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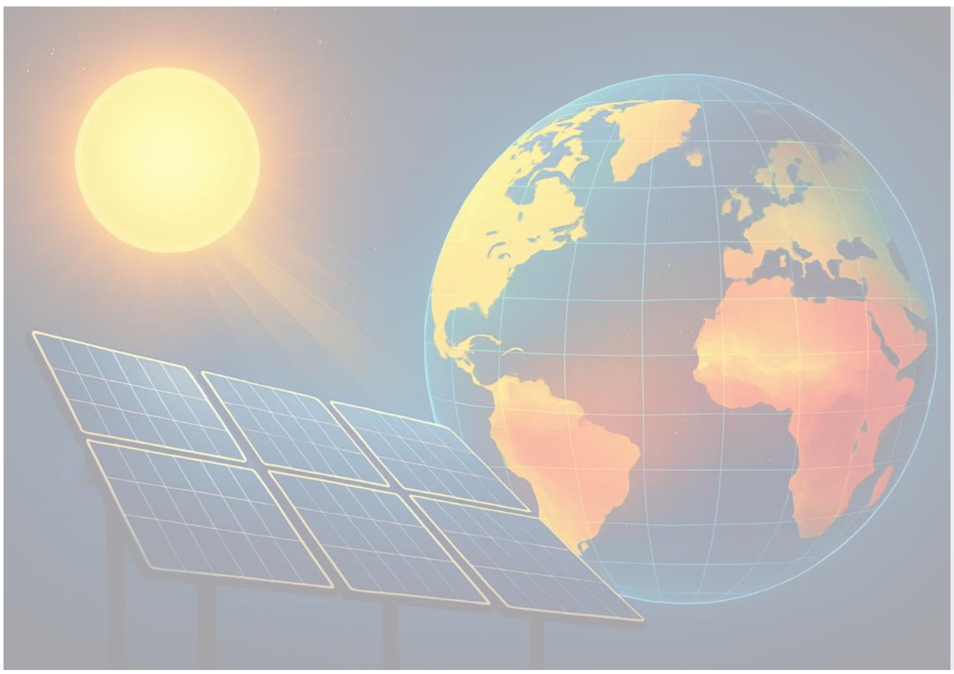
Solar Radiation Big Data Analysis for Strategic Positioning of Residential Solar Panels



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SOLAR RADIATION BIG DATA ANALYSIS FOR STRATEGIC POSITIONING OF RESIDENTIAL SOLAR PANELS

Abstract

This research project investigates how adjusting the tilt angle of solar panels can improve residential solar energy output in South Texas. The team compared real-world irradiance measurements in Corpus Christi and Kingsville, TX with model-generated data from the SOLPOS solar positioning tool. Environmental conditions such as humidity and sun angle play a crucial role in determining solar panel efficiency in these areas. After validating the SOLPOS data, the research investigated how the solar panel output can be increased by changing the solar panel tilt angle, using the big data available on SOLPOS. The research also incorporated educational components, developing curriculum modules for secondary mathematics courses to demonstrate the practical application of solar energy concepts. These findings are valuable not only for residential energy optimization but also for enhancing STEM instruction in high school classrooms.

1. INTRODUCTION

Maximizing the output of solar panels requires precise alignment with the sun's path. For residential setups, where tracking systems may be impractical or costly, determining the best fixed tilt angle becomes essential. South Texas, with its high solar potential, presents an ideal setting for this study. By exploring optimal tilt angles and validating model data against experimental results, we aim to identify the most effective strategies for residential solar panel placement. This study also offers an opportunity to introduce high school students to real-world

STEM applications, making solar engineering tangible and relevant through mathematics instruction.

2. OBJECTIVES

The primary goal of this project is to optimize solar panel positioning through tilt angle adjustment, supported by both modeled and experimental data. Specifically, we aim to: (1) determine the optimal fixed tilt angle for maximum daily, monthly, and annual irradiance in South Texas; (2) assess the accuracy and usability of the SOLPOS modeling tool; and (3) develop interdisciplinary STEM curriculum modules that integrate solar data analysis into Algebra II, Geometry, and Precalculus classes.

3. BACKGROUND

Solar panels function most efficiently when they are perpendicular to incoming sunlight. However, the sun's position changes throughout the day and across seasons. Fixed installations must therefore compromise between the extremes to find a "best average" orientation. For residential users, a fixed tilt that maximizes annual energy production is preferable due to lower cost and maintenance compared to dynamic tracking systems. Figure 1 shows the working mechanism of solar panels. When sunlight (photons) strikes the photovoltaic (PV) cells, the energy excites electrons from their ground state, generating direct current (DC) electricity. This DC electricity is then passed through an inverter, which converts it into alternating current (AC) suitable for household use or for feeding into the utility grid via a meter. This project explores how irradiance data varies with tilt angle and how accurately SOLPOS can predict this performance. By translating these results into classroom activities, the project also addresses a growing need for contextual, data-rich STEM education.

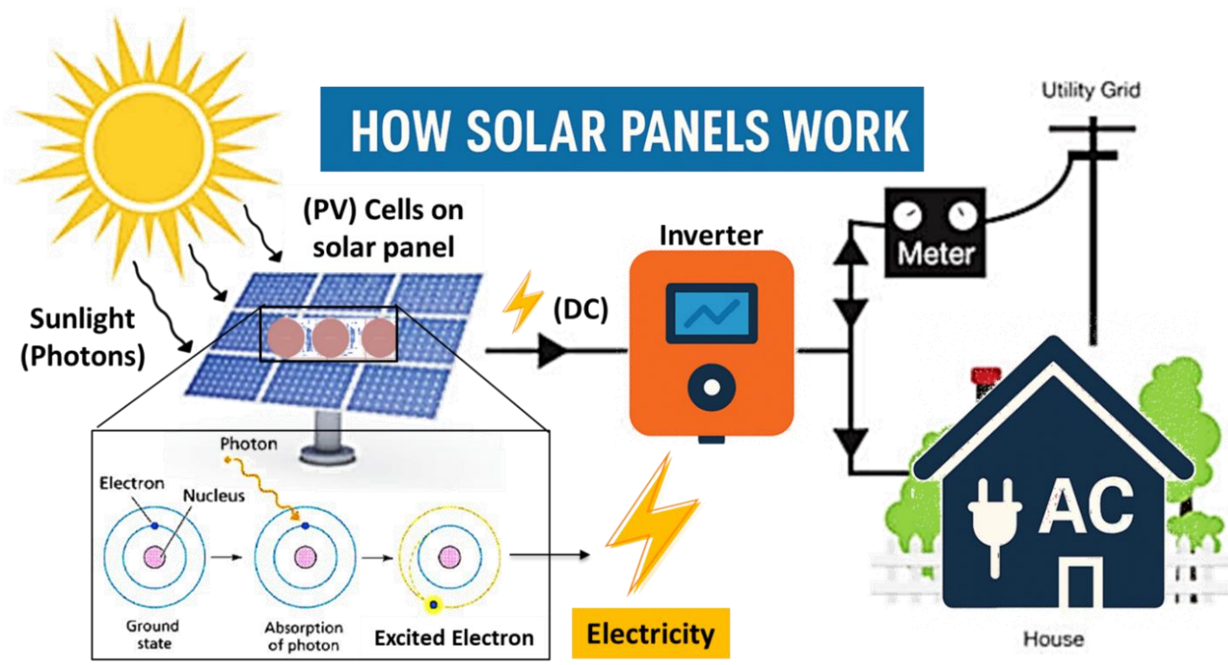

Figure 1: Working principle of solar panels from sunlight absorption to AC power output.

Energy output depends on the absorption of sunlight, which is influenced by several factors such as tilt angle, panel type, time of day, and weather conditions. Reflective losses can further reduce the system's efficiency. As sunlight intensity (irradiance) increases, the electrical power output also rises, indicating a direct relationship between solar input and system efficiency. The energy output from a solar panel can be calculated using the equation [1]:

$$\text{Energy} = A \times r \times H \times PR \qquad (1)$$

where A is the panel area (m^2), r is the panel efficiency, H is the irradiance (W/m^2), and PR is the performance ratio (typically around 0.75).

Figure 2 illustrates the use of the SOLPOS calculator developed by the National Renewable Energy Laboratory (NREL) to estimate solar position and irradiance based on specific time and location inputs [2]. Users are required to enter a start and end date, which define the period over which solar data will be generated. The interval time, set to 30 minutes in this case, determines the frequency of data output. Site location is specified using latitude and longitude coordinates. The time zone input adjusts the solar calculations to the local time. Additional inputs include the azimuth angle of the panel surface, which is set to 180°, meaning the panel faces due south, a typical configuration for optimal solar gain in the northern hemisphere. The tilt angle is set at 0°, representing a flat panel. Based on these inputs, SOLPOS calculates the sun's position (azimuth and elevation) and the solar irradiance (W/m^2), both of which are essential for determining potential energy output. As noted, the tool is used in this project to compare predicted values with field data to validate its accuracy, while highlighting the effect of tilt angle on solar panel performance throughout the year.

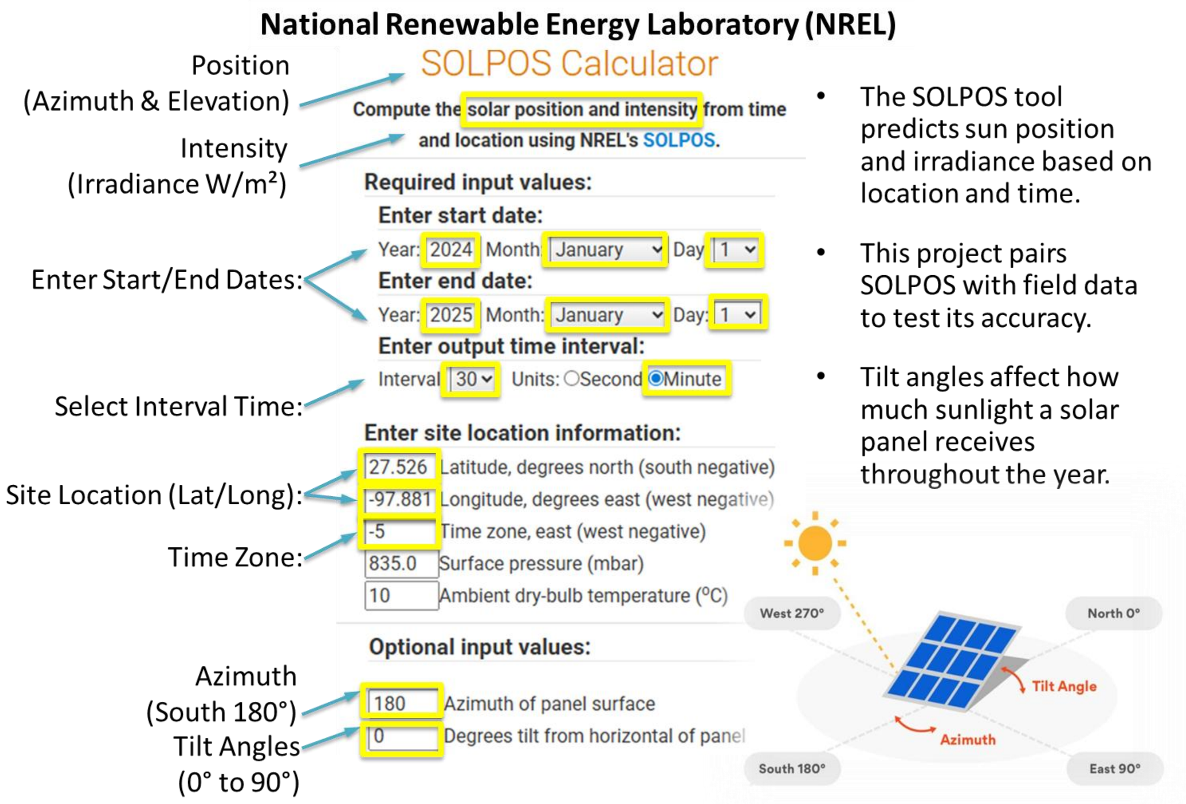

Figure 2: Input parameters and interface of the SOLPOS calculator used to estimate solar position and irradiance based on time, location, and panel orientation.

4. LITERATURE REVIEW

Numerous studies [3] highlight the influence of tilt angles on photovoltaic efficiency. Research confirms that optimizing tilt can improve energy capture by 10–20% over panels installed at a default or horizontal position. The National Renewable Energy Laboratory's SOLPOS model is widely used in the solar industry to predict solar position and irradiance based on geographic and atmospheric conditions. By validating these predictions with real-world data, we can assess the model's educational potential. Integrating solar engineering into the curriculum aligns with the Next Generation Science Standards (NGSS) and promotes analytical skills through project-based learning.

Building on the importance of tilt and sun-tracking in maximizing solar efficiency, Table 1 provides a comparison of three types of solar panel system based on their tracking capabilities, energy output boost, and typical applications. Fixed-tilt systems, which maintain a constant angle, serve as the baseline for energy output and are suited for rooftops and low-cost installations. In contrast, single-axis systems track the sun from east to west throughout the day, enhancing output by 15–25% and making them suitable for utility-scale solar farms. Dual-axis systems offer the highest efficiency by tracking both the sun's angle and direction, increasing output by 30–45%, and are ideal for high-output. To further illustrate the versatility of dual-axis tracking systems, Figure 3 illustrates different configurations of dual-axis tracking systems, including simple dual-axis mechanisms, frame-mounted setups, and rotating-axis designs, all of which maximize sunlight capture throughout the day.

System Type	Description	Output Boost	Common Use
Fixed-Tilt	Panels at a fixed angle	Baseline	Rooftops, low-cost installs
Single-Axis	Rotates east to west throughout the day	+15–25%	Utility-scale solar farms
Dual-Axis	Tracks both sun angle and direction	+30–45%	High-output or space-limited systems

Table 1: Solar panel types by tracking method and output gain.

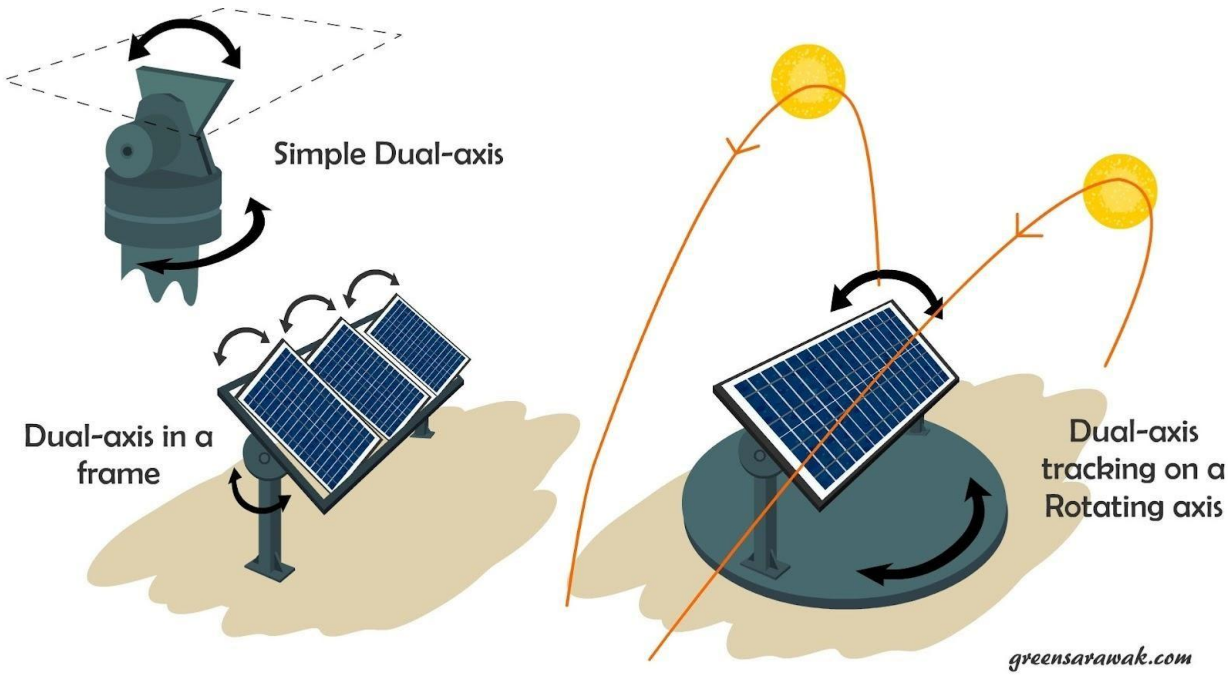

Figure 3: Types of dual-axis systems for sun-tracking optimization.

5. METHODS

Our experimental setup (see Figure 4) was located in Corpus Christi and Kingsville, Texas, a region known for its high solar insolation. Each site features multiple solar panels arranged at varying tilt angles for comparative analysis. The geographic coordinates for Kingsville are 27.526° N, -97.881° W, and for Corpus Christi are 27.775° N, -97.401° W. We used several solar panels fixed at tilt angles 0°, 35°, 40°, and 50° and measured irradiance using calibrated sensors at 30-minute intervals on clear July days. Simultaneously, we ran the SOLPOS model to generate predicted irradiance data for the same location and time intervals. We used Excel to process, visualize, and compare the results. We also recorded temperature readings to account for potential efficiency losses due to panel heating.

Figure 4: Solar panel test setups at Kingsville (top) and Corpus Christi (bottom) for irradiance comparison.

Experimental Parameters:

- Irradiance (W/m^2)
- Surface temperature (°F)
- 30-minute intervals
- 9:30 AM to 7:00 PM
- Time Zone: (-5)
- July 2025 (SOLPOS 2025)
- Tilt Angles: 0°, 35°, 40°, 50°
- Azimuth: 180° South

6. RESULTS AND DISCUSSIONS

Figure 5 presents a comparison between experimental and SOLPOS predicted irradiance data for Corpus Christi (Texas) across four different tilt angles 0°, 35°, 40°, and 50° recorded at 30-minute intervals throughout a day in July 2025. When compared to SOLPOS predictions, our experimental data aligned closely, with deviations appearing mainly due to horizon obstructions or sensor angle limitations. Temperature data showed minimal differences between panels, with the 50° panel occasionally registering slightly higher midday temperatures. This information supports the hypothesis that moderate tilt angles provide the best overall performance while minimizing heat-related losses.

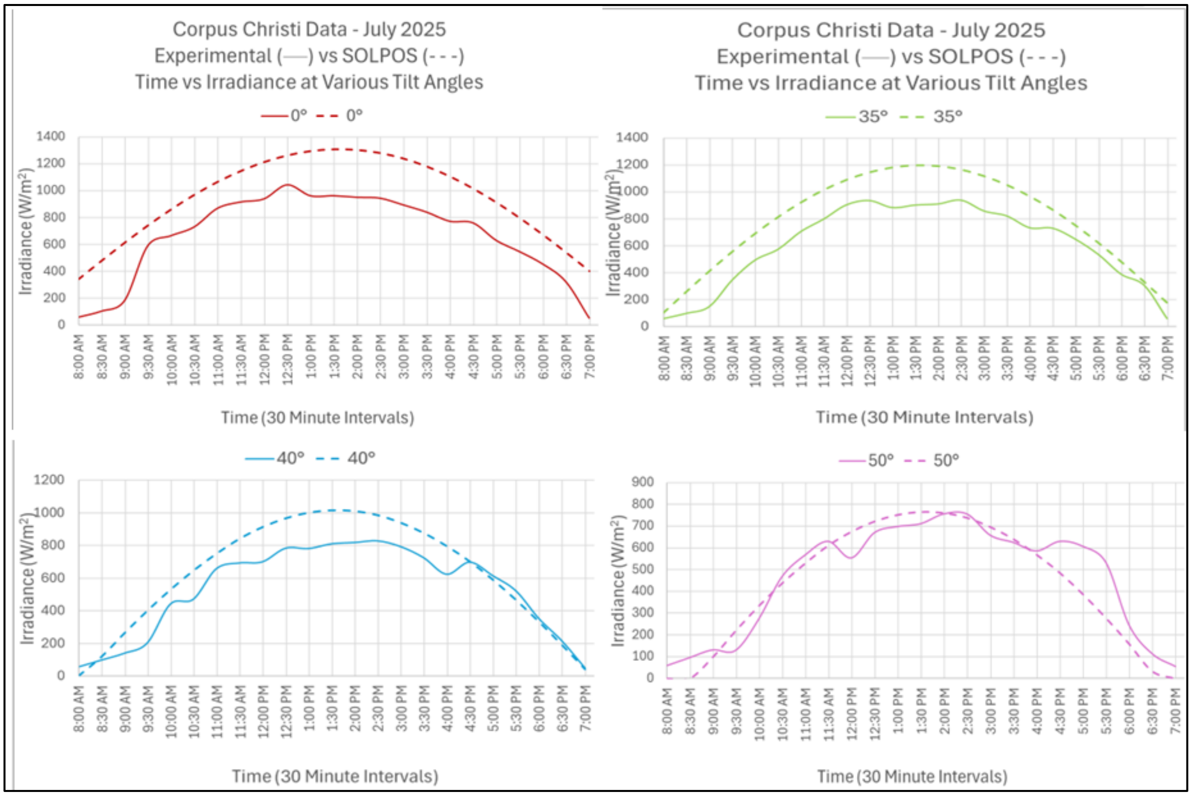

Figure 5: Experimental vs. SOLPOS irradiance data for Corpus Christi at four tilt angles (0°, 35°, 40°, 50°) over a single day in July 2025.

