

Large Language Models (LLMs) for Energy Systems Research

Grant Buster

Workshop on Solar Applications of Artificial
Intelligence and Machine Learning
November 1st, 2023

NREL Produces a LOT of Text!



The Los Angeles 100% Renewable Energy Study



One-Year Progress Summary Report:

Preliminary Modeling Results and High-Resolution Solar and Wind Data Sets



The North American Renewable Integration Study: A U.S. Perspective—Executive Summary



Renewable and Sustainable Energy Reviews

Volume 119, March 2020, 109541



Future integrated mobility-energy systems: A modeling perspective

[Matteo Muratori](#), [Paige Jadun](#), [Brian Bush](#), [David Bielen](#), [Laura Vimmerstedt](#), [Jeff Gonder](#), [Chris Gearhart](#), [Doug Arnt](#)



Grid-interactive Efficient Buildings Technical Report Series

Overview of Research Challenges and Gaps

Adapting Existing Energy Planning, Simulation, and Operational Models for Resilience Analysis

Caitlin Murphy, Eliza Hotchkiss, Kate Anderson, Clayton Barrows, Stuart Cohen, Sourabh Dalvi, Nick Laws, Jeff Maguire, Gord Stephen, and Eric Wilson



Solar Futures STUDY

The Potential for Electrons to Molecules Using Solar Energy

Alex Badgett, William Xi, and Mark Ruth

National Renewable Energy Laboratory

Storage Futures Study Key Learnings for the Coming Decades

What qualifies as effective dissemination of research?

LLMs for the Dissemination of Research

Q: Tell me about technical progress in the Puerto Rico 100% study (PR100)?

A: The PR100 study's first-year progress includes initial modeling and analysis results, as well as the development of high-resolution wind and solar resource datasets for Puerto Rico. A major accomplishment to date is the development of feasible scenarios for Puerto Rico to reach its goals of **100% renewable energy by 2050, with interim targets of 40% by 2025, 60% by 2040, the phaseout of coal-fired generation by 2028, and a 30% improvement in energy efficiency by 2040**, as codified in the Puerto Rico Energy Public Policy Act of 2019 (Act 17).

The model was provided with the following documents to support its answer:

- PR100 One-Year Progress Summary Report

ChatGPT: As of my last update in September 2021, there was no specific study or project titled "Puerto Rico 100% study (PR100)" that I'm aware of.

LLMs for the Dissemination of Research

Q: What would happen if the population of Puerto Rico were to suddenly double?

A: **I do not know** the exact consequences of the population of Puerto Rico suddenly doubling, as the provided articles do not discuss such a scenario..

ChatGPT: A sudden doubling of Puerto Rico's population would lead to a wide range of social, economic, environmental, and infrastructural challenges and changes. Here's a breakdown of some potential impacts...

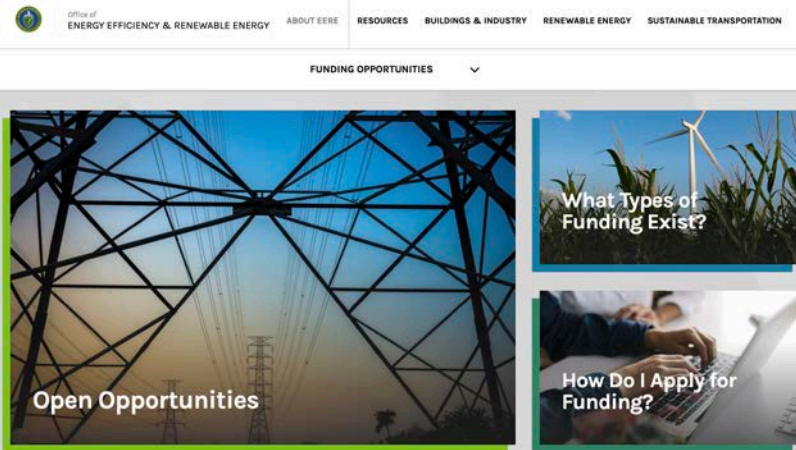
Potential Applications... Lots!



