Wind Institute Fellows' Research Project Abstracts (2023-2024 Cohort)

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Economic, Policy, and Stakeholder Impacts

Ashley Bhandari
Rutgers University, Undergraduate Student
Advisors: Dr. Mariya Naumova and Moulik Kallupalam Balasubramanian

Economic Impact Research of Offshore Wind Energy Using Machine Learning Algorithms

The objective of the project is to study the multi-variable linear regression model (derivation of the coefficients, Gauss-Markov assumptions, and statistical tests on the significance of independent variables) and use it to analyze the economic effect of offshore-wind farm performance on security prices in European markets. Additionally, we explore neural-network models for the same purpose. Implementation is done in Python programming language.

Isabele Bittencourt
Montclair State University, Graduate Student
Advisor: Dr. Aparna Varde

Sentiment Analysis and Topic Modeling on Offshore Wind Energy in New Jersey

The building of offshore windfarms by the coast of New Jersey has brought controversy among residents that live by the shore of the state. Based on New Jersey's initiative of producing 100% clean energy by 2050 and the potential of offshore wind energy in helping to achieve this goal, we perform opinion mining and topic analysis on data collected from social media and news websites. We deploy three different models, TextBlob, VADER, and SentiWordNet, as they have different functions and present different outcomes. We also perform topic modeling using Latent Dirichlet Allocation (LDA) on news data to observe the correlation between social media opinion and information being spread by the news media. We use data visualization tools to display the overall results of our work. Despite the controversial nature of offshore wind energy in New Jersey, the models indicate some positive reception regarding the topic. However, the negative and neutral opinion percentage was not far behind. The topic analysis shows main themes being discussed by the news media, that when compared to the sentiment analysis results aid very similar topics of discussion. Both analyses can potentially be useful in decision-making contexts for energy development, considering the involvement of the local population as a factor in decision support systems aligned with principles of citizen science.

Dylan Irmiere
Stockton University, Undergraduate Student
Advisor: Dr. Tina Zappile

Jersey Shore Sentiments – New Jersey Residents' Outlook on Offshore Wind Farms on the Horizon

My research assesses New Jersey (NJ) residents' knowledge of issues related to offshore wind farm (OSW) projects, and what effect this knowledge has on opinions of OSW projects in NJ. To determine people's knowledge regarding the visual impact of turbines, environmental issues and regulations to protect marine mammals, and the potential of future economic benefits of OSW in NJ, we conducted a two-stage survey experiment through Qualtrics that was distributed and weighted by Marketing Systems Group (MSG). Respondents were given a set of questions to determine the baseline of public opinion and knowledge of environmental and other issues. Approximately 6 weeks after the initial survey, we surveyed respondents again and provided them with additional detailed information regarding the visual impacts of turbines based on the number of miles from shore, NOAA regulations for marine mammal protection, projections of economic benefits, and more. We also asked for a level of support for specific OSW projects with a mix of different characteristics, all drawn from public information. When given information about specific OSW plans, respondents were more supportive of actual projects. Results imply that NJ residents lack the knowledge to make an informed decision regarding OSW on the Jersey Shore. Our findings also conclude that the public is more supportive of projects located 12 miles or greater from the shore. An education campaign should be developed to inform the public about the basics of OSW and to highlight details of specific project plans including its location offshore, economic benefits, and environmental protections.

Kevin Leach
Rutgers University, J.D Student
Advisor: Steve Gold

Are the Laws Enough? Opposition to Offshore Wind Energy in New Jersey and Solutions Through Comparative Law Analysis

The laws of the federal and New Jersey state governments were created to ensure offshore wind projects are environmentally safe, economically feasible, and effective at easing the state's reliance on fossil fuels. However, opponents to offshore wind can take advantage of these laws and file lawsuits challenging the projects every step along the way. Federal laws like the Marine Mammal Protection Act, the National Environmental Policy Act, the Outer Continental Shelf Lands Act, the Coastal Zone Management Act, and the Endangered Species Act, as well as state procedures, like permitting and zoning, all provide abundant legal avenues for opponents to attempt to block the offshore wind projects. The offshore wind industry will face inevitable legal challenges that, without preparation, can lead to injunctions, heavy fines, or extensive delays that will drive up the costs of the projects and potentially deter developers from continuing their projects. To move on from an overreliance on executive orders from President Biden and the Governor Murphy, offshore wind proponents should push for new legislative laws promoting offshore wind that cannot as easily be overturned after the November 2024 and 2025 elections. Proponents must also continue to spread accurate and understandable scientific information about the projects. While greater scientific communication will not block the flood of lawsuits, it may create a better sense of trust between the public and the government.

Faith Monesteri
Montclair State University, Undergraduate Student
Advisor: Dr. Meghann Smith

Applying SWOT-AHP Analysis to New Jersey Offshore Wind

This research aims to conduct a thorough examination of New Jersey offshore wind by performing a SWOT-AHP analysis of it. To begin, information was gathered on offshore wind from both scholarly articles, official websites, and recent studies. This information was then used to identify about 10 strengths, weaknesses, opportunities, and threats of New Jersey offshore wind. A list of relevant stakeholders was compiled with information from various lists and sources. Stakeholders were then solicited for interviews, and each interviewee was requested to rank their top five attributes from the compiled list of strengths, weaknesses, opportunities, and threats. The most commonly chosen attributes were identified and placed in a survey, using an AHP model. This survey was then sent out, and the results were placed in an AHP matrix, which will generate valuable data on opinions of offshore wind from relevant stakeholders. This will provide context for policy makers and the offshore wind industry at large.

