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Stakeholder Perspectives on Increasing Electric Power Infrastructure Integrity

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Dr. James D. McCalley, Iowa State University

James D. McCalley received the B.S., M.S., and Ph.D. degrees from Georgia Tech in 1982, 1986, and 1992, respectively. He was employed with the Atlanta Gas Light-Company from 1977-1982 and with Pacific Gas and Electric Company (PG&E), San Francisco, from 1985 to 1990. He is an Anson Marston Distinguished Professor and the London Professor of Power Systems Engineering in the Department of Electrical and Computer Engineering at Iowa State University (ISU) where he has been employed since 1992. He was elected as an IEEE Fellow in 2003. He was a registered professional engineer in California.

Dr. Anne Kimber, Iowa State University

As the Director of the Electric Power Research Center in the College of Engineering at Iowa State University I work with faculty, undergraduate and graduate students as well as diverse power industries to develop research projects of common interest. The Center started in 1963, and strong collaborations among faculty and industry have been key to our success. Members of the EPRC include Investor Owned Utilities, Municipal Utilities, Rural Electric Cooperatives and an ISO. Prior to joining Iowa State University in 2014 I worked for 14 years with Iowa municipal electric, gas and water utilities through the Iowa Association of Municipal Utilities (IAMU). The goal was to manage risk and increase long term sustainability through wide-ranging projects ranging from analyses of energy efficiency and renewable energy options, to rate studies, air quality permitting and advocacy for transmission ownership.

Mr. Robert Haug, Public Power Services

Robert Haug is the retired executive director of the Iowa Association of Municipal Utilities. He has over 30 years of experience working with small rural communities that operate city-owned electric, gas, water, and telecommunication systems and has worked extensively in promoting energy efficiency and renewables.

Stakeholder perspectives on increasing electric power infrastructure integrity

Efraín O'Neill-Carrillo, James D. McCalley, Anne Kimber, Robert Haug

Abstract

This paper presents results from ten stakeholder engagement activities held in Puerto Rico after hurricane María in 2017. This was part of an NSF-funded project to identify, refine, and examine five visions for redeveloping and enhancing the local electric infrastructure in Puerto Rico. The results from the project will be shared with local decision-makers to inform energy policy directions. The ten group activities were divided in two rounds. The first round consisted of six different focus groups: Four groups had mainly technical background while the other two were community focus groups. Questions in this first round were related to participant's perceptions on what failed, and on recommendations on changes to make the electric infrastructure more resilient. The results of the first phase were used to guide some of the assumptions used in the modeling and simulation of the five proposed visions. In the mid-point of the project, stakeholders were again engaged to provide feedback on initial results and to fine-tune the project's simulations and analysis. The participants without power background were more positive about new ideas, although in general, these were for a different kind of approach to build and manage the local electric infrastructure. As the number of years of experience in the power industry increased, so did resistance to new ideas for the power grid. Further discussion of the results from all ten group activities is presented in the paper.

I. Introduction

The 2017 hurricane season brought three major events to U.S. jurisdictions. Local and federal responses were strained beyond their capacities, especially towards the end of the year. Such severe events are expected to occur in the future with greater frequency than they have in the last 100 years. Under this assumption, it is imprudent to invest in rebuilding without significantly increasing the integrity of key infrastructure. NSF funded a RAPID project focused on infrastructure integrity, to identify, and examine five different visions for redeveloping and enhancing the local electric infrastructure in Puerto Rico, one of the most affected U.S. jurisdictions in 2017. Researchers from Iowa State University partnered with a local consultant with engineering and policy experience relevant to the project. A recent PhD graduate with experience in the modeling of the local power system is also part of the team. The results from the project will be shared with decision-makers to inform energy policy directions.

This paper presents the stakeholder engagement tasks performed for this project during the initial stage that identified threats, failures, and recovery impediments to restoring electric energy services following occurrence of natural disasters. Data gathered from the first round of engagement was used to guide the modeling assumptions for the five proposed visions. A second round of stakeholder engagement occurred halfway through the project to provide feedback on initial results and to fine-tune the project's simulations and analysis. The insertion of stakeholders into the policy making process has been recommended as a way to get policies "more grounded in people's concerns and lived experience" [5]. This approach can yield a sense of ownership among stakeholders, that could reduce future difficulties in the policy implementation phase. Stakeholder engagement was done in accordance with the Institutional Review Board requirements for work with human subjects.