Figure 6 presents a comparison between experimental and SOLPOS predicted irradiance data for Kingsville across four different tilt angles 0°, 35°, 40°, and 50° recorded at 30-minute intervals throughout a day in July 2025. The experimental curves closely match the SOLPOS predictions, confirming the model's accuracy under clear-sky conditions.

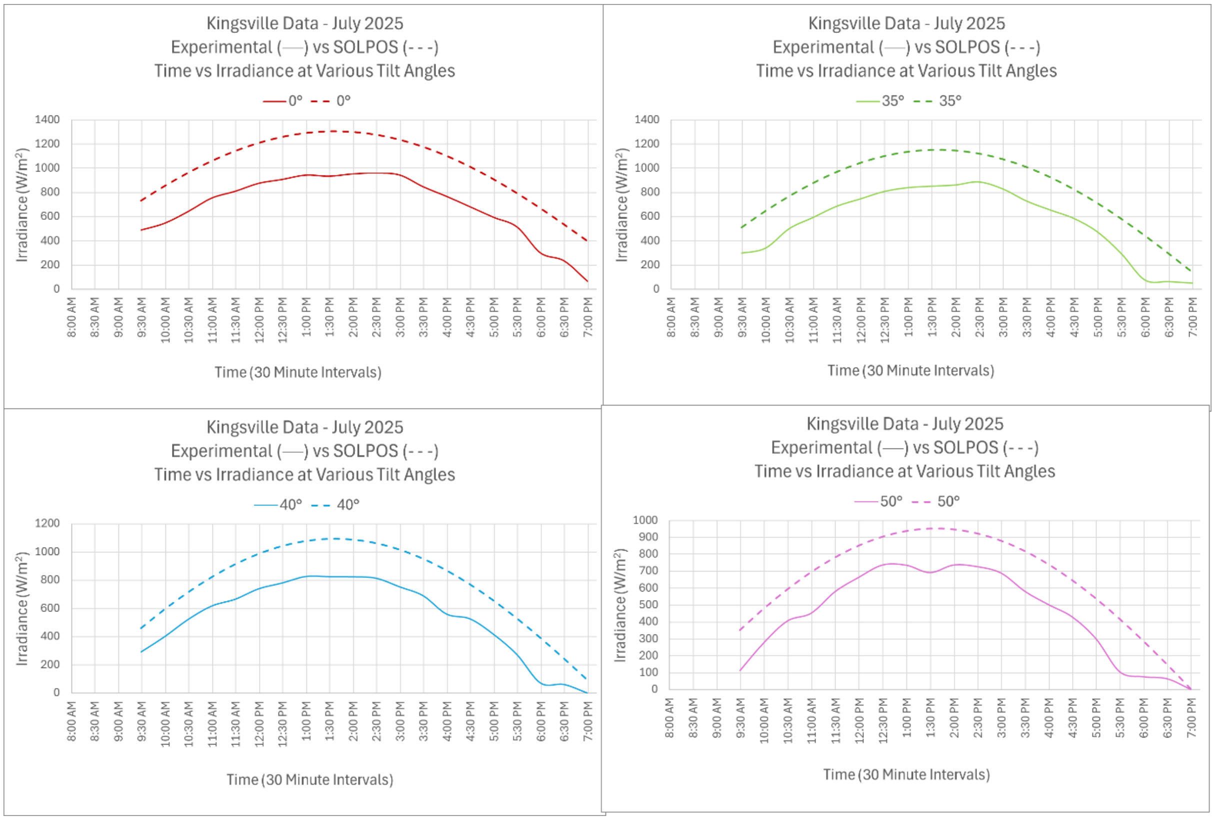

Figure 6: Experimental vs. SOLPOS irradiance data for Kingsville at four tilt angles (0°, 35°, 40°, 50°) over a single day in July 2025.

The close alignment between experimental and SOLPOS data in Figure 5 and 6 validates the latter as a reliable planning tool for solar installations. Discrepancies during low-angle sunlight hours emphasize the importance of site-specific factors like shade and sensor orientation. From an educational perspective, this project demonstrates how scientific modeling and real data can converge in a classroom setting to promote critical thinking and applied learning.

Figure 7 presents 3D surface plots of solar irradiance in 2024 at 27.526° N, -97.881° W across the year for four different fixed tilt angles: 0°, 30°, 60°, and 90°. Each plot displays irradiance intensity (W/m²) as a function of both time of day (x-axis) and day of the year (y-axis), with irradiance values represented by the z-axis and color gradient. At 0° tilt, maximum irradiance occurs during the summer months, but the low tilt limits performance in winter. The 30° tilt shows more balanced performance across the year, with a broader peak during midday, making it favorable for consistent output. 60° tilt performs better during the winter months due to the steeper angle aligning better with the sun's lower position in the sky, though it captures less during summer. Finally, 90° tilt (vertical) shows poor performance overall, with very limited irradiance except during early morning and late afternoon when the sun is low on the horizon.

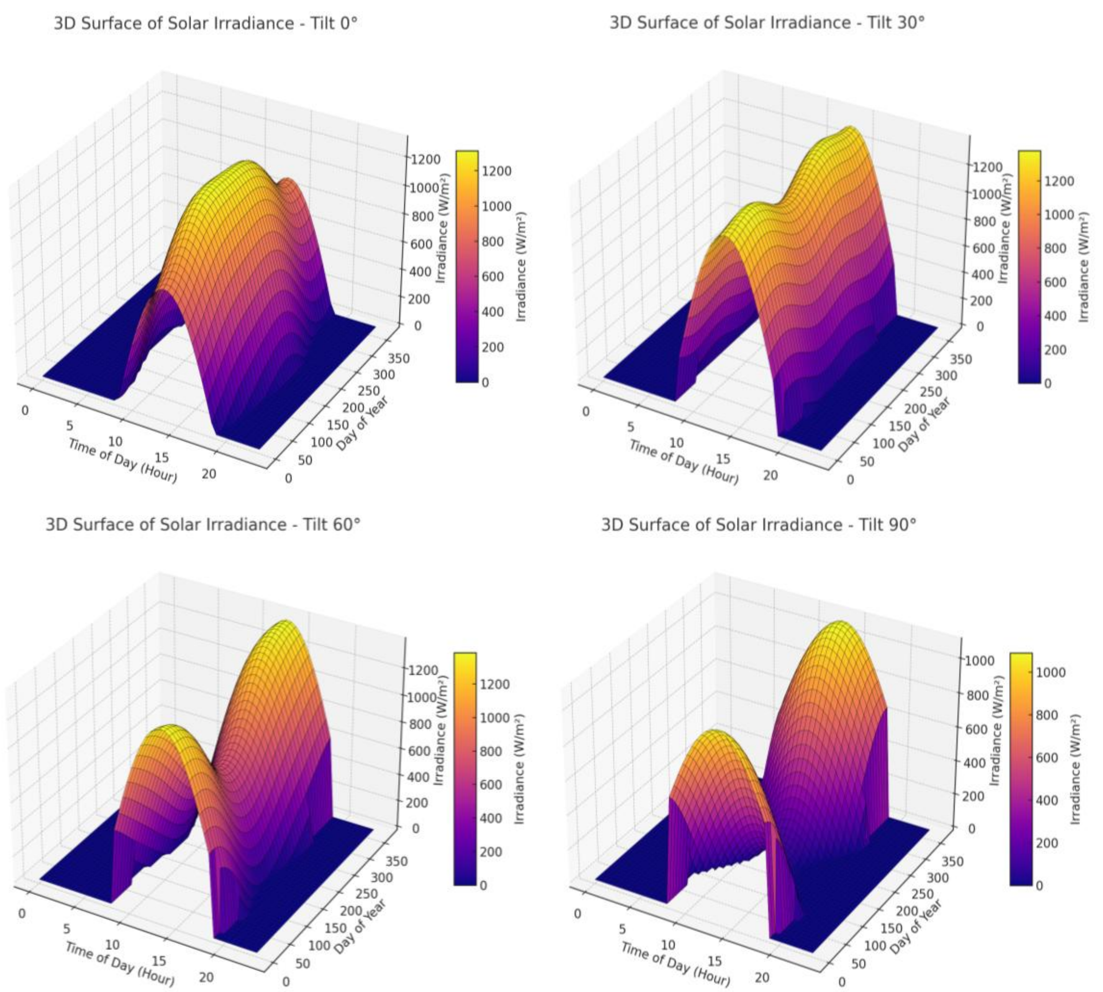

Figure 7: 3D surface plots showing solar irradiance variation by time and day of year for different tilt angles (0°, 30°, 60°, 90°).

Figure 8 shows the SOLPOS monthly average irradiance for the year 2024 at 27.526° N, -97.881° W across different fixed tilt angles ranging from 0° to 90°. The x-axis represents each month of the year, while the y-axis indicates irradiance in W/m². The data reveals a clear seasonal trend, with higher irradiance values occurring during November-February and lower values during mid-summer, depending on the tilt angle. Panels with lower tilt angles (0° to 30°) provide consistent irradiance throughout the year, suggesting that they are more balanced options for fixed installations. while steeper angles (45° to 90°) show increased performance during November-February.

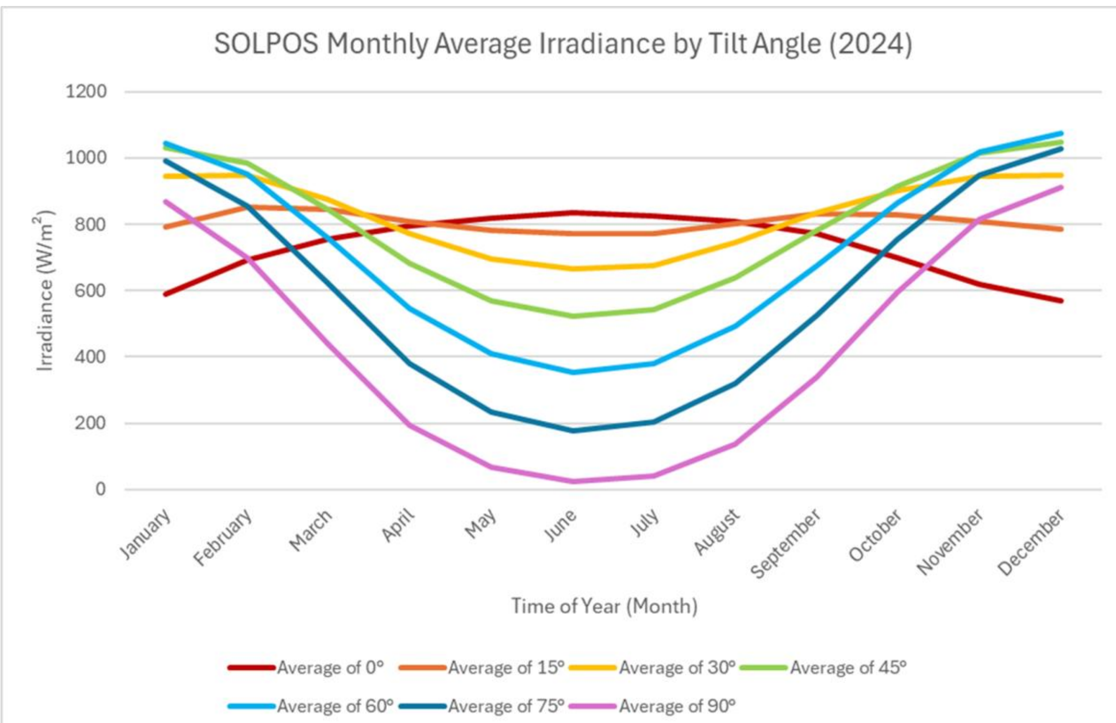

Figure 8: Monthly average irradiance for various fixed tilt angles in 2024 based on SOLPOS data.

Figure 9 shows an irradiance map that identifies the optimal solar panel tilt angle across different times of the day and throughout the year. The x-axis represents the time of day (in hours), while the y-axis shows the day of the year (from 1 to 365). The color scale on the right indicates the best tilt angle in degrees, ranging from 0° (horizontal) to 90° (vertical). This heatmap-style graph offers a powerful visual tool for understanding how the optimal tilt angle varies with both time and season. During mid-year (summer months), lower tilt angles (around 0°–30°) dominate throughout most of the day. Conversely, during the start and end of the year (winter months), the map shifts toward higher tilt angles (50°–80°), especially during the early morning and late afternoon. Around solar noon throughout the year, the optimal tilt remains relatively low, reinforcing the benefit of moderate tilt settings for fixed systems aiming to capture peak irradiance. The graph's resolution enables detailed throughout the day and seasonal optimization, which can be particularly useful for advanced solar tracking systems or for designing seasonally adjustable mounts. For educational and research applications, this figure demonstrates how dynamic the solar environment is, and how real-time or adaptive tilt strategies can significantly improve solar energy capture compared to static configurations.

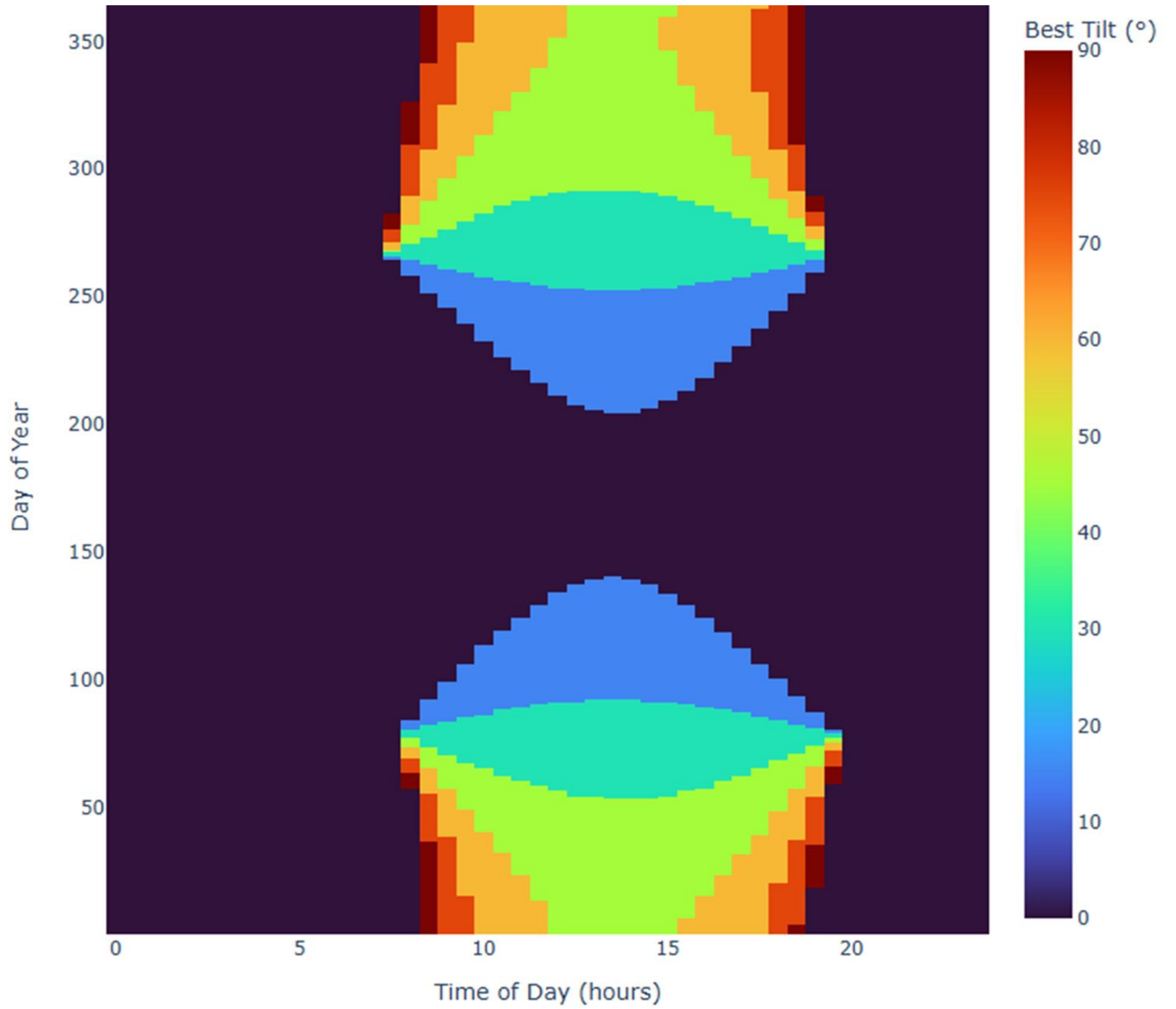

Figure 9: Irradiance map showing optimal tilt angles by time of day and day of year.

7. CURRICULUM INTEGRATION

The research was directly translated into two mathematics modules. In Geometry, students will explore solar panel angles using concepts such as angle of elevation and triangle trigonometry, with activities include designing sun-path models and calculating optimal tilt angles. In Algebra II, students will analyze time-series irradiance data using regression techniques to determine peak outputs and model real-world systems. Tools such as Project Passport booklets and the “Ask the Architect” question box will encourage reflection and inquiry. These modules provide engaging, standards-aligned content that connects abstract math to renewable energy solutions.

8. CONCLUSION

Optimizing tilt angles is a simple yet powerful method to enhance the efficiency of fixed solar panel systems. The SOLPOS tool proved to be an accurate and accessible model, making it a valuable resource for both homeowners and educators. The project provides useful guidelines on how the change the solar panel tilt angles during the day and month can facilitate maximizing the solar irradiance, and, thereby increasing the solar panel output. By integrating these findings into high school math curricula, we can foster a deeper understanding of renewable energy while strengthening data literacy and problem-solving skills among students.

9. CURRICULUM MODULES

Algebra 2 Module

Algebra 2 Lesson Plan: Exploring Data Collection and Analysis with Solar Panels
Integrating Mathematics and Environmental Science

Lesson Overview

This lesson combines Algebra 2 concepts with an engaging, hands-on experiment using solar panels. Students will collect irradiance data every 5 minutes during a 40-minute interval using four solar panels set at different angles.

Algebra 2 TEKS

- TEKS 111.39(c)(2)(A): Representing and analyzing data using graphs and functions.
- TEKS 111.39(c)(2)(D): Formulating and solving problems involving linear functions and their applications.
- TEKS 111.39(c)(6)(B): Applying quadratic functions to real-world scenarios, including data modeling.
- TEKS 111.39(c)(4)(A): Collecting and organizing experimental data systematically.

Lesson Objectives

By the end of this lesson, students will be able to:

- Understand how to collect and organize experimental data in a systematic manner.
- Interpret data patterns and relationships using graphs and functions.
- Apply mathematical concepts such as linear and quadratic regression to real-world data.
- Recognize the impact of solar panel angles on energy collection.

Materials Needed

- 4 small solar panels (set at 0°, 35°, 40°, and 50° angles).
- Irradiance meters or multimeters to measure light intensity.
- Stopwatches or timers.
- Graph paper or graphing software (e.g., Desmos, Excel).
- Student notebooks and pencils.

Lesson Duration

Approximately 45 minutes:

- 5 minutes: Introduction and instructions.
- 35 minutes: Data collection and observation.

- 5 minutes: Data analysis and discussion.

Lesson Procedure

1. Introduction (5 minutes)

- Begin by explaining the purpose of the experiment: to explore the relationship between the angle of solar panels and the efficiency of light capture.
- Review concepts of data collection, including how to take accurate measurements and record them systematically.
- Introduce the mathematical focus: students will analyze the data to identify trends and create models.
- Assign students to small groups (e.g., 4–5 students per group) and distribute materials.
- Ask students to come up with the angle they believe will have the optimum output and why.

