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Advancing Energy Justice in Power and Energy Systems: A Project-Based Learning Approach

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Abstract

The way a power system is designed and operated has a direct impact on the environment and society. Power generation technologies have nonnegligible impacts on macro/microclimate, land usage, and/or material usage, albeit to varying degrees. Moreover, the infrastructural resilience of the power grid as well as its component and resource redundancy levels determine the number and duration of outages experienced by customers, particularly in the aftermath of major events. Although these topics are covered in relevant electrical engineering courses, the focus remains on the engineering side of things. Students learn about general environmental concerns associated with various power generation technologies as well as the importance of power system reliability and resilience. However, how such issues affect energy justice are often left unexplored, and the students fail to learn the delicate interrelation between energy, environment, and society. This paper presents a project-based pedagogical intervention designed to expose students in the field of power and energy to realistic grid operation and design scenarios in which engineering excellence and cost efficiency compete with energy justice. The goal of the exercise is to help students view problems beyond engineering principles alone and guide them to make environmentally and socially aware decisions.

1. Introduction

The design and operation of energy systems have direct impacts on the environment and society. Generating electricity by burning fossil fuels leads to greenhouse gas emissions and is one of the main culprits for the changing climate. Even renewable energy resources such as wind, solar, or hydro can have negative impacts on material usage, local environment, and/or microclimate. Moreover, the way electricity is produced, transmitted, and distributed to consumers can potentially bring up many energy (in)justice issues. Particularly, as large-scale power outages due to weather-induced natural disasters become a common occurrence, we are witnessing more evidence of how socially vulnerable populations are being disproportionately affected by the failure of the power system.

Traditionally, the field of power and energy engineering has not been developed in conjunction with environmental and energy justice concerns. This needs to change, and the new generation of engineering students must be trained to view power grid design and operation as a multidimensional problem that encompasses technical, environmental, and societal criteria within a unified framework. Although some of these concepts are starting to be incorporated into the academic curricula, much of the discussion still remains at the high level. Modern courses on energy systems now cover renewable energy technologies as alternatives to fossil-fuel based generation. However, the negative impacts of these resources, e.g., local impacts on wildlife, land,

and microclimate, or the need for resource extraction, are not discussed in depth or at all. Societal impacts related to energy justice are examined even less. Students are generally taught that certain demand centers such as hospitals and fire stations are critical, but do not normally learn about various distributional, procedural, and recognition justice issues related to how modern power grids are designed and operated.

Most homework assignments, class activities, or course projects focus on engineering excellence and cost efficiency. What seems to be missing is having the students exposed to realistic operation and design scenarios which present one or more environmental and/or social ethics dilemmas. It is only then that the students learn to make environmentally and socially aware decisions and view the problem beyond engineering principles alone. This paper presents a project-based learning (PBL) exercise conducted at a graduate level course related to the operation and management of the power system, where the students are presented with a design scenario in which many environmental and energy justice issues are intertwined with the technical design criteria. The goal of the exercise is to create ethical awareness in students and develop their ethical judgment through a realistic exercise.

2. Electric Power Grid: The Case for Energy Justice

Environmental justice tries to address the inequity in the way communities are impacted by non-sustainable practices in extraction, usage, and disposal of natural resources. It can be viewed from a *distributive justice* perspective, which concerns how the benefits and harms are distributed and experienced, regardless of the causation [1], *procedural justice* perspective, which concerns the ability of all individuals regardless of background and social status to participate in and influence decision-making processes, and *recognition justice*, which deals not only with the way in which we accommodate and respect different people, their cultural practices, their identities, and their knowledge systems, but is also relevant to issues of self-respect and self-worth [2]. Energy justice is an environmental justice issue that is closely related to the way power and energy systems are designed and operated and can similarly be viewed from the three dimensions above [3]. Injustice can occur at any and all levels, i.e., generation, transmission, and consumption.