Rylee Nelson
Seton Hall University, Graduate Student
Advisor: Dr. Ruth Tsuria

Wind Energy Barbie: Ecofeminism and the Wind Sector in New Jersey

Ecofeminism is the study of how the philosophical and political aspects of the feminist movement have combined with those of the environmentalism movement to provide a new lens through which to analyze the climate change phenomenon. However, current research has not evaluated the way ecofeminism and other forms of feminist thinking have influenced the clean energy sector, specifically the wind energy sector in New Jersey. We must ensure that the clean energy sector is forward-thinking and innovative in social areas as well as scientific areas. Therefore, it is imperative to use an ecofeminist, as well as an overall feminist, view when building the wind sector to ensure that it is inclusive from the beginning and does not leave lasting negative effects that need to be corrected in the future. This paper analyzes the historical implication of ecofeminism, the role of feminism in the workplace, and the current inclusivity plans of the wind energy sector in New Jersey to identify existing weak points in the clean energy sector as a whole, critically analyze the current state of feminism and inclusivity in the companies that are at the center of the wind energy sector in New Jersey, and make recommendations for a feminist and inclusive wind energy sector moving forward.

Laura Page
Seton Hall University, Undergraduate Student
Advisor: Dr. Kwok Chuen T Teo

Lessons from the European Union

This project is a comparative study researching the political and regulatory position of offshore wind power in the European Union and countries with a special look at France and Germany. This study is relevant to New Jersey in that it will evaluate where the European countries have succeeded in progressing offshore wind power via goal setting, European country synchronization with the European Union, obstacles faced, and assess what aspects New Jersey could replicate to further their offshore wind growth.

Jessica Parineet
Rutgers University, Graduate Student
Advisor: Dr. Mark Paul

The Socioeconomic Implications of Offshore Wind Policy in New Jersey

This research evaluates how the policy approach New Jersey lawmakers are using to establish the offshore wind industry impacts socioeconomic equity in the state. Offshore wind energy projects will contribute to key decarbonization targets and provide high-quality jobs to historically marginalized communities. Identifying gaps in the current policy landscape can help New Jersey institutions develop strategies to maximize and properly distribute the benefits of this new industry while accounting for potential negative impacts. This analysis employs a framework that organizes equity issues into the following sub-topics: climate justice, environmental justice, energy burden, and economic justice. The evaluation was conducted through a combination of literature review, examination of current plans and legislation, and comparison with approaches of mature offshore wind industries in the EU and UK. The results indicate that while significant strides have been made in all four areas, institutions in the state must incorporate equity related goals more explicitly and strategically in complementary legislation and in future planning endeavors. Recommendations for decision-makers include the development of protocols for data collection to assess socioeconomic impacts of the industry in the coming years, procedural requirements for community benefit funds, development of a just transition plan, and codifying decarbonization goals. Moreover, there is a mandate for increased federal funding and coordination that can enhance the capacity of individual states to implement offshore wind in a manner that is just and equitable.

Kripa Shrestha
Montclair State University, Ph.D. Student
Advisor: Dr. Pankaj Lal

Offshore wind development and associated impact on recreational fisheries in New Jersey: A socio-spatial approach

Offshore wind is rapidly being developed to generate renewable carbon-free electricity for the grid. However, the development of offshore wind farms (OWFs) faces resistance, especially from the recreational fishers. Few empirical studies have been conducted to assess the OWFs impact on recreational fisheries. This research focuses on charter boat captains' and owners' perception regarding OWFs in New Jersey (NJ). To understand interactions between OWFs and recreational fisheries, we assessed the impacts through an online survey of boat captains and owners. The survey was administered during February-March 2024, and achieved 22% response rate. The majority of respondents (71%) had over 15 years of experience in the occupation, and 97% were recreational anglers themselves. The survey results suggested that 91% of boat captains and owners were opposed to OWF development in NJ. The result highlighted concerns regarding issues such as the industrialization of the ocean in unwanted way (82%); disturbing marine species like fishes and scallops (73%); and negative impact towards marine environment (70%). The survey respondents advocated for science-based evidence that demonstrates minimal impact on the marine ecosystem and a phased approach of OWF development whereby a single demonstration project is developed before scaling up to others. The study findings underscore the critical need for communicating with these recreational fishing boat captains, understanding the reasons behind their opposition to OWF, and making concerted efforts to ameliorate their concerns. The findings are significant as they can be used for targeted outreach for boat captain and can help minimizing disruptions to recreational boating and fishing activities.

Kaitlyn Spitzer
Seton Hall University, Graduate Student
Advisor: Dr. Michael Taylor

Navigating Resistance: Understanding Opposition to Wind Farms in New Jersey

The study's main purpose is to identify opinions regarding the development of the proposed offshore wind farms in the state of New Jersey. A better understanding regarding support of and opposition to the implementation of offshore wind farms is critical to the successful adoption of policies and approaches in the industry. Data focusing on opinions regarding offshore wind farms, such as perceived economic, environmental, recreational, and aesthetics impacts will be collected from a representative sample of New Jersey residents using a 22-question survey. The data will be analyzed to examine how the participant's geographic location within the state, annual beach visitation rate, and level of knowledge regarding impacts and benefits of offshore wind power affects their opinion. This research seeks to improve our understanding of the sources of positive and negative attitudes towards offshore wind farms in New Jersey, with applicability to similar renewable energy projects across the United States.

Engineering and Design

Ian Bain
Rowan University, Graduate Student
Advisors: Dr. Yashwant Sinha and Dr. Francis (Mac) Haas

Arduino-Powered Weather Station for Wind Power Generation Prediction

This research seeks to prototype a final project for Rowan University's Wind Energy curriculum, which focuses on developing an engineering technology workforce for both wind power and adjacent industries. Students will build and design a compact weather station, based on the present prototype, capable of monitoring the current weather through Arduino-integrated sensor modules that collect information on temperature, pressure, humidity, and wind speed. Using these variables as inputs, students will also develop code to predict future weather metrics based on algorithms covered in their Wind curriculum coursework, which permits estimation of the future power production of a hypothetical wind turbine at the monitoring location. Collected data is displayed in real-time on the weather station, but users can also switch between current and predicted values for each variable. Considerations for the project balance important learning objectives, feasibility of classroom deployment, and project impact toward enhancing students' understanding of data collection, analysis, and modeling relevant to wind turbines. It will also leave students with a practical tool to understand the impact of weather on wind turbine performance. This project is flexible in implementation: for a simpler version of the project, instructors can provide the Arduino code, permitting students to concentrate on hardware implementation; for a more challenging project, the addition of a Bluetooth module allows students to send data back to their respective laptops for additional processing.

