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Wind farm acoustics course: Use of a real-world case study to address ABET student outcomes

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Introduction

Effective engineers are skilled at applying their expertise to complex problems that require balancing competing objectives and taking into consideration a wide range of technical, ethical and societal concerns. The Accreditation Board for Engineering and Technology (ABET) has addressed the need for students to develop these skills in two different Student Outcomes (SO). The first addresses the need for students to consider factors that contribute to societal well-being when designing engineering solutions (ABET Student Outcome 2). The second relates to the ethical and professional judgement of the engineer in considering the impact of engineering solutions in their broader contexts (ABET Student Outcome 4). It can be challenging for educators to find opportunities for their students to develop these skills due to the demands of teaching the extensive technical material associated with the curriculum. This paper describes our experience using a current event related case study in a technical elective to address ABET student outcomes 2 and 4.

Case studies involving sustainability and environmental issues provide a unique opportunity for engineering students to tackle technical and ethical issues. Including a role-playing component in a case study presentation provides additional opportunities for students to develop awareness of social justice issues. A wind energy workforce development and engineering education grant provided an opportunity for our campus to develop a series of short courses related to wind energy, including one on wind farm acoustics. Noise from wind farms can have negative impacts on residents living nearby and frequently is a barrier to community acceptance. Therefore, instruction in wind farm acoustics should include consideration of the human and environmental impacts, providing a rich opportunity for students to meet ABET student outcomes 2 and 4 via consideration of real-world case studies of wind farms noise and community impacts.

Wind Farm Acoustics Course

The goal of this course is to encourage science and engineering students to engage in analyzing systems and devising strategies to reduce human impacts of wind farm noise and promote acceptance of this form of green energy within the context of global, societal and economic factors. It is open to any student who has completed a course in introductory physics, including students with a major or minor in environmental science and is under review for campus designation as a “sustainability-related’ course.

Course Structure

The 5-week course was designed as "flipped classroom" hybrid, with 75-minute weekly in-person classes reserved for discussion, demonstrations, lab activities, and homework support. The first four weeks consisted of online readings, video lectures, quizzes, assignments and in-class activities. The fifth week students prepared and presented their case study project.

Case Study

The Windfarm selected for the first iteration of this course was Na Pua Makani Wind Farm in Kahuku, Honolulu, Hawaii. The siting, construction and operation of this wind farm has been very controversial, due to the proximity of the turbines to community areas such as schools, and the negative effects experienced by local residents. Along with environmental and noise assessment reports, documents describing the residents' concerns are readily accessible on the internet. Links to the primary source resources provided to students can be found in the Appendix.

The group of three students was instructed to gather information about this specific wind farm including wind turbine specifications, engineering reports, noise survey data, and any related media reports. Each of the students in the group was instructed to select a different role. These roles were developed based on our perception of different groups who may employ an acoustics engineer to represent their concerns. The three roles used included (descriptions of each of these roles can be found in Appendix):

- Role 1: Acoustics engineer for wind turbine farm.
- Role 2: Acoustics engineer for the local municipality.
- Role 3: Acoustics engineer for the residents.

Project requirements for the presentation can be found in the Appendix.

On the last day of the course, the students collaboratively presented the acoustical background information, and then engaged in an informal discussion to develop a plan for addressing each of the invested parties' concerns. After completing the discussion, students were asked to share their impressions of the experience.

Outcomes of first offering

Student Case Study Presentation

Three students completed the course; two senior mechanical engineering majors and one junior electrical engineering major. The students worked individually to develop background material, then collaboratively presented their proposed solutions and engaged in discussion from the perspectives of their assigned roles. Students effectively gathered factual information from primary sources and used calculations developed in class to support their positions. They each demonstrated effective use of skills and knowledge acquired through the 4 course units. The resulting discussion addressed a number of significant technical and societal issues.

Student Reaction

Due to the small class size, the college's student evaluation of instruction was not available. About four months after the course ended, the students were asked to send us comments about what they learned from the course and any perspectives they had gained. Two of the three students responded to our request. One student wrote that the final presentation "helped me a lot to learn about the problems that today's society faces and how it can be improved." Another wrote that" it's not so simple to just implement clean energy and there's positives and negatives to something that just seems like it should be an obvious solution." The town meeting simulation …. gave me a new perspective on how lawmakers operate and how it might not be so simple to do the right thing..." That student concluded, "Renewable energy actually isn't the perfect solution I had originally thought it was....I still believe it's the correct solution, but it comes with some downsides that professionals will have to continue to iron out and have to explain transparently to the public before simply making the switch to green energy in every circumstance.... I genuinely had a black and white perspective before this course."