2. Experimentation (35 minutes)

- Set up the solar panels at the designated angles (0°, 35°, 40°, and 50°).
- Students will begin data collection at 10:00 am and take irradiance readings every 5 minutes until 10:40 am, recording the results for each panel.
- Encourage students to observe external factors (e.g., cloud cover) and note them in their records.
- Teachers should circulate among the groups to ensure accurate measurements and provide guidance.

3. Data Analysis (5 minutes)

- Students will plot their data on graphs, using time on the x-axis and irradiance on the y-axis. Each panel's data should be represented as a different line or curve on the graph.
- Discuss any patterns observed: Which angle was most efficient? Were there fluctuations in irradiance?
- Introduce regression analysis if appropriate (linear or quadratic) and have students fit equations to their data.
- Encourage students to hypothesize why certain angles performed better than others.

Discussion Questions

- What trends did you notice in the data for different panel angles?
- How might the angle of the solar panel affect its efficiency in collecting light?
- What other factors could influence the results of this experiment (e.g., weather, time of year)?
- How can the concepts in this experiment be applied to real-world solar energy systems?

Assessment

Students will be assessed on:

- Accuracy and completeness of their data collection.
- Clarity and organization of their graphs.
- Their ability to analyze and interpret the results meaningfully.
- Participation in group work and class discussions.

Extension Activity

For advanced students or extra credit:

- Have students research the optimal angle for solar panels in their geographic location and compare it to their experimental results.
- Encourage them to explore how solar panel efficiency changes over the course of a day or a year.

Conclusion

This lesson allows students to see the intersection of mathematics and environmental science in action. They will not only practice critical Algebra 2 skills but also gain a deeper understanding of renewable energy and its importance in addressing global challenges.

Geometry Module

Geometry Lesson Plan: Solar Panel Experiment
Exploring Time vs Irradiance with Angles

Objective

Students will apply geometric principles to understand and analyze the relationship between angles and solar panel irradiance. The lesson will help students connect geometric concepts to real-world applications, specifically solar energy optimization.

Materials Needed

- Solar panels (small-scale, suitable for classroom experiments)
- Light source (e.g., a lamp or sunlight)
- Timer
- Device to measure irradiance (e.g., a solar power meter or smartphone apps)
- Graph paper or spreadsheet software

Relevant Geometry TEKS

- TEKS 111.41(c)(9)(B): Apply properties of angles formed by parallel lines and transversals to solve problems.
- TEKS 111.41(c)(10): Use trigonometric ratios to model and solve problems involving right triangles.
- TEKS 111.41(c)(13): Apply geometric concepts to solve real-world problems.

Lesson Outline

Introduction (5 minutes)

- Begin by discussing the importance of solar energy and the role of solar panels in sustainable living.

- Introduce the experiment: measuring the irradiance of a solar panel at different angles (0°, 35°, 40°, 50°) and analyzing the data to find the optimal angle for maximum solar energy collection.

Conceptual Foundation (10 minutes)

- Review geometric concepts related to angles and their measurement.

- Explain how the angle of a solar panel impacts the amount of sunlight it absorbs using trigonometric ratios.

- Introduce the concept of irradiance and its dependence on panel orientation relative to the sun.

- Ask students to come up with the angle they believe will have the optimum output and why.

Experiment Setup (10 minutes)

- Divide students into 4 groups and provide materials.

- Show how to record time and irradiance data for their specified angles: 0°, 35°, 40°, and 50°.

- Ensure students understand how to use the irradiance measuring device and timer.

Data Collection and Observation (15 minutes)

- Allow students to conduct the experiment, recording irradiance readings at each angle for a set period.

- Encourage students to observe trends and differences in data as the angle changes.

Analysis and Discussion (5 minutes)

- Guide students in plotting time vs irradiance for each angle using graph paper or spreadsheet software.

- Discuss results: Which angle yielded the highest irradiance? Why might this be the case?

- Relate findings back to geometric principles, emphasizing the real-world application of mathematics in optimizing solar energy systems.

Homework/Extension Activity

- Assign students to research how solar panel orientation varies by geographic location and how trigonometry is used in designing solar farms.

- Optionally, have students calculate the optimal panel angle for their local latitude using trigonometric formulas.

- GT extension: Do research on the azimuth angle and identify azimuth angle use in their experiment.

Conclusion

This lesson not only teaches key geometric concepts but also demonstrates their relevance to solving real-world problems. By applying mathematics to sustainable technology, students gain valuable insights into the practical applications of geometry.

Precalculus Module

Lesson Title: Sun Smarts: Optimizing Solar Panel Angle Using Precalculus

Grade Level: High School (Precalculus)

TEKS (Texas Essential Knowledge and Skills) for Precalculus Relevant standards from the Texas Essential Knowledge and Skills:

1. **(2)(B)** - Analyze and evaluate the graphic and numeric representations of functions as models of real-life situations to interpret and predict outcomes.
2. **(3)(D)** - Use trigonometric ratios and identities to solve problems involving right triangles and circular functions.
3. **(4)(A)** - Graph trigonometric functions, describe the key features, and relate the functions to real-life scenarios.
4. **(4)(C)** - Solve equations involving trigonometric functions.
5. **(5)(A)** - Represent and solve problems using parametric equations. *(Optional extension)*
6. **(7)(A)** - Use regression to determine an appropriate function to model real-life data.
7. **(1)(F)** - Connect mathematics to the study of Earth and space sciences.

Objectives: By the end of this lesson, students will be able to: - Understand how the tilt angle of a solar panel impacts the solar irradiance it receives. - Use trigonometric functions to model and analyze solar irradiance. - Apply regression or trigonometric graphing to determine optimal angles. - Interpret and justify real-life decisions using mathematical models.

Materials Needed: - Graphing calculator or Desmos - Irradiance data set (tilt angle vs. irradiance) - Student worksheet with tasks - Projector or interactive whiteboard - Optional: Solar simulation tool or spreadsheet output (e.g., SOLPOS)

Lesson Activities:

1. Hook (5 minutes): Pose the scenario: "Your family wants to install solar panels in Corpus Christi. What angle should they be tilted to get the most energy in July? Should that angle change in the winter?"

Display an image of solar panels with adjustable tilt. Briefly discuss how solar panels work and why angle matters.

2. Direct Instruction (15 minutes): Introduce the idea of solar irradiance and how it depends on the incident angle of sunlight. Explain how irradiance is affected by tilt angle and can be modeled using a cosine relationship. Relate this to sun elevation and how optimal tilt changes with season.

3. Guided Practice (20–30 minutes): Distribute irradiance data table showing measurements at the following tilt angles: 0°, 35°, 40°, and 50°.

Students will: - Plot data points on graphing calculator or Desmos. - Fit a trigonometric or polynomial regression curve. - Identify the angle that yields maximum irradiance. - Interpret the graph and validate results.

Challenge question: How would the optimal tilt change in January?

4. Real-World Wrap-Up (10 minutes): Lead a class discussion: - What assumptions did we make? - How could this model be improved? - Would a fixed or adjustable solar panel be better in South Texas? - How does this connect to careers in STEM or environmental science?

Optional Extensions: - Use parametric equations to model sun path during the day. - Use NREL data or SOLPOS output to analyze irradiance across the year. - Discuss engineering solutions like solar trackers and their costs vs. benefits.

Assessment: - Completion of worksheet with graph, calculations, and written justification. - Exit ticket: "What angle gives the most sunlight in July and why?" - Optional quiz on modeling and graphing trigonometric functions.

Teacher Notes: - This lesson works best near the unit on trigonometric functions. - Consider flipping the classroom by assigning a video on solar energy before the lesson. - Emphasize real-world math connections to build engagement.

Data Table Example (Can be provided on worksheet):

Tilt Angle (degrees)	0	35	40	50
Irradiance (W/m^2)				
Temperature (F°)				

10. ACKNOWLEDGMENTS

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Wind Condition Prediction Using Different Machine Learning Algorithms

National Science Foundation (NSF) Research Experiences for Teachers (RET)

Site at Texas A&M University-Kingsville

Integrating data-driven research in Renewable Energy Across Disciplines (I-READ)

Teacher Participants: Kelsey Correa, Denise Gonzalez

Faculty Mentors: Dr. Hua Li, Dr. Marsha Sowell

Student Mentor: Joaquin Haces-Garcia

Industrial Advisor: Rene Ramirez, Jr, P.E., PMP

Abstract

This project looks at how machine learning can help us better predict wind speeds in different parts of Texas, both along the coast and inland. Using real historical data from the National Solar Radiation Database (2017–2023), three models were tested: Random Forest, Support Vector Regression, and Long Short-Term Memory (LSTM). The models were trained in three different ways: using data from a non-hurricane year, hurricane year, and a mix of both to see how weather conditions affect performance. At first, all three models were used to predict wind speeds one hour ahead on randomized dates. Once performance was compared, the project narrowed in on the LSTM model to make more complex, 24-hour forecasts. We tested different input sizes using previous windows of 24 hours, 168 hours (one week), and 720 hours (one month) to see which input sizes gave the most accurate predictions. The results helped us understand how model performance changes based on weather patterns, location, and input size.

1. Introduction

As renewable energy becomes a larger part of our power grid, knowing how much wind energy we will have tomorrow is essential. In Texas, where wind is one of the state's biggest energy sources [1], power companies participate in what's called the day-ahead wind energy market. The day-ahead wind market is a segment of the electricity market where energy produced from wind resources is traded a day in advance [2]. Machine learning plays a crucial role in optimizing energy use by analyzing historical data, allowing for more efficient management of resources. By predicting wind conditions such as wind speeds, machine learning enhances decision-making processes for energy providers.

One of the previous studies used LSTM models to predict wind speeds across five Texas cities [3]. Results showed that larger, more diverse training datasets improved accuracy, especially for wind speed. Monthly data led to better predictions than weekly data, and terrain complexity affected performance, with models struggling more in areas with varied topography. Another study [4], though focused on vegetation, showed that LSTM outperformed Random Forest and SVR in tracking environmental patterns over time especially when a 2-month time lag was added. Random Forest worked well during training but struggled with new data due to overfitting. Finally, one study [5] found that larger training datasets improved LSTM accuracy for next-hour wind predictions, while adding extra features like temperature hurt performance. Models also struggled to transfer across locations, showing the importance of local or mixed-region training.

2. Methodology

This study used real hourly wind speed data from 2017 to 2023, collected from the National Solar Radiation Database (NSRDB) by the National Renewable Energy Laboratory. We focused on two locations in South Texas to see how geography affects prediction accuracy. One site was Port Aransas, TX, a coastal town influenced by changing Gulf weather, and the other was Sinton, TX, an inland area with generally more stable wind patterns.

After obtaining raw hourly data from the NSRDB for Port Aransas and Sinton, TX, the dataset was cleaned and formatted for modeling. Only wind speed (m/s), hour, day, month, and year were used for analysis. All other variables such as temperature, wind direction, humidity, etc. were removed to focus the models solely on wind speed. The cleaned data was exported and organized in Microsoft Excel.

Three machine learning models were chosen for comparative analysis: Random Forest (RF): A model that uses many decision trees to make predictions. [7] Support Vector Regression (SVR): A model that fits data with a best-fit line [8], Long Short-Term Memory (LSTM): A neural network designed to learn from time-series data [9]

To assess how weather conditions influence prediction accuracy, models were trained under three distinct conditions: The first phase focused on a Non-Hurricane Year (2022), the second phase focused on a Hurricane Year (2020), and the third phase focused on combined years (2020 and 2022). Each model was trained and tested independently on data from Port Aransas and Sinton.

Three input window sizes were tested to evaluate how much historical data improves prediction accuracy: 24 hours, 168 hours (1 week), 720 hours (1 month). Two forecast types were conducted: Stage 1 focused on Next-Hour Predictions. All three models (RF, SVR, LSTM) were used to predict the next hour of wind speed. Stage 2 focused on Next-24-Hour Prediction. The LSTM model was used to predict the next 24 consecutive hours of wind speed using sequence to sequence predictions.

Model accuracy was assessed using the Root Mean Squared Error (RMSE), which measures the average deviation between predicted and actual values. Lower RMSE values indicate higher accuracy and better model performance.

3. Results

For the task of predicting next-hour wind speed in Port Aransas, TX, model performance was evaluated using Root Mean Squared Error (RMSE). For next-hour wind speed forecasting, all three models were used, and all models were trained using Hurricane year (2020), Non-Hurricane year (2022), and combined-year data (from both a hurricane and a non-hurricane year). Among the three models tested, Long Short-Term Memory (LSTM) consistently outperformed the others, delivering the lowest RMSE values in 67% of the test cases. Random Forest (RF) performed best in the remaining cases, while Support Vector Regression (SVR) had the highest error rates overall, making it the least effective model for this prediction task. When comparing input window sizes, the 24-hour input consistently yielded the best performance for next-hour forecasts. This suggests that recent, short-term wind patterns are most useful for making accurate one-hour-ahead predictions. Interestingly, the models performed especially well when predicting the hurricane year (2017), particularly when they were trained on combined data from both hurricane and non-hurricane years. This finding indicates that training on diverse weather patterns, including both stable and extreme conditions, can help models generalize better and improve accuracy under more variable coastal conditions. Figure 1 shows the RMSE results for next hour predictions in Port Aransas, TX.

When predicting next-hour wind speed in Sinton, TX, model performance again varied by algorithm. For next-hour wind speed forecasting, all three models were used, and all models were trained using Hurricane year (2020), Non-Hurricane year (2022), and combined-year data (from both a hurricane and a non-hurricane year). In this inland location, Random Forest (RF) consistently outperformed the other models, achieving the lowest RMSE in 74% of the test cases. LSTM performed best in the remaining cases, while SVR once again showed the poorest performance overall, with the highest error rates across all input sizes. Similar to the results in Port Aransas, the 24-hour input window produced the most accurate predictions. This confirms that short-term historical data is most effective for next-hour forecasting, even in more stable inland environments like Sinton. These results suggest that Random Forest may be better suited for inland wind forecasting, where wind patterns are generally more stable and easier for tree-based models to interpret. Figure 2 shows the RMSE results for next hour predictions in Sinton, TX.

Port A---MODELS TRAINED USING HURRICANE YEAR 2020 (HANNA)									
	PREDICTING HURRICANE AND NON-HURRICANE YEARS			PREDICTING NON-HURRICANE YEARS			PREDICTING HURRICANE YEAR		
Input Size	RF	LSTM	SVR	RF	LSTM	SVR	RF	LSTM	SVR
24 hours	0.13	0.12	0.42	0.15	0.14	0.52	0.11	0.10	0.29
168 hours (1 week)	0.13	0.13	1.77	0.16	0.15	2.09	0.09	0.10	1.38
720 hours (1 month)	0.15	0.11	2.34	0.16	0.13	2.09	0.13	0.10	2.56

Port A---MODELS TRAINED USING NON-HURRICANE YEAR (2022)									
	PREDICTING HURRICANE AND NON-HURRICANE YEARS			PREDICTING NON-HURRICANE YEARS			PREDICTING HURRICANE YEAR		
Input Size	RF	LSTM	SVR	RF	LSTM	SVR	RF	LSTM	SVR
24 hours	0.21	0.15	0.72	0.17	0.14	0.96	0.24	0.16	0.33
168 hours (1 week)	0.24	0.16	1.49	0.21	0.16	1.75	0.27	0.17	1.18
720 hours (1 month)	0.21	0.66	1.49	0.18	0.73	1.75	0.25	0.59	1.17

Port A---MODELS TRAINED USING COMBINED YEARS (HURRICANE 2020 AND NON-HURRICANE 2022)									
	PREDICTING HURRICANE AND NON-HURRICANE YEARS			PREDICTING NON-HURRICANE YEARS			PREDICTING HURRICANE YEAR		
Input Size	RF	LSTM	SVR	RF	LSTM	SVR	RF	LSTM	SVR
24 hours	0.14	0.13	0.43	0.19	0.15	0.58	0.08	0.12	0.19
168 hours (1 week)	0.15	0.13	1.57	0.20	0.15	1.75	0.09	0.10	1.36
720 hours (1 month)	0.23	0.43	1.57	0.30	0.53	1.75	0.09	0.30	1.36

Figure 1: Next-hour Wind Speed Prediction Results of Port Aransas

Sinton---MODELS TRAINED USING HURRICANE YEAR 2020 (HANNA)									
	PREDICTING HURRICANE AND NON-HURRICANE YEARS			PREDICTING NON-HURRICANE YEARS			PREDICTING HURRICANE YEAR		
Input Size	RF	LSTM	SVR	RF	LSTM	SVR	RF	LSTM	SVR
24 hours	0.13	0.17	0.46	0.12	0.19	0.59	0.13	0.13	0.27
168 hours (1 week)	0.24	0.48	1.43	0.25	0.48	1.59	0.23	0.47	1.33
720 hours (1 month)	0.25	0.73	1.46	0.25	0.70	1.58	0.25	0.77	1.32

Sinton---MODELS TRAINED USING NON-HURRICANE YEAR (2022)									
	PREDICTING HURRICANE AND NON-HURRICANE YEARS			PREDICTING NON-HURRICANE YEARS			PREDICTING HURRICANE YEAR		
Input Size	RF	LSTM	SVR	RF	LSTM	SVR	RF	LSTM	SVR
24 hours	0.20	0.17	0.34	0.18	0.18	0.27	0.22	0.16	0.39
168 hours (1 week)	0.18	0.16	1.45	0.17	0.16	1.44	0.19	0.16	1.46
720 hours (1 month)	0.21	0.71	1.44	0.18	0.58	1.43	0.24	0.82	1.45

Sinton--MODELS TRAINED USING COMBINED YEARS (HURRICANE 2020 AND NON-HURRICANE 2022)									
	PREDICTING HURRICANE AND NON-HURRICANE YEARS			PREDICTING NON-HURRICANE YEARS			PREDICTING HURRICANE YEAR		
Input Size	RF	LSTM	SVR	RF	LSTM	SVR	RF	LSTM	SVR
24 hours	0.15	0.17	0.19	0.14	0.19	0.19	0.15	0.14	0.19
168 hours (1 week)	0.19	0.21	1.38	0.15	0.20	1.41	0.22	0.21	1.35
720 hours (1 month)	0.19	0.40	1.37	0.12	0.41	1.39	0.25	0.38	1.34

Figure 2: Next-hour Wind Speed Prediction Results of Sinton

For next-day wind speed forecasting, only the LSTM model was used, and all models were trained using combined-year data (from both a hurricane and a non-hurricane year). Three input window sizes were tested: 24 hours, 168 hours (1 week), and 720 hours (1 month) to evaluate the impact of historical context on 24-hour forecasts. Across both Port Aransas and Sinton, the one-month input window (720 hours) produced the most accurate predictions in 67% of cases, highlighting the importance of long-term pattern recognition when forecasting a full day of wind speeds. The one-week window performed best in the remaining cases. The 24-hour input window was not effective for next-day forecasting and was therefore excluded from this phase. Both locations showed exceptionally strong performance when predicting wind speeds for the hurricane year (2017), suggesting that the LSTM model effectively captured the more dynamic wind patterns present during extreme weather periods, especially when trained on a mix of stable and volatile data. Figure 3 shows the RMSE results for both Port Aransas, TX and Sinton, TX.

LSTM Model Combined Year Training (2020 & 2022)
Port Aransas,TX

Input Size	Hurricane and Non-Hurricane Year Predictions	Non-Hurricane Year Predictions	Hurricane Year Predictions
24 hours	1.49	1.63	0.97
168 hours (1 week)	1.26	1.37	0.85
720 hours (1 month)	1.16	1.27	0.76

LSTM Model Combined Year Training (2020 & 2022)
Sinton, Tx

Input Size	Hurricane and Non-Hurricane Year Predictions	Non-Hurricane Year Predictions	Hurricane Year Predictions
24 hours	0.88	0.93	0.70
168 hours (1 week)	0.80	0.86	0.57
720 hours (1 month)	0.85	0.94	0.52

Figure 3: Next-day Wind Speed Prediction Results

To better illustrate how input window size affects prediction accuracy, Figure 4 and Figure 5 were created. One for Port Aransas and one for Sinton comparing actual wind speeds to LSTM predictions using 24-hour, 1-week (168-hour), and 1-month (720-hour) input windows. These graphs reflect next-day predictions generated using combined-year training data. In both graphs, the 1-month input most closely matched the overall trend of actual wind speeds, particularly in Sinton. The Sinton graph shows consistently strong performance across all input sizes, with the model capturing both low and high wind speeds relatively accurately. In contrast, the Port Aransas graph reveals more variability and less precision especially in predicting wind speed peaks and drops. This suggests that the coastal environment, with its more complex and volatile wind patterns, posed a greater challenge for the model. Overall, these visualizations reinforce earlier findings: longer input windows improve next-day forecast accuracy, and Sinton's inland stability makes it easier to predict than Port Aransas's coastal variability.

