Green Solution: Visualizing, Exploring, and Forecasting Using Existing Renewable Energy Data

Team 7: Darren McEwan, Isabel Chang, Anjing Bi, Edmund Dale, Hanh Pham, Kelly Seto

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Introduction and Problem Definition

Renewable energy sources (RES) such as solar, wind, water, biomass, and geothermal are gaining increasing attention as a primary energy source due to their faster replenishment rate [21]. The Biden administration aims to achieve 100% carbon-free electricity supply by 2035 and net-zero greenhouse gas emission economy wide by 2050 [28]; The challenges of state-level implementation include geographical barriers [16], workforce shortages [10], transmission and storage limitations [13][26], and permit requirements [19]. Despite these hurdles, half of the 50 states have set goals to achieve 100% renewable/clean energy.

Green Solution is a "one-stop-shop" for renewable energy information using Streamlit, an open-source framework. Upon selection of a state and renewable energy type (solar, wind, or hydro-electric), users can explore renewable energy trends up to 2050. The date by which each state is predicted to reach 100% renewable energy is compared against the state's current energy goal. With an interactive design, users can freely manipulate the displayed map to find the renewable energy data they are interested in. This makes it a valuable resource for anyone who wants to learn more about renewable energy. We will also provide links to incentives for renewable energy by the chosen state.

Literature Survey

Despite the challenges associated with the development of RES, they provide many benefits such as economic growth, energy resiliency, grid decentralization, job creation, climate, and health benefits[12][7]. The US will need to replace most of its power plants by 2050, giving a significant opportunity for the development of RES in the coming years [11].

RES vary widely in their cost-effectiveness and in their availability across the United States. The potential of RES producing electricity for an area can be evaluated as four types of Renewable Energy Potential (REP)[6]. They are Resource Potential, Technical Potential, Economic Potential, and Market Potential. Each potential has its own assessment methods and assumptions which are shown in Table 1.

The final recommendation of a REP for an area is typically based on Levelized Cost of Energy (LCOE) and Levelized Avoided Cost of Energy (LACE) [6][2]. LCOE refers to the estimated revenue required to build and operate a generator over a specified cost recovery period. LACE is the revenue available to that generator during the same period. The ratio of LACE- to-LCOE provides a reasonable comparison of first-order economic competitiveness among a wider variety of technologies. Projects with a ratio greater than one are more economically attractive as new builds than those with a value-cost ratio less than one [2].

Studies have assessed the resource potential [6] of solar [26], wind, biomass, marine, geothermal [31][23], and hydropower [9][22][29]. Others expand upon what was learned and discuss the technical/economic/market potential [21][3][5][14][18] of RES using LCOE and LACE. An even higher order of analysis is done by [20] and [27]. [20] forecasts solar power through clustering and neural networks while [27] simulates scenarios that will meet regional renewable goals. Construction of wind turbines on or next to buildings where local wind regimes are created [17] or solar farms in deserts and degraded areas [26][8] are also explored.

Table 1: Summary of the Current Renewable Energy Potential Studies

Renewable Energy Potential	Key Assumptions	Granularity Level	Reference
Resource Potential	- Physical Constraints - Theoretical Physical Potential - Energy Content Resource	State	[15] [16] [17] [18] [20]
Technical Potential	- System/Topographic Constraints - Land-use Constraints - System Performance	State	[15] [20] [21] [22]
Economic Potential	- Projected Technology Costs - Projected Fuel Costs	State	[20]
Market Potential	- Policy Implementation/Impacts - Regulatory Limits - Investor Response - Regional Competition with other	U.S. Region	[19]

Despite all of the in depth literature and analyses, there is no "one-stop shop" that integrates REP, forecasting, and policy information at a per region (e.g., State/County) level in an interactive and concise way allowing the users to grab and understand the information quickly.

One of the key features of the app is forecasting. To tackle forecasting we consider the non-stationary time series data of renewable energy production, which is influenced by policies/incentives as well as material/installation/maintenance costs [4]. To make the data stationary, trend and random variation are considered within the context of double exponential smoothing [25][30]. While training the model, the forecast coefficients (α, β) are fine-tuned to decrease error. Coefficients closer to 1 emphasize the current value whereas coefficients closer to 0 emphasize past values.