Next Steps / Further Development

The next iteration of this course will be in an asynchronous online modality. Although most of the materials are already available in the college's learning management system, this transition will require revision of some components of the course. Some of the lab activities will be conducted individually by students rather than in a group setting. Other demonstrations have been filmed, and students will be provided with the data to analyze rather than making the measurements themselves. The case study project will require students to collaborate online to give their final presentations and conduct their discussions, which will then be submitted as a video.

Conclusion

Overall, this course provided the technical background that the students needed to analyze a topical engineering case study and grapple with human well-being, environmental, societal, and ethical issues. Student reactions from this first offering suggest that this scaffolded case study project can help students meet the two ABET student outcomes. Because the course is open to students in other majors who have completed a physics course, there is the potential to have a mix of students from engineering and environmental science, which would bring multiple perspectives to the discussion to the benefit of both student groups.

An additional benefit is that students were exposed to noise control engineering. Engineering students typically receive no training in acoustics or noise control engineering. It is not required for licensure as a professional engineer and is not included explicitly in ABET learning outcomes.[1]

Because this is an elective course, it does not obviate the need for ABET outcomes 2 and 4 to be met through other, required courses, but it provides an additional opportunity to reinforce these outcomes in a more focused manner. The approach described here provides a general framework and could be adapted to other engineering topics that relate to a wide range of current societal and/or environmental problems.

References

1. Deaton, R. J., & Bartz, M. J. (1996, June), Role Playing In Engineering Education Paper presented at 1996 Annual Conference, Washington, District of Columbia. 10.18260/1-2—6275
2. Walther, J., & Miller, S. E., & Kellam, N. N. (2012, June), Exploring the Role of Empathy in Engineering Communication through a Transdisciplinary Dialogue Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. 10.18260/1-2--21379
3. Wang, L.M., Beamer, B., Moore, K.J., and Krain, C., Case study - Lesson plan for noise control engineering concepts for use in ABET accredited engineering programs. Proceedings of Inter-Noise 2021, Aug. 1-5, 2021.

Appendix

Student Learning Outcomes

Student Learning Outcomes for the course and the ABET Student Outcomes that they address:

Upon successful completion of this course students will have demonstrated an ability to:

- Articulate and critically analyze the effects of wind turbine noise on the environment and both human and non-human species. (ABET 2, 4)
- Calculate wind turbine noise power levels using Class 1 and Class 2 estimation techniques. (ABET 1)
- Estimate the sound pressure levels in the area surrounding a wind farm and relate them to standards and regulations. (ABET 1, 2)
- Calculate the result of noise control redesign and administrative controls to reduce the sound emitted from wind farms to meet regulatory requirements. (ABET 1, 2)
- Evaluate the acoustical performance of a planned wind farm, identify potential acoustical concerns and propose improvements to address these concerns. (ABET 1, 2, 3,4)

ABET Student Outcomes

Applicable ABET Student Outcomes addressed through the case study:

2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Course Structure

The following describes the content of the four one-week units included in the course

Unit 1: Intro to Acoustics and Psychoacoustics / Environmental Effects

- Basics of sound and the human perception of sound
- Effects of wind farm noise on humans and the environment
- Psychoacoustics activities and demonstrations (e.g., pitch, loudness, and annoyance, beats, prominent discrete tones, impulsive sounds, amplitude modulation)
- Homework assignment: basic problems in basic acoustics.

Unit 2: Acoustics, Wind Farms and Noise Generation

- Basic acoustics (sound level measurement, decibel calculations, emission vs emission, and the standard for estimating sound power of wind turbines)
- Mechanisms of sound generation by wind turbines including aerodynamic noise and noise generated by mechanical components (gearbox, colling fans, etc.)
- Class 1 and class 2 sound power level estimates using data from a specific wind farm.

Unit 3: Noise Propagation Unit 3

- Simple models of propagation over both land and water involving spherical and/or cylindrical spreading, air absorption, etc.
- Factors that affect sound pressure levels (temperature gradients, wind etc.), and effects of transmission into buildings.
- Wind farm noise standards and regulations.
- Lab demonstrations using sound measurement aps on students' phones: real-time analysis, the effects of A-weighting and of different measurement time constants, test of the inverse square law
- Assignment: Use of simple models to predict sound levels due to wind turbines with known emission levels after propagation over a specific distance over land or water.

Unit 4: Noise Control

- Occupational hearing loss, health impacts of noise, community noise metrics, principles of noise control
- Examples of specific noise control methods that can be applied to various components of a wind turbine.
- Lab demonstrations using air moving devices. (e.g., effects of a adding damping materials, measurement of sound pressure levels of a fan at various rotation speed and comparison the results to a predictive equation, effects of multiple fans on noise.
- Assignment: computation of noise reductions due to modification of various components of a wind turbine.