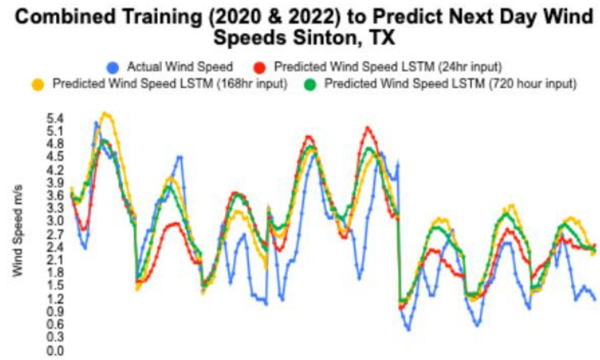

Figure 4: Next-day Wind Speed Prediction Results of Sinton

Figure 5: Next-day Wind Speed Prediction Results of Port Aransas

4. Conclusions

This study explored how different machine learning models perform when predicting wind speeds in coastal and inland regions of Texas, using historical weather data. Several important patterns emerged from the results. First, predicting wind speed just one hour ahead was consistently more accurate than trying to forecast the next 24 hours. When it came to model performance, Random Forest (RF) and Long Short-Term Memory (LSTM) both clearly outperformed Support Vector Regression (SVR) in every scenario tested. Model effectiveness also varied by location. In Sinton, the inland site, Random Forest delivered the best overall performance, likely due to the area's more stable wind conditions. In contrast, LSTM performed better in Port Aransas, where coastal wind patterns are more complex and require models that can recognize long-term trends. The size of the input window played a major role in accuracy. For next-hour predictions, the 24-hour input window provided the best results. But for next-day predictions, the 1-month window was more effective, allowing the model to learn broader trends over time. Interestingly, the models performed better when forecasting data from a hurricane year compared to calmer years or combined datasets. This suggests that training on a wider range of wind conditions may help the models generalize better. Lastly, predictions were most accurate for wind speeds in the normal range—models struggled more with very high or very low wind speeds, which are harder to predict due to their rarity and unpredictability. Overall, the findings highlight the importance of choosing the right model, input size, and training data based on the forecasting goal, location, and conditions. These insights could help improve wind forecasting methods used in energy planning, especially in support of the day-ahead wind market.

Course Modules

Algebra 1

In this real-world STEM project, students will collect daily wind speed data using a portable weather station, graph and model the data using linear regression (A.4C), and later use machine learning tools to compare predictive models. Students will evaluate which method—linear regression or machine learning—produces more accurate next-day wind speed predictions.

Algebra 1 Project-Based Module:

Predicting Wind Speeds with Math and Machine Learning

Grade Level: Algebra 1

Duration: 10 Days

TEKS Addressed:

- **A.4(C)**: write, with and without technology, linear functions that provide a reasonable fit to data to estimate solutions and make predictions for real-world problems
- **A.12(B)**: evaluate functions, expressed in function notation, given one or more elements in their domains

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Module Overview

In this real-world STEM project, students will collect daily wind speed data using a weather machine, graph and model the data using linear regression, and later use machine learning to compare predictive models. Students will evaluate which method—linear regression or ML—produces more accurate next-day wind speed predictions.

Essential Questions

- How can we use algebra to model wind speed?
- Which type of model (linear or ML) gives more accurate predictions?
- What are the limitations and advantages of each model?
- Why is wind speed forecasting important for renewable energy?

Materials

- Computer
- Graphing Technology (DESMOS, calculator)
- Weather Machine-CLICK FOR LINK

Day 1 – Introduction & Hook

Topic: Renewable Energy and Machine Learning

- Discuss the importance of wind energy in Texas
- Discuss how math models help predict wind speed
- Watch a short video or demo on machine learning (ML) in real life
- Explain how weather machine works
- Explain project goals and expectations
- Set up weather machine to start collecting data

Days 2– 3 — Reviewing Key Concepts

Topic: Linear Regression and LSTM

- Students will review linear regression
- Introduction to Long Short Term Memory
- Students will practice using LSTM code on google colab

Days 4–5 – Analyzing Data with Algebra

Topic: Scatterplots & Linear Regression

- Students input collected data into Desmos, Google Sheets, or calculators

- Create scatterplots
- Determine line of best fit using technology
- Use the equation to **predict next-day (24 hours) wind speeds**
- Evaluate prediction accuracy by comparing it to actual data

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Days 6–7 – Introduction to Machine Learning

Topic: Predicting with ML

- Use prebuilt Google Colab notebooks to load the same dataset
- Use a simple **LSTM model** (teacher-guided)
- Train the model to predict the next value
- Record ML-based predictions

Day 8 – Compare Models

Topic: Linear Regression vs. Machine Learning

- Students compare predictions from both models
- Discuss which was more accurate and why
- Introduce the concept of RMSE in simple terms (optional)

Days 9–10 – Summarizing & Presenting Findings

Topic: Data Storytelling

- Students write a short summary of their findings
- Include: scatterplot, linear model, ML prediction, and final comparison
- Present findings as posters or slides

- Reflect on where linear vs. ML models are best used in real life

<u>6th Grade Math</u>

Predicting Wind Conditions & Calculating the Mean

Grade Level: 6th Grade

Subject: Math

Time Duration: 60 minutes

TEKS Standards:

- **6.12(A)** – Represent numeric data graphically, including dot plots, stem-and-leaf plots, histograms, and box plots.
- **6.12(C)** – Summarize numeric data with numerical summaries, including the mean and median, the range, and the interquartile range.

Lesson Objective:

Students will:

- Collect and record wind speed data (real or simulated from your ML model).
- Calculate the **mean** wind speed from a given data set.
- Create a **dot plot** to represent wind speed predictions.
- Interpret patterns and make predictions based on data analysis.

Materials Needed:

- Wind speed data set (real or simulated from your ML model – 10–20 data points recommended)
- Student handouts (tables, graph templates)

- Calculators or devices with spreadsheet tools (optional)
- Chart paper / whiteboard
- Markers

Vocabulary:

- Mean (Average)
- Dot Plot
- Range
- Wind Speed
- Prediction
- Data Set

Engage (10 minutes):

Hook: Show a short video or image set of different weather patterns, asking:

- "How do meteorologists predict wind speed?"
- "Why is predicting wind important for safety and planning?"

Bridge to Math: Introduce your project: *"I've been working on a model that predicts wind speed using machine learning. Today, you'll be data scientists and help interpret the data."*

Explore (20 minutes):

Activity – Wind Speed Data Collection & Mean Calculation

1. Provide students with a wind speed dataset (daily/hourly wind speeds over a week from a local or simulated source).
    - Example: [10, 12, 14, 11, 15, 9, 13]

2. Students:
    - Organize the data into a table.
    - Calculate the **mean**: add all values and divide by the number of data points.
    - Record their calculation process.

Optional Extension:
If devices are available, use a basic spreadsheet to input values and apply a formula for the average.

Explain (10 minutes):

Model how to create a **dot plot** using the class dataset:

- X-axis: Wind Speeds (in mph)
- Y-axis: Frequency (how many times that speed occurred)
- Each dot represents a data point.

Discuss:

- What does the shape of the plot tell us?
- Where is most of the data concentrated?
- How does the **mean** reflect the center of the data?

Elaborate (15 minutes):

Pattern Discussion:

Have students make a prediction

- Ask students to look at the dot plot and mean:

    - “Is the wind speed mostly consistent or does it vary a lot?”
    - “What might that tell us about predicting weather?”
    - “If we see a pattern in the wind speed over time, how could that help with weather forecasting?”

Group Work:
In small groups, have students compare another mini dataset and calculate a second mean. They can compare how mean values differ depending on patterns (steady vs. variable winds).

Evaluate (5 minutes):

Exit Ticket Questions:

1. What does calculating the mean tell us about the data?
2. How can a dot plot help us make predictions?
3. Why might wind speed predictions be important in the real world?

Differentiation:

- **For advanced students:** Introduce range, median and mode as additional summary tools and challenge them to describe data variability.
- **For struggling learners:** Provide a step-by-step guide with visuals for calculating mean and constructing dot plots.

Assessment:

- Observation of group discussions and individual participation
- Accuracy of mean calculation and dot plot
- Completed handouts and exit ticket responses

Acknowledgements

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Daylighting Performance and Energy Consumption in Classrooms

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I-READ Program

July 18, 2025

Introduction

Lighting has always played a role in how successful a person is in completing a task. This is especially important in all classrooms regardless of the educational level. Daylighting has always been utilized in classrooms as a source of light but in the mid 1960's there was a shift in the designing of schools. Schools were now being built with air conditioners, promotion of open classrooms and cost saving construction. As of recently, there has been another mindset shift in how schools should be designed based on multiple factors. Some main factors include reducing energy cost for schools and improving students' performance and overall health. In this experiment we were able to determine the optimal distance a student can be from a day light source to ensure comfortability. This also allowed us to determine how much artificial light is needed to supplement the missing daylight within the classroom. This will help determine how much energy can be saved and essentially determine the overall financial benefits.

Literature Review

It has been proven that classroom lighting plays a role in how successful students are with their academics. It has been shown that, "Classroom lighting does affect cognition, and it is proven in terms of academic achievement, attention rates, working speed, productivity and accuracy among other reported effects" (Mogas-Recalde, J., & Palau, R. 2021) It is important for schools to be self aware about the best working environments for our students and use this information to support it.

The negative effects of only utilizing artificial lighting ranges from students' visual to their mental health and even their social interactions. It has been seen that students' eye sight is being affected by the use of only artificial light during the whole day. This is very common for adults even to experience which is which is called visual fatigue and this can be caused by “unfavorable non-visual impacts” which in turn “will diminish learning efficiency and affect eye health.”Mogas-Recalde, J., & Palau, R. (2021) Now with the increased use of technology in the classroom, lighting is now more important than ever. Schools now are using SMART boards, projectors and laptops for the full school day which is where the visual fatigue comes into play. This is definitely something which needs to be taken into consideration when discussing classroom lighting because now we have to consider factors we didn’t before such as glare. The glare on screens when using daylighting needs to be considered when determining the best way to utilize the daylight so as not to cause more eye strain. There has to be a balance between using artificial lighting and daylighting.

Not only does the lack of daylighting affect students' eye sight, it has also been linked to mental disorders such as depression which can heavily impact students' motivation inside and outside of school. It has been shown that the use of daylight will improve the overall mood and behavior of students. (Samiou, A. I., Doulos, L. T., & Zerefos, S. 2022) This now becomes a discussion of how can we use daylight to combat some of these mental disorders while also being mindful of other factors that also impact students such as the glare from a screen or the visual fatigue.

The main goal of this research is to determine the most optimal window placement to ensure the use of daylight in the classroom is possible and save as much energy as we can. The overall benefits of utilizing daylight are so crucial to student success so by utilizing daylight in classes we should see “increased student sociability and concentration, less stressful environment for students, improved academic performance.”(Lakhdari, K., Sriti, L., & Painter, B. (2021)

Research Methodology

The overall goal of this research experiment is to determine how much light comes into a classroom on a given day between the hours of 8:00 am to 4:00pm and use this information to determine how much energy overall can be saved by utilizing daylight. The data we would be collecting would be quantitative data, dealing with the amount of light and solar radiation coming into the classroom and converting that data to come to a conclusion. Due to the nature of the experiment and the possible scenarios in a classroom, we also wanted to determine if the orientation of the window played a role in the useful daylight illuminance. The task then came with finding 4 rooms of similar sizes, same number of windows and that the windows had different orientations. We decided to use classrooms at Santa Gertrudis ISD Academy High School. Each of the four rooms have windows facing a different direction (North, South, East, and West). The room with the West facing window was later omitted from the experiment due to having a larger window size compared to the other three classrooms. This would not affect our results much since the West window orientation data would be similar to the East window orientation data since the sun rises at the East and sets on the West. We only had enough equipment to conduct the research in one room at a time, so we had to make sure the weather was conducive to the needs of the experiment for each room. The experiment was conducted over a two week period, in 2 day increments.

Experimental Setup

The three classrooms have windows with different orientations, we only focused on utilizing one of the windows. Due to the classroom setup and the desk placement, the middle window was used as the daylight source during this experiment. The first room we began with was room S9 which has windows with a South orientation. The experiment was started in room

S9 on 6/27/2025 at 2:15P.M. and was stopped at 12:00A.M. on 6/30/2025. One LI-COR light (L1) sensor and one LI-COR radiation sensor (S1) were attached directly to the window. The remaining 4 light sensors (L2, L3, L4) were then stationed perpendicular to the window in 3 feet increments. The remaining 2 radiation sensors (S2, S3) were placed perpendicular to the window in 7.5 feet increments. The blinds on the middle window were pulled all the way up, while the blinds on the other 2 windows remained completely closed. To collect the data, HOBOware software was used to set up the HOBO Data loggers to collect data for two days in 5 minute increments. After two days, data loggers were stopped and the data was extracted into an excel file. This process was repeated for room E2, which has an East window orientation, on 7/1/2025 at 1:41P.M and was stopped at 12:00A.M. on 7/4/2025. The data collecting for room N10, which has a North window orientation, began on 7/4/2025 at 1:30P.M and was stopped on 7/7/2025 at 12:00A.M.

Calculations

All the raw data collected by the LI-COR sensors was in volts. For each of the five light sensors, the volts recorded were converted to Lux with the equation shown in the table. The five LI-COR light sensors each had an unique multiplier and dividend that was given by the manufacturer. For the three LI-COR radiation sensors, the raw data in volts was converted to W/m^2 by using the equation W/m^2 = volts*multiplier/0.02. Each radiation sensor has an unique multiplier assigned by the manufacturer but the dividends are all the same.

LI-COR Light Sensor	Mulipler	Equation
L1	3.66	Lux = Volts*Multiplier / 0.06*1000
L2	3.77	Lux = Volts*Multiplier / 0.12*1000
L3	3.64	Lux = Volts*Multiplier / 0.12*1000.
L4	3.83	Lux = Volts*Multiplier / 0.6*1000.
L5	4.05	Lux = Volts*Multiplier / 3.6*1000.

LI-COR Radiation Senor	Multipler
S1	12.86
S2	13.88
S3	14.76

Results and Discussion

When looking at the raw data from the six days we had to make some adjustments to what we were analyzing. The data was cut down from two full days to only data between the hours of 8am to 4pm, to mimic a school day. The data was then converted into lux which is what we needed to determine the DA (Daylight Autonomy) and UDI (Useful Daylight Illuminance). Looking at figure 1.1, each room's average for daylight autonomy was calculated and shown in the graph. Daylight autonomy is how often the daylight lux can maintain a lux of 500 which is a comfortable working environment. In the graph we set the parameters at less than or equal to five hundred lux when determining the usable data for daylight autonomy, staying within that comfortable daylight range. The horizontal axis shows how far each light sensor was from the window and the vertical axis showed the DA percentage. While analyzing the data it can be seen that the north facing window room had the highest percentage with the sensor at three feet. After this we were able to determine the UDI, which is how much illuminance was given that can be utilized in place of artificial lighting. Looking at figure 1.2, it can be seen that the most UDI for all rooms is when the sensors are three to six feet away from the window. This is showing that for schools to get the most UDI within a class students would have to be three to six feet away from a window. The percentage of UDI is not enough to only use within the classroom so artificial lighting will have to be used to supplement the lack of daylight to reach that comfortability of five hundred lux. Using this information we were able to calculate how much kilowatts being used for a full day in a classroom at Academy high which can be seen in future 1.3. The school is being charged around $0.35 for each room when all of the lights are in use. The data showed us that if we use the projected daylight we get from each room we can save energy and cut down the daily cost in each room by ten cents. Overall the data helped us determine how much each room can save by cutting the use of artificial lighting by using the daylight.

Course Modules Developed

The student objective for the course modules does not differ from the middle and high school content because the goal for all students is the same. The student objective is, students will investigate how natural daylight and artificial room lighting affect productivity and focus within a learning environment. Using their findings, they will design and present their own ideal classroom space that promotes effective learning and conservation of energy. In the next two paragraphs, teacher-created course modules will be explained and it's important to note that the length of each module will depend on the grade level it is focused on.

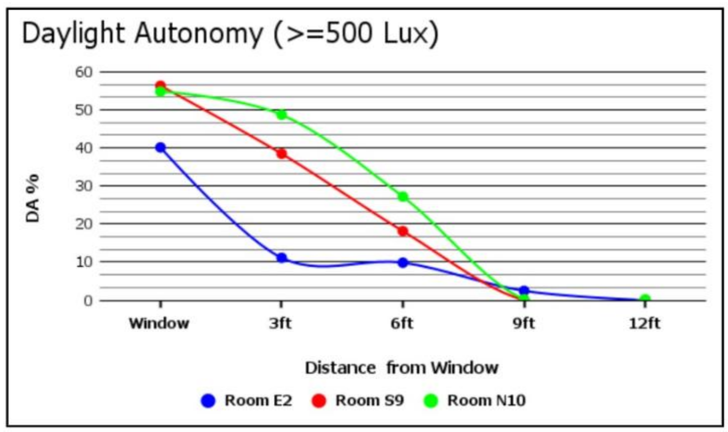

Figure 1.1

Middle School Curriculum Module

The module for the middle school math class has been split into four different parts with each part building upon one another to then get to the main project. The main goal for students is to become familiar with conducting research, doing experiments,

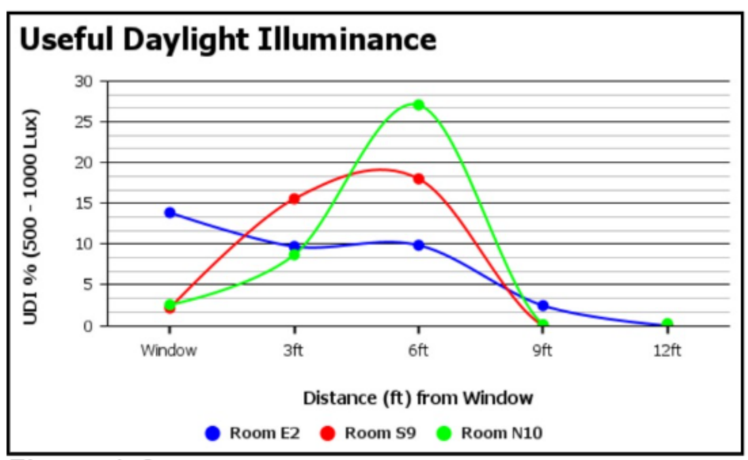

Figure 1.2

analyzing data and being able to construct a design in response to a problem. In the next few paragraphs, I will break down each part along with explaining how the math comes into play.

Room	# of Light Bulbs	Watts per Bulb	KWh Used Daily (lights ALL on)	Cost per KWh	Total Cost /Day (Lights ALL on)	Artificial Light Consumption (KWh) needed if Daylighting is Used	Total Cost of Artificial Light needed (KWh) with Daylighting	Savings / Day Estimate
S9	12	32	6.72	$ 0.0494	$ 0.33	1.183288	$ 0.06	$ 0.27
E2	12	32	7.04	$ 0.0494	$ 0.35	4.78094825	$ 0.24	$ 0.11
N10	12	32	7.104	$ 0.0494	$ 0.35	2.541737	$ 0.13	$ 0.23

Figure 1.3

PART 1: Social Emotional Learning- Survey

To engage the students into the module and connect it to outside the classroom, they will get a survey. The survey has ten student-friendly scaled questions (using a 1–5 Likert scale) about daylight and artificial light in a classroom. These can help gather opinions on lighting quality, comfort, and usefulness. Afterwards we will look at the overall responses from the class and discuss how we think lighting plays a role in their learning. After students have a chance to discuss their opinions, each group will receive chart paper and break it into three sections. The sections will be personal, school, and real-world. In each section, they will be asked to share some examples of how light plays a role in each one. This will be referenced back to in the next activity when students conduct the first experiment as human subjects.

PART 2: Student Experiment-Human Subjects (Whole Class)

Before students begin working on their projects to design the most effective classroom layout, they will conduct a self experiment with the provided material. They will have to read the article, answer the questions so data can be gathered on how they perform in different light settings in the class. The class will be broken into four different lighting scenarios and students will be asked to complete the same assignment. After that students will get a chance to analyze the data. When analyzing the data, they will be given questions to prompt them on what the data is showing and what conclusions can be made. This way students will have a better understanding of how lighting affects their learning and those around them while being able to use some math skills.

