Capstone Design Projects as Foundation for a Solar Community

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Abstract— **This paper presents a collaboration between the University of Puerto Rico-Mayaguez (UPRM) and a community to establish Puerto Rico's first solar community in the southern part of the Island. This community-university collaboration is leveraging on well-organized community leadership and their efforts towards community self-reliance. Electrical engineering capstone design projects have been used as the cornerstone for the technological aspects of the collaboration. The community had initially planned to expand its community center building to provide more services to residents. Their initial idea of including a solar power system was expanded with help from UPRM researchers, to a solar community initiative. Using the community center as the spearhead for the initiative, and going beyond technology, the solar community project combines citizen empowerment, technology, social and environmental justice to yield sustainable energy and energy self-reliance.**

Keywords— capstone design; sustainable energy; community collaborations; capacity building.

I. Introduction

For over 15 years, power engineering professors at the University of Puerto Rico-Mayaguez (UPRM) have participated in energy-related projects in collaboration with communities in Puerto Rico. The collaborations are usually one or two semesters long. In addition to the benefits to each community, each collaboration represented important capacity building opportunities for professors, helping them transcend their traditional outreach mindframe which is common in many community-related initiatives [1].

On December 9th 2014 community leaders from El Coquí visited UPRM to explore the possibility of a collaboration in their plans to expand their community center building. The existing installations were not large enough to accommodate the number of participants in community activities (e.g., summer camps for kids). They wanted to install a solar PV system on the roof of the building as part of the renovations.

In order for the collaboration to be sustainable, and considering there was no budget available, the UPRM contribution was conceived as a capstone design project in electrical engineering. The capstone project is part of an electrical engineering course that represents the students' culminating design experience as required by ABET. Capstone projects at UPRM routinely require students to visit off- Campus sites (e.g., an industrial facility, a manufacturing plant, etc). Previous capstone projects have been linked to service learning activities [1], [2].

There are many examples of engineering or education initiatives related to renewable energy projects in communities. Engineers without Borders for example, sponsors sustainable energy projects for communities around the world. The IEEE Smart Village program is another example. The service learning literature is quite extensive as well. There are also examples of the integration of renewable energy into engineering capstone courses. Long-term renewable energy collaborations with communities are less common and initiatives in which social and environmental justice goals determined by a community are founding principles of a partnership with industry or an academic institution are even rarer. Such partnerships require a well-organized community and socially-sensitive participants from industry or academia. One example is a smart management and control system for solar energy which was studied for two locations in Europe. These were chosen because of their current and potential solar energy consumer use on a community scale. The goal was to make the system relevant to a community of end-users. User-centered design was pursued as means to achieve this goal. The main challenge faced by the project was finding a way to motivate people to use more renewable energy and sharing renewable energy within these communities [3]. One shortcoming of this type of initiative is its top-down nature, which might generate apprehension from potential users and does not contribute to the development of a true partnership.

Another community-related energy initiative took place in Westwood, a Denver community. Graduate students created a

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simple technology solution that could alleviate high bills related to heating. A solar furnace was built using recycled materials, and the team hoped to implement the solution in the community. This was a project-based initiative to address a specific issue in the community. The social aspects were initially addressed, however it seems that a consulting approach guided the collaboration and the community was not fully integrated in the design process [4]. A third example captures a long-term energy community partnership to deploy a smart grid automation solution for rural villages in parts of Africa. The proposed solution is based on old African values and wisdom related to collective dependability to sacrifice in order to care for and help protect nature and fellow human beings. Socio-technical dimensions of the problem such as the social circumstances and operational characteristics of village customers were considered in the energy management automation procedures (e.g., self-configured retail pricing signals). The expected outcome is to establish a village microgrid based on clean energy technology to replace paraffin, fuel wood and candles [5].

What differentiates the experiences described in this paper from others is the long-term aspect of this community-university partnership. Although it began as a seemingly typical service learning project through a capstone course, it evolved into something greater. The community's context, its history, its vision and principles guided the work. Constant communication and reporting was essential to ensure the objectives of the collaboration were being met, and eventually yielded a partnership to establish Puerto Rico's first solar community. Elements from participatory action research were used to structure parts of the project.