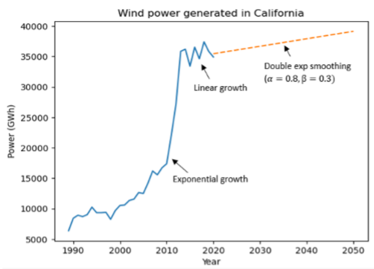
Our goal is to help the user identify which states are on track for their renewable energy goal through forecasting. This can provide incentive for more policy shifts to lower the hurdles of renewable energy development. The renewable resource map has the data to aid in identifying the best resources to develop.

Proposed Method

Forecasting of statewide renewable production and percentage of power from renewable sources

Our team utilizes double exponential smoothing (Holt's method) to predict non-combustible renewable energy production for each state in the US from 2021 – 2050. "Non-combustible renewable energy" includes sources that do not emit CO2 when used, such as solar, wind, geothermal, and hydroelectric energy. We have time series data for each source from 1960 – 2020; however, we focus on data from 1989 onwards, when all 50 states began producing non-combustible renewable energy. We recognize that some renewable sources, such as solar and wind, exhibit significant fluctuations in production in a single year as shown in the plot below. Holt's method involves a forecast equation and two smoothing equations (one for the level and one for the trend):

$$\text{Forecast: } Y_{t+h|t} = S_t + h * b_t$$
$$\text{Level: } S_t = \alpha * x_t + (1 - \alpha) * (S_{t-1} + b_{t-1})$$
$$\text{Trend: } b_t = \beta * (S_t - S_{t-1}) + (1 - \beta) * b_{t-1}$$



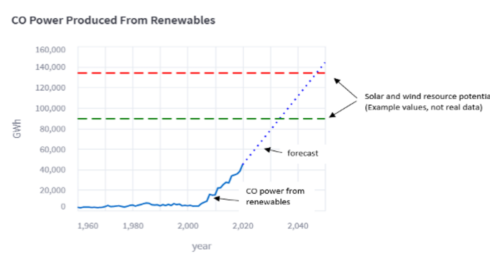
For such power sources, we set large α values in the forecasts so that recent production trends are weighed more heavily than past trends. For hydroelectric power, we chose small α values to ignore yearly fluctuations in power production (based on yearly water levels) and reflect the fact that hydroelectric production is not growing in the United States. After making yearly predictions for power production from solar, wind, geothermal, and hydroelectric energy, we sum their values to produce final predictions of renewable power production for each state.

We use a similar scheme to predict the percentage of power from non-combustible renewable sources. Here the percent power from renewable sources is defined as:

$$\%Power_{renewable\ sources} = \frac{noncombustible\ renewable}{noncombustible\ renewable + nuclear + coal + natural\ gas + biomass}$$

Calculating and displaying maximum solar and wind resource potential for every state

We are using the "Wind and Solar Technical Generation Potential (2020)" data set from NREL [24] to calculate the wind and solar resource potential in each county in the United States. This dataset considers solar and wind resources, system performance, topographic limitations, environmental and land use constraints, but not market conditions. We are using distributed-wind values and (residential solar PV + commercial PV + utility scale PV) values to estimate the upper bound for generation.



These resource potential values are displayed as selectable layers on our interactive map and on the statewide renewable generation chart to give users an idea of how far each state is from reaching its potential.

- **Data Collection:** We have identified the most informative RES data from credible sources and compiled them into one application. Our RES data set will include wind, solar, hydropower, biomass, and geothermal, which are available across the United States.

- **Algorithm:** Holt's method [1] generates forecasts having a constant trend (increasing or decreasing) indefinitely into the future. It tends to over-forecast based on empirical evidence, especially for longer forecast horizons. Gardner & McKenzie [15] introduced a parameter that "dampens" the trend to a flat line sometime in the future. Both methods will be explored for best forecasting results.

- **Data Visualization:** The RES data has been cleaned, sorted, and organized to allow the users to get the visual impact of the data. The presentation of the data includes a map, line charts, and data trends.