PART 3: Daylight Conservation Research and Experiment

Students will research daylight conservation in schools along with looking at their own school district specifically. This is to get them thinking more about how schools are designed and the different factors that affect lighting placement. This will then lead us into the next experiment which is measuring how much daylight comes into the class and determine how much can their school save from utilizing daylight. Very similar to our own experiment, students will measure daylight in the classroom but we will focus on different lighting scenarios such as having the blinds fully open, then maybe only having some open and having the blinds slightly open. Students will use a light sensor that connects to a calculator which will present students with the data in real time. Students can analyze how much daylight comes into the classroom with the help of the instructor. They will be provided more functions to determine exactly how much their school could save in a day, a month and even a full school year.

PART 4: Classroom Design Project

Students will use their research from part three to determine the best classroom design to use both natural daylight and artificial lighting to improve productivity and focus in the learning environment. Using their findings, they will design and present their own ideal study or classroom space that promotes effective learning. They will have to come up with a draft of their design and provide measurements and reasoning for the layout. Afterwards they will create a 3-D model of the classroom along with a presentation showcasing their design process and the math involved.

High School Physics Curriculum Module

The high school Physics curriculum module was created for students in grades 11 - 12. This module follows the 5 E instructional model that is an inquiry based approach to learning that guides the students through the 5 phases of learning that include: engage, explore, explain, elaborate, and evaluate. This curriculum module was designed to be completed in five days (each class period is 75 minutes). The curriculum module will focus on Physics TEK 3(A), 3(B), and 3(C) that focuses on scientific and engineering practices. This TEK reads as follows: The student develops evidence-based explanations and communicates findings, conclusions, and proposed solutions. The student is expected to: (A) develop explanations and propose solutions supported by data and models and consistent with scientific ideas, principles, and theories; (B) communicate explanations and solutions individually and collaboratively in a variety of settings and formats; and (C) engage respectfully in scientific argumentation using applied scientific explanations and empirical evidence.

Upon walking into the classroom, for the “engage” activity, students will complete a concept map on light. This will start the discussion on why light is important to us and gauge their prior knowledge of light. After that, students will participate in a Daylighting Summary Salad activity. The Summary Salad activity was designed by an educational organization called Lead4ward. During this activity, students will form groups and read a small reading on Daylighting then they will be using post it notes to collaborate with their peers and summarize the main points. This activity will introduce them to the term “daylighting” and allow the students to start inquiring how daylighting affects them in everyday life.

For the “explore” part of this curriculum, two small lab activities have been designed to allow the students to explore how daylighting affects them in the classroom. For the first lab activity, students will explore how sunlight affects classroom temperature and energy consumption. This activity was designed with the idea that the students relatively understand temperature and how it works and affects our lives. For this activity, the class will pick two classrooms: one with sunlight and one with little/no windows. They will record the temperatures every class period for one day. The data will be shared with every class. On the next day, the students will discuss how sunlight affected the temperature in the rooms and how this can affect their learning. The second lab activity will help students explore light intensity by measuring and analyzing natural and artificial light levels in various parts of the classroom during different times of the day, and understand how spatial variations impact energy consumption and student comfort. For this activity, students will use a light meter /sensor to measure the light intensity at 5 different locations in our classroom (near the window, back of the room, etc.) at 3 different times of the day (morning, midday, afternoon). This data will be shared among all the class periods. The students will use this data to discuss what different types of daylighting strategies could be used to lower the energy consumption of our classroom.

The “explain” part of the curriculum module is next. During this part, students will watch 2 short You Tube videos: Energy 101 Daylighting and What 10 Minutes of Sun Does to Your Body. These videos will help explain how daylighting can impact energy consumption and human health. After a short class discussion, the students will partner up with one of their peers and create a Daylighting One Pager. A one pager is an activity created by the education organization called AVID that allows students to be creative while they explain their knowledge of the concept presented in the lesson which in this case would be “Daylighting”.

For the “elaborate” portion of the module, the students will create real world connections of the idea of bringing more daylight into the classroom through a choice board.. This choice board will give them 6 different options in deliverables and allow the students to further their understanding of daylighting by conducting their own research on how daylighting affects energy consumption and human health in their community and their own life.

Finally, we are now at the “evaluate” portion of the curriculum. During this part, students will create their own daylit classroom that would minimize energy consumption and provide the benefits of sunlight to human health.   The students will need to either hand draw their daylit classroom or create it digitally. Along with their drawing, students will be required to turn in the following: collected light & energy data, description of daylighting strategies (window placement, materials, etc.), energy-savings estimate, summary of expected impacts on student well-being and performance, and citations for any research used.

Conclusion

Within the conclusion we would like to address three things which are the window orientation, distance of student desks from a window and other possible saving energy scenarios. Looking at the window orientation it can be seen that the north facing windows had the most UDI, useful daylight illuminance, for that classroom. The data we collected was over the course of two weeks in 2 day increments so our belief is that the data is not true. It would need to be tested at the same time for all three rooms to make a true analysis of the given data. This is not to say that the data collection was useless because we were able to determine the optimal distance students desks would need to be from a window to collect the most UDI which was three to six feet. This puts them around or above the 500 lux which is the measure for a comfortable room setting. This in turn gave us a chance to look at how much can be saved when using the daylight within the classroom. Lastly, it was noted that while we only tested a single scenario within the classroom, by having the blinds fully open, we believe testing other scenarios can provide more of a clear overview on how much more energy could be saved.

Acknowledgement

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Potential of Converting Food Waste into Renewable Energy in the Backyard

NSF RET I-READ TEXAS A&M UNIVERSITY KINGSVILLE

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Potential of Converting Food Waste into Renewable Energy in the Backyard

ABSTRACT

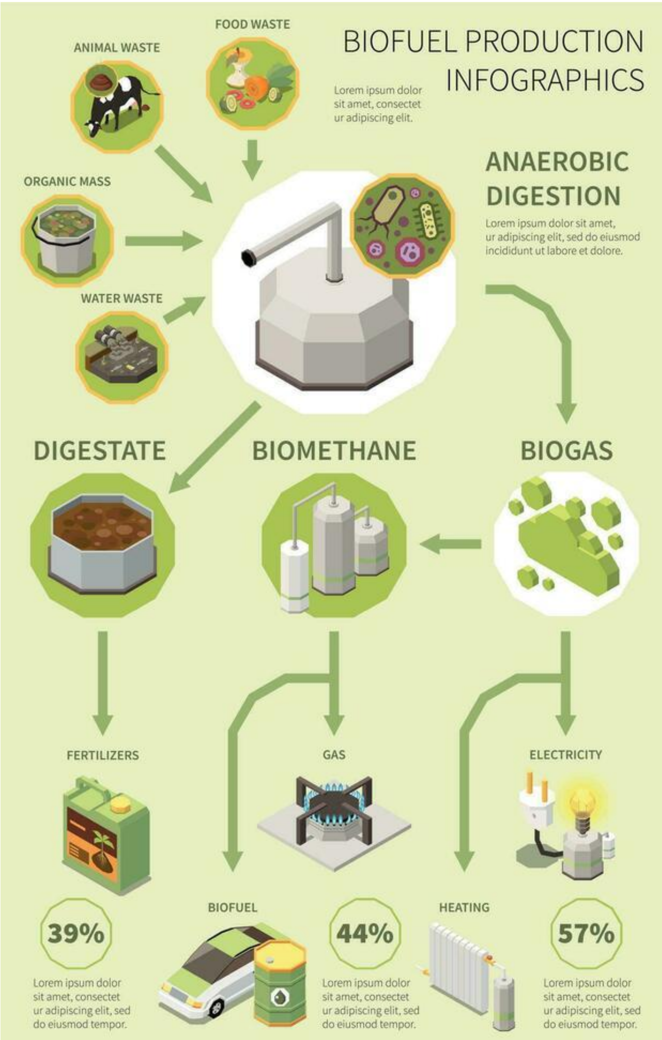
This research project investigates the potential of converting everyday household food waste into renewable energy through a small-scale setup. This was conducted as a part of a STEM initiative at Texas A&M University-Kingsville. The study explored the viability of a project that could be conducted in a backyard or a classroom. By using commercially available items and typical food waste, this project allowed for a better understanding of the larger problem of food waste. The simulation conducted allowed for an education application that brings awareness about waste-to-energy for students as well as demonstrating how simple experiments can contribute to sustainability.

INTRODUCTION

Because we are facing fast-growing and concerning environmental challenges due to the rapid exploitation of fossil fuels, there is an ever-growing driving force toward more sustainable practices and a shift toward the use of renewable energy sources such as solar energy, wind energy, hydro energy, and energy generated from food waste. Instead of throwing out food leftovers, imagine if we could convert that food into energy to power our homes, our cars, or even our cities. We would also reduce waste and create energy at the same time. Clean energy sources significantly reduce harmful emissions and promote the responsible and environmentally friendly use of natural resources, ensuring that future generations can thrive.

OBJECTIVES

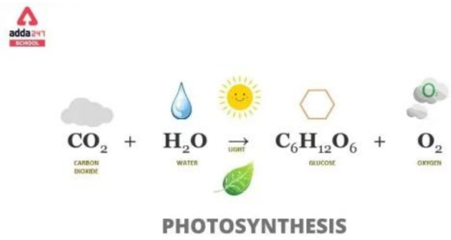
The possibility of converting food waste into renewable energy is an exacting, interesting, and "smart" way of developing technologies that will produce efficient and cost-effective power for our daily life needs. It's like turning trash into treasure!



A key goal of this research is to convert everyday food waste into renewable energy and to maximize energy recovery from organic waste while minimizing negative impacts on the environment. Ultimately allowing for the creation of curriculum that can be utilized with students at the high school level so that they can practice the STEM skills and gain a better understanding of sustainability, resources, and the biological processes involved.

Ultimately, this research aims to create and provide sustainable solutions that address food waste management challenges and support the transition to renewable energy practices, and long-term well-being for smaller communities worldwide.

BACKGROUND

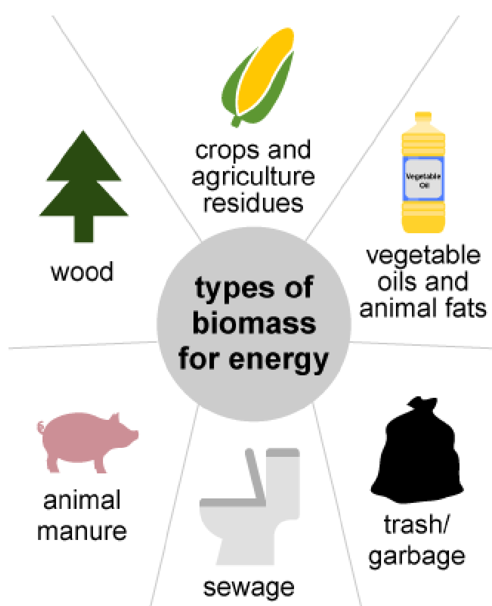


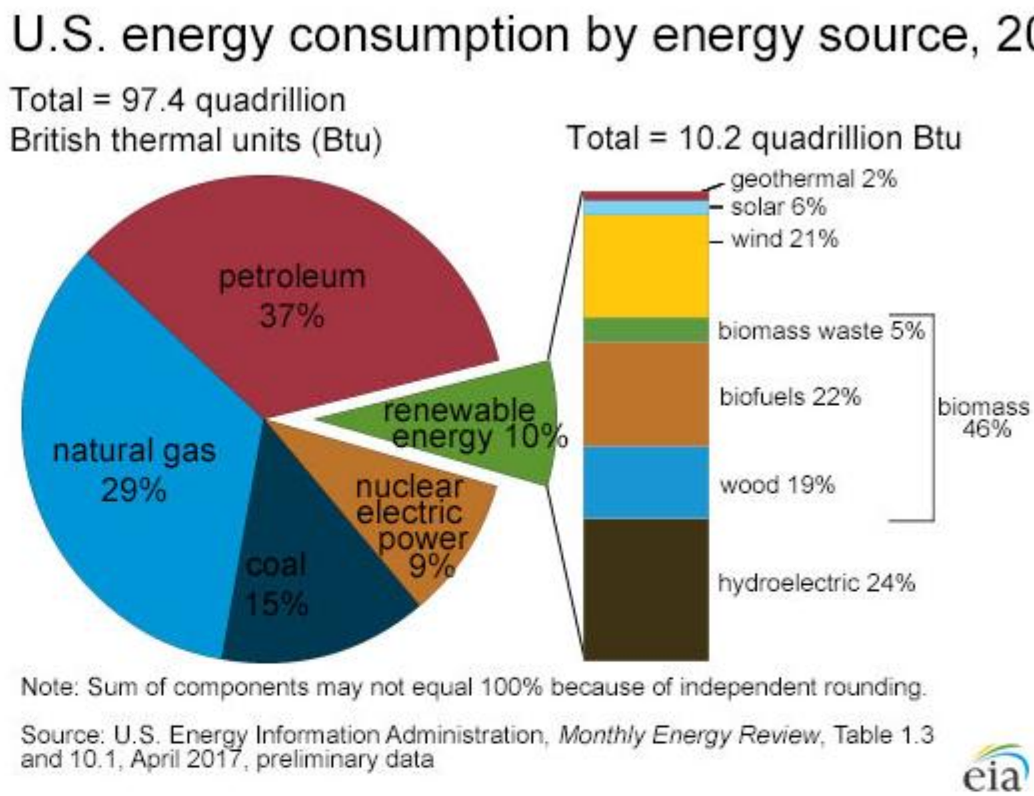
Biomass is organic material that comes from plants and animals. Biomass can be burned directly for heat or converted to liquid and gaseous fuels through various processes. Biomass was the largest source of total annual U.S. energy consumption until the mid-1800s. After that period, coal overtook biomass as the dominant energy source due to industrialization and the rise of railroads and manufacturing. In 2023, biomass accounted for about 5% of U.S. energy consumption. The types, amounts, and the percentage shares of total biomass energy consumption in 2023 were:

Biofuels—53%

Wood and wood waste—39%

Municipal solid waste, animal manure, and sewage—8%





Global Energy Overview (2023)

- Total primary energy consumption: 620 EJ (Exajoule, Unit of energy equal to 10^18 joul), up 2% from 2022
- Fossil fuels (oil, coal, gas) still dominate with ~81–82 % share_Oil: 32 %, Coal: 26 %, Gas: 23 %
- Renewables (including hydro, wind, solar, bio): ≈15 % of global primary energy, a record high

So how is biomass used? When organic materials such as plants, wood, and food waste decompose, they release energy that can be captured and converted into heat, electricity, or fuel. In composting, biomass isn't converted into energy in the same way as burning for heat or producing fuels like biogas or ethanol. Instead, composting relies on a biological process of aerobic decomposition where microorganisms break down organic materials, releasing heat as a byproduct.

Aerobic processes require oxygen for the microbes to function. In these conditions, bacteria and fungi break down organic matter through aerobic

Aerobic HOT compost	Anaerobic COOL compost
e.g. 3-Bay System	e.g. black council bin
Fueled by OXYGEN & moisture	Fueled by BACTERIA & moisture
Turned weekly	Not turned
Large (at least 1 cubic metre)	Small (less than 1 cubic metre)
Quick Ready in 6 weeks	Slow Ready after 6 months
Kills pathogens & weeds	Can spread pathogens & weeds

respiration. This process produces carbon dioxide and water, which are less harmful to the environment. Aerobic composting is a popular method for managing organic waste that has the potential of converting food waste into renewable energy and it’s more suitable for our backyards.

LITERATURE REVIEW

Food waste is one of the largest contributors to landfill waste in the United States, with over 30% of the food supply being discarded (U.S. EPA, 2021). When food waste breaks down in landfills, it releases methane, a greenhouse gas over 25 times more potent than carbon dioxide. Researchers and policymakers are trying to find more ways to recycle food waste into renewable energy through anaerobic digestion and composting (Papargyropoulou et al., 2014).

Anaerobic digestion is a biological process where microorganisms break down organic matter in the absence of oxygen, producing biogas which can be used as fuel (Kibler et al., 2018). This process is already used at industrial levels, but studies show that small-scale, home-based systems could also contribute to energy production while reducing household waste.

Composting is another simple and effective method to break down food waste. While it does not produce energy directly, it creates nutrient-rich soil and supports sustainability by reducing methane emissions. Both composting and the many ways to make it happen are essential for a successful environment.

Additionally, incorporating real-world environmental problems like food waste into school science curriculum has been shown to improve student engagement and understanding of sustainability concepts. Project-based learning, especially in STEM fields, helps students develop critical thinking and problem-solving skills while applying scientific methods to relevant issues (Blumenfeld et al., 1991). The increase of engineering practices has been used more recently. By getting students involved in small-scale experiments that convert food waste into energy or compost, educators can promote environmental responsibility, awareness, and support state science standards related to ecosystems, energy transformation, and human impact on the environment. Such hands-on activities also align with the Next Generation Science Standards (NGSS), which encourage inquiry-based learning and cross-cutting concepts like energy flow and matter cycling (NGSS Lead States, 2013).

METHODS

Initially, a decision to purchase a composting bin was made. It needed to have two compartments so that two combinations of materials could be compared. A

composting bin that was divided into two compartments was located at a local hardware store. Made of black plastic, this was important to maintain heat in the sun to move the reaction forward. We set it uop so that Compartment A, left side, had a material height of 3.72" and Compartment B, right side, had a material height of 2.4".

The material within the composting bins consisted of a mixture of grass clippings, vegetable matter (green), various fruits such as banana, berries, oranges.

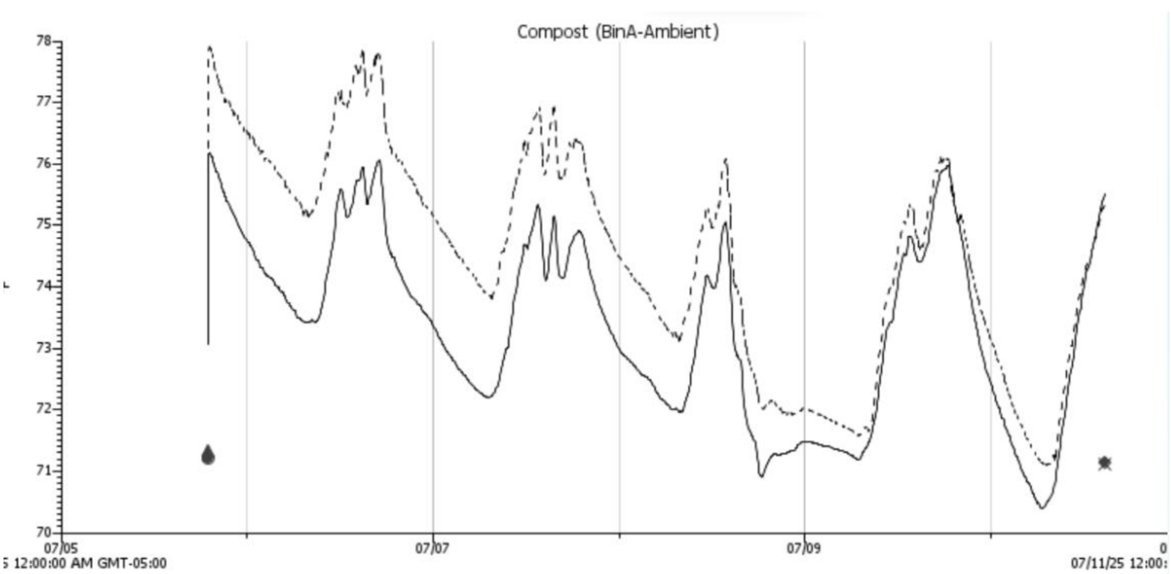
A thermometer was placed inside the composting bin to monitor temperature changes, which indicated microbial activity and energy release during composting. These were placed at the highest point on each bin to collect ambient temperature inside the bins.

Temperature data was recorded automatically every 5 minutes from July 5th to July 11th. The collected temperature data was analyzed to compare the thermal energy generated by the different depth on each side of the bin.