II. Brief description of the model and simulations

The five proposed visions represent significantly different approaches; they also incur different levels of cost and achieve different levels of infrastructure integrity (II) for redeveloping the local electric infrastructure. A conceptual framework has been developed, together with metrics and computational methods for assessing infrastructure integrity [1-4]. II is the ability of an infrastructure system to exhibit reliability, flexibility, resilience, and adaptability. Although II is useful for application to any infrastructure system, it is particularly applicable to electric systems, and it provides a foundation on which to build in considering the future development of electric grids. For each vision, strengths and weaknesses, and in so doing, we intend to provide strong rationale regarding the best path forward for re-developing the local electric system with high II. The future might have aspects of more than one vision, and we will be able to adapt our work if conditions change or new data become available. The first vision focuses on the current infrastructure model, with centralized resources and improved overhead transmission and distribution (T&D). The existing generation and transmission systems will be modeled with reinforced T&D structures. A modest growth will be assumed for utility-scale and distributed renewable energy systems. The second vision increases participation of decentralized resources with existing overhead T&D systems. A high growth will be assumed for utility-scale and distributed renewable energy systems, as well as some microgrid development. Vision number three also focuses on decentralized resources with hardened distribution in critical zones (e.g., raised substations, reinforced poles). Vision four adds a hardened transmission and distribution systems to the third vision 3, replacing critical transmission links with underground HVDC as well as reconfigured transmission. This vision also includes increased storage capabilities. The last vision adds new transmission connections to the fourth vision.

The model used for this project is based on co-optimized expansion planning (CEP). The main goal is to identify investments in generation, transmission and distributions systems (what, when, where, how much) that would minimize net present value investments and operations over a 20-year period. For each combination of investment choices, operation and management (O&M) costs (including production costs) are determined over entire period. The analysis will yield a plan which best minimizes total investment plus O&M. It is a decision-making tool, exploratory and predictive, if all decisions are economic. This model has been successfully implemented and tested for various case studies in the continental U.S. and was adapted to Puerto Rico electric infrastructure context. This select plan would be used by decision- and policy-makers in implementing policies in support of the implementation of the plan. The implementation would require further specific operational analyses.

Even though the model is based on economic variables, the team was convinced of the importance of considering the social and economic realities of Puerto Rico. Due to time and budgetary limitations, a comprehensive socio-economic study was not an option. Thus, the team decided to integrate, albeit in a limited way, social considerations in the development of the simulations. Focus groups were held in the first months of the project. Figure 1 shows how the stakeholder engagement activities discussed in this paper connect with the modeling and simulation, and were used to fine-tune the five visions initially developed by the team of researchers.

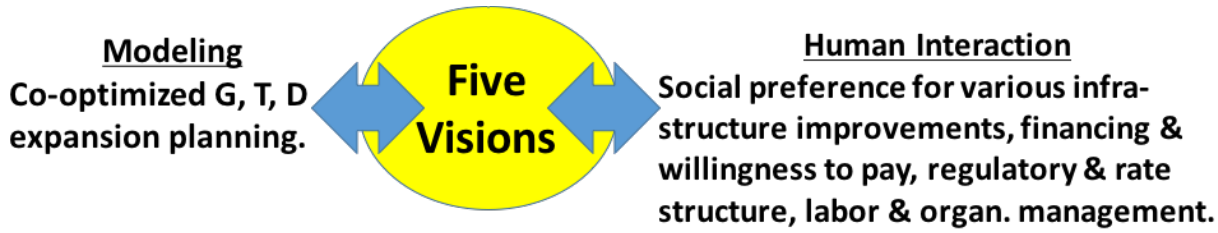

Figure 1: Stakeholder engagement informing the five visions used in the modeling and simulation tasks

III. Stakeholder engagement design – First round

The goal of Stage 1 of the project was to identify the main threats associated with maintaining continuous electric energy services in an area vulnerable to natural disasters. Common failures and recovery impediments were also studied. Data was gathered in three ways:

1. Six focus groups were convened to engage electric customers and get their perspectives on what failed, what impeded a quick restoration and what they thought of the elements of the proposed visions for enhancement of local infrastructure integrity.
2. Formal and informal discussions were held with former and current utility employees to solicit specific types of data. Key utility personnel in charge of recovery during previous natural disasters in Puerto Rico were also engaged.
3. Publicly available data: Data was also obtained through the internet or through contacts with organizations such as FEMA, the US Department of Energy, and the Electric Power Research Institute. Representatives from U.S. utilities with experience in disaster management and response were also consulted.

This engagement was led by a local consultant, with experience in energy stakeholder engagement activities [6,7,8,9]. This effort was essential to guide the refinement of the proposed infrastructure visions in the subsequent stage (infrastructure visions) and for the modeling and simulation stage. The questions used in the six focus groups were not intended to constrain discussions or limit the kinds of questions that could be asked. Some of the questions may not have been appropriate for a particular person or group. If that was the case, they were not addressed at all. This first round of stakeholder engagement focused on participant's perceptions on what failed, and on recommendations on changes to make the electric infrastructure more resilient. The questions were divided in two groups:

What was your experience during the Hurricane? What failed?

1. What was the equipment failure or type of equipment failure that interrupted the most people in your area?
2. What effects of power interruption bothered you the most?
3. What was the most significant effect of power interruption, direct or indirect, in your area?
4. What was the "last repair" that, once it was made, restored your power delivery?

5. What equipment in your area presented the greatest challenge to repair and restore?
6. Of the electric infrastructure damage caused by the hurricane, what was primarily due to
    a. high winds?
    b. flooding?
7. To what extent did solar panels withstand the hurricane
    a. when they were located on the ground as "utility scale"?
    b. when they were located on roofs?
8. To what extent did wind turbines withstand the hurricane?