Rojyar Barhemat
Stevens Institute of Technology, Ph.D. Student
Advisor: Dr. Yi Bao

Feasibility study on monitoring scour for underwater cables of offshore wind turbines using distributed fiber optic sensors

Subsea cables are critical components of offshore wind turbines and are subjected to scouring. Monitoring the scouring conditions of subsea cables plays significant roles in improving the operation efficiency and reducing the levelized cost of electricity. This paper presents a feasibility study on monitoring the scouring conditions of subsea cables using distributed fiber optic sensors, aiming at evaluating the technical and economic feasibility as well as the performance in detecting, locating, quantifying, and visualizing scouring conditions. A finite element model was developed to evaluate the impact of scouring on the mechanical responses of subsea cables, and laboratory experiments were conducted to validate the finite element model and verify the performance of distributed fiber optic sensors in monitoring scouring effects. The results showed that the proposed method was feasible for monitoring subsea cables technically and economically. This research offers insights into monitoring subsea structures for offshore wind turbines.

Daniel Bindas
Rowan University, Undergraduate Student
Advisor: Dr. Jie Li

Defining Resilience, Risks, and Readiness of Offshore Wind

In recent years, there has been a push worldwide to reduce carbon and other greenhouse gas emissions due to the worsening of extreme weather events from global climate change. Since the energy sector is one of the largest producers of carbon, one of the major initiatives has been to replace traditional fossil fuel burning electric generation plants with renewable energy sources, such as offshore wind turbines. While this movement is necessary to meet state and federal mandates, it introduces increased complexity in the bulk electric grid, as their power output cannot be controlled like traditional generation plants. This is of particular concern during extreme weather events, such as hurricanes, extreme heat, and extreme cold, when the operating limits of the offshore wind turbines are exceeded, significantly decreasing their ability to produce electricity. This work looks to evaluate how the increased penetration of offshore wind capacity in the PJM market will impact operational reliability by estimating the power production of the Atlantic Shores wind farm during extreme weather events, such as hurricanes, extreme heat, and extreme cold. First, a literature review was conducted to understand which

weather conditions impact the production of offshore wind turbines. Then, the power curve of the V236 turbine, the one to be used in the Atlantic Shores project, was estimated using publicly available information. This curve was modified for extreme temperature conditions, based on the literature review. Lastly, the power generation of the wind farm was estimated using this power curve for a hurricane event, a 10-day period of extreme heat, and a 10-day period of extreme cold, to compare to its normal power generation. The results of this are still under development. Future work could incorporate additional extreme weather, such as icing and high turbulence, to further evaluate impacts on offshore farm production.

Nicholas Conlin
Princeton University, Ph.D. Student
Advisor: Dr. Marcus Hultmark

Coastal Boundary Layer Effects on Offshore Wind Energy in New Jersey

Wind power differs from conventional power sources because it depends on the environment. The power produced by a wind turbine varies strongly with the wind speed. Characterizing changes in wind speed over a broad range of scales is therefore important for synergistic planning across different power sources. Modern turbines operate in the lowest portion of the atmosphere where surface friction and temperature influence the wind speed. Offshore turbines are further complicated by the presence of heterogeneous surface roughness and temperature. These effects are geography specific and require data on many different timescales to characterize. This project used data collected by floating buoys over 13 years at various offshore locations to determine the spatiotemporal variations in wind speed on timescales from hours to months. We also developed a custom three-dimensional particle tracking system for studying turbulent fluctuations with timescales of tens of milliseconds to minutes. Helium-filled soap bubbles are released and tracked using four digital cameras. A field campaign was conducted at the southern tip of Island Beach State Park using the bubble tracking system. We report on data from the field campaign and long-term buoy data and discuss implications for wind power off the New Jersey coast.

Justin Dworacek
Rowan University, Undergraduate Student
Advisor: Dr. Adriana C. Trias Blanco

Structural Assessment of Offshore Wind Turbines Using Remote Sensors

Wind turbines provide 10.2% of the total U.S. utility-scale electric energy (U.S. Energy Information Administration, 2022), and their growth has been exponential in the last 20 years; in particular, off-shore wind turbines have become popular on the New Jersey coast since the turbines can be exposed to higher winds leading to higher energy production. To support this growth, engineers are constantly working to improve the maintenance of such structures and ensure they can operate at total capacity throughout their service life. To achieve this, deploying structural health monitoring (SHM) systems for condition assessment in response to high wind speeds and wave impact has become essential. Existing SHM systems incorporate the use of (a) acoustic emissions, (b) thermal imaging, (c) ultrasonic methods, (d) strain gauges, and (e) accelerometers to detect and quantify cracks, turbine blade dynamics, corrosion, and thermal stress to evaluate the structural performance and responses at a local scale. Of particular

interest, the objective of this research was to develop an SHM technology that would leverage the implementation of remote sensors to aid in the shortcomings of the current deployment of contact sensors. For this, a mobile Light Detection and Ranging (LiDAR) sensor was used to scan a scale wind turbine subjected to horizontal vibrations to capture the full-filed responses and generate computational models that allowed us to predict behaviors under extreme weather conditions. The research consisted of (1) Literature review to broaden the knowledge of the current design and operating requirements of offshore wind turbines; (2) Data collection plan based on current monitoring requirements; (3) Data processing using point cloud data software as CloudCompare; (4) Data analysis which will include a comparison of the proposed method to current monitoring approaches; and (5) Conclusions and recommendations.