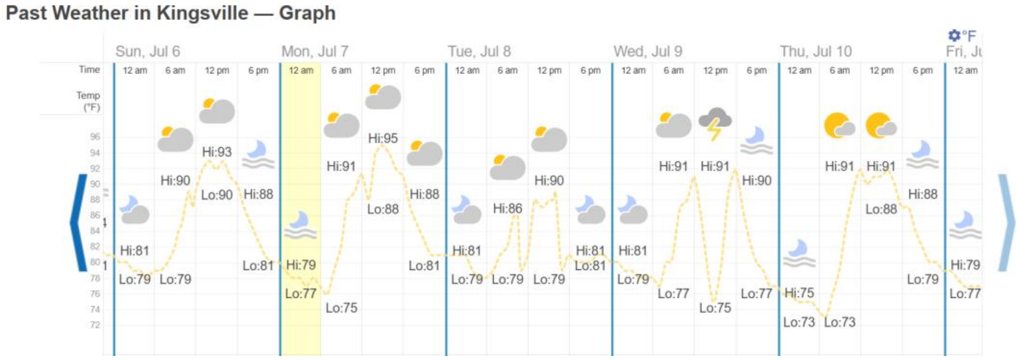
Results were visualized using a graph to show temperature variations over time and to compare the energy output from the left side versus the right side regarding different depth.

RESULTS AND DISCUSSIONS

The temperature was fluctuating between ~70°F and ~78°F over the course of 6 days due to day/night changes and different microbial activity within the compost . We can conclude that the compost is not creating a discernable heat difference from the ambient temperature. This was due in part to a limited time window. Materials were not secured in time to properly run the experiment. However, with consideration for the value of the experiment and design, and in terms of its value for curriculum, it was sufficient.



Upon looking at the numbers, Compartment A had a depth of 2.4" and recorded a lower temperatures than Compartment B with a depth of 3.72", indicating that deeper compost retains more heat, higher temperature trends were seen and it is more stable.



We were able to get local historical temperatures for the days that the experiment was conducted. It was useful to see the correlation in the swings in temperature to that of the weather locally.

CONCLUSION

-This six-week research project aimed to explain how much thermal energy can be generated and evaluate composting efficiency in our backyard composting bins by monitoring temperature fluctuations in a single compost bin with compartments A and B from July 5 to July 11, 2025.

-Data collected showed that temperatures ranged between 71°F and 78°F, with the deeper compartment B (3.72") maintaining slightly higher and more stable temperatures than compartment A (2.4"). These readings were below the optimal temperature range, which should be between 130°F and 160°F, required for rapid microbial activity, the start of decomposition, and heat release.

-Given the six-week limited time window, the compost has not reached its full decomposing potential. This study showed some biological activity, but the conditions were not sufficient for active composting that would generate the heat needed for energy conversion. However, further long-term studies are needed and recommended to explore the feasibility of converting food waste into energy in our backyards.

There was stable but low composting activity: the temperature remains relatively cool (low 70s °F), which suggests compost is in a stagnant phase rather than an active thermophilic phase.

Depth matters as we saw that deeper areas maintain slightly higher and more stable temperatures which is important for microbial breakdown efficiency.

Ultimately, there was a lack of microbial heat spike and activity. The composting process must be active in order to generate heat, which we did not get the see in the time tested.

Time was the variable that was not on our side for this experiment. A redesign and approach earlier on would have been prudent to obtain results. Given the lack of data, there was still value in the exercise overall. The aspect of obtaining curriculum for the student was still possible and highly valuable.

CURRICULUM MODULES

Converting Food Waste into Renewable Energy: Transforming Trash into Treasure

LEARNING OBJECTIVE:

I will analyze the impact of human activities on the environment, describe the interdependence of organisms in an ecosystem, and explain the process of composting and its role in converting food waste into renewable energy.

TEKS 10.11 (B) - describe the flow of energy through food webs and the roles of producers, consumers, and decomposers in an ecosystem.

TEKS 10.12 (B) - analyze how human activities impact ecosystems, including pollution and resource consumption.

TEKS 10.13 (C) - explain the significance of biodiversity in maintaining the health of ecosystems.

KEY POINTS:

-The process of composting involves the breakdown of organic matter by microorganisms, producing nutrient-rich soil.

--Food waste significantly contributes to landfill mass and greenhouse gas emissions.

-Ecosystems rely on the recycling of nutrients, and composting facilitates this process.

-The interdependence of organisms plays a crucial role in maintaining a balanced ecosystem

STUDENT ACTIVITY:

Students will complete a project where they set up a composting bin and create a presentation based on the composting processes and its benefits, demonstrating their understanding of the interdependence of organisms and the impact of food waste on the environment.

*SEE ATTACHMENTS

Renewable Energy and Composting: Potential of Transforming Food Waste into Sustainable Power

Objective: I will analyze the impact of human activities on the environment, describe the interdependence of organisms in an ecosystem, and explain the process of composting and its role in converting food waste into renewable energy.

We will:

Evaluate the impact of waste management methods such as reduction, reuse, recycling, upcycling, and composting on resource availability in the local environment. TEKS ENV.5.F (ENV.6D)

Explain the flow of energy in an ecosystem, including conduction, convection, and radiation. TEKS ENV.6.C (Science.ENV.7C)

Investigate and explain the effects of energy transformations in terms of the laws of thermodynamics within an ecosystem. TEKS ENV.6.D (Science.ENV.7D)

Key Points: The process of decomposing is the breakdown of organic matter by microorganisms; Food waste contributes to landfill mass and greenhouse gas emissions; Ecosystems rely on the recycling of nutrients, and decomposing facilitates this process; The interdependence of organisms plays a crucial role in maintaining a balanced ecosystem

Activity: students will complete a project where they set up a composting bin and create a presentation based on the exploration and data collected regarding composting processes and its benefits, demonstrating their understanding of the interdependence of organisms, nutrient cycling, and the impact of food waste on the environment.

Module 1

Engagement: 1 Day (50 min class), What Happens to Our Food Waste?

Opening question: Where does your lunch waste go?

Quick facts: Americans waste 30-40% of their food supply

Class discussion: Environmental impact of food waste in landfills. Teacher guided demonstration of decomposing food samples in sealed containers. Students will brainstorm the ways of how to reduce food waste. Module 1 will serve as a directive to students for food waste collection

Module 2

Guided Activity: 3 Days (150 min), Backyard Biogas Engineering Design Challenge.

In teams, students will design a small-scale composting system suitable for a small backyard (this will be utilized for 4 wks). Students will explore and include methods for monitoring temperature/moisture, list of materials, potential outputs, formulation of hypothesis, and application of scientific method.

Module 3

Exploration: 3 Days (150 min), Understanding Composting Basics, Nutrient and Energy Cycling.

Students will explore and explain how composting and anaerobic digestion return nutrients to the environment. Students will compare composting to other microbial activity and processes including Definition of Composting, the natural process of decomposing organic matter; Green materials (Nitrogen-rich): Food scraps, grass clippings; Brown materials (Carbon-rich): Dry leaves, paper; Water and oxygen.

Activities: Students build mini compost in a jar. Students will predict what will happen over a week regarding smell and color change.

Question to explore: "Which waste system is best for energy and the environment?" Students will record their findings in their science journal. Students will research landfilling, composting, and anaerobic digestion and compare and contrast researched waste management systems.

Module 4

Understanding: 1 Day (50 Minutes), The Invisible World of Microbes
Students will explain aerobic and anaerobic processes and the importance of microorganisms.

Activity: Students will play "Microbe Match Game" in order to understand the role of bacteria in breaking down organic matter. Students will be provided cards with the names of different bacteria involved in waste digestion (e.g., methanogens, acidogens), and cards with their functions. Students will match bacteria to their roles.

Extension: Quiz at the end of the module for reinforcement and overall understanding

Module 5

Analysis: 2 Days - (100 minutes), From Waste to Energy; Aerobic Vs. Anaerobic digestion process; Bacteria break down organic matter; Production of biogas (mainly methane), heat, and compost.

Benefits: Reduction of greenhouse gas emissions, production of renewable energy, and fertilizer as byproduct.

Activity: Student will collect and share data from the compost bin readings. Data collected will be recorded in science/composition journals for analysis. Students will work in small groups and share their findings, and initiate whole class collaboration. Students will explain aerobic and anaerobic processes by creating a diagram.

Module 6

Conclusion: 3 Days (150 minutes), Real World Application.

The Students will apply learning from their practical design and explain "The Science of Decomposition and the Potential of Converting Food Waste into Renewable Energy in our Backyards".

Activity: School research project presentation, discussion, and reflection on the interdependence of energy production, consumption, and ecosystem health.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Award No. 2206864. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Curriculum Development

Converting Food Waste into Renewable Energy: Composting in Action

LEARNING OBJECTIVE:

We will:

TEKS 112.5. (b) (6) (B) - Analyze the impact of human activities on the environment.

TEKS 112.5 (b) (7) (C) - Describe the interdependence of organisms in an ecosystem.

I will: explain the process of composting and its role in converting food waste into renewable energy.

PART 1

Introduction to hands-on activity

Students will create a composting plan using household waste, demonstrating their understanding of composting processes and renewable energy concepts.

KEY POINTS:

- Composting- the natural process of recycling organic matter, such as food scraps and yard waste (into a valuable fertilizer.
- Renewable energy sources include solar, wind, and bioenergy, with composting contributing to bioenergy.
- Key terms: biodegradation, microorganisms, nutrients, and carbon-nitrogen ratio.
- The composting process involves aerobic and anaerobic decomposition
- Misconceptions: Many believe that composting requires a large amount of space, but small-scale composting is possible at home.

Warm up and opening: a brief video showcasing the transformation of food waste into compost.

Question: "What do you think happens to our food waste after we throw it away?" This will prompt a quick discussion about students' current understanding of waste management and renewable energy.

This is the opportunity to discuss the composting process and what materials can be composted, the role of microorganisms, and the environmental benefits.

Display of the composting cycle and explanation that composting can be done in small containers or bins, ideal for limited spaces and peoples backyards.

Student activity and guided practice:

Students will be divided into small groups and provided with various food waste items (real or pictures). Students will work in categorizing these items as compostable or non-compostable.

"Why can we compost this item?" and "What nutrients does it provide?"

Independent work:

Students will create their own **composting plan** using a worksheet that includes sections for materials, methods, and expected outcomes.

Students are expected to illustrate their understanding of composting and renewable energy in their plans.

Lesson wrap up: a quick "gallery walk" where students will display their composting plans.

Exit Ticket example: students share one key takeaway about composting and renewable energy from the lesson.

*Alternative or /and extended activity: a research task on different types of renewable energy sources and their environmental impacts.

Part 1 will require students t**o track their household food waste for one week and write a reflection on how they could incorporate composting into their daily lives.** It is preparation for the Part 2 and experiment set up.

PART 1 a little extras

Renewable Energy and Composting: Transforming Food Waste into Sustainable Energy

What Happens to Our Food Waste?

• Where does your lunch waste go?
• Quick facts: Americans waste 30-40% of their food supply
• Class discussion and demonstration : Environmental impact of food waste in landfills and decomposing food samples in sealed containers or and pictures • Student brainstorm ways to reduce food waste

Understanding Composting Basics

• Definition: Composting is the natural process of decomposing organic matter • Key ingredients:

- Green materials (nitrogen-rich): Food scraps, grass clippings
- Brown materials (carbon-rich): Dry leaves, paper
- Water and oxygen
  - Chemical equation for composting: $C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O+energy$

From Waste to Energy

• Anaerobic digestion process:

1. Bacteria break down organic matter
2. Produces biogas (mainly methane)
3. Biogas can be used for electricity
   - Benefits:
4. Reduces greenhouse gas emissions
5. Creates renewable energy
6. Produces fertilizer as byproduct

Types of Waste-to-Energy Systems • Biogas digesters

- Industrial scale
- Farm operations
- Community systems
  - Landfill gas capture
  - Thermal conversion
  - Real-world examples
- Local community initiatives

Environmental Impact

• Greenhouse gas reduction:

- Methane capture prevents release into atmosphere ● 1 ton

- 1 ton of food waste = 2.5 tons
- 2.5 tons CO_2 equivalent
  - Energy production potential
  - Soil enhancement benefits
  - Waste reduction metrics

Composting Methods

- Aerobic composting
  - Backyard bins
  - Windrow systems
  - In-vessel composting
    - Temperature monitoring
    - Moisture control
    - Common problems and solutions

The Science of Decomposition

- Microorganism roles
- Optimal conditions:
  - Temperature:
  - 135°F−150°F
  - $135°F-150°F$
  - Moisture: 40-60%
  - Carbon to Nitrogen ratio:
  - 30:1
  - 30:1
    - Timeline of decomposition
    - End product characteristics

Real-World Applications

- School composting programs
- Municipal waste management
- Agricultural applications
- Energy generation statistics
- Success stories from around the world

Student Action Plan

• Starting a school composting program • Home composting tips

PART 2: Composting in the school, Lab and hands on activity

Objective:

We will**:** Analyze and evaluate different sources of energy, including renewable and nonrenewable resources. 7A

Examine the role of energy transformations in the preservation of ecosystems. 7B

I will: explain the composting process and its role in renewable energy.
I will: collect data on temperature changes and analyze the decomposition process and apply it to the concept of converting food waste into energy.

1. We will need the following materials:

- Composting bins (one for each group)
  - Fruit and vegetable waste (from home or cafeteria)
  - Thermometers
  - Gloves
  - Notebooks and pens
  - Labels and markers
  - Watering can
  - Shovels or trowels
  - Safety goggles

Procedure:

1. **Introduction** will connect to the prior knowledge from part 1

This will include discussion of the concept of composting and its environmental benefits. Also, it will include explanation on how composting relates to renewable energy by breaking down waste into usable resources.

2. **Setup**

Each class will be actively involved in this project. Composting bin will be set up by the teacher on /at an appropriate place on the school background. Close the bin and ensure it's placed in a suitable location, away from direct sunlight.

Students will be guided on a daily basis. Each class will consist of two students, bin supervisors and the data takers.

3. **Filling the Bin**

Students will be instructed to layer fruit and vegetable waste in the bin. Alternate layers of green waste (fruit/vegetable scraps) with brown waste (dried leaves or shredded paper). Moisten each layer lightly using a watering can.

4. **Monitoring and Data Collection**

a) Insert a thermometer into the compost pile and record the initial temperature over a few weeks
b) Regular intervals of collecting data will be scheduled for students to measure and record temperature changes over several weeks.

5. **Data Analysis and Reflection (PART 3)**

After several weeks, students will analyze the temperature data to observe the decomposition process.

PART 3 will consist of reflection on how heat generation in composting relates to energy conversion.

Reflection Questions to consider:

- What changes did you observe in the composting bin over time?
- How does the temperature change relate to the decomposition process?
- What are the environmental benefits of composting?
- How can composting be linked to renewable energy concepts?

Students will submit a lab report detailing their observations, data, and analysis. Students will be required to propose ways to enhance the composting process or suggest other renewable energy applications suitable for their backyards.

Students will reflect on how simple actions like composting can contribute to broader energy solutions and environmental sustainability.

Mitigating the Loss of Potential Energy Production in Wind Farms Due to Wake Effect.

Presented By:
Teachers
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RET Site: Integrating Data-Driven Research in Renewable Energy Across Disciplines (I-READ)

Texas A&M University – Kingsville
Frank H. Dotterweich College of Engineering

July 4, 2025

Abstract

As wind energy continues to expand as a major source of renewable electricity, optimizing turbine layout to mitigate wake effects has become a critical engineering challenge. This study investigates the impact of hub height variation and lateral turbine staggering on wind speed recovery and voltage output in small-scale wind turbine arrays. Using cost-effective educational materials, three experimental configurations were tested: a baseline linear layout with uniform hub height, a vertically staggered linear layout, and a vertically staggered layout with lateral offsets. Wind speed and voltage were measured across all configurations using anemometers and multimeters, and results were analyzed using a simplified Jensen wake model. Findings reveal that increasing turbine hub heights significantly reduces downstream wake losses, with the tallest turbines achieving the highest voltage output due to improved wind access. While the staggered layout enhanced recovery for the final turbine, it intensified wake effects on the middle unit, suggesting a need for careful balance in nonlinear designs. These results support hub height variation as an effective passive strategy for wake mitigation and provide a foundation for future research into combined spatial optimization methods for wind farm efficiency.

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ACKNOWLEDGMENTS

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CHAPTER 1

1.0. Introduction

1.1.0 Background of Study

As global energy demand increases and concerns over environmental sustainability intensify, the transition to renewable energy sources has become a global imperative. Among these sources, wind energy has emerged as a leading candidate due to its scalability, cost-effectiveness, and zero carbon emissions during operation (Kaygusuz, 2004). In recent years, electricity generated from wind turbines has surpassed coal as the second-largest contributor to energy production in the United States, underscoring its expanding role in the energy sector (U.S. Energy Information Administration [EIA], 2023). Wind farms, particularly in regions like Texas, have seen a dramatic rise in capacity, driven by both policy incentives and technological advancements (Gungor & Eskin, 2008; Akpinar, 2006).

Despite these advances, challenges remain in optimizing energy capture from wind farms, especially as turbine sizes continue to increase, with projections indicating hub heights exceeding 150 meters (approximately 500 feet) by 2035 (National Renewable Energy Laboratory [NREL], 2021). Larger turbines are capable of accessing stronger and more consistent wind resources; however, they are also more susceptible to aerodynamic interactions, such as wake effects, which can significantly diminish downstream turbine efficiency (Ramos et al., 2011). As a result, maximizing energy production from wind farms requires careful consideration of turbine placement, layout optimization, and wake mitigation strategies.

One promising approach to improve wind farm performance is wake steering, wherein upstream turbines are deliberately misaligned to redirect wake effects and improve the performance of downstream units. Studies suggest this method can increase overall energy output by up to 13% (Fleming et al., 2019), making it a compelling target for continued investigation. This paper builds upon prior research by examining wake steering strategies in the context of wind farms utilizing both the same and mixed hub height configurations in a linear and nonlinear layout. The findings aim to advance the understanding of integrated layout and wake control strategies, ultimately supporting more efficient and economically viable wind farm designs.

1.2.0 Problem Statement Introduction

The problem presented relates to the best practice and optimization of wind turbines in the field by utilizing controlled experiments to obtain data which supports certain strategies. The problem consists of two parts. Part one we will study is if changing the vertical height of a wind turbine will lessen the wake effect of having all of the wind turbines located at the same height. Part two we will study if staggering locations in addition to height of the wind turbine can also lessen the wake effect to a greater extent.

1.3.0 Objectives Introduction

- Investigate the effectiveness of turbine height variations to optimize power production and reduce wake effect.
- Investigate how the use of turbine coordination techniques may enhance overall performance.
- Investigate the use of height and layout coordination may enhance overall performance by reducing wake effect

1.4.0 Research Questions Introduction

In this study, we aim to explore potential solutions to mitigate the wake effect and enhance and maximize the energy output.

CHAPTER 2

2.0 Literature Review

2.1.0 Wind Energy and Wake Effect

Wind energy continues to grow as a leading source of renewable electricity, driven by global decarbonization efforts and advancements in turbine technology (Global Wind Energy Council [GWEC], 2024). However, the optimization of wind farm layouts remains a critical engineering challenge, primarily due to the wake effect, a phenomenon where downstream turbines experience reduced wind speed and increased turbulence due to upstream turbine interference (Barthelmie et al., 2010). Wake losses can account for 10–20% of total energy production loss in large-scale farms (Archer et al., 2013).

A considerable body of research has focused on wake mitigation through spatial optimization of turbine placement. Traditional linear layouts, while logistically simpler, are particularly susceptible to wake-induced energy deficits (Stevens & Meneveau, 2017). Researchers have explored various strategies including staggered arrangements, yaw control, and hub height variation to reduce these losses (Gebraad et al., 2016; Munters & Meyers, 2018). Among these, altering hub height offers a promising passive method to influence vertical wake expansion and energy recovery without increasing control complexity.

2.1.0 Hub Height Adjustment.

Hub height heterogeneity, particularly in non-linear or staggered configurations, has been shown to improve vertical mixing and reduce cumulative wake effects (Kaiser et al., 2021). By positioning upstream and downstream turbines at varying heights, wake overlap can be minimized, thereby enhancing downstream wind speed availability. Churchfield et al. (2013) utilized large eddy simulations (LES) to demonstrate that vertical staggering in turbine arrays enhances entrainment of high-momentum air, thus accelerating wake recovery.