Changes to infrastructure that could avoid, mitigate, and/or speed restoration time:

1. What kinds of changes to generation, delivery and end-use of electric energy do you suggest as beneficial to avoid future power interruptions, mitigate their effects, and decrease the restoration time?
2. What is your reaction to the ideas of "hardened" community or neighborhood centers with sufficient back-up generation to offer critical services in the event of an emergency, such as centers for operation of electric health-care devices (example would be an oxygen concentrator)?
3. Would you be willing to accept advanced metering and load controls (with explanations of these)?
4. Would you be interested in, or accept, smaller-scale distribution grids built around community needs?
5. To what extent do you believe the electric infrastructure can be made more hurricane-proof by:
    a. changing the distribution infrastructure? In what ways?
    b. changing the transmission infrastructure? In what ways?
    c. changing the generation infrastructure? In what ways?
6. Underground AC or DC power lines are frequently suggested as ways to harden electric infrastructure from hurricane-strength winds. To what extent do you perceive this to be an attractive approach for
    a. distribution systems?
    b. transmission systems?
7. The various regions of the local power system have significantly different planning reserve margins (ratio of total installed capacity in the region to the region's annual peak). To what extent would levelizing these reserve margins so that each region is able to supply its own load contribute towards enhancing the local ability to avoid extended power interruptions?
8. To what extent do you see grid reconfiguration
    a. At the distribution level
    b. At the transmission level

    to enhance the local ability to avoid extended power interruptions?

Four focus groups had mainly technical background. The other two were community focus groups. The key findings from each of the six focus groups are listed in the next sections. The data are important not only for the RAPID project, but as a benchmark that could be used in the future to prevent the problems faced in Puerto Rico and in other places vulnerable to natural disasters.

IV. Professional/trade organizations focus groups

Six members (3 engineers, two lawyers, one lawyer/engineer) of the energy committee of the state Chamber of Commerce participated in a focus group arranged on February 13, 2018. A second focus group was convened separately that day, with nine board members (all engineers) of the local trade organization of PV installers and contractors. Common comments from both groups are included below.

What failed:

1. The wind was the main cause for failures, its force and duration (between 12 and 14 hours). The intensity of the winds was too much, it caused fatigue in many components of the electric infrastructure.
2. The transmission system failed, so everything else failed.
3. Vegetation management was a huge problem, too much vegetation in the rights of way. Downed trees would make the lines and poles break. Many access roads were obstructed, delaying repairs.
4. There was no plan in place to react to a disaster of this magnitude.
5. The local and federal governments failed in terms of logistics. They were incapable of responding quickly to re-start main economic drivers.
6. Lack of communications was the root cause of all problems, this impeded a fast recovery of electric power. Lack of communications limited the ability of individuals and the government to deal with the crisis. It was very difficult to diagnose damage to electric infrastructure. There was too much dependence on cellular communications.
7. Government did not call upon amateur radio volunteers to help with communications, communications as they had done in earlier emergencies (though many volunteers did so in 2017 through informal networks that carried news within geographical regions).
8. Even when some communications were re-established, the government failed in providing information to the public, did not provide a sense of security and being "on top" of things, even within the limitations the crisis brought. For example, government officials would announce help was on the way, materials for the electrical recovery were on the way, but a lot of the help ended up arriving months later.
9. Economic activity came to a full stop, how were we supposed to re-establish it all without communications and power?
10. The North-South demand-generation imbalance complicated the restoration.
11. Direct impacts of lack of power: Houses are not well-designed for the local weather, thus many persons suffered because of the lack of a/c during a very humid September/October period. Lack of refrigeration for food/medicines, pollution and noise from portable generators.
12. Rooftop PV systems did not suffer much. A lesson: correctly-installed rooftop PV systems are able to withstand hurricane-force winds.

Suggested changes to infrastructure:

1. Regionalize generation.

2. Must deal with the North-South imbalance (most generation in the South, large part of the demand in the Metro area in the North).
3. Must establish very aggressive vegetation management strategies. Keep right-of-ways cleared.
4. Reform the electric utility industry
5. Smaller-scale grids are an acceptable option
6. Underground systems in some cases are acceptable (e.g., hospitals, critical areas, town centers). But not economically viable in general and is not an "all-fix" alternative.
7. In all communities, there must be a place to provide emergency services.
8. Microgrids can help, but they will cost considerably
9. Distributed generation will help, and will allow the regional operation of the power grid
10. Reconfiguration – there is some reconfiguration capabilities in the local transmission and distribution systems. Are people willing to pay to increase those automated capabilities?

V. Community-based focus groups

On March 6, 2018 nine members of a rural, mountainous community in Puerto Rico, still without power at the time, shared their views on what failed and what could be improved. Among them were a couple of community leaders and one retired utility employee. Their answers provided a valuable social perspective to the project and to disaster management in general.