Power generation, if not carefully managed and designed, can lead to myriad of distributional injustice issues. Most fossil fuel based power plants are built in remote rural areas, leading to poor air quality, environmental toxicity, and reduction in land value, yet the power produced is normally transmitted to populated urban areas—a clear lopsided distribution of benefits and harms. The same trend exists on a global scale. The detrimental impact on global climate aside, extraction of coal, oil, or uranium leaves negative consequences on local lands, often in poorer countries in Global South, whereas the benefits, i.e., produced power, are enjoyed in wealthier countries. Even renewable energy resources are not immune to ethical issues. Large-scale developments often take place in poor, rural areas (where there is enough space) on common property land previously used by the community for activities such as grazing animals and harvesting plants [4]. Procedural justice issues can also arise when communities are not informed about the negative consequences of certain technologies and/or do not get a say in the approval of the project. Many residents may not be fully aware of the impact of a new power plant on their land value or health issues. In the absence of private ownership, governments either allow renewable energy developments without needing to pay compensation to communities or buy land at low rates from uninformed residents [4].

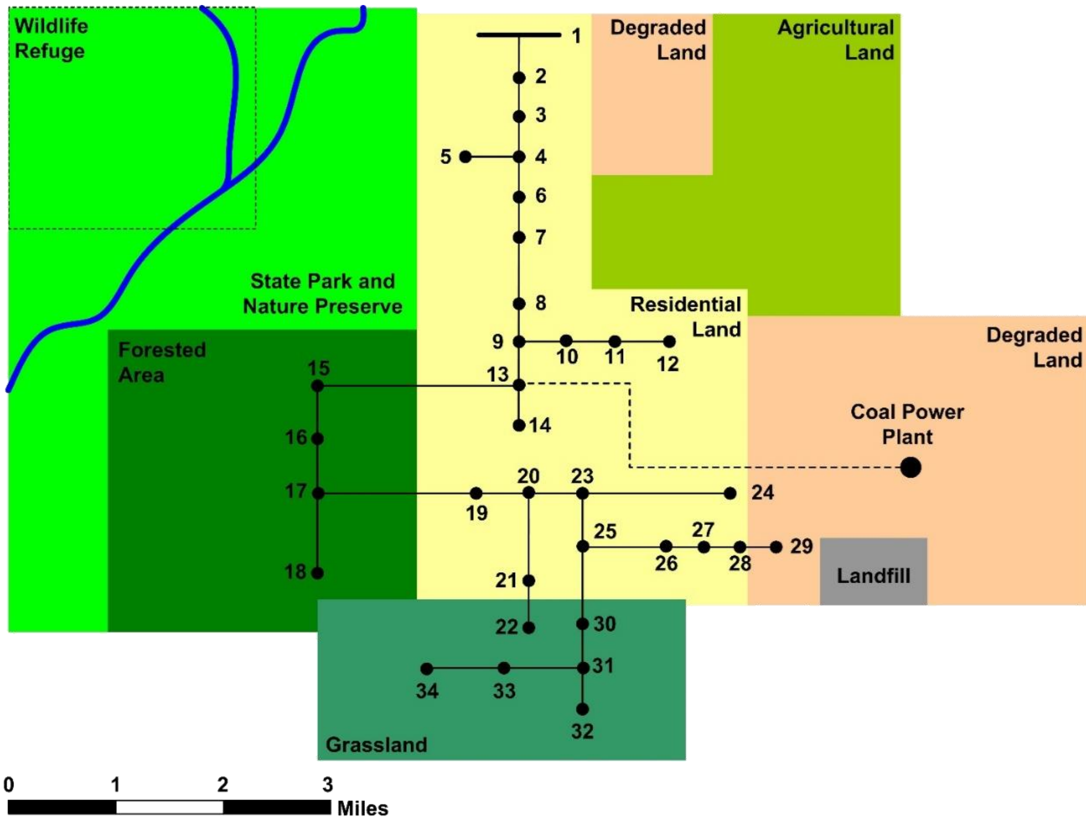
On the consumption side, power utilities have traditionally been negligent when it comes to recognition justice. There are many socioeconomic and demographic aspects that determine the extent to which individuals are impacted by a long-duration outage and/or their ability to mitigate those effects [5]. For instance, children and the elderly, individuals with electricity-dependent medical conditions, and those with mobility limitations or underlying health conditions sensitive to temperature extremes are at a higher risk of injury or death due to a long-duration power outage. On the other hand, an individual's income level, the size of their household, and other family or work-related constraints are among factors that may impact the level of preparedness of the household against long-duration outages or their ability to evacuate upon need **Error! Reference source not found.**. This indicates that a 'color blind' approach to power grid resilience and reliability enhancement is not necessarily equitable, and instead, power utilities must incorporate social vulnerabilities in design, operation, and post-event service restoration of their systems.