In linear configurations, however, the benefit of hub height differentiation is less straightforward. Zhang et al. (2020) noted that in straight-line arrays, minor height variation yielded modest improvements in wake recovery, especially under stable atmospheric conditions. Yet, when

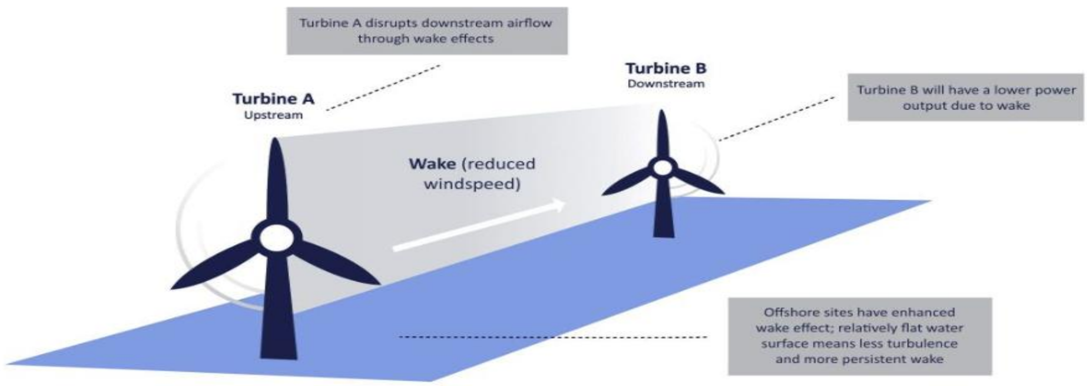

Figure 1. Displays model of wake effect on two linear turbines.

coupled with yaw offset or dynamic control strategies, the combined effects can significantly boost performance.

Recent studies suggest that nonlinear arrangements, such as arc or semi-random patterns combined with variable hub heights, exhibit synergistic benefits (Wu & Porté-Agel, 2015; Lu & Porté-Agel, 2021). These configurations allow for enhanced turbulence mixing and more effective vertical wake dispersion, particularly in low-turbulence boundary layers. Field data from offshore and complex terrain sites corroborate these findings, indicating up to a 12% increase in annual energy production when vertical and lateral staggering are jointly implemented (Kanev et al., 2023).

Despite growing evidence, practical implementation faces challenges such as increased structural loads on taller turbines, uneven maintenance access, and electrical infrastructure complexity. Nevertheless, advancements in lightweight materials and modular tower designs are gradually alleviating these concerns (Rivas et al., 2022).

This literature supports the efficacy of hub height variation especially in nonlinear layouts as a viable and cost-effective strategy for wake mitigation. Continued development of high-fidelity simulation tools and real-world experiments will be essential to optimize these configurations and validate their long-term benefits.

CHAPTER 3

3.0 Materials and Methods

3.1.0 Materials Used

With the ultimate objective of developing instructional modules for classroom use, the researchers prioritized the selection of materials that were cost-effective, appropriately sized for educational settings, and capable of supporting lessons that enhance students' conceptual understanding. The materials listed below were selected to meet these criteria and were used throughout the experimentation phase.

Figure 2. Wind turbine kit used.

- Wind Turbine Kit

  The wind turbine model used was the *Thames & Kosmos Wind Power V4.0 STEM Experiment Kit*. This kit includes components that allow energy generation through rotor rotation, which charges a connected battery. The rotor blades are adjustable in both placement and pitch, enabling variations in wind capture and providing opportunities for investigating aerodynamic efficiency. The kit also includes the capability to measure voltage output during operation.

- Anemometer

  Used to measure wind speed during each experimental trial accurately.

- Multimeter

  Employed to measure electrical output, specifically voltage, generated by the turbine under varying conditions.

- Wind Source

  A *RIDGID 1625 CFM 3-Speed Portable Blower Fan* was the primary wind source. This device was selected for its ability to generate consistent and sufficiently high wind speeds required for the experiments. It is important to note that a standard household box fan was tested but found inadequate for producing the necessary airflow to yield measurable results.

Figure 3. Image of blower used.

These tools and equipment were used in combination to simulate controlled wind conditions, allowing researchers to collect data relevant to wind energy generation and system performance under classroom-accessible conditions.

3.2.0 Experimental Methodology

This study was structured into three distinct phases to evaluate the impact of hub height variation and horizontal displacement on wind turbine performance within a linear array.

3.2.1 Step1: Baseline Configuration

The first objective was to gather baseline wind data using a linear formation placed on a table. The baseline configuration consisted of one linear row, containing three wind turbines. Turbines were uniformly spaced 100 cm apart within each row, with the first turbine positioned 100 cm from the wind source (Figure 4). All turbines were of identical height, measuring 40 cm from the base to the center of rotor rotation. Three independent trials were conducted under identical conditions to ensure consistency and data reliability.

The same anemometer was used for all trials. Each trial was repeated three times by each member of the research team, and the results were averaged together. Each blower was measured with the anemometer by each team member to ensure accurate results. A banana plug style multimeter with the needle nose attachment was inserted into the turbines to measure voltage generation. Voltages were recorded every thirty seconds for ninety seconds, with results then averaged together. Two portable blowers were placed on top of each to create different levels of air movement since different vertical hub heights were being tested.

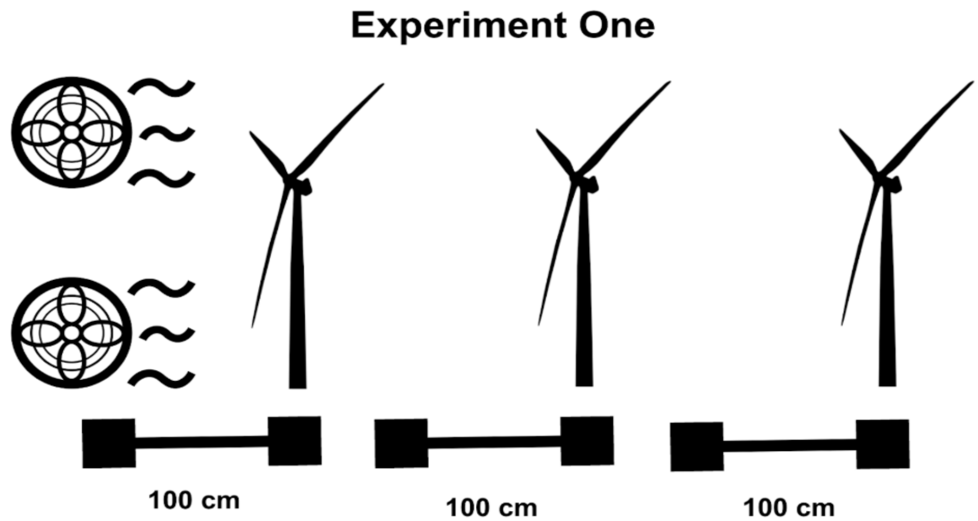

Figure 4. Model of experiment one showing the same height and linear formation.

3.2.2 Step2: Variable-Height Configuration

The second phase introduced vertical variation in turbine hub height (Figure 5). The overall arrangement remained the same—one row with three turbines spaced 100 cm apart, with the first turbine in each row located 100 cm from the wind source. However, in each row, turbine heights were incrementally increased: the first turbine was set at table height (0cm/0inch), the second at 6.2 inches (188 cm), and the third at 12.4 in (376 cm). The height was determined by using the width of the wind turbine boxes. Each box had a width of 3.1 in (7.8cm). This configuration was designed to assess how increased vertical positioning influences wake effects and downstream turbine performance (Figure 2).

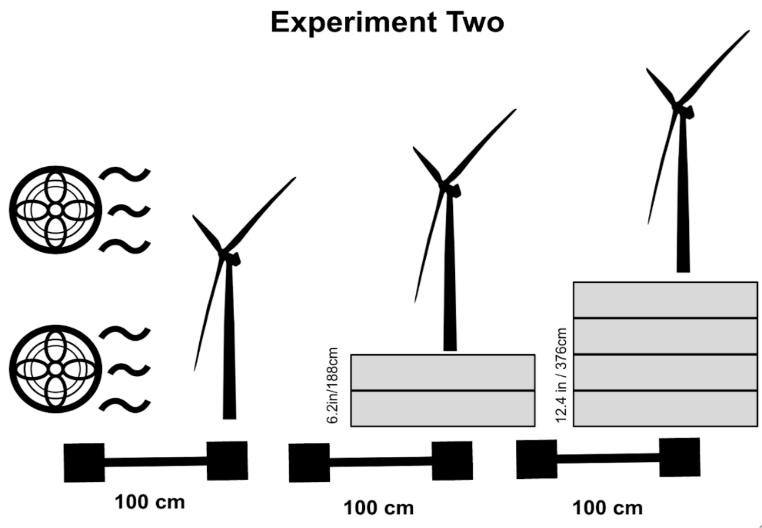

Figure 5. Model of experiment two illustrating increased height for each turbine but linear formation.

3.2.3 Step 3: Variable-Height and Offset Configuration

The final phase built upon the increased-height configuration by introducing horizontal offsets (Figure 6). The row structure and turbine spacing remained consistent, but turbines were laterally displaced relative to the second turbine in the row. Specifically, the second turbine was offset 50 cm to the left (−50 cm), the first turbine remained centered (0 cm), and the third turbine was offset 50 cm to the right (+50 cm). This arrangement created a nonlinear layout intended to simulate more realistic wind farm configurations and further investigate the combined impact of vertical and horizontal staggering (Figure 3). Minor adjustments to spacing were made during setup to ensure proper alignment and airflow consistency

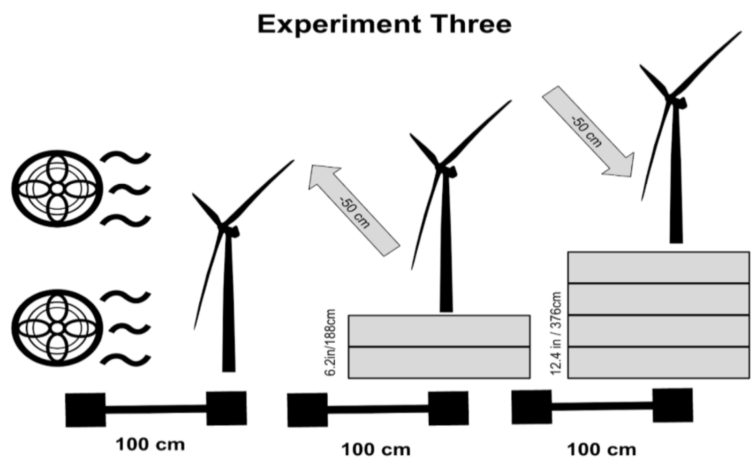

Figure 6. Model of experiment three illustrating increased height and nonlinear formation of turbines.

3.2.3 Step 3: Establishment of Singular Turbine Voltage and Wind Speed for Each Experiment

A baseline wind speed was measured for each turbine position, including vertical. Each turbine's wind speed and voltage were measured without any other turbines. The same measurements and protocols from the previous experiments were repeated.

CHAPTER 4

4.0 Data and Data Analysis

4.1.0 Data Collected

4.2.0 Data Analysis

4.2.1 Part 1- Establishment of Singular Turbine Voltage and Wind Speed for Each Experiment

A baseline wind speed was measured for each turbine position, including vertical. Each turbine's wind speed and voltage were measured without any other turbines. The chart confirms the relationship between wind speed (km/h) and average voltage (V) generated by the three wind turbines in all three configurations. In all three configurations, turbine 2's wind speed and voltage decreased. Since there were no other turbines, this was from the wind flow decreasing, not the wake effect. Turbine three consistently has the highest wind speed and produces the highest voltage output. This is likely due to the second fan's air flow combining with the first fan at turbine 3's location. These observations highlight the importance of position and proximity to other turbines when considering wind speed measurements in experimental setups.

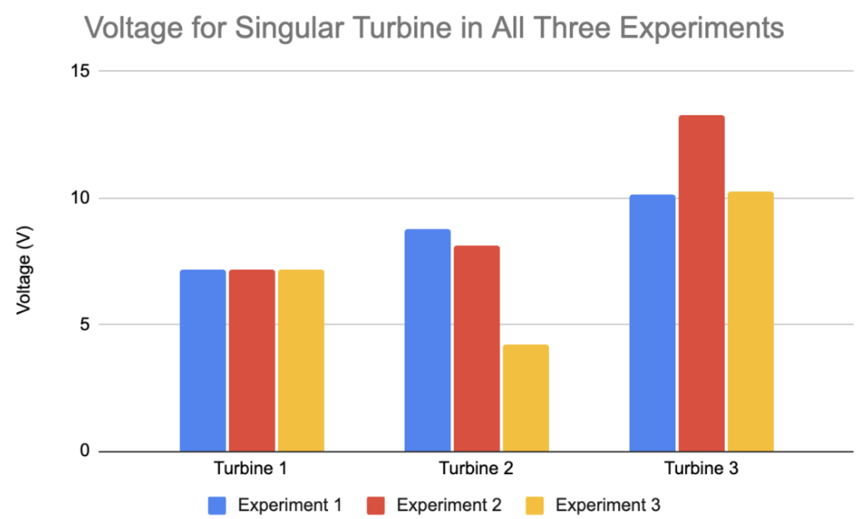

Figure 7. Displays the voltage for each turbine with the two others removed in all three experiments.

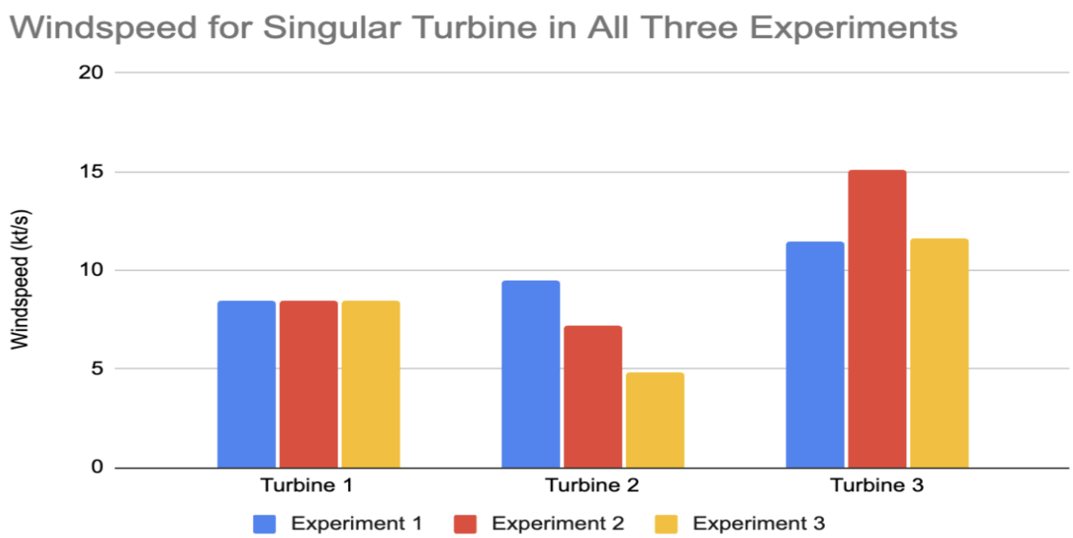

Figure 8. Displays the wind speed for each turbine with the two others removed in all three experiments.

4.2.2 Part 2- Wind Speed Recovery After Each Turbine

The wake effect can be calculated using different mathematical equations. For this experiment, we utilized a simplified version of the Jensen Model (Figure 9).

$$U_x = \left\{ U_0 \, (2a) \frac{2a}{1 + \frac{\alpha x}{r_0}} \right\}^2$$

Where U_x is the wind speed at a distance x behind the turbine, U_0 is the free stream wind speed (baseline, before the first turbine), a is the Axial induction factor, **α** is the Entrainment constant, r_0 is the rotor radius, and x is the distance from the upstream turbine. Using this equation, we determine how wind speed recovers behind the upstream turbine.

Experiment 1 shows that wind speed decreases behind the first turbine (5.01 kt/s) and is much larger wind speed decreases behind the second turbine (3.69 kt/s). This suggests that a cumulative wake effect is occurring behind turbine 2. The result is a classic wake compounding effect.

In Experiment 2, we see a decrease in wake effect with turbine 2 having a U_x value of 4.46 kt/s

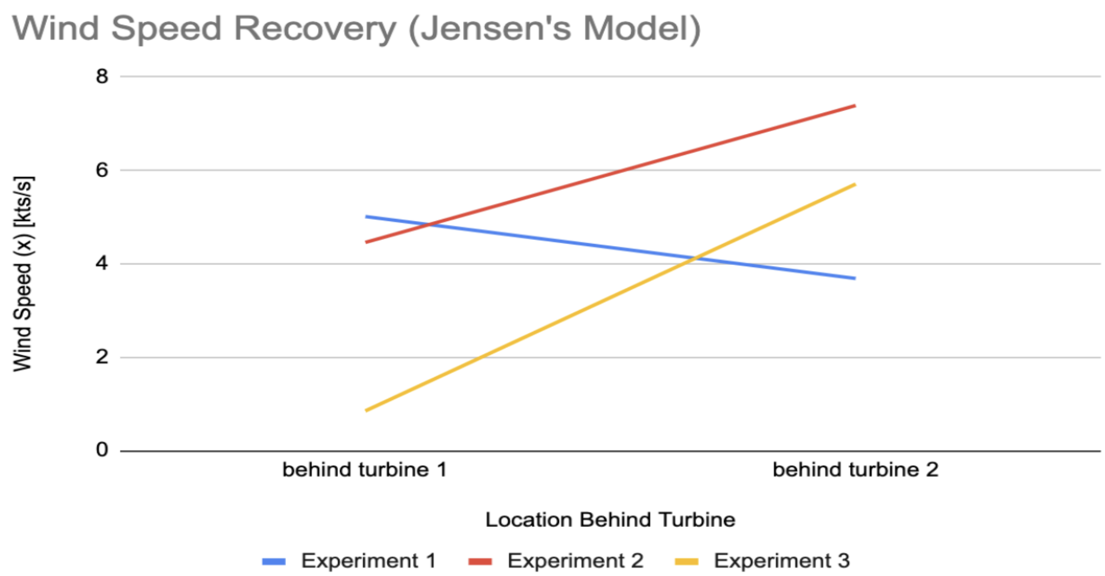

Figure 9. Displays the wind speed recovery behind each turbine using a simplified Jensen Model.

and turbine 3 having a U_x value of 7.39 kt/s. This shows that wind speed is increasing behind the second turbine. The increased vertical heights of each turbine helped flow recover before reaching turbine 2 and turbine 3, thereby mitigating the wake effect.

4.2.3 Part 3- Wind Speed and Voltage output for hub height for both linear and staggered layouts

Each experiment was run to determine the effect hub heights have on the reduction of the wake effect (Figure 11). The baseline experiment, or experiment one, shows a classic wake effect pattern with voltage and wind speed decreasing on each subsequent wind turbine. Each hub height remained constant, meaning a turbulent wake was generated.

In experiment 2, increased hub heights are utilized to reduce the wake effect. Turbine 1 remained at base level while turbine 2 was slightly elevated (6.2 in) and turbine 3 was elevated at the highest level (12.4 in). Turbine 2 received better wind compared to that of the baseline height (0 in). Turbine 3 captures the strongest wind and therefore generates the highest voltage, even higher than turbine 1. This is likely because it is elevated above the wake from turbine 1 and 2 allowing for faster airflow. The data demonstrates in experiment 2 that increasing height greatly decreases wake effect and enhances energy capture.

In experiment 3, a nonlinear layout was utilized with the same height as experiment 2. Turbine 2

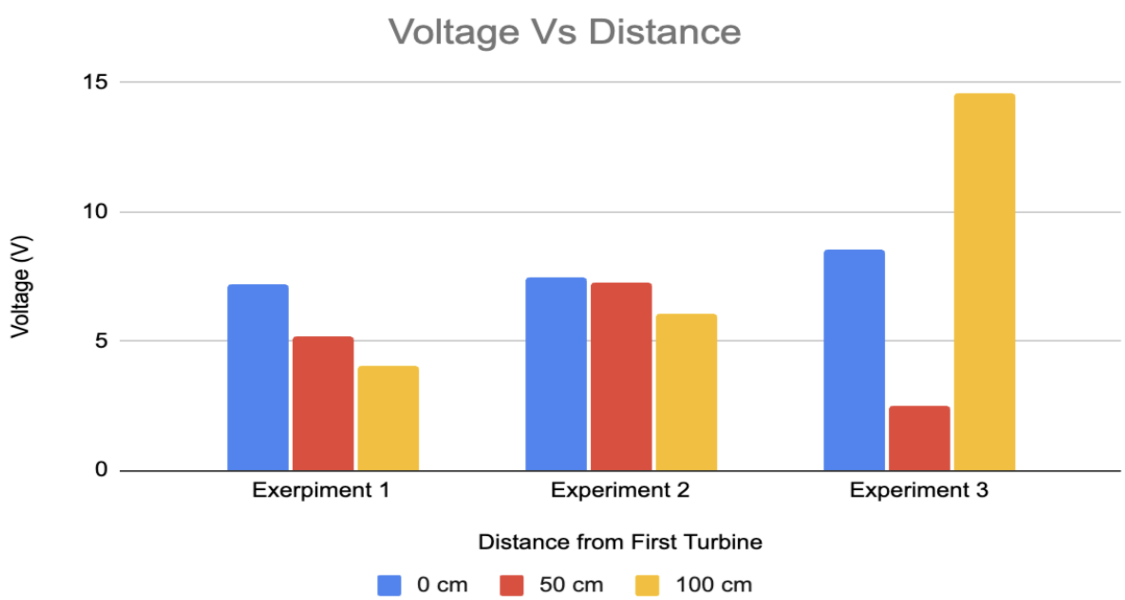

Figure 10. All three experiments are shown with voltage versus distance.

suffers the largest wake effect, even larger than the baseline. Turbine 3, however, shows high wind recovery and reduced wake effect.