What failed:

1. The distribution lines and poles of this community run through the wilderness and were not properly maintained.
2. The utility had not gone to the community after the hurricane.
3. Direct impacts of lack of power: A community with a majority of elderly citizens, who suffered the lack of power even more. Cost of fuel for emergency generators. Some community members had to purchase a second or even a third emergency generator because of failures.
4. They knew of at least four (4) deaths, related to lack of power (e.g., dialysis machines and oxygen supplies).
5. The emotional impact was also important to consider. They felt abandoned. They re-stated that they are clients too, and they pay their bills.
6. Local people, with expertise in electrical systems wanted to help and submitted a proposal to the Major. No one responded.

Suggested changes to infrastructure:

1. Relocate the distribution lines closer to the main roads. Improve system maintenance.
3. Educate the communities such that access roads and right of ways are kept cleared.
4. If the local utility or the government had come to supervise cleaning efforts, citizens would not have cut downed power lines which could have been used in the reconstruction.
5. There is a window of opportunity to educate people, because the negative impacts are fresh in people's minds.

6. An important lesson they learned after the hurricane is to be flexible in terms of their energy use. Reduce energy use. What and how can we satisfy our needs?
7. The aftermath of the hurricane encouraged solidarity among people.

The other community focus group was convened on April 14, 2018 with sixteen persons representing five different southern communities. Their key answers are included below.

What failed:

1. Winds were the main cause of failures (although there was flooding in the coast, especially the North & East). Communications were lost all over Puerto Rico.
2. No effective planning, no education to prepare for this. Government said there was a plan, but there was none.
3. Government collapsed. Utility was not prepared.
4. Main Effects: no access to water, scarcity of food, the most vulnerable population suffered the most (elderly, people immobilized in bed, people in mountain towns).
5. Community needs were not addressed.
6. Since state and local governments did not help, many Communities reacted and began providing services themselves (e.g., community meals)

Suggested changes to infrastructure:

1. Use more underground systems
2. Use schools (those that serve as emergency shelters) as places to have minimal emergency electric power. Those places should not depend on external resources.
3. People are more receptive now, after the experience of the hurricane.
4. The hurricane taught us them they do not need so many electric devices.
5. The conditions after the hurricane made them go outside, meet their neighbors.
6. Learn from the experience to prepare better next time and to help others that cannot help themselves.
7. There are opportunities after the crisis: transform their reality into something else, from individuality to collective action and solidarity
8. Need to emphasize local development, so that we do not depend so much from resources from other places, especially during emergencies.
9. Encourage local generation through rooftop PV systems – "Rooftop resource"
10. Organize meetings in communities to talk about what was here before, what we have now, and what we could have in the future (regarding power infrastructure).

VI. Regional responder focus group

On March 15, 2018 eight persons assembled for a focus group on the Western region of Puerto Rico. Some were former utility employees, two government employees in charge of civil infrastructure, two consulting/construction contractors, and one person very active in the regional radio after the hurricane, informing people about the challenges of the recovery.

What failed:

1. Contingency plans existed at all levels, but were not enough because no one expected the devastation and chaos that came after this hurricane. Contingency planning fell short of what was needed.
2. T&D line maintenance was very poor in the previous 10 years. Vegetation management was extremely poor.
3. Transmission lines reached their design limits. Lines were designed to sustain the winds, but NOT to carry the weight of fallen trees. Nevertheless, it is recommended to increase the threshold of wind resistance in lines.
4. The destruction of large transmission towers (230kV & 115kV) caused most of the delay during the first months. No other previous storms had caused such damage on the transmission infrastructure.
5. In the early recovery phase, since materials were scarce, many crews were reusing parts that fell to the ground and were in good condition. This was not always the case since pressure to clear roads made people cut cables and destroy infrastructure that could have been used for a faster recovery in some places.
6. It was a rule within the utility to establish "command centers" in each of the utility's seven operational regions. These Centers were used to coordinate recovery work with state and city agencies. Those centers were not used. The Western command center was closed for the first two months. Since the Communications infrastructure was affected, those regional command centers were necessary after the hurricane more than in any other moment in history.
7. In previous hurricanes droves of volunteers helped the utility. But after this hurricane, many volunteers, even some retired utility employees with vast experience, were not allowed to help.
8. After previous disasters, private contractors were used strategically to help during recovery. Those are the same contractors that built most of the private electric distribution systems that are later passed to the utility after a construction project. That did not happen this time, at least in the first two months.
9. Forty days were lost in the Western region, waiting for out-of-state crews to arrive, while there were able hands locally that could have begun the recovery process from Day 1.
10. Inexperience from regional managers caused mistakes. One of the main follies was the lack of coordination with the state water authority.
11. There was no coordination regionally or across Puerto Rico: without the regional command center, coordination was just not possible. Local decisions were not made by regional managers, but by people in the capital city with no first-hand knowledge of what was going on in each region.

Suggested changes to infrastructure:

1. Need a continuous maintenance program
2. Regionalization could be achieved; however, it is very difficult within the utility's current bureaucracy. Need to address inexperience and excessive bureaucracy.
3. We must look for places and opportunities to do something different with the electric infrastructure
4. We must embrace collaborations with universities in microgrids and control-related projects.

5. Collaborations among industry, university and professional associations, combined with an effective public opinion movement would be needed to facilitate the proposed visions of a different electric energy future.
6. The distributed option should be sought.
7. It is very important for projects to be supported with local (private) capital, as much as possible, and with local expertise.