II. Community Background

El Coquí was founded over 100 years ago by workers of the Central Aguirre sugar mill (which no longer operates). With 3,293 persons, it is the second largest community in Salinas (a municipality in southeastern Puerto Rico). More than half of Salinas' residents are under the U.S. poverty levels and unemployment is close to 20%. Salinas' economic activities have been historically dictated by outsiders that did not understand its resources nor its social, economic and environmental realities or circumstances. Furthermore, El Coquí suffers disproportionate environmental and social impacts related to the operation of two nearby power plants and other contaminating industries. Because of these environmental and social injustices, there is an urgent need for activities led by residents that can create local socio-economic development. Communities around Jobos Bay (including El Coquí) have organized to improve themselves, to protect their quality of life and to protect their unique natural environment. The following principles to address its social and economic challenges:

1. El Coquí needs community-based, sustainable and socio-productive development strategies that emerge from a participative community diagnosis.

2. The strategies must be inclusive, support sustainable development and include direct, non-partisan and secular citizen participation.

3. Proposals must come from the community, without pressure from city or state governments. Consensus will be sought to reach decisions among community residents.

4. All government entities can participate as facilitators of the community's processes and proposals.

5. Approved proposals must secure financing that is free of government control.

El Coquí's Community Board ("La Junta Comunitaria del Poblado Coquí, Inc.") is a community, non-profit organization. Regular meetings are convened to discuss and deliberate issues and opportunities with residents. El Coquí has a successful track record of partnerships. These have always been founded on self-reliance and cooperation, rather than dependency, so that social changes occur in line with the community principles. UPRM has significant experience as well with sustainability and community collaborations [6]-[11]. Thus, it was not difficult to find common ground within the community's principles to begin the Coquí-UPRM collaboration.

III. Project Planning

After the December 2014 meeting, the capstone course professor maintained email communication with community leaders, leading to a community visit on January 15th 2015. The meeting's objectives were to clarify the expectations of all stakeholders, fine-tune the objectives of the students' project, and ensure that all the work was aligned to the community's vision and principles. The professor and community leaders had met for the first time in the Fall of 2013, which helped speed up agreements. From the beginning the community made it clear that local resources were to be used as much as possible. There are licensed electricians in the community, that can provide labor for the electrical renovation of the building. Local youth can be encouraged to pursue technical studies as electricians. Furthermore, the proposed PV project had to be linked to workforce development for young people. A resident assembled and installed his own solar panels, and the Board wanted to use that expertise to assemble PV panels for use in stand-alone solar light poles. Again, the Board's proposal involves training local youth to enable their participation in the project.

A. Solar Community

After various interactions with the Community Board, and understanding the principles they followed and the plans they had for the renovated community center building, the professor suggested the expansion of the long-term scope of the initiative so that El Coquí could become Puerto Rico's first solar community.

Solar photovoltaic (PV) systems that serve communities have diverse names: community solar, "shared solar" or "solar gardens". Others define "community shared solar" as a system that provides economic or electric power benefits to a community [12]. The Rocky Mountain Institute (RMI) compares these community systems to chameleons that adapt to the local conditions [13]. Developers seem to prefer the model in which one large system is shared by members of the community because it appears to be easier to implement and manage. However, the spirit of true community might be better reflected if multiple rooftop systems are used. In Delaware and

Massachusetts this combination of individual systems "behind the meter" is allowed in their shared or solar community programs [12]. DOE has links to resources, information and reports that are valuable when studying solar communities [14]. Community solar systems have a great potential in Puerto Rico. Act 133, signed on August 2016, authorized the establishment of solar communities in Puerto Rico. All possible modes of solar communities should be allowed in Puerto Rico. However, all the studies and reports made elsewhere, and their conclusions and recommendations need to account for the local context before applying them in Puerto Rico.

One of the main appeals of the solar community model is the potential to create a new tool for local socio-economic development through technology, citizen empowerment, environmental and social justice, aligned to sustainable energy principles. Not all solar communities embody these ideals, but El Coquí is in a position that allows it to be a true solar community, in this broader sense. During these early conversations, the project was given a name: "Coquí Solar".