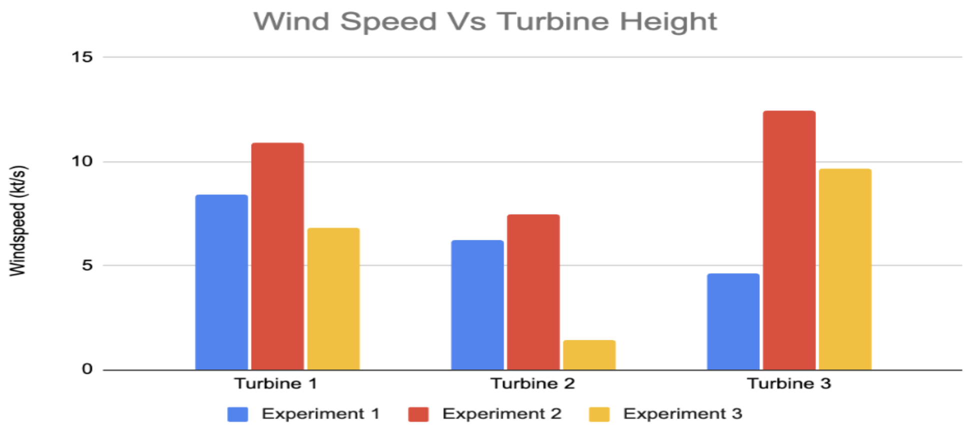

Figure 11. The figure displays the wind speed vs the turbine height with each experiment represented in different colors.

The data supports the effectiveness of increased hub height as an optimization strategy for reducing wake effect (Figure 12). Raising downstream turbines can mitigate wake losses and even exceed upstream wind speeds. However, using staggered formations in the proportions of experiment three needs to be further investigated to reduce middle position turbines' wake effects

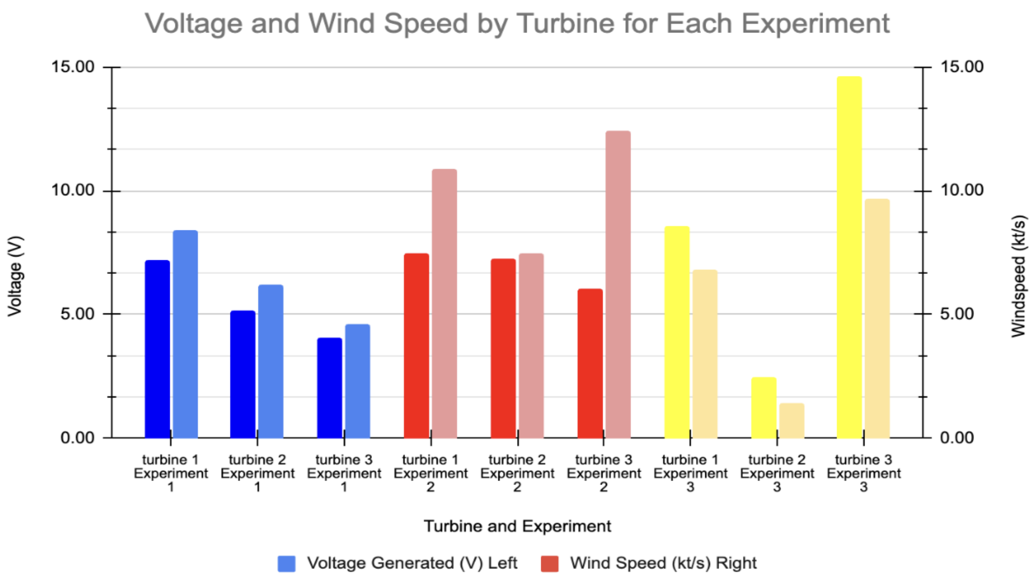

Figure 12. The chart displays the results of all the three experiments for each turbine. The darker bar on the left represents voltage and the lighter bar on the bar represents wind speed.

CHAPTER 5

5.0 Conclusion and Recommendation

5.1.0 Conclusion

This study contributes to the growing body of research aimed at enhancing wind farm efficiency through strategic turbine layout and hub height variation. Through controlled classroom-based experiments using cost-effective, scalable materials, we evaluated the influence of both vertical and horizontal staggering on wind speed recovery and voltage output within linear and nonlinear turbine configurations. The baseline configuration confirmed the expected cumulative wake effect, with successive turbines experiencing reduced wind speed and electrical output.

The introduction of variable hub heights in Experiment 2 demonstrated a measurable improvement in downstream performance, supporting the hypothesis that vertical staggering enhances vertical mixing and mitigates wake losses. Notably, the tallest downstream turbine in this configuration generated higher voltage than the upstream unit, indicating successful wake avoidance and increased airflow access. Experiment 3, which added lateral staggering to the vertical variation, yielded mixed results: while the final turbine benefited from enhanced wind recovery, the middle turbine experienced elevated wake interference. These findings suggest that while combined vertical and horizontal staggering holds promise, careful spatial optimization is critical to avoid unintended flow disruption, particularly in midstream turbine positions.

Overall, the data underscores the potential of hub height variation as a low-complexity, passive solution for reducing wake effects and improving wind farm energy yield. The results also highlight the need for further investigation into optimized nonlinear layouts, particularly those that balance flow distribution across all turbine positions.

5.2.0 Recommendation

Future research should incorporate more complex modeling tools, such as computational fluid dynamics (CFD), and explore additional variables including atmospheric stability, yaw control, and rotor diameter scaling to validate and extend the applicability of these findings to full-scale wind farm environments.

CHAPTER 6

6.0 Learning Modules

6.1.0 IREAD Lesson Plan 1: Energy Card Sort

Lessons modified and adapted from example

Video: https://www.youtube.com/watch?v=QrnagJSTHKk

Implement this lesson: First of wind lesson plans

Learning objective: Students will be able to begin to understand that devices we use every day require electrical power.

Texas Essential Knowledge and Skills (TEKS):
Science TEKS https://docs.google.com/document/d/11zRTVjaiAW8Qjr4GffsepdSiX2LiX4WvdKsXOcDJ5Qs/edit?usp=sharing
Math TEKS 5.3.A
ELAR 5.12A-B

Overview:
Students will be asked what devices they use every day, example, microwave, light bulb, tv, computer, etc. They will lead students to think about sources of electricity and how everyday devices are powered. Students will then be given a group of cards and ask to put them in order of electricity usage. Students can then determine how much electricity they use every day.

Note: Watts are energy consumed per second

Materials

- Several printed card sorts https://docs.google.com/document/d/1vXgTD6h3Gj-IltJ1u0YMr4DjevGyibk8T88HPO7jiY4/edit?usp=sharing
- Answer Key- Electricity Card Sort Answer Key

Advanced Prep:
Print card sort

Procedure:

1. **Engage**: Ask students what electricity they have used today: toaster, car, computer, etc. Write down students' answers on the board. Probe students on where electricity comes from. Probe students on how much electricity each item uses.
2. **Explore:** Put students into small groups (partners, groups of four, etc). Give them the cards and ask them to sort them in order of least energy usage to most energy usage.
3. **Explain**: After students have had proper time to sort and discuss the cards, go over the card together.
4. **Elaborate:** Have students generate a list of items that require electricity that they use every day and have them add how much electricity they consume every day.
5. **Evaluation**: Students write a sentence or two on everyday energy use.

Worksheets

*Note: This worksheet can be also entered into a google sheet and used to teach students about basic calculations. This chart can also be created using scratch paper or printed as a worksheet.

Device	**Watts**	**Time Device is Used in Second** (1hour=3600s, 30minutes=1300s, 1day=86,400s)	**Total Wattage Used Per Day**
Example 1 Coffeemaker	480 Watts	5 minutes->300 seconds	300*480=144,000Watts
Example 2			
Total			

Extensions:

- Energy usage calculator: https://www.energy.gov/energysaver/estimating-appliance-and-home-electronic-energy-use
- Read Charged up: The story of energy or another electricity or energy book

Evaluation:

- Read students sentences or look at the electricity chart.

6.2.0 IREAD Lesson Plan 2: Circuit Building with Batteries and Wind Turbines

Modified from:
https://www.pps.net/cms/lib/OR01913224/Centricity/Domain/193/Lesson%206_%20Solar%20Power%20Lesson.pdf

Video: Setting Up A Simple Circuit and How to Connect DC Motor to Solar Panel with On/Off Switch | Make a Simple Electric Circuit Model

Implement this lesson: Second of wind turbine lesson plans. Students have already built basic circuits.

Learning objective: Students will be able to build basic circuits using energy generated by wind turbines and understand that wind energy can be used in place of traditional electricity such as batteries.

Texas Essential Knowledge and Skills (TEKS):
Science TEKS Wind TEK Lessons
Math TEKS NA
ELAR 5.12A-B

Overview:
Students will be asked to create basic circuits with a battery using a variety of tools: buzzers, fans, light bulbs. Students will then be asked to complete the same task except with a wind turbine instead of a battery.

Note: this lesson will need a fan

Materials

- Batteries
- Wires
- Light Bulbs
- Buzzers
- Fans
- Small Wind Turbines
- Fans

Advanced Prep:
Print card sort

Procedure:

1. **Engage**: Ask students how to create a basic circuit:
    1. What materials do you need?
    2. Can you use other materials besides wire, light bulb, and battery?
    3. What all can you use basic circuits for besides illuminating a light bulb?
2. **Explore:**
    1. Students create a basic circuit using a battery.
    2. Allow students time to create a variety of different basic circuits.
    3. Ask students what wind power and wind turbines are? What happens when the battery runs out? Is there a way that we have a power source that does not run out?
    4. Swap out batteries for wind turbines
    5. Students complete the same circuits using wind turbines instead of batteries
3. **Explain**: That wind energy is energy from the wind that naturally blows around our Earth. Wind energy can be used indefinitely unlike a battery which is thrown away. Use YouTube to help illustrate this concept.
4. **Elaborate:** Students can participate in challenges:
    a. Challenge 1: Can you get the fan to rotate in both directions
        i. If you switch the positive and negative leads the fan will reverse
    b. Challenge 2: How many lightbulbs can you light up using series and parallel circuits
        i. Wind turbines need to be in parallel to add to the turbine
5. **Evaluation**: Students write a paragraph describing their thoughts and ideas learned in the experiment.

Worksheets
None needed

Extensions:
Read book, "The Boy Who Harnessed the Wind"

Evaluation:
Read students' sentences

6.3.0 IREAD Lesson Plan 3: Place Wind Turbines at Various Locations and Measure their Output

Video: https://www.youtube.com/shorts/8_odgFOqW_4

Implement this lesson: Fourth of wind lesson plans. Students already have an understanding of wind energy and its applications

Learning objective: Students will measure wind output at different locations around their school and determine the best location using data collected.

Texas Essential Knowledge and Skills (TEKS):
Science TEKS Wind TEK Lessons
Math TEKS 5.3.A
ELAR 5.12A-B

Overview:
Students will place a wind turbine at a location and measure its output ideally throughout the day to measure winds increase and decrease. The following day the turbines can be moved to a second location and measured several times. Repeat the process each day. The students will then determine the best location by analyzing the data and creating a graph.

Materials

1. data sheet
2. wind turbines
3. multimeter

Advanced Prep:
Understand how to use a multimeter tool and use it to measure wind energy output.

Procedure:

1. **Engage**:
    - Ask students what kind of weather is needed to utilize wind turbines?
    - Ask students to create a list of good places to place a wind turbine around their campus?
    - Using the students' answers to create a list of their suggestions.

2. **Explore:** Every day place the solar panel in an area the students listed (wetlands, school roof, sidewalk, etc). Measure the energy being generated several times during the day. Record the answers on a data sheet. Repeat the process for several days and if possible, repeat each location twice.
3. **Explain**: Students will use the data to create a graph showing the energy output of each location. Let students determine which area is the best for wind energy and which is the worst.
4. **Elaborate:** Students look at the Global Wind Database to see different solar irradiance around the world.
5. **Evaluation**: Students write a paragraph describing their thoughts and ideas learned in the experiment.

Worksheets

	Location 1	Location 2	Location 3	Location 4
Time 1 Ex 8am	Write in the energy output			
Time 2 Ex 10am				
Time 3 Ex 12pm				
Weather conditions	Ex. windy			

Extensions:
Play around with wind farm simulations

Evaluation:
Students graphs and paragraphs to determine knowledge gained

6.4.0 IREAD Lesson Plan 4: Create Cars, Boats, and Other Using Wind Turbines

Video:
https://www.youtube.com/playlist?list=PL4eGC8h9QjBxGJM124YMzPbUtGCbmQT_3
https://www.youtube.com/playlist?list=PL4eGC8h9QjBy7MoQoxKfNmevjPlaqFyMQ

Implement this lesson: Fourth of wind turbine lesson plans. Students have already built basic circuits and circuits using wind turbines. This may take several days.

Learning objective: Students will create different boats and cars using the engineering process.

Texas Essential Knowledge and Skills (TEKS):
Science TEKS 5.8.A Investigate and describe the transformation of energy in systems such as energy in a flashlight battery that changes from chemical energy to electrical energy to light energy 5.8.B Demonstrate that electrical energy in complete circuits can be transformed into motion, light, sound, or thermal energy and identify the requirements for a functioning electrical circuit 5.11 Design and explain solutions such as conservation, recycling, or proper disposal to minimize environmental impact of the use of natural resources
Math TEKS NA
ELAR 5.12A-B

Overview:
Giving students a variety of different tools and materials students will create boats, cars, robotics, etc. using wind turbines.

Materials
- A wide variety of materials such as popsicle sticks, styrofoam, plastic bottles

adhesive: tape, hot glue, Elmer's glue, etc
- Resources for motors, here is a kit that can be used for template projects and or wind source

Advanced Prep:
Get materials

Procedure:

1. **Engage**: Show students different videos or examples of items to make with wind turbines: boats, cars, Ferris wheel, etc. Optional to have a couple completed projects for students to view and gain ideas from
2. **Explore:** Student are allowed to create their own project with a partner or small group
3. **Explain**: Using a 'gallery walk' allow students to view other projects and talk to their creators
4. **Elaborate:** Students research other wind power projects e.g. google search
5. **Evaluation**: Students write a paragraph describing their thoughts and ideas learned in the experiment.

Worksheets
None needed

Extensions:
Create different types of robots

Evaluation:
Student robots

IREAD Lesson Plan 5: Create a Floating Wind Farm

Video: NA

Implement this lesson: This lesson can be taught in conjunction with the next lesson of this unit or as a standalone. This can be used as the fifth of wind lesson plans. Students already have an understanding of solar energy, its applications, and have made solar boats, cars, etc.

Learning objective: Students will design and test out a floating wind turbine

Texas Essential Knowledge and Skills (TEKS):
Science TEKS Wind TEK Lessons
Math TEKS 5.3.A
ELAR 5.12A-B

Overview:
Students will create a float for a wind turbine panel and test it out.

Materials
- data sheet
- wind turbine
- multimeter
- variety of maker space materials: tape, styrofoam, plastic bottles, etc.

Advanced Prep:
Determine a water body that can be utilized for testing out the float

Procedure:
1. **Engage**: Show students the video on floating solar panel farms
2. **Explore:**
    2.1. Students create a float that will hold the wind turbine, be able to keep it dry, and be pulled in and out of the water without the user getting wet.
    2.2. Test out the designs without the wind turbine to make sure it can withstand being used
    2.3. If the design is sturdy and secure, test it out using the wind turbine
    2.4. Measure the turbine for energy output. Repeat the same step with each of the securely built floats.
3. **Explain**: Students will discuss the different ways offshore wind turbines are being used around the world. Discuss the pros and cons of using wind turbines on water bodies. Discuss what water bodies work best for wind turbines
4. **Elaborate:** Students research the best water bodies for wind turbines
5. **Evaluation**: Students write a paragraph describing their thoughts and ideas learned in the experiment.

Worksheets

	Design 1	Design 2	Design 3	Design 4
Energy produced	Write in the energy output			

Extensions:
- Use the wind farm simulator to run simulations of different areas
- watch videos of different types of floating and offshore wind turbines

Evaluation:
Students' Designs

6.5.0 Texas Essential Knowledge and Skills TEKS

K.8.A. Communicate the idea that objects can only be seen when a light source is present and compare the effects of different amounts of light on the appearance of objects
K.8.B. Demonstrate and explain that light travels through some objects and is blocked by other objects, creating shadows
K.9.A. Observe, describe, and illustrate the Sun, Moon, stars, and objects in the sky such as clouds
K.9.B. Identify, describe, and predict the patterns of the day and night and their observable characteristics

1.5.F. Identify forms of energy and properties of matter
1.6.B. Explain and predict changes in materials caused by heating and cooling

2.9.A. Describe the Sun as a star that provides light and heat and explain that the Moon reflects the Sun's light
2.11.E. Describe how human impact can be limited by making choices to conserve and properly dispose of materials such as reducing use of, reusing, or recycling paper, plastic, and metal

3.8.A Identify everyday examples of energy, including light, sound, thermal, and mechanical
3.9.A Construct models and explain the orbits of the Sun, Earth, and Moon in relation to each other
3.10.A Compare and describe day-to-day weather in different locations at the same time, including air temperature, wind direction, and precipitation.
3.11.A Explore and explain how humans use nature resources such as in construction, in agriculture, and make products
3.11.B Explain why the conservation of natural resources is important
3.11.C Identify ways to conserve natural resources through reducing, reusing, or recycling

4.11.A Identify and explain advantages and disadvantages of using Earth's renewable and nonrenewable natural resources such as wind, water, sunlight, plants, animals, coal, oil, and natural gas
4.11.B Explain the critical role of energy resources in modern life and how conservation, disposal, and recycling of natural resources impact the environment

5.8.A Investigate and describe the transformation of energy in systems such as energy in a flashlight battery that changes from chemical energy to electrical energy to light energy

5.8.B Demonstrate that electrical energy in complete circuits can be transformed into motion, light, sound, or thermal energy and identify the requirements for a functioning electrical circuit
5.8.C Demonstrate and explain how light travels in a straight line and can be refracted, reflected, or absorbed
5.11 Design and explain solutions such as conservation, recycling, or proper disposal to minimize environmental impact of the use of natural resources

6.8.B Describe how energy is conserved through transfers and transformations in systems such as electrical circuits, food webs, amusement park rides, or photosynthesis
6.11.B Explain how conservation, increased efficiency, and technology can help manage air, water, soil, and energy resources

6.6.0 Environmental Science

E.1(G) Develop and use models to represent phenomena, systems, processes, or solutions to engineering problems
E.6(A) Compare and contrast land use and management methods and how they affect land attributes such as fertility, productivity, economic value, and ecological stability
E.6(C) Document the use and conservation of both renewable and non-renewable resources as they pertain to sustainability
E.6(D) Identify how changes in limiting resources such as water, food, and energy affect local ecosystems
E.6(E) Analyze and evaluate the economic significance and interdependence of resources within the local environmental system
E.6(F) Evaluate the impact of waste management methods such as reduction, reuse, recycling, upcycling, and composting on resource availability in the local environment
E.7(D) Identify and describe how energy is used, transformed, and conserved as it flows through ecosystems
E.12(A) Evaluate cost-benefit tradeoffs of commercial activities such as municipal development, food production, deforestation, over-harvesting, mining, and use of renewable and non-renewable energy sources
E.12(C) Analyze how ethical beliefs influence environmental scientific and engineering practices such as methods for food production, water distribution, energy production, and the extraction of minerals

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