VII. First responder focus group

The focus group convened on May 2, 2018 was composed of ten employees from an out-of-state utility that came to help in the restoration of the distribution system mostly in a rural, mountainous sector. This group was mainly linemen and a few crew supervisors and managers. These perceptions provided an important “outsider perspective” of the recovery effort.

What failed:

1. Problems with availability of materials, sometimes had to work with what they brought on the company trucks and what they could scavenge from components on the ground.
2. Downed vegetation was a challenge.
5. Lack of maintenance: It was evident throughout the distribution system, that many parts of the system had not been touched in years. Area was neglected, maybe because there was not enough load to justify investments.
3. Accessibility was a major problem, in two ways:
    a. Getting to some circuits in the mountains was very difficult.
    b. Getting to some circuits in alleys between houses was very difficult as very little room between houses.

   In these situations, it would be better to re-locate the circuit to the road.
4. Local people where fantastic, they were very good to them. They knew the system that provided them power, they even drew maps on where the lines were and that was helpful. The locals’ concern was with continued help. They kept asking “Are you coming back?”
5. Damage: 90% of damage was wind-related;

Suggested changes to infrastructure:

1. Re-routing and reconfiguring could help. Use loops whenever possible.
2. Improve access to lines (in some places, there was no ally or entrance between houses to allow access to damaged infrastructure). Where possible, it was suggested that primary distribution lines be moved to the streets and installed underground where possible.
3. Many installation errors were found on the secondary side. Must follow best practices.
4. Underground lines at the distribution level seemed to be a strong suggestion from multiple people. Even though costly, it could have many benefits

5. The duration of future outage on distribution system could be reduced by adding sectionalizing fuses, which the crews did in some instances. Sectionalizing would shorten the time needed to diagnose the cause of the outage. Being able to reconfigure would help.

VIII. Summary of Common Results from Focus Groups

Table 1: Summary of focus groups in Round 1 of stakeholder engagement activities

Focus group	Description
Professionals from the energy committee	February 13, 2018. Members of the Chamber of Commerce
State trade organization of PV installers and contractors	February 13, 2018. Nine board members (all engineers).
Community-based focus groups	March 6, 2018 nine members of a rural, mountainous community, still without power at the time.
Regional responder focus group	March 15, 2018 eight persons assembled for a focus group on the Western region of the jurisdiction, including former utility employees, city government employees and consulting/construction contractors.
Community-based focus groups	April 14, 2018 Sixteen persons representing five different southern communities.
First responder focus group	May 2, 2018 Ten employees from an out-of-state utility that helped in the restoration of the distribution system mostly in a rural, mountainous sector.

What failed:

- Transmission lines due to high winds and lack of maintenance
- Communications collapsed, fast response was not possible
- The North-South demand-generation imbalance complicates the restoration
- Vegetation management
- Many distribution lines run through wilderness, and received little maintenance
- Materials not available
- Volunteers (including local contractors) were barely used in the beginning
- Little coordination between emergency headquarters and the regions
- Mountain communities felt abandoned: “we’re clients too”

Suggested changes to infrastructure:

- A comprehensive reform of the electric utility industry (with no political intervention)
- Very aggressive vegetation management and maintenance strategies
- Look for places and opportunities to do something different with the electric infrastructure

- Smaller-scale grids are an acceptable option, regionalize generation.
- Use underground lines in town centers.
- Relocate distribution lines closer to the main roads.
- A window of opportunity to educate people, because the negative impacts are fresh in people's minds.

These results confirmed some of the assumptions the research team had posed in the initial scenarios for the five visions. The results also provided additional information that was used either to adjust scenarios or to better present the information that was later used in the second round of stakeholder engagement. Some of the data was not directly used for the modeling and simulations. However, it is presented here and will be shared in other venues, because the human dimensions of this tragedy cannot be forgotten and must be used to better prepare for future events.

IX. Second round of stakeholder engagement

At the six-month mark (early July 2018), the preliminary results of the project were presented in the capital city (San Juan), and in the Western region (Mayaguez). Participants received continuing education credit for their participation in the 3-hour seminar. For this second round, written exercises were developed and distributed among participants. The first three questions were general questions about professional background. The remaining questions These participants became new stakeholders that were engaged to provide feedback to fine-tune the project's analysis. The main questions asked were (renumbered 1 to 5 for clarity):

Q1: What is your reaction to the ideas of "hardened" community or neighborhood centers with sufficient back-up generation to offer critical services in the event of an emergency, such as centers for operation of electric health-care devices (example would be an oxygen concentrator)?
Q2: Would you be willing to accept metering and load controls that would change your energy use pattern in exchange for an incentive (e.g., lower rate)?
Q3: Can the service territory be divided into independent operating regions that can sustain their respective electric demand? Can this shorten the blackout time in the jurisdiction?
Q4: To what extent do you think grid reconfiguration can enhance the region's ability to avoid extended power interruptions?
Q5: Choose 1 or more of the following types of electric power system equipment and describe ways to increase the ability of the equipment to maintain function during severe hurricanes.

a. Generation resources:
    i. Rooftop solar
    ii. Ground-mounted solar
    iii. Wind turbines/wind farms
b. Transmission lines
c. Distribution lines

This stakeholder engagement round took place in two different locations, in San Juan (155 participants) and in Mayaguez (91 participants). The written responses from each site was divided between those with experience in the electric power industry and those without such experience. Thus, data from a total of four different groups were gathered in this second round of engagement.