Daniel Enrique Guerrero
Seton Hall University, Ph.D. Student
Advisor: Dr. Jose L. Lopez

Using a Plasma Actuator for the Enhancement of a Wind Turbine's Airfoil Performance

Zaynab Hazaveh
Rowan University, Graduate Student
Advisor: Dr. Behrad Koohbor

Multiscale Mechanics and Failure Analyses of Wind Turbine Composites by Experimental Characterization

This research investigates one of the most common damage types developed in wind turbine blades, "transverse cracks." The development of this damage can significantly deteriorate the blade's structural integrity. Transverse cracks are mainly developed by fiber-matrix interfacial debonding. Numerous computational studies have investigated the fiber-matrix debonding mechanisms with no or limited experimental verifications. This research project uses an experimental approach to systematically characterize the fiber-matrix interface at different length scales, from single-fiber to RVE scales. Given that glass and carbon fiber are the leading candidates for manufacturing turbine blades, we use glass fibers embedded in an epoxy matrix to create tensile test samples with >25 randomly distributed macro fibers (1 mm) to replicate RVEs in transversely loaded fiber composites. We use the full-field measurement technique, Digital Image Correlation (DIC), to experimentally characterize the deformation and strain fields developed near the fiber-matrix interface at different length scales. The proposed approach enables accurate and high-resolution characterization of the strain fields and crack path. The experimental measurements presented in our study reveal that DIC is a practical and precise approach for characterizing deformation and failure characteristics at fiber-matrix interfaces and the mechanisms that control the evolution of interface cracking to transverse matrix failures in fiber composites. Furthermore, our results indicate that our research efforts could lead to the manufacturing of larger, more durable wind turbine blades with higher mechanical load-bearing capacities and lower weights.

Michelle Hernandez
New Jersey Institute of Technology, Graduate Student
Advisors: Dr. Philip Pong and Dr. Marcos Netto

Optimizing Wind Power Generation: Developing a Digital Twin for Real-Time Monitoring and Analysis

In the evolving landscape of renewable energy, the digital twin technology emerges as a transformative tool for enhancing system performance and reliability. This project is centered around the development of a digital twin of the electrical system of an offshore wind turbine, a critical component of sustainable energy generation. A digital twin serves as a sophisticated virtual representation of a physical system, capable of real-time monitoring, optimizing performance, and predicting the system's transient behaviors in response to anomalies. The development of this project involves the design of a mathematical model of the wind turbine in Simulink/Matlab, followed by the design of a data-driven model derived from the state space measurements of the system using dynamic mode decomposition. This novel approach captures the system's dynamics through critical parameters, facilitating an accurate projection of future system states by synchronizing real-time data with the turbine's reactions to control inputs and environmental variables. The project will culminate with a power-hardware-in-the-loop (PHIL) simulation setup, including real but downscaled power-electronics modules, controllers, and a 6-kW permanent magnet synchronous generator driven by a controlled-speed induction motor that emulates the wind turbine. As the global energy landscape shifts towards more sustainable sources, the deployment of digital twins in renewable energy projects offers a promising avenue for achieving higher efficiency and reliability in energy production.

Jayden Johnson
New Jersey Institute of Technology, Undergraduate Student
Advisor: Dr. Pramod Abichandani

A Review of Drone Applications in the Wind Energy Industry: Purposes and Methodologies

As the popularity and usage of renewable energy technologies are increasing on a global scale, significant investments have been made in the field of wind energy. Subsequently, interest in research and development in the industry has also increased, presenting opportunity and motivation for researchers and corporations alike to find ways to improve on the safety, efficiency, and effectiveness of all aspects of the industry. To this end, many have leveraged the capabilities of unmanned aerial vehicles(UAVs), otherwise known as drones, to assist with and improve inspections, remote sensing, maintenance, and other operations that support wind energy. In this paper, we performed a qualitative review of 100 sources from academic journals and industry leaders to provide insight into the future of drone usage in the wind energy industry. The objectives and methodologies used in each of these sources were analyzed to identify current industry trends and focuses in research. Prominent topics of interest revealed in our review were inspection and damage detection, wind farm navigation, and measuring wind characteristics, among other more niche or less-represented topics. To this end, methodologies used primarily included a variety of machine learning and deep learning approaches and a range of visual, atmospheric, and other sensors.

Riya Karande
New Jersey Institute of Technology, Undergraduate Student
Advisors: Dr. Philip Pong and Dr. Sotirios Ziavras

IoT Sensing Platform for Wind Turbines

This research focuses on addressing the challenges encountered by offshore wind farms in data collection and monitoring, emphasizing the importance of efficient data monitoring and communication infrastructure. Traditional methods involving wired connections are costly and lack the flexibility needed for modern data processing techniques. The primary objective is to develop an Internet of Things (IoT) platform utilizing a wireless sensor network to enable real-time data collection, analysis, and storage for monitoring offshore wind turbine operations.

Key parameters such as current, voltage, wind speed, and vibration will be monitored with high accuracy and resolution. Findings indicate that implementing a wireless sensor network significantly reduces investment costs and improves scalability and flexibility in data transmission. This platform outperforms traditional systems by capturing data with higher temporal resolution, providing detailed insights into turbine performance and health.

The proposed IoT platform not only facilitates local communication for active and reactive power control, but also enables communication between onshore and offshore substations for multiple subsystem interconnections, fault detection, predictive maintenance, and wind power prediction. A prototype integrating various sensors is developed to collect data, which is then analyzed and compared to a virtual system, forming a real-time IoT/big data platform. This research holds significant implications for the offshore wind industry, offering a cost-effective and advanced solution for monitoring and managing wind farms, ultimately enhancing operational efficiency and ensuring sustainable energy production.