Search NREL.gov

SEARCH

About ▾ Research ▾ Partner With Us ▾ News ▾ Careers ▾



search energy data

Search

So how does this work?



One-Year Progress Summary Report:

Preliminary Modeling Results and High-Resolution Solar and Wind Data Sets

Renewable Energy Potential In Puerto Rico

One of the most important questions for reaching 100% renewable energy is whether Puerto Rico's renewable resource potential is sufficient—is there enough sun, wind, hydro, and other sources of renewable energy? To answer this question, we conducted assessments of the technical potential of a variety of renewable energy resources in Puerto Rico,¹ and we generated high-resolution, multiyear resource data sets for land-based wind, offshore wind, and solar, as well as wind and solar forecast data. We found that the *renewable technical resource in Puerto Rico significantly exceeds the current and projected total annual loads through 2050*.

We include in our modeling only generation technologies that meet the definition of renewable energy in the Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act ([Act 82 of 2010](#), as amended). Consistent with this policy, technologies considered in PR100 include solar energy, wind energy, hydropower, marine and hydrokinetic renewable energy, ocean thermal energy, and combustion of biofuel derived solely from renewable biomass.

The solar resource data from 1998–2021 are publicly available at <https://nsrdb.nrel.gov>, and the wind resource data from 2000–2021 are publicly available at <https://www.nrel.gov/grnd/wind-toolkit.html>. Wind and solar resource forecast data generated during an earlier phase of the project are also available on request. Marine, hydropower, and pumped storage hydropower assessments are in progress, and data sets will be made publicly available once they are complete. Other resources will be considered (either for local production or the cost of import) as they emerge in the study.

Land Availability

Throughout discussions with the Advisory Group, one of many members' key priorities was to ensure the preservation of agricultural lands and other areas of environmental, historical, and social value. In response, we integrated this feedback into land exclusions for our land-based wind and utility-scale solar PV assessments. Land exclusions for both PV and wind energy projects include waterbodies, rivers, roads, buildings, habitat areas, protected areas, urban areas, and a contiguous area restriction.⁶ Additionally, for utility-scale PV, the land must have less than a 5% slope, while for wind, the land must have less than a 13% slope. For the protected and agricultural areas, we used data from the Puerto Rico Planning Board (PRPB 2015).

Once all the exclusions are applied, the results show areas assumed to be suitable for utility-scale PV and wind energy development. Figure 2 shows land available for utility-scale solar PV development with agricultural lands excluded (left) and included (right); white space indicates excluded area and green is developable area.

Chunked Text

Renewable Energy Potential in Puerto Rico

One of the most important questions for reaching 100% renewable energy is whether Puerto Rico's renewable resource potential is sufficient—is there enough sun, wind, hydro, and other sources of renewable energy? To answer this question, we conducted assessments of the technical potential of a variety of renewable energy resources in Puerto Rico,¹ and we generated high-resolution, multiyear resource data sets for land-based wind, offshore wind, and solar, as well as wind and solar forecast data. We found that the *renewable technical resource in Puerto Rico significantly exceeds the current and projected total annual loads through 2050*.

We include in our modeling only generation technologies that meet the definition of renewable energy in the Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act ([Act 82 of 2010](#), as amended). Consistent with this policy, technologies considered in PR100 include solar energy, wind energy, hydropower, marine and hydrokinetic renewable energy, ocean thermal energy, and combustion of biofuel derived solely from renewable biomass.

The solar resource data from 1998–2021 are publicly available at <https://nsrdb.nrel.gov>, and the wind resource data from 2000–2021 are publicly available at <https://www.nrel.gov/grnd/wind-toolkit.html>. Wind and solar resource forecast data generated during an earlier phase of the project are also available on request. Marine, hydropower, and pumped storage hydropower assessments are in progress, and data sets will be made publicly available once they are complete. Other resources will be considered (either for local production or the cost of import) as they emerge in the study.