It is evident from the above discussion that design and operation of the electric power grid requires an approach based on the nexus of efficiency-sustainability-equity. These objectives may at times be competing or even contradictory, but it is only through a holistic approach and a vulnerability-informed paradigm that energy justice issues can be properly addressed.

3. Project-Based Intervention

The objective behind the exercise discussed in this paper is to present the students with a power grid design problem that contains several environmental and social ethical dilemmas. These are subtly embedded in the project description to assess the students' ethical awareness and judgement. A summarized version of the project description appears below.

> *A power utility is experiencing shortage of generation during summer peak load hours. This has resulted in several instances of involuntary load shedding, where multiple load areas (supplying hundreds of customers) have been left de-energized for several hours. Many residents have indicated their frustration during town hall meetings, especially because this summer has been one of the hottest on record. After investigating the matter, a task force formed by the utility concludes that the only viable option is to add generation capacity to the network so that it can operate as a standalone system during summer months. The utility has now issued a request for proposal (RFP) and your company is planning to submit one. Your options include installing new distributed generation resources in the network, installing new or redundant overhead lines, recommissioning the decommissioned coal-fired power plant, implementing a demand response program to provide demand flexibility, or implementing localized rotating load shedding.*
>
> *The following figures illustrate the schematic diagram of the system under study along with the topography and land classification of the local area, and the overlay of the distribution grid with the census tracts, with the relevant socioeconomic and demographic data in the accompanying table. Data on hourly demand, line distances, cost of different generation technologies, geographical wind profiles, and hourly solar irradiances are also provided.*


Wildlife Refuge
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Forested Area
Degraded Land
Agricultural Land
Residential Land
Degraded Land
Coal Power Plant
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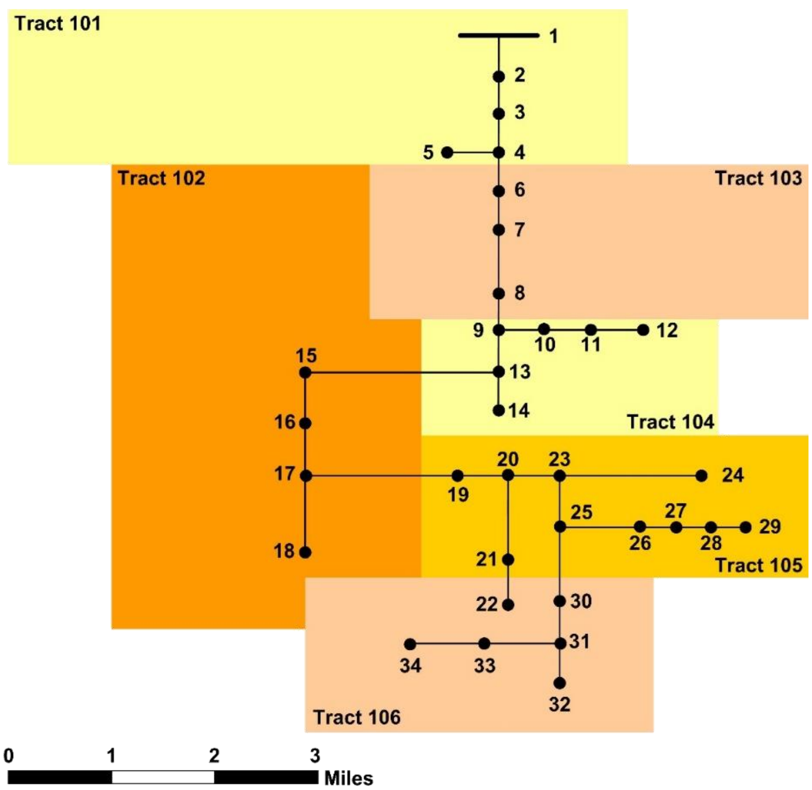
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Tract ID	Population above 65 yrs. (%)	Population below 5 yrs. (%)	Homeownership Ratio (%)	African American Population (%)	Household Median Income ($)	Median Age of Homes (yrs.)	Average House Size (sq. ft)	Average Size of Household
101	12	21	28	48	46,000	52	1,000	6
102	25	10	92	5	178,000	10	4,500	4
103	21	14	56	12	72,000	25	2,500	3.2
104	15	7	44	21	61,000	29	2,100	3
105	5	4	21	63	57,000	66	1,200	2.5
106	20	16	78	8	134,000	28	3,800	4