IV. Initial Capstone Project

By the end of January 2015, three UPRM students and the course's professors visited El Coquí. Before the visit, the professor had explained in detail the scope and objectives of the project, provided a brief history of the community and assigned readings to ensure the students possessed the relevant basic knowledge. During the first meeting with community leaders, the students discussed their initial ideas for the design. They received valuable feedback from the Community Board, that clarified a few areas of the design. After the formal meeting, students and residents walked around the streets near the community center to get acquainted with the surroundings. As part of this walkabout, students evaluated the electrical infrastructure, determined the number and size of transformers and their approximate locations. Students and the professor also inspected the community center building rooftop, to identify any challenges for the installation of a PV system such as structural problems or shade from nearby objects.

Fig. 1: A meeting with El Coquí residents

A. *Progress Report to the Community*

After the visit, students finished their written proposal, including the following problem description: "El Coquí needs to expand its community center building. This renovation entails a re-design of the electrical wiring of the premises. The Community also wants to include a rooftop PV system in the design. The expanded facilities should facilitate the Community's path to energy autonomy."

During the first half of the Spring semester the three-student group completed design work compliant with the NFPA's National Electric Code and the local utility. They also designed interior and exterior lighting systems (Fig. 2). The lighting design complies with the Illuminating Engineering Society of North America (IESNA) standards. The students also completed a pre-design of a new computer center to be part of the building expansion. The computer center would be used as a tutoring center for the children of the community. This new space would have a separate entrance from the main building, and would also have its own electric panelboard.

(a) (b)

Fig. 2: (a) Inspection of the rooftop, (b) Community feeder at the substation

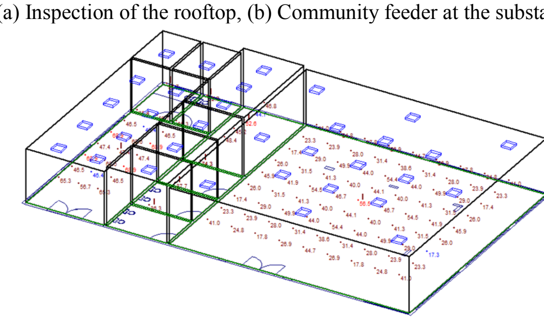

Fig. 3: Part of the Illumination Analysis for the Expanded Building

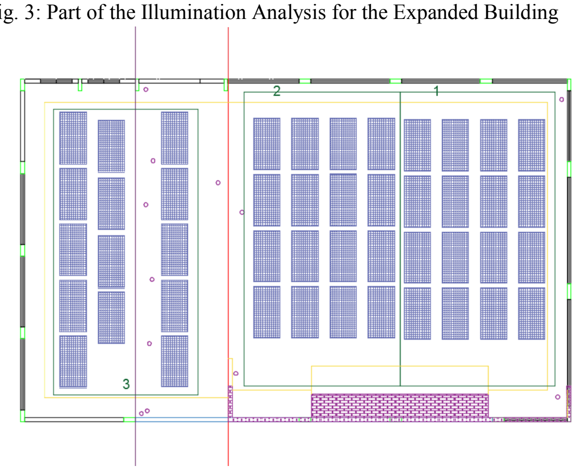

Fig. 4: Top View of the Expanded Building with proposed PV System Layout

Finally, the students worked on the design of a rooftop photovoltaic (PV) system for the community center building. The PV system would provide power to basic loads identified by the Board. Although the main area and the computer center have separate panelboards, the areas are electrically combined in the building's main panelboard. Thus, the PV system can serve both areas. Furthermore, the PV system would operate in parallel to the power grid under a net metering contract since the building has a single utility meter.

All phases of this work included the creation of computer blueprints for each of the tasks, technical calculations and preliminary specification of materials and equipment. This work was described by the students during a progress report delivered to El Coquí in mid-March 2015. At the meeting, the students received final feedback that was needed for the remaining tasks of their capstone project.

B. Final Tasks

During the second visit, the students and their professor visited the power substation that supplies electricity to the community. They followed the power line that leaves the substation all the way to the community center building, to approximate its length, study its configuration and determine its conductors' size. That information was needed for the second phase of the capstone project, which entailed a feasibility study for the conversion of El Coquí into a solar community.