Mian Liao
Princeton University, Ph.D. Student
Advisor: Dr. Minjie Chen

Advanced Power Electronics for Impedance-Based Stability Analysis of Offshore Wind Power Systems

The design challenges of offshore wind farm power systems typically include uneven distribution of wind resource through each wind turbine. The varying wind speeds at each turbine within an offshore wind farm can introduce potential instability issues into the power grid. The mechanical and electrical systems of distributed wind turbines oscillate with the power systems, leading to stability concerns. Additionally, with the gradual replacement of traditional synchronous generators by inverter-based resources for renewable electric grid, sudden load changes may exacerbate instability issues or even lead to blackouts. This research mainly focuses on addressing grid stability by proposing a three-phase inverter topology and corresponding multi-inverter control system. An analysis is conducted on a novel three-phase inverter topology based on dual-active-bridge (DAB) and cycloconverter, which effectively decouples power flow in each individual phase. Simulation results validate the fast transient response of this topology, demonstrating the grid's ability to be rebalanced within a single AC cycle. A hardware prototype has been developed for future testing. Furthermore, in a typical configuration, each turbine in a wind farm is connected to the power grid via an inverter. In large-scale wind farms, multiple inverters interface with the grid, leading to complex control challenges. This research explores methods to manipulate power flow between multiple inverters based on output impedance. Simulation results confirm that the impedance of each inverter can be determined, and a two-inverter system can maintain stability. In summary, this research emphasizes the importance of fundamental stability analysis for grid-tie inverters used in offshore wind farms.

Anthony Marino
Stockton University, Undergraduate Student
Advisor: Dr. Patrick Hossay

Reduction of Noise Pollution by Changing the Surface of the Blades

This research aims to reduce the noise generated, or more precisely to improve the noise to power-generation ratio, of wind turbines by altering the surface texture of the blades. By delaying that separation, the surface area experiencing laminar flow will increase in size, thus improving lift, and reducing the overall turbulence. Turbulence is characterized by highly disordered air flow, generally tending to eddies and complex vortexes. The resulting waves of pressure are perceived as noise, and this noise contributes to much of a turbine's sound pollution. The result of this alteration is a possible reduction in overall noise, and a potentially more significant increase in the lift to noise ratio.

Changing the surface texture can increase the presence of high-energy air at the surface and thus delay the separation of the air boundary layer. With this increase of energy, the point of boundary layer separation from the turbine blade will occur later. This delay in separation will allow for more lift and decrease the overall amount of turbulence. This increase of lift will allow for more energy to be generated for the same amount of turbulence being generated.

For this experiment, textured surfaces of varying abrasiveness were tested to observe their effectiveness. Initial testing included analyzing 7 differing coarse surfaces ranging from 22-360 micron diameter particles coating to the surface in an aerodynamic simulation. The point of separation was the main point of observation. The coarse surface of 260 microns diameter particles provided a significant delay in boundary layer separation, and thus allowed a larger surface area of the airfoil to experience laminar flow". New blades were designed to fit an A30 turbine. Once the blades were fabricated, 260 (experimental) and 22 (control) micron surface was applied to the blades to identify performance variations more precisely. To test the effects of differing blade surface characteristics, multiple trials were conducted utilizing an A30 turbine under varying angles of attack.

The results indicate a coarse surface significantly impacted separation characteristics, and thus relative noise production. Furthermore, the results showed that when the angle of attack of the blade was at 15 degrees, the coarse surface power to sound ratio increased by 26.5% when compared to the control. The coarse surface did not decrease the absolute noise level of the turbine as predicted at the beginning of this research. It did, however, increase the overall power to noise ratio of the turbine.

Juan Lopez Muro
Rutgers University, Ph.D. Student
Advisor: Dr. Laurent Burlion

Control Co-Design of a Floating Offshore Wind Turbine

Floating offshore wind turbines represent a promising avenue for clean energy production but pose unique challenges due to their complex dynamics and exposure to harsh marine environments. This study focuses on refining control co-design strategies for floating offshore wind turbines to optimize power efficiency while minimizing the total system mass, accelerating the transition towards a sustainable energy future.

Robust H-infinity control techniques and reference governors drive the blade pitch, nacelle yaw, generator torque, and platform actuators, aiming to maximize the power while mitigating extreme loads on the structure. A comprehensive model of the floating offshore wind turbine, integrating dynamic behaviors of structural components, is derived and used through the controller synthesis process. Simulations using open-source resources like *OpenFast* validate the developed control strategies in realistic environments.

Primary findings indicate that active control of the floating platform effectively reduces the effect of hydrodynamic perturbations, mitigating structural loads. Additionally, power analysis suggests a minimal consumption of the generated power by the active control system. These have implications for the design of floating offshore wind turbines, improving performance and economic viability. Overall, this research aims to advance the prospects for sustainable offshore wind energy production and support the continued growth of the renewable energy industry.

Javad Saeidaskari
Stevens Institute of Technology, Ph.D. Student
Advisor: Dr. Raju Datla

The Effect of Water and Vibration-Induced Scour on the Offshore Wind Turbine Foundation: Numerical Study

Offshore wind farms represent a rapidly growing sector in the renewable energy industry. One critical challenge in the design of monopile offshore wind turbines (OWTs) is the scour phenomenon, which can compromise the integrity of monopile foundations. The current gap in the literature lies in the lack of comprehensive models that consider the effect of wind turbine vibration on scour formation. In this research, a series of OWT monopiles with different diameters were first modeled using Flow 3D software under various water levels and velocities. Subsequently, the scour depth was calculated for each scenario. Next, utilizing the geotechnical software PLAXIS 3D, the same OWTs with a calculated scour depth from the previous step were remodeled to investigate the effect of turbine vibration on scour depth. The results from Flow3D indicated that an increase in monopile diameter, water velocity, and water depth, without considering vibration, led to a corresponding rise in scour depth. Conversely, the geotechnical results demonstrated that an increase in the frequency and amplitude of vibration resulted in a decrease in flow-induced scour depth, likely attributable to the sediment ratcheting motion on the scour hole's surface. Notably, the influence of amplitude exceeded that of frequency. This study also showed that the effect of vibration on the scour is influenced by monopile length, diameter, and embedded depth.