Land Availability

Throughout discussions with the Advisory Group, one of many members' key priorities was to ensure the preservation of agricultural lands and other areas of environmental, historical, and social value. In response, we integrated this feedback into land exclusions for our land-based wind and utility-scale solar PV assessments. Land exclusions for both PV and wind energy projects include waterbodies, rivers, roads, buildings, habitat areas, protected areas, urban areas, and a contiguous area restriction.⁶ Additionally, for utility-scale PV, the land must have less than a 5% slope, while for wind, the land must have less than a 13% slope. For the protected and agricultural areas, we used data from the Puerto Rico Planning Board (PRPB 2015).

Once all the exclusions are applied, the results show areas assumed to be suitable for utility-scale PV and wind energy development. Figure 2 shows land available for utility-scale solar PV development with agricultural lands excluded (left) and included (right); white space indicates excluded area and green is developable area.

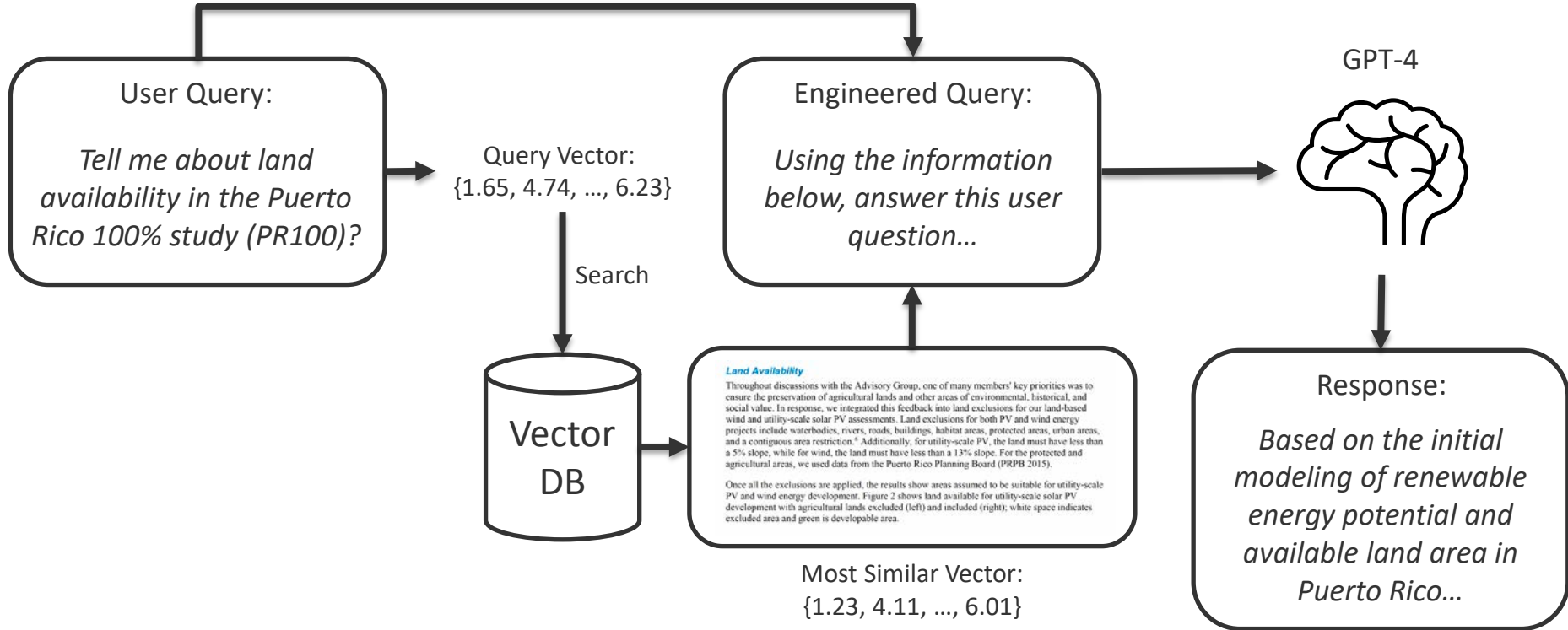
Vector Embeddings

{0.19, 0.17, ..., 0.98}

{1.23, 4.11, ..., 6.01}

Vector
DB

So how does this work?



