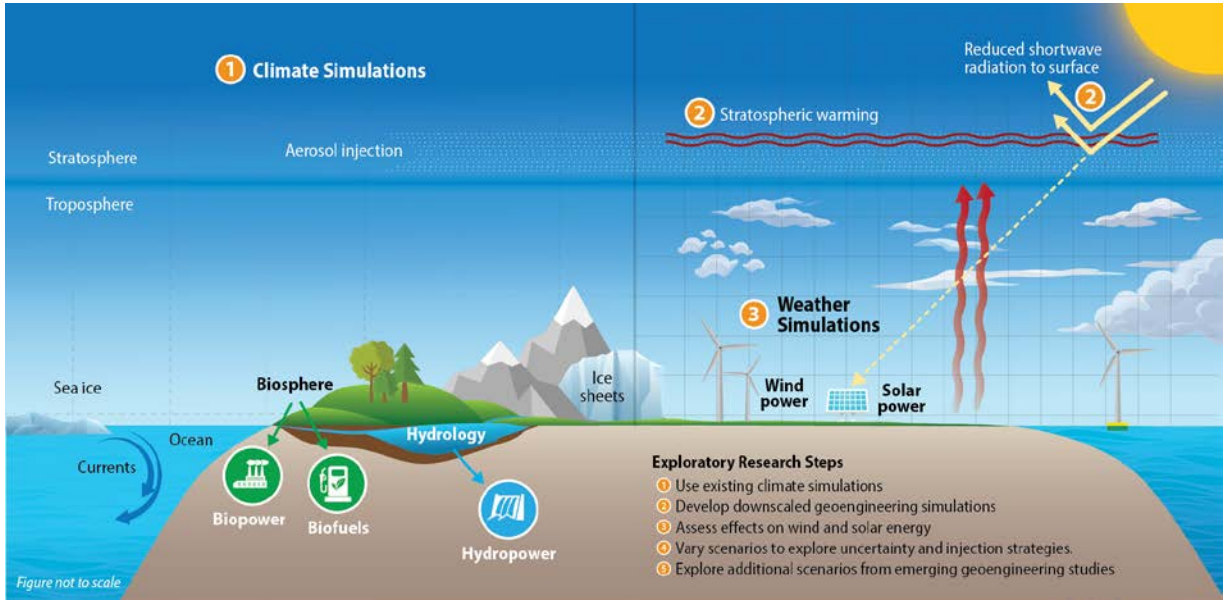


Varying distribution scenarios from NREL Capacity Planning models.

Preparing for geoengineering?

Increasing likelihood that climate change will exceed a tipping point means geoengineering is a possibility. An NREL LDRD is seeking to understand what the impact of this might be on energy systems.





C Draxl, *et al*, AMS Meeting, 2022.

What remains to be done?

Interactions between energy systems and a changing climate are significant enough to impact decision-making.

Answering these questions requires a combination of *creating new scientific tools* and *effectively integrating existing scientific tools.*

The challenges are not purely scientific, but societal. *Environmental justice* and *energy equity* frameworks need to be incorporated *at early-stage research.*

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the Joint Institute for Strategic Energy Analysis. The views expressed herein do not necessarily represent the views of the DOE, the U.S. Government, or sponsors.

NREL/PR-6A50-86722