Ahmed Shalaby
Stevens Institute of Technology, Ph.D. Student
Advisor: Dr. Muhammad Hajj

Alyson Zhang

Stevens Institute of Technology, Undergraduate Student
Advisor: Dr. Raju Datla

Particle Damping Enhancement in Offshore Wind Turbine Monopiles, A Comprehensive Study Using ANSYS Simulation and Experimental Insights

This research explores the structural integrity and performance of monopiles, which are foundational elements in offshore wind turbines, under the combined influence of wind and wave forces. Performing ANSYS simulations, we quantified stress and strain distributions within the monopile structure. The approach models the soil-structure interaction by integrating a multi-layer spring system at the base of the monopile, thereby simulating varying soil conditions with adjustable spring stiffness. This simulation will be further validated through experimental testing at the Davidson Laboratory of Stevens Institute of Technology, employing optical fiber technology for strain measurement and load cells for force quantification within a controlled wave tank environment.

An important aspect of this investigation is the introduction of a particle damping mechanism specifically designed to attenuate the monopile's vibrations. This tailored approach not only increases the monopile's lifetime by reducing impact of high loads and their damaging effects, such as cracking, but should also enhance the operational efficiency of the wind turbine. By adjusting the spring system to mimic different soil types, the study comprehensively examines the monopile's behavior under a spectrum of environmental conditions.

By combining simulation and experimental methods, this study advances our understanding of soil-structure interactions and the effectiveness of vibration damping techniques in ensuring the durability and reliability of offshore wind turbines.

Mike Supple
Rutgers University, Undergraduate Student
Advisor: Dr. Richard Riman

Carbon Negative Foundation Materials for Wind Energy Generation

Global warming is a serious problem in today's world. There are many ways to take action against this issue, such as cleaner energy sources like wind energy. However, concrete is used in the towers of many wind turbines and is not a sustainable material; large amounts of CO_2 are released during its production. Concrete is the most used material by volume globally and accounts for 8% of global CO_2 emissions. This issue can be addressed by developing and utilizing carbon-neutral or carbon-negative materials. In this study, a wollastonite-based cementitious material was investigated. This material sequesters CO_2 during its curing process and is believed to be a competitive alternative to concrete. One of the major focuses of this project was developing a "strong" wollastonite-based cementitious material. "Strong" means having sufficient compressive strength to be competitive with concrete. One of the known ways to increase a material's compressive strength is to use a mixture of multiple particle modes during fabrication. This will allow smaller particles to fill in the interstices between larger particles, increasing density and strength. In addition to the wollastonite, a second material, ball clay, was chosen to provide the smallest particle size. This was selected due to the platelet shape, hoping to add platelet reinforcement, and having a particle size over 10-times smaller than that of wollastonite. The two materials of different sizes were mixed at different volumetric ratios to maximize the packing fraction. The theoretical density vs the actual density is used to calculate the percent packing fraction. The dry tap density was measured before being cast, and additional densities were recorded after being cast and cured. The highest percent packing for the tapped dry powder was at 90% wollastonite by volume. For the cast pieces, the highest percent packing was at 70% wollastonite. Compressive strength measurements were done on cast and cured pieces.

Akhyurna Swain
New Jersey Institute of Technology, Ph.D. Student
Advisor: Dr. Philip Pong

Enhanced Condition Monitoring Systems for Offshore Wind Turbine Drive Trains through Hilbert-Huang Transform and Supervised Machine Learning Algorithm

This project aims to improve the current operations and maintenance practices in the offshore wind turbine drive trains by developing efficient, economical, and commercially realizable condition monitoring systems. With the increase in size and ratings, offshore wind turbines need to adapt to fluctuating wind and grid conditions to ensure reliable power quality. Consequently, data obtained from the traditional condition monitoring systems e.g., SCADA systems exhibit non-linear and non-stationary characteristics, reflecting the dynamic nature of the environmental and grid conditions. Various signal processing techniques such as conventional Fourier transform analysis have been utilized to interpret these signals. However, they have not been commercialized due to their complexity, accuracy, and large response time issues. This work attempts to address the issue by developing a machine learning model for classification of various faults on mechanical and electrical components of the wind turbine drive train based on the common magnetic flux density (MFD) of the electric generator. To efficiently capture the faults and its effect on the electromagnetic coupling, Hilbert-Huang Transform Data Processing System (HHTDPS) is applied on the MFD to adaptively decompose the signal into a series of time and frequency dependent components. Unlike the conventional signal processing techniques, the HHTDPS utilizes relationships between arbitrary signals and local extrema to find the instantaneous spectral representation of the signal through a finite set of Intrinsic Mode Functions, without assuming signal linearity and stationarity. Through the HHTDPS and supervised machine learning algorithm, a remote condition monitoring system is demonstrated that could extract fault signatures in the amplitudes and frequencies of non-linear and non-stationary signals and is also capable of processing large amounts of data in real time. The next step is the development of real-time power hardware in loop experimental setup with wind turbine emulator and OPAL-RT and validation of simulation results with practical experimentation.

Kevin Vargas
Montclair State University, Graduate Student
Advisor: Dr. Ashwin Vaidya

Innovating Wind Energy: Analyzing the Efficiency and Performance of Vertical Axis Wind Turbines

This research builds on previous work on fluid-structure interaction done at the Complex Fluids Laboratory at Montclair State University. This includes work on small-scale models in a wind tunnel and controlled autorotation experiments of small particles in a flow tank. The current project seeks to explore further refinements on the design and configuration of vertical axis wind turbines (VAWTs) based on commercially available models and newer designs. Work on small-scale models in the laboratory helps us begin to understand the physics and real-world performance through controlled experiments in the wind tunnel. These experiments have been supported by computational fluid dynamic (CFD) studies to understand the impact of design and flow variations upon the model systems, beyond the scope of our experiments. CFD analysis allows us to compute relevant forces, torques, RPM, velocities, and other physical phenomena that can help point towards the most optimal design and configuration for power generation and efficiency of these turbines. The present work can further be applied towards the development of wind farms/ arrays by studying various configurations of multiple VAWTs. Using CFD software helps reduce cost and saves time from changing models physically to get similar conditions in a simulation and notice similar patterns in simulations such as change in number of blades, sizing of the blades, shape, gap between the blades, and change in other design features.