Wind and Solar Siting Ordinances

- High-impact, high-effort
 - **1,500 intern hours** to parse legal documents
- Siting ordinances for renewables is a rapidly changing legal landscape
 - National wind ordinances **increased by more than 540%** from 2018 to 2022

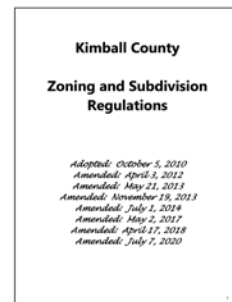
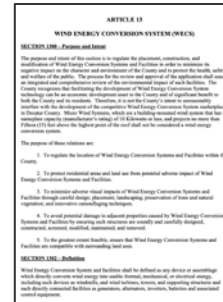
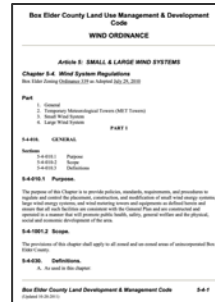
- >3k counties in the U.S.
 - Some states have ordinances per township and municipality (>16k in the U.S.)

Read our September issue

This month we look at siting ordinances for wind and solar farms, advanced models for energy poverty forecasting, Si-based batteries, energy losses in organic photovoltaics, and more.



Lopez, A., Cole, W., Sergi, B. et al. "Impact of siting ordinances on land availability for wind and solar development". Nat Energy 8, 1034–1043 (2023). <https://doi.org/10.1038/s41560-023-01319-3>



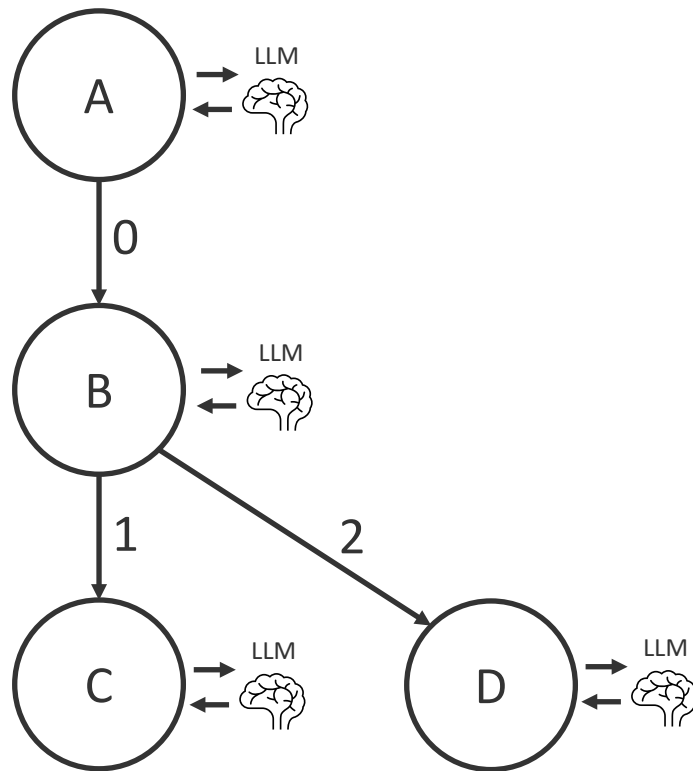
LLMs for Parsing Siting Ordinances

- 21 counties, 5 wind setback features, 105 total ordinances
 - Structures
 - Property lines
 - Roads
 - Railroads
 - Transmission lines
- Initial Results:
 - Ordinance database: **82% accurate***
 - LLM with single prompt: **86% accurate**
 - LLM with decision tree: **90% accurate**