In San Juan, on July 2nd, 125 persons (from 155 participants) completed the written exercise. Based on their hometown, their experience/answers could be considered to be coming from “a city context experience”. A total of 30 persons did not have a power background or experience. On the other hand, 93 persons did have some experience in the electric industry. Some of the questions were open ended and many participants provided written comments, but it is significant that responses to the first four questions show overwhelming support for the following:

1. Community emergency centers
2. Active load control
3. Regional operating centers
4. Grid reconfiguration

Figures 2 to 4 show support among both types of participants (with electric industry experience and those without). Blue bars represent favorable views, orange bars represent negative views, gray bars represent neutral or “maybe” opinions.

In Mayaguez, on July 3rd, 71 persons (from 92 participants,) completed the written exercise. Based on their hometown, their experience/answers could be considered to be coming from “a mixed city-rural context experience”. About 26 persons did not have power background, while 45 persons had some experience in the electric industry. Figures 4 and 5 show the results for the second location. For simplicity, results show “yes/no answers” to written questions Q1 to Q5 above. Many also provided written comments for each question.

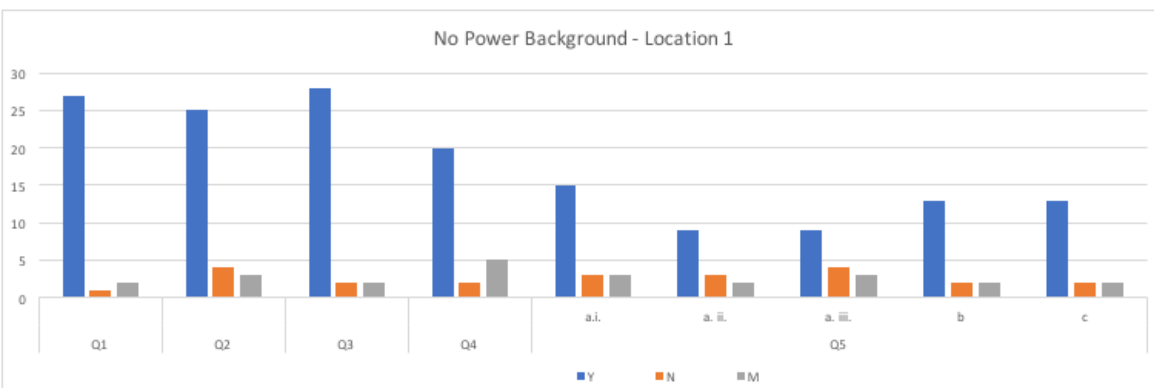

Figure 2: Responses from persons with no power experience (San Juan). Blue represents affirmative answers, orange are negative answers to second round questions.

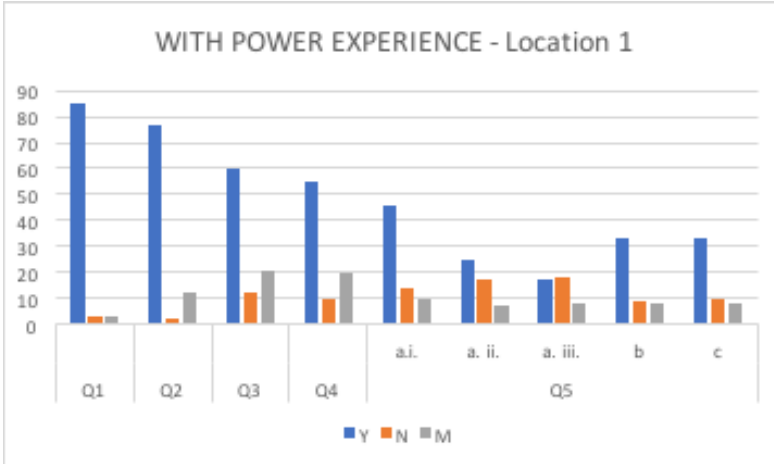

Figure 3: Responses from persons with electric utility background (San Juan).