Ryan Weightman
Rutgers University, Ph.D. Student
Advisor: Dr. Benedetto Piccoli

A mathematical model for the optimal design and network integration of an offshore wind farm in New Jersey

The purpose of this project is to model two major aspects of building an offshore wind farm and connect to a power grid, and tune the model parameters using data specific to the state of New Jersey. First, the influx of renewable energy into the classical power system presents unique hurdles such as a large injection of externally driven fluctuations in power generation, a large amount of power newly coming from one section of a connected grid, and more. Second, there is a question of how to optimally place turbines so as to minimize the global cost corresponding to multiple criteria, such as connectivity, impact to offshore industry, and maximizing the total energy output from the turbines. First we develop the mathematical models representing these two problems. The two models are connected since the solution to the first problem provides one criterion for the cost of the second, while the solution to the second problem provides the wind energy input to the first. The output of these models will help understand what the energy landscape of New Jersey will look like by the year 2040.

Hannah Hata Williams
Princeton University, Ph.D. Student
Advisor: Dr. Michael E. Mueller

Relative Impacts of Environmental Factors on Finite Offshore Wind Farms

Further development of offshore wind energy on the United States' Atlantic Outer Continental Shelf requires computationally efficient ways to predict full-scale farm power production for siting, design, and operation. Understanding the transfer of momentum between the marine atmospheric boundary layer (wind) and ocean waves as well as the impact that such environmental factors have on the velocity at turbine hub height are key components of accurately predicting power production. In this project, a recently developed wave drag model for waves is combined with wind turbine models and realistic incoming wind profiles to create a Computational Fluid Dynamics (CFD) framework for full-scale, finite offshore wind farms. The ideal power production calculated using this new framework is compared to results using a standard representation of waves with a static model that does not account for wave phase dynamics. The two approaches, while having similar computational costs, predict different power production and blade loading. The framework developed through this project can be used to learn more about the complex dynamics between different atmospheric and oceanic environmental parameters and their relative impacts on the power production of offshore wind farms.

Environmental Issues, Monitoring, and Forecasting

Avery Barnett
Princeton University, Ph.D. Student
Advisor: Dr. Jesse Jenkins

Resilience of Offshore Wind Technologies under Hurricane Landfalling Within PJM
New Jersey (NJ) is not spared from hurricane impacts and will have to work towards ensuring that social and technical impacts are mitigated, and that infrastructure is sufficiently hardened. In line with the recent executive orders that mandate 100% clean energy by 2035 and 11,000MW of offshore wind by 2040, my research project focuses on the resilience of offshore wind technologies under hurricane landfall within PJM. Through varying the penetration of offshore wind technologies in the grid, I will investigate the options available to balance resilience and affordability, the impact of offshore wind on the overall system, and the level of electricity supply disruption at different hurricane intensities. By using GenX and an extreme weather model, the impacts of the electric grid within NJ will be assessed and solved for a range of different configurations, including varying offshore wind penetrations and other resilience factors, which will then be impacted by varying intensities of hurricanes where wind speed is used as a proxy. The impact of electricity supply disruption that results from the failure and how much failure is attributed to offshore wind within each configuration will be assessed. This research hopes to provide a first step in understanding the resilience of NJ, and by extension, the PJM grid against hurricanes. Future research can be informed through adaptation to consider other electricity grid threats such as storm surges, flooding, and similar hazards.

Teemer Barry
Rutgers University, Ph.D. Student
Advisor: Dr. Grace Saba

Understanding the Seasonal Linkages of Underlying Oceanographic Conditions and Phytoplankton Dynamics In and Around Offshore Wind Development Areas
The highly variable oceanographic conditions within the New York/New Jersey portion of the Northern Mid-Atlantic Bight (MAB) are heavily influenced by the physical structure of the shelf ecosystem alongside freshwater input from several rivers and present coastal storm systems. With the ongoing development of offshore wind, there is an exceptional interest in resolving the interactions between the seasonal physical processes and the highly responsive planktonic community from which to assess the potential impacts of wind turbine operations. I am

conducting seasonal, vessel-based sampling to collect a suite of oceanographic data and discrete water samples in coastal New Jersey shelf waters that will identify relationships between ocean water column structure, seasonal patterns of taxon-specific phytoplankton abundance and biomass, and phenology. Preliminary observations from 2023-2024 showed a 29% increase in mean chlorophyll-a concentrations from early to late winter. With previous estimations of phytoplankton chlorophyll within the area being almost entirely dependent on satellite observations, these discrete measurements, along with upcoming analyses that will provide species-specific community compositions alongside other seasonal measurements, will establish essential baseline information for primary producers on the coastal shelf.

Zain Kamal
Rutgers University, Undergraduate Student
Advisor: Dr. Ruo-Qian (Roger) Wang

Observing and Analyzing Global Offshore Wind Farms from the Space

This research focuses on quantifying and comparing mesoscale wake effects in various offshore wind farms using Synthetic Aperture Radar (SAR) data from the Copernicus Sentinel-1 satellite. Most modern wake analyses use some combination of simulations, traditional meteorological measurements, and/or remote sensing. SAR's advantage lies in its ability to reliably detect surface water roughness patterns over massive regions, enabling the observation of sea-atmosphere interactions as a proxy for near-surface wind properties (including characteristic signatures of wakes), even in adverse weather conditions and during nighttime. Our research overcomes previous limitations in spatial resolution and sample diversity by using a specialized Geophysical Model Function (GMF), which takes advantage of the inherent anisotropy constraint in wake analysis (i.e. unidirectionality) to more accurately isolate and quantify wind speed deficits. This approach allows for a larger dataset of SAR images to be used, improving statistical certainty and providing new insights into how wind farm geometries affect wake characteristics. Specifically, wind farms with closely spaced turbines exhibited more pronounced wake effects, leading to a reduction in wind speed by up to 15% at downstream turbines. Interestingly, certain geometric configurations mitigated these effects, suggesting a strategic approach to turbine placement could enhance overall efficiency. Furthermore, we found that wakes from larger wind farms extended further than previously estimated, impacting neighboring farms over 20 kilometers away. This discovery has significant implications for the planning and placement of future offshore wind farms. Our findings suggest that incorporating SAR data into wind farm design, specifically spatial dynamics of farm efficiency, can optimize turbine placement to minimize inter-farm wake interference.