**some ordinance database errors may be due to legal amendments made after April 2022*

LLMs Guided by Decision Tree

- Decision tree structure can improve the accuracy of LLM reasoning
 - Nodes and edges have prompts and functions that define states and transitions
- Takes advantage of slow-logic symbolic reasoning and fast-logic text comprehension from GPT-4
- Rudimentary implementation of a neuro-symbolic AI system



Complex Rules: Monroe County, Wisconsin

Setback Description	Setback Distance
Occupied community buildings	The lesser of 1,250 feet or 3.1 times the maximum blade tip height
Participating residences	1.1 times the maximum blade tip height
Nonparticipating residences	The lesser of 1,250 feet or 3.1 times the maximum blade tip height

Complex Rules: Monroe County, Wisconsin

Setback Description	Setback Distance
Occupied community buildings	The lesser of 1,250 feet or 3.1 times the maximum blade tip height
Participating residences	1.1 times the maximum blade tip height
Nonparticipating residences	The lesser of 1,250 feet or 3.1 times the maximum blade tip height

- Setback from structures:
 - Ordinance database: 1.1x max tip height
 - Single-query LLM:
 - “The setback for large wind energy systems from occupied community buildings and nonparticipating residences is the lesser of 1,250 feet or 3.1 times the maximum blade tip height. For participating residences, nonparticipating property lines, public road right-of-way, and overhead communication and electric transmission or distribution lines, the setback is 1.1 times the maximum blade tip height.”

Complex Rules: Monroe County, Wisconsin

Setback Description	Setback Distance
Occupied community buildings	The lesser of 1,250 feet or 3.1 times the maximum blade tip height
Participating residences	1.1 times the maximum blade tip height
Nonparticipating residences	The lesser of 1,250 feet or 3.1 times the maximum blade tip height

LLM with decision tree:

- **USER:** Is there text in the following legal document that describes how close i can site a large wind energy system to buildings and structures? Ignore text on small, mini, or private wind energy systems. Ignore text regarding setbacks from parcels, rights-of-way, and utility easements. Please only say "Yes" or "No".
- **ASSISTANT:** Yes
- **USER:** Based on your last message, choose the option that best describes the required setback from buildings and structures:
 - #1.1 The setback from buildings and structures is a single distance value
 - #7.1 The setback from buildings and structures has multiple conditions such as a fixed distance and a multiple of the total system height
 - #0 None of the above options are descriptive of this ordinance related to setbacks from buildings and structures
- **ASSISTANT:** #7.1 The setback from buildings and structures has multiple conditions such as a fixed distance and a multiple of the total system height

Complex Rules: Monroe County, Wisconsin

Setback Description	Setback Distance
Occupied community buildings	The lesser of 1,250 feet or 3.1 times the maximum blade tip height
Participating residences	1.1 times the maximum blade tip height
Nonparticipating residences	The lesser of 1,250 feet or 3.1 times the maximum blade tip height

LLM with decision tree:

- **USER:** Lets assume the supporting tower is 377 feet with blades 279 feet long. So the rotor diameter would be 558 feet and the total system height would be 656 feet. What would the multiple setback distances be? Please show your work.
- **ASSISTANT:** Based on the information provided, we can calculate the setback distances for the different types of buildings and structures:

1. Occupied community buildings: The lesser of 1,250 feet or 3.1 times the maximum blade tip height $3.1 * 656 \text{ feet} = 2,033.6 \text{ feet}$. The lesser value is 1,250 feet.
2. Participating residences: 1.1 times the maximum blade tip height $1.1 * 656 \text{ feet} = 721.6 \text{ feet}$
3. Nonparticipating residences: The lesser of 1,250 feet or 3.1 times the maximum blade tip height $3.1 * 656 \text{ feet} = 2,033.6 \text{ feet}$. The lesser value is 1,250 feet.