The students are asked to specify their design criteria (e.g., cost effectiveness, sustainability, etc.) and justification for each one, identify technologies they will and will not adopt along with relevant reasoning for each one, and simulate their proposed solution to demonstrate the improvement in their chosen design criteria. There are several non-obvious energy justice aspects in the problem statement, for instance:

- The cost functions are designed in a way that favors polluting generation resources over the clean renewable ones. In particular, recommissioning the coal power plant is an inexpensive and readily available option. It is however located in a lower socioeconomic tract; hence, its recommissioning will result in significant damage to air quality in a poorer community in order to provide power to the rest of the network, including the more affluent neighborhoods,
- There are challenges with renewable energy resources as well. The highest river flow rate and the best wind profile are assigned to the nature preserve area. Installing these resources could have negative consequences for the wildlife. Moreover, since those areas are not electrically connected to the rest of the grid, new overhead lines are needed, which would have to cut through forested areas,
- Houses in the poor neighborhoods are older, which indicates a lower thermal mass. This can lead to high indoor temperatures if power and hence access to A/C is lost for a few hours. A view based on recognition justice needs to consider that the impacts of power outages are disproportionately felt in different areas,
- Further, larger house sizes are assigned to tracts that constitute wealthier neighborhoods. These houses require higher A/C consumption and account for a significant portion of demand in the network. A view based on distributional justice needs to find a balance between harm (cost to the community and the environment) and benefits (electrifying more affluent areas).

4. Preliminary Findings and Conclusions

This exercise is a work in progress. It was first implemented in a graduate level course titled 'Power System Operation and Management' as a semester-long group project. A total of 31 students were enrolled in the class and were divided into 6 groups. Throughout the semester, two lectures were given on environmental impacts of fossil fuels and renewable energy resources as well as several micro-insertions and case studies related to the impacts of power outages on socially vulnerable populations, e.g., the 1995 heat wave in Chicago, IL, and the 2021 winter power outages in Texas. Active learning exercises were also conducted to discuss various dimensions of energy and environmental justice. Project deliverables were divided into three phases: general design criteria (phase 1), detailed design proposal (phase 2), and proof-of-concept simulations (phase 3). Majority of feedback related to social and environmental justice was provided after submission of phase 1 reports. Here, the students were expected to suggest design criteria that cover relevant technical, environmental, and social aspects of the problem, and provide justification for each one. Specific to environmental and social justice concerns, detailed feedback was provided to the teams on how well their proposed design criteria covered underlying issues in the problem statement and how convincing their justifications were to a power utility who may be evaluating the proposal.

Some of the preliminary findings from the exercise are summarized below:

- All student groups identified engineering objectives (cost, reliability, etc.) and environmental objectives (e.g., emissions) in their design criteria.
- A few groups extended the environmental criteria to also include land classification (fertile vs. degraded soil) and impacts of renewable resources on microclimate and wildlife.
- Fewer groups addressed energy justice in their models. Those who did mainly focused on recognition justice in the form of social vulnerability assessment. This could have been due to a relevant micro-insertion exercise that had been conducted during class. No groups considered the distributional aspect of energy justice.
- The justifications provided in support of non-engineering design criteria were mostly high level. Most groups cited climate change as the reason to include sustainability objectives in their models. Justifications provided in support of energy justice were mainly ambiguous and not as well-thought-out as those provided for the engineering criteria and objectives.
- All groups excelled in simulating and validating their design and focused on reporting the electrical variables associated with the power grid. Few attempts were made to quantify the improvement in environmental footprint or energy justice.

Overall, the students who participated in this exercise managed to identify the need for sustainable power generation. Much of this can be attributed to the fact that climate change is brought to the forefront of national conversations. How this relates to environmental justice, however, is not as clear to most students. Without truly understanding why it matters, there is always the possibility that, in real life engineering projects, those criteria be sacrificed to the advantage of more traditional engineering objectives. Energy justice in power systems seems to be an even more abstract concept to many students. While most acknowledge its importance, why it matters and how it can be improved may be more challenging to answer.

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