- **UI Design** The users will be able to interact with the UI we designed to explore not only the RES data shown on the U.S. map, but also the status of RES by state including the following:

- Time series line chart by non-combustible renewable power generation (GWh) and by % power from renewables

- The most technically feasible RES of the state

- The predicted year of reaching 100% renewable energy vs the state energy goal and state specific incentives.

Design of Experiments and Evaluations

Our predictions for non-combustible renewable power generation, and % power from renewables go from the year 2020 out to 2050. One way to evaluate the error in our forecasts is to compare predicted values from 2021-2022 to actual values during these years. Alternatively, we can split the time series data between training (1989-2014) and validation (2015-2020). We will attempt to make these comparisons by the project deadline.

Plan of Activities

Gantt Chart: Division of Labor

RENEWABLE ENERGY PROJECT | Team 7				2/2	2/9	2/16	2/23	3/2/	3/9	3/16	3/23	3/30	4/6	4/13	4/20
TASK	ASSIGNED	START	END	1	2	3	4	5	6	7	8	9	10	11	12
Phase I															
Select Topic	All	1/19/23	2/9/23	X											
Search Data Set	KS/IC	2/9/23	3/1/23	X	X	X	X								
Literature Survey	All	2/9/23	2/23/23	X	X	X									
Exploring UI Tool	DM/ED	2/16/23	2/23/23	X	X	X									
Submittal	AB/HP	2/23/23	3/1/23				X	X							
Phase II															
Get/Clean Data	All	3/2/23	3/31/23					X	X	X	X	X			
Model Calcs	All	3/9/23	3/31/23						X	X	X	X			
Data Visualization	KS/IC	3/9/23	3/31/23						X	X	X	X			
Implementing UI	DM/ED	3/2/23	3/31/23					X	X	X	X	X			
Submittal	AB/HP	3/23/23	3/31/23								X	X			
Phase III															
Data Visualization	KS/IC	4/1/23	4/21/23												
Implementing UI	DM/ED	4/1/23	4/21/23												
Exp Design/Eval	All	4/1/23	4/21/23												
Submittal	AB/HP	4/20/23	4/21/23												

All team members contributed equal effort

The project team's first meeting was held on Thursday, January 19, 2023. The team continues to meet every Thursday at 8PM PST through April 2023. The team's work will be divided into three phases corresponding to each of the three required deliverables in the course schedule: the proposal due on Friday, March 3, 2023, the progress report due on Friday, March 31, 2023, and the final report due on Friday, April 21, 2023. Please see The Gantt chart on the left for division of responsibilities.

Conclusions and Discussion

Renewable energy is crucial for our future, and data analytics is essential in assessing its potential. Our app uses exponential smoothing and data visualization to highlight the renewable energy technical potential by state, including solar and wind energy. We provide a comprehensive and reliable tool that utilizes NREL and EIA data to drive the renewable energy transition. Moreover, our app visualizes trends from 1960 to 2020, making it a valuable resource for renewable energy enthusiasts and data analytics professionals.

In the next few weeks, we plan to continue working to improve our app to provide more value to users. We aim to enhance the user experience by adding features to the heatmap such as a scalebar and legend, as well as annotating and adding legends to the plots. We also plan to change the heatmap format to display county lines for better visualization. In addition, we will calculate the statewide potential for wind and solar power and include this data in the renewable power production plot. Finally, we will examine the accuracy of our forecasts by comparing 2021-2022 renewable production predictions to actual data.