Emma Morrone
Stockton University, Undergraduate Student
Advisor: Dr. Joseph Trout

Wind Energy and Its Effect on Local Weather and Climate

The need for clean, safe energy production has led to an accelerated deployment of wind farms around the world, including the eastern coast of the United States. An obvious question to ask is whether wind farms have an effect on the local microscale, mesoscale, and/or synoptic weather systems. The synoptic weather scale (large scale, cyclonic scale) is a horizontal length scale of

the order of one thousand kilometers. Weather systems with this scale include extratropical cyclones, high and low pressure systems, and hurricanes. The mesoscale includes systems with a length scale of five kilometers to hundreds of kilometers. These systems include sea breezes, squall lines, and convective thunderstorms. Microscale weather systems or features have a length scale smaller than five kilometers. Microscale systems include smaller clouds and breezes. These systems and features control the mixing and dilution processes in the atmosphere. Although this scale may seem unimportant, microscale meteorology studies processes such as heat transfer and gas processes involving soil, vegetation, surface water and the atmosphere caused.

Two avenues of research were followed in this study. The first avenue of research was to evaluate the historical weather records for areas with existing wind farms. In the pilot study, two locations were chosen. The first location chosen was the Turtle Creek Wind Farm in Iowa and the second location was the Jersey-Atlantic Wind Farm in New Jersey. Historical data from several locations surrounding the wind farms were analyzed. The analyzed data was compared for a period prior to the beginning of operation of each wind farm and after the wind farms began operation. The second avenue of research which is continuing evaluated the data using the Weather Research and Forecasting (WRF) Model.

Jeevanandan Ramasamy
Rutgers University, Undergraduate Student
Advisor: Dr. Aziz Ezzat Ahmed

Wind/Whale Co-Existence: Artificial Intelligence for Predicting NARW Occurrences Near Offshore Wind Farms

The rising U.S. offshore wind (OSW) sector holds great promise, both environmentally and economically. Hence, it is very important to ensure its co-existence with the valuable marine ecosystem. Our research leverages recent glider-based surveys and exogenous satellite information in order to analyze the spatio-temporal presence of the North Atlantic Right Whale (NARW)—an endangered marine mammal species with less than 370 whales alive today, especially at, or in proximity to, the OSW lease areas in the U.S. Mid-Atlantic. The aim of the project is to develop a predictive model to estimate the probability of NARW presence, given local spatio-temporal exogenous information, in order to aid in identifying regions, time windows, and conditions prone to encounters with NARWs. The analysis can, therefore, aid in ensuring the responsible development and operation of OSW projects in the region. This is a joint work with Jiaxiang Ji and Dr. Aziz Ezzat (Rutgers School of Engineering), Travis Miles, and Josh Kohut (Rutgers Marine & Coastal Sciences).

Leon Green-Tkacenko
Rutgers University, Ph.D. Student
Advisor: Dr. Julie Lockwood

An Ecological Vulnerability Index to Assess Impacts of Offshore Wind Facilities on Migratory Songbirds of the Northwest Atlantic

As offshore wind (OSW) energy expands globally, migratory songbirds are at risk of mortality from collisions with turbine blades, though the magnitude of this threat, and which species are most vulnerable, remains poorly understood. Ecological vulnerability indices are commonly used to assess species' susceptibility to harmful factors. We modified ecological vulnerability indices for seabirds to assess vulnerability of migratory songbirds to OSW related mortality, considering the songbirds that fly across the Northwest Atlantic during their autumn migration. We utilized readily available information on each species' migratory pathway, behavior, life history, and conservation status to calculate an index score. For the 101 songbird species that migrate through each autumn we labeled the species in the top 10% of the observed index distribution as 'highly vulnerable', and the top 35% as 'vulnerable', with New World warblers (Parulidae) over-represented in the former group. We found that up to 60% of species labeled as 'vulnerable' or 'highly vulnerable' could switch group membership if uncertain category scores were changed slightly, highlighting the importance of considering scoring uncertainty when evaluating ecological vulnerability indices. Finally, we explored how improvements in a species' conservation status could lower their vulnerability index and found that for 7 of the 10 'highly vulnerable' species, modest improvements could lower them into the 'vulnerable' category. Our methodology is readily applicable to other regions where OSW development is planned and songbird migration is common, allowing research and monitoring activities to be targeted to species most likely to be negatively affected by OSW facility encounters.

Emily Zembricki
Stockton University, Graduate Student
Advisor: Dr. Peter Straub

Mapping the Ecological Succession of Submerged Structures on the Little Egg Artificial Reef as a Proxy for Biological Community Development on Wind Turbine Bases

The goal of this project was to utilize acoustic and video observation techniques to document the ecological succession of newly submerged structures and provide a living timeline for biological faunal development on wind turbine bases and monopile structures in New Jersey. An integrated side scan sonar (SSS), multibeam echosounder (MBES), and direct observation approach via remotely operated vehicle (ROV) was used to document the study sites and the ecological succession of newly submerged structures in three locations: a bare ground control site, an established control site (1997), and the new reef site (2021) which contains a sunken 140' barge, a 52' crew boat, and a 45' tugboat to serve as a foundation for developing reef structures. The project design has allowed for the close monitoring of the ecological succession of the sites over a two-year period (roughly 3, 6, 12- and 24-months post-sinking) while developing and testing the effectiveness of water column data collection methods using ROV. The study thus far has produced high resolution MBES maps and 3-D models of the new reef areas and control sites. Initial faunal surveys have been completed and video analysis of ROV footage is ongoing. Currently, there are only five offshore wind turbines on Block Island and one in Virginia. All of these turbines, including those that are to come, are expected to develop biological communities. The results of this project will provide a baseline for comparison for both ongoing wind farm operations and once more offshore wind farms are constructed in NJ.