Case Study Resources Provided to Students.

Wind Farm Reports / Hawaii Regulations

Note that the Noise Impact Assessment document is missing the images for the Operational Sound Level Isopleths. These images can be found in section 4.6 (pages 4-40 to 4-76) of the Na Pua Makani Habitat Conservation Plan

- https://dlnr.hawaii.gov/ld/files/2016/07/Appendix-D_Noise-Impact-Assessment.pdf
- https://health.hawaii.gov/opppd/files/2015/06/11-46.pdf
- https://dlnr.hawaii.gov/ld/files/2016/07/Na-Pua-Wind-Project-HEPA-Final-EIS.pdf
- https://casetext.com/regulation/hawaii-administrative-rules/title-11-department-of-health/subtitle-1-general-departmental-provisions/chapter-46-community-noise-control
- https://www.aes.com/na-pua-makani-project
- https://energy.hawaii.gov/what-we-do/energy-landscape/renewable-energy-resources/

Local Controversy over Wind Farm

- https://dlnr.hawaii.gov/ld/files/2016/07/Appendix-M_Public-Comment-Letters-and-Responses-to-Comments.pdf
- https://www.staradvertiser.com/2022/02/28/hawaii-news/court-upholds-decision-on-north-shore-wind-farm/
- https://www.civilbeat.org/2022/09/the-struggle-over-towering-wind-farms-is-at-the-center-of-a-honolulu-city-council-debate/
- https://ejatlas.org/conflict/indigenous-hawaiians-and-local-residents-protest-na-pua-makani-industrial-wind-farm
- https://nonapua.com/
- https://www.civilbeat.org/2021/06/this-north-shore-community-has-had-enough-of-towering-wind-turbines/

Engineering Roles include in Case Study

You will use this information to develop a presentation which you will give at a mock townhall-style meeting with the local concerned residents. Your team will be made up of 2 students, you will each take one of the following roles:

Role 1: Acoustics engineer for wind turbine farm. You are employed as an acoustical engineer for the company which owns and/or operates the wind farm. You have been involved in the acoustical aspects of the development, construction and operation of this wind farm. You feel strongly that wind energy is a critical component of your state's commitment to increasing its usage of renewable energy, and strive to develop efficient and inexpensive noise control measures which will allow the wind farm to continue operating as efficiently as possible without causing harm to the local residents.

Role 2: Acoustics engineer for the local municipality. You are an acoustics consultant who has been hired by the local municipality to help them address the concerns that have been raised by local residents. Your goal is to evaluate the residents' concerns based on the local regulatory statutes as well as information that has been provided to you by the Wind farm developers in the Noise and Sound Level Assessment Report(s), and use this information to help the city council address the concerns that have been addressed in a way that continues to address the state's required clean energy initiatives, continues to promote the economic well being of the city, does not put undue cost on the municipality and can withstand legal challenges by the wind farm.

Role 3: Acoustics engineer for the residents. You are an acoustics consultant who has been hired by the local residents to help them address their concerns. Your goal is to evaluate the residents' concerns based on the local regulatory statutes as well as information that has been provided to you by the Wind farm developers in the Noise and Sound Level Assessment Report(s), and use this information to help the residents have their concerns met in a way that promotes their wellbeing, is not interpreted as being anti-clean energy, and does not put undue cost on the residence (through either price hikes in their energy or increased local taxes).

Description of Case Study Requirements

Acoustical Background

Location

Identify the location of the wind farm using The U.S. Wind Turbine Database, including distances between the turbines on the farm and residential dwellings and rural structures.

Acoustical Assessment

Use the Noise / Sound Assessment Report(s) to determine the published measurement/modeled sound pressure levels at locations of residential and rural structures, or measurement locations near these structures. Use a map to show the expected and/or measured SPLs at these locations.

Regulations

Use the Assessment Report to determine the state and local regulations for the wind farm's location. If possible, find the appropriate sections of the regulatory statutes and evaluate whether or not the local regulations are being met.

History of Residential Concerns

Briefly describe the history of the wind farm (development, construction, operation), and any concerns related to acoustics that have been documented throughout this process. Describe the noise-related concerns that are currently being raised by the local residents. Identify whether any of the concerns presented by the residents may be caused by unmet regulations

Noise Control Measures by Role

This section should be developed individually, with each group member developing arguments and a noise control strategy based on their designated role. They will each be given an opportunity to present their proposed arguments / solution.

Regulations

Provide any additional insight as to the interpretation and implementation of the regulations from your point of view.

Administrative Controls

State any suggested Administrative controls which should be placed on the operation of the wind farm.