Appendix

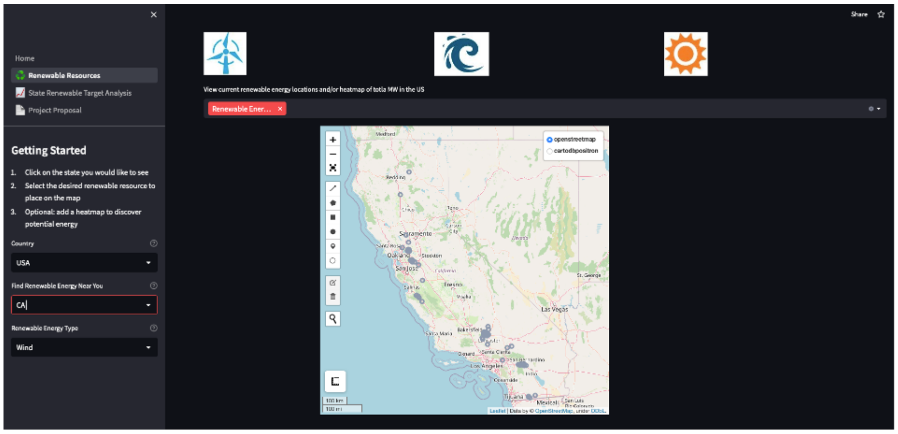


Figure 1 The displayed map will change according to the chosen state and renewable energy type (left panel). The map itself has a multi-selection tool (top) that can switch between layers. Possible layers you can select: 1) existing renewable energy locations, 2) heatmap of solar technical potential, 3) heatmap of wind technical potential.

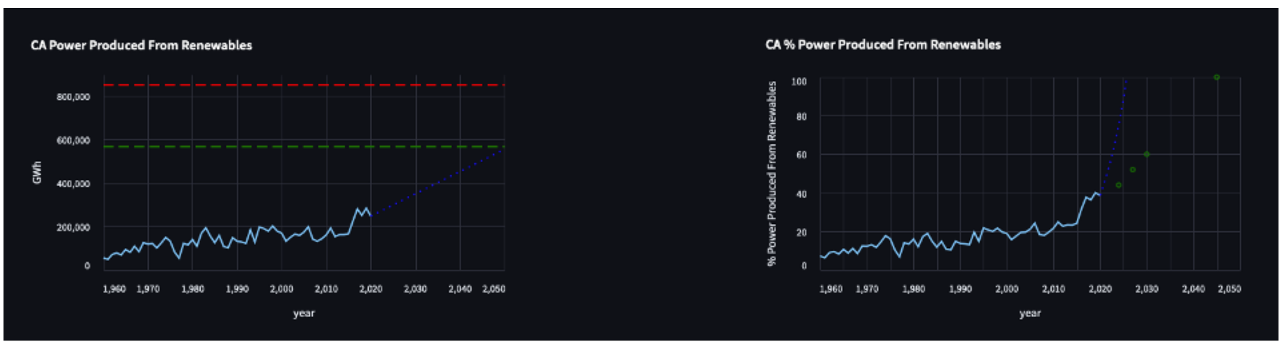


Figure 2 The displayed line charts will change according to the chosen state (left panel). One chart displays time series data by GWh produced from renewable energy. The other chart displays time series data by % power produced from renewable energy. Each chart forecasts up to the year 2050.

Incentives for renewable energy in CA:

Program Name	Category	IncentiveType	Created
LADWP - Net Metering	Regulatory Policy	Net Metering	6/7/2011
Partial Sales and Use Tax Exemption for Agricultural Solar Power Facilities	Financial Incentive	Sales Tax Incentive	12/13/2012
Sales and Use Tax Exemption for Electric Power Generation and Storage Equipment	Financial Incentive	Sales Tax Incentive	2/8/2018
Property Tax Exclusion for Solar Energy Systems and Solar Plus Storage System	Financial Incentive	Property Tax Incentive	4/19/2001
Self-Generation Incentive Program	Financial Incentive	Rebate Program	4/16/2001
Sales and Use Tax Exclusion for Advanced Transportation and Alternative Energy Manufacturing Program	Financial Incentive	Industry Recruitment/Support	3/29/2010
California Solar Initiative - Solar Thermal Program	Financial Incentive	Rebate Program	4/30/2010
Net Metering / Net Billing	Regulatory Policy	Net Metering	1/1/2000
Santa Clara Water & Sewer - Solar Water Heating Program	Financial Incentive	Leasing Program	1/1/2000

Figure 3 The displayed table of renewable energy incentives will change according to the chosen state (left panel). Each table row provides a link to more details regarding the selected incentive. An incentive is categorized as financial or regulatory. The incentive type is more specific and includes, but is not limited to: net metering, rebate program, loan program, tax incentives, and benefit funds. The last column lists the date the incentive was created.

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