So, the multiple setback distances are:

- 1,250 feet for occupied community buildings
- 721.6 feet for participating residences
- 1,250 feet for nonparticipating residences

Complex Rules: Monroe County, Wisconsin

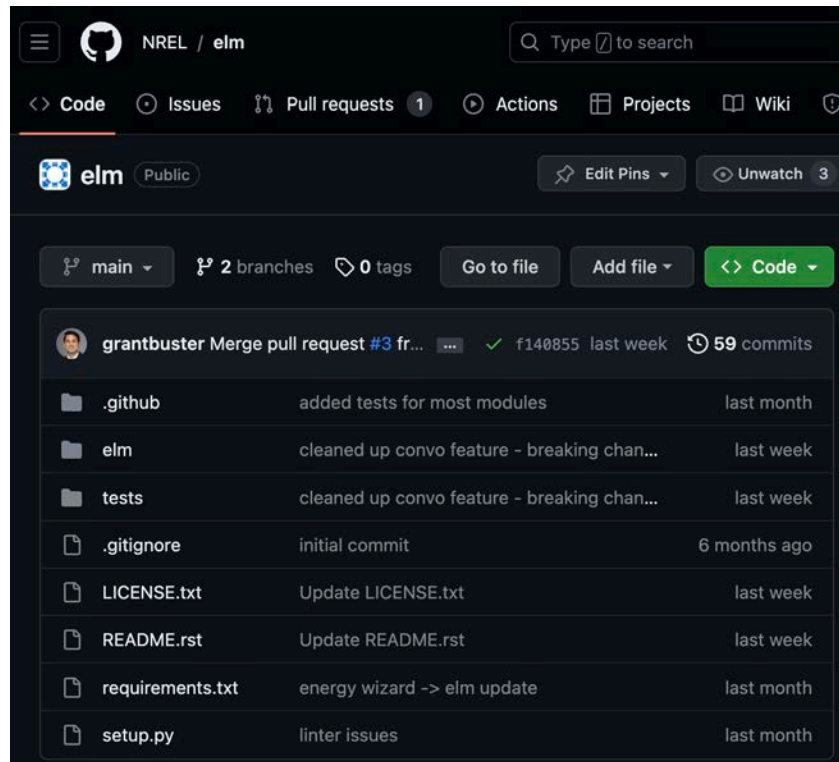
Setback Description	Setback Distance
Occupied community buildings	The lesser of 1,250 feet or 3.1 times the maximum blade tip height
Participating residences	1.1 times the maximum blade tip height
Nonparticipating residences	The lesser of 1,250 feet or 3.1 times the maximum blade tip height

LLM with decision tree:

- **USER:** What is the final setback value? If the ordinance states which of the multiple distances should be chosen, use that guidance. Otherwise, choose the largest setback value.
- **ASSISTANT:** The ordinance does not provide specific guidance on choosing between the multiple distances. Therefore, we will choose the largest setback value. The final setback value is 1,250 feet.
- **USER:** State the final setback like this: "The setback is XXX (units)"
- **ASSISTANT:** The setback is 1,250 feet.

Powered by Open-Source Software

- [ELM: Energy Language Model](#)
 - Utilities to work with the OpenAI API
 - Text embedding search
 - Decision tree framework
 - PDF-to-text utilities
 - Recursive summarization and text processing
 - Asynchronous API calls



Thank you

www.nrel.gov

Grant.Buster@nrel.gov

<https://github.com/NREL/elm>

NREL/PR-6A20-87896

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 DOE Solar Energy Technologies Office (SETO), DOE Wind Energy Technologies Office (WETO), and internal research funds at the National Renewable Energy Laboratory. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