Wind Turbine Remediation

Suggest at least one aerodynamic or machinery remediation. Identify where you predict there might be the most likely to be imissions above the regulations. State a suggested component retrofit which may be needed as a contingency plan if other measures do not allow the wind farm to meet the specified regulations. Provide scope (e.g., all turbines of a specific type, all turbines in farm, 50% of turbines etc.), description of the retrofit, a calculation of the estimated sound power level emission after implementing the retrofit and a estimates of the sound pressure level imission at the problematic locations.

Additional Compensation

If it makes sense to use other compensation to help alleviate the negative effects of the wind turbine noise, provide a description of any additional compensation that may be offered to residents to further address their concerns.

Examples of student work which demonstrate their identification with their specified role:

Introduction of their role by student in Role 2 (Acoustics engineer for the local municipality):

Local Municipality Introduction

- Acoustics Engineer
  - Unbiased
  - Live here among the residents
  - Feel passionate Hawaii's future with clean energy
- Purpose
  - Introduce the states goals for clean energy
  - Help the city and council address residential concerns
  - Find a solution that works for all parties involved including the city

Assessment of the 'concern' by student in Role 1 (Acoustics engineer for wind turbine farm):

Wind Farm is Not Harmful

- Infrasound only causes pain are above 165 dB at 2 Hz or 145 dB at 20 Hz [9]
- Scientific studies show there is no link between wind farms and health effects, sleep disturbance, and annoyance [11]
- There is no added effect to people with autism or noise sensitivity [11]
- Blades rotate at .59 Hz, which is below the 5 Hz that can cause shadow flicker [11]

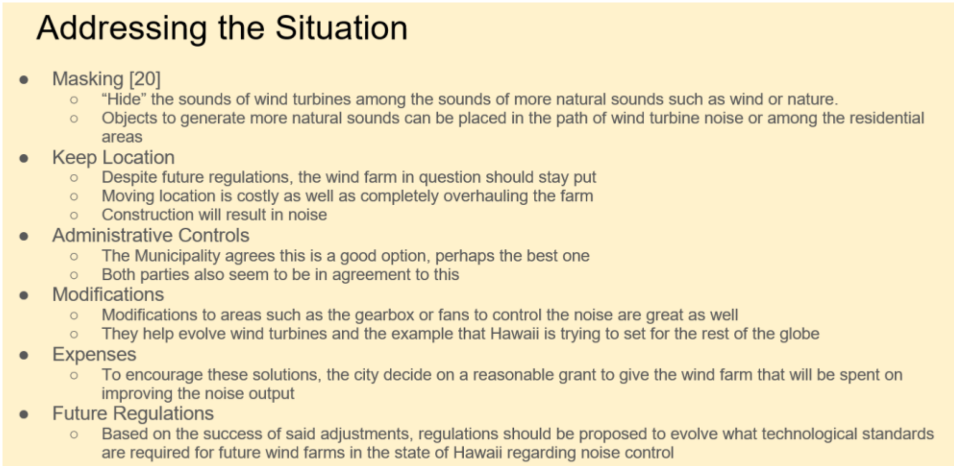
- Works with Na Pua Makani's Habitat Conservation Plan to protect wildlife and provide funding to help [11]
- Did not endanger and animals during construction or clearing of land
- Only accounts for 10% of bird deaths due to collisions

Solutions provided by student in Role 1 (Acoustics engineer for wind turbine farm):

Remediation

- Administrative controls should be implemented because they are the easiest and cheapest
- Machinery fixes are more expensive
  - The gearbox is the best option because it will get rid of the annoying tonal noises and reduce overall sound levels as to not bother nearby schools and houses
  - Costs as much as $350,000 to replace the gearboxes
  - Estimated completion time is 1 month
  - An engineer designs a new gearbox for a crane operator to lift into the turbine

Solutions provided by student in Role 2 (Acoustics engineer for the local municipality):


Addressing the Situation
Masking [20]
"Hide" the sounds of wind turbines among the sounds of more natural sounds such as wind or nature.
Objects to generate more natural sounds can be placed in the path of wind turbine noise or among the residential areas
Keep Location
Despite future regulations, the wind farm in question should stay put
Moving location is costly as well as completely overhauling the farm
Construction will result in noise
Administrative Controls
The Municipality agrees this is a good option, perhaps the best one
Both parties also seem to be in agreement to this
Modifications
Modifications to areas such as the gearbox or fans to control the noise are great as well
They help evolve wind turbines and the example that Hawaii is trying to set for the rest of the globe
Expenses
To encourage these solutions, the city decide on a reasonable grant to give the wind farm that will be spent on improving the noise output
Future Regulations
Based on the success of said adjustments, regulations should be proposed to evolve what technological standards are required for future wind farms in the state of Hawaii regarding noise control