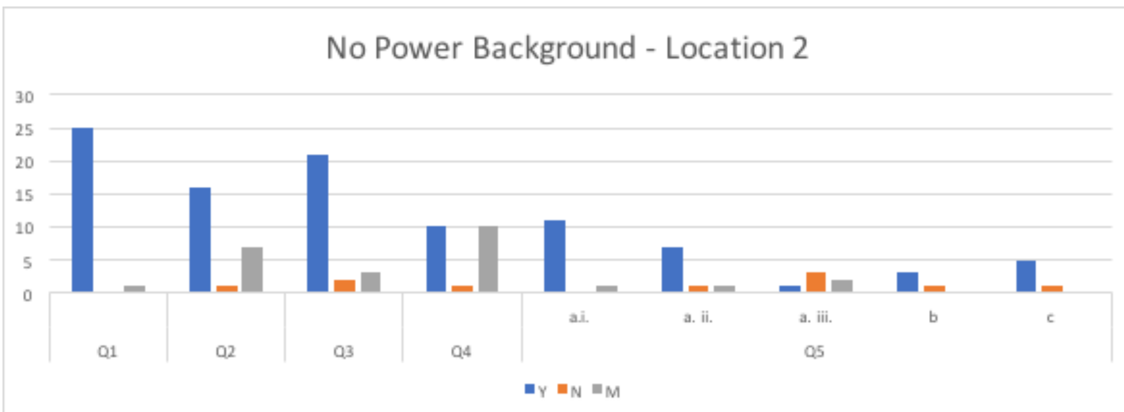

Figure 4: Responses from persons with no power experience (Mayaguez). Blue represents affirmative answers, orange are negative answers to second round questions.

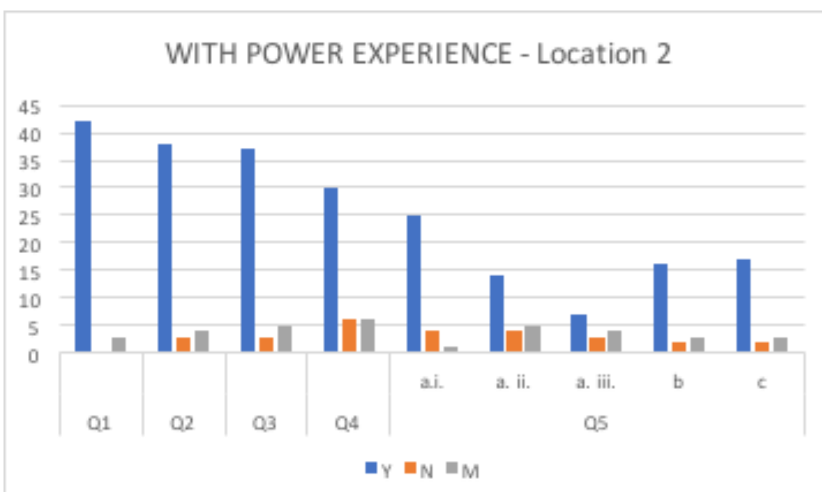

Figure 5: Responses from persons with electric utility background (Mayaguez).

The results were similar in both locations. The participants without power background were more positive about new ideas, although in general, there was much support for a different kind of approach to build and manage the local electric infrastructure. The responses from people with utility or power background were sub-divided into years of experience (up to 10 years, 11 to 18 years, over 19 years). As the number of years of experience in the power industry increased, so did resistance to new ideas for the power grid. Participants were given an evaluation form to rate the benefits of the seminar, delivery methods and materials. The average rating for the first location was 90% while for the second location, it was 88% showing participant high satisfaction with the information shared about the project.

X. Policy and engineering education implications

On May 10th, 2018, a federal taskforce hosted a one-day Energy Sector Summit to present an overview and status of the reconstruction efforts in San Juan. One of the authors was invited to a panel on microgrids, and also took notes during the summit. Many of the findings presented at the summit validated the information obtained from the stakeholder engagement activities. One of the most striking statements came from the federal taskforce leader of the emergency response effort: “Figuring out what we needed, took us a long time.” The organizational interactions among federal, state and local governments were described as a “spaghetti chart”. This confirms the statements from the focus groups, about the inaction and delays suffered in most places outside the metropolitan area (near the capital city). Another important statement during a panel of communications experts addressed the shortcomings of the centralized approach to emergency management: “Regional communications should have been used from the beginning.” This again was a confirmation, from official sources, of the general perception that the emergency response agencies failed in properly communicating through the early stages of the emergency, and even months after the event. On the engineering side, statements from lead engineering personnel mirrored some of the recommendations from the focus group participants. For example, a key recommendation was that the North-South path of transmission lines over the mountains be limited as much as possible. Another recommendation addressed the need for standardization, because the number of voltages in the system and the diversity of needed components represented a logistical nightmare.

Based on the information from the stakeholder engagement activities, confirmed by the information presented in the energy sector summit, the key lessons learned from this hurricane were the following. The aftermath of this hurricane was different from other post-hurricane recoveries because of unprecedented winds and rain. Electric and communications infrastructure collapsed completely. Relief after disaster arrived slower than in previous emergencies. There was an over-reliance on the centralized model for emergency response and recovery. The state government did not respond immediately, and initially focused on the Metropolitan Area. The western and central regions, especially rural areas, were without communications for days. Thus, a key outcome of this tragedy must be the development of public policies about how to manage the electric infrastructure during emergencies and how to strengthen it to withstand future emergencies and/or recover quickly.

Based on this information, policy directions must urgently address the need to re-think the state response to disasters, with a renewed focus on resiliency. Policies should steer away from traditional crisis planning, into resiliency planning. Local, renewable energy resources have economic, social and environmental benefits as well as resiliency and sustainability advantages. However, conventional power systems were not designed for intermittent renewable energy and this challenge must be acknowledged and dealt with. Furthermore, conventional business models & regulation in the electric utility industry are insufficient. Finally, a resilient policy approach requires that passive consumers become active and engaged participants in energy issues. For example, regardless of which future vision is pursued a key action from citizens is to adopt aggressive conservation and efficiency measures. This policy direction aligns with one of the focus groups' suggestions: "be flexible in terms of energy use. Reduce energy use."

Thus, it is the opinion of one of the authors, who has local energy policy experience, that a new, resilient and renewable based policy direction requires a new way of envisioning and managing local electric infrastructure. It requires new forms of interaction among sectors, knowledge sharing and capacity building. Furthermore, besides suggestions for infrastructure improvement, a common theme across the different stakeholder groups was related to capacity building and workforce development. Stakeholder concerns such as education of communities, flexibility in energy use, communities doing things themselves, emphasis on local development, local generation, embracing collaborations with universities would be addressed through workforce development or capacity building. This capacity building is perhaps the key and most challenging of the tasks ahead. The following are specific recommendations:

1. Workforce development is a broad area of opportunity. It is not limited to existing utility employees or persons directly working on utility-related areas. Workforce development can be K-12, college level (including graduate level), existing and retired utility employees, workforce from energy-related firms, communities, city employees (including Mayors and their staff), legislative employees, state employees (including agency leadership, and Governor's advisors) among others.
2. Each of the areas listed above has workforce development opportunities and challenges. However, usually workforce development has been limited to a professional elite, augmenting through technical knowledge the separation between those pushing projects, and those suffering the impacts of many of such projects. Capacity building for communities and the legislative branch is of particular importance since usually those are not included in these activities.
3. To truly achieve lasting impact, capacity building from the bottom-up is key. The knowledge shared and received from communities could yield more effective energy strategies and projects, regardless of changes in the state government.
4. Any capacity building or workforce development effort should not be perceived as paternalistic or condescending. Participants should be treated as partners in a two-way process, not as individuals that "need to be educated". Many outsiders come to teach about microgrids, DG, renewable energy. They have not spent the time to find out the local knowledge that already exists in those areas.
5. The utility has most of the workforce that will be needed to build a new, local electric infrastructure. Any workforce development effort should account for the experience and knowledge of utility personnel at all levels. A collaborative relationship with utility

employees would give much better results than just ignoring them. Furthermore, an effort should be made to tap on the experience and knowledge from retired utility personnel.

6. Pay attention to the local context. What works elsewhere in the continental U.S. will not necessarily work in Puerto Rico. When exploring needs and opportunities do not just focus on organizations/individuals that usually get access to formal meetings, or professional associations. There is much to learn from communities and other local stakeholders. In fact, even the local "technical people" do not understand the need to sincerely addressing concerns and questions from communities and other local "non-technical stakeholders".
7. Many people do not understand that the true challenge in energy is not economic or technical, but social. “The transition toward sustainable energy is inherently social…” [10]. Thus, part of the workforce development needs to address social issues such as social acceptance, perceptions, policy, governance. Partnerships among university, industry and communities are required to properly address the challenges ahead.

Workforce development and capacity building necessarily lead to a discussion of the implications for engineering education with regards to emergency preparedness and a more resilient electric infrastructure. ABET’s Criterion 3 calls for “... solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.” The topic of this paper, and the results from the stakeholder engagement present an opportunity to integrate social and policy issues into engineering curricula, in particular to capstone design projects. Furthermore, Criterion 3 also emphasizes on “…the impact of engineering solutions in global, economic, environmental, and societal contexts.” The teaching of infrastructure-related courses and capstone courses could be enhanced by including emergency preparedness, resiliency and collaboration with communities, giving students a broader view of the engineering practice and their social responsibility as engineering professionals. Besides topics for capstone design projects [6], [11], [12], modules and class examples on resiliency and emergency management could be developed and integrated into infrastructure-related courses.

Besides the traditional integration of these topics into courses, a deeper revision of engineering education might arise when considering electric power infrastructure integrity and the insertion of stakeholders in emergency preparedness and resiliency plans. A discussion between one of the authors and Dr. Cecilio Ortiz, a public policy researcher and professor at UPR-Mayaguez, yielded interesting recommendations regarding the role of engineering education in places vulnerable to natural disasters (in particular at state universities).

- It is key to share engineering expertise in service of society. Thus, engineering educators should play a more active role with regards to emergency preparedness and state resiliency plans. For example, engineering educators could be part of technical advisory groups in service to decision- and policy-makers.
- Engineers need to join forces with state, local government and local stakeholders in key areas of emergency preparedness. Thus, engineers should be trained and prepared to consider, respect and collaborate with people with diverse backgrounds and perspectives.
- Engineering education should include the creation of extended peer communities where engineers, far from relying on the dominant role their expertise has played in the past, learn and practice convergence processes needed to create a more inclusive vision of a

sustainable and resilient jurisdiction. Thus, engineers need to create broad communities with other disciplines in order to tackle resiliency challenges. The focus must be on collaborative actions to enhance social welfare, not on separate actions from disciplines.

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