The students assumed that a first stage of the solar community would include the 200 houses closest to the community center building. This is a fair assumption given that the building will probably be the first structure in that vicinity with a shared PV system (shared in the sense that it would provide electricity for activities in a common area, not to benefit a particular individual). With information obtained during the visits, students completed PV designs for two typical residential structures. Power consumption from the houses was assumed from electricity averages publicly available for Puerto Rico. An introductory analysis for the operation of the power distribution system was performed, assuming the existence of a solar community. Another task in this second phase was to determine storage requirements for the community center building and the houses. This is important to ensure minimal impact of the solar energy variations to the power grid, and to provide some level of independence in case of emergencies (e.g., during hurricanes the community center can be used as a shelter). Finally, a basic economic analysis was completed for the electric renovation in the community center building.

In May 2015, students returned to the community for the final presentation of the project.

C. Project Deliverables

Puerto Rico's laws require all engineering designs and blueprints to be made and signed by a licensed engineer. Thus, the work done by the students in their capstone project cannot be considered a complete or final design, ready to be built. This was explained and disclosed to the community. The students also understood this constraint, but did not feel unmotivated or discourage. They understood that all their work can be used by a licensed professional as a starting point for a final design. Thus, all the original electronic documents and blueprints were provided to the Community Board as a contribution towards their Coquí Solar goal.The deliverables were:

1. A pre-design (or student design) of the electrical wiring of the expanded community center building, including interior lighting and suggested electrical equipment.
2. A pre-design (or student design) of the electrical wiring of a proposed community computer center, including interior lighting and suggested electrical equipment.
3. A pre-design (or student design) of a rooftop PV system for the renovated building, including storage.
4. A suggested back-up generator, for extended emergency conditions (and shelter operation at night).
5. Exterior lighting pre-design of "stand-alone" PV lighting poles.
6. Initial analysis for the operation of El Coquí as a solar community. Two scenarios studied: 70 and 200 houses with rooftop PV systems.
7. Recommendations of steps towards a Solar Community

Furthermore, the process through which these products were developed allowed the community to familiarize itself with the ideas and possibilities that PV systems offer to their community center and to the community at large. The Community Board was now in a better position to negotiate possible partnerships, sponsorships or grants.

V. Benefits and Follow-up Activities

During 2015 and 2016, a graduate student worked on a thesis using the data gathered during the capstone project, developing more simulation scenarios for the proposed solar community [15]. This increased knowledge regarding the use of demand management strategies in combination with solar energy is also available to El Coquí. Interestingly, during the same period a graduate student from Indiana University completed interviews for her PhD work that prominently used Coquí Solar as a case study. Meanwhile the UPRM professor continued supporting Coquí Solar through phone calls, emails and formally linking the collaboration with a DOE SunShot project (GridEd). Most efforts where directed at securing the installation of a rooftoop PV system in the community activity center building. Also during 2015 and 2016, the community drafted a proposal using the information produced in the capstone project, and support from collaborators such as the UPRM professor. El Coquí's proposal was successful in obtaining part of the funds needed for the first stage of the project. That in itself, is evidence of the success of the Capstone students in achieving their goals of helping the Coquí Solar project.

As part of the initial stage of the Coquí Solar project a workshop series was held in the Summer of 2016. The activity's key themes were: energy and local socio-productive activities. The workshops were complemented with a mentorship program for participants. In July 2016, the UPRM professor delivered his workshops on topics that included fundamentals of electric energy, an overview of renewable energy resources, energy efficiency and basic concepts of electric design amounting to contact hours in excess of 8.5 hours. A total of 10 persons participated in all the seminars, an additional 5 attended some of the activities. Participants learned how to conduct an energy inventory in homes. Assessment results from short pre-test and post-test, as well as results from the energy inventory (of one community house) performed by the participants showed the effectiveness of the capacity building activities.

On September 10th 2016 Coquí Solar participants visited UPRM for a day of follow-up capacity building activities (Fig. 5). Along with the workshop students, a group of 8 collaborators including various UPRM faculty and students joined in on certain activities. The activities included a visit to the power electronics laboratory, with a focus on microgrids and LED public lighting, and a visit to a manufacturing laboratory with a focus on LED lighting. They also visited the Eco-Solar House, a former "participant" of DOE's Solar Decathlon, now transformed into a lab and showcase of sustainable technologies and practices. The day ended with a seminar on solar communities, that included a description of the scenarios developed in the UPRM thesis described earlier in this section. The group was also able to listen to part of the public hearings held at UPRM regarding a rate case for the local utility.

Fig. 5: A group of El Coquí residents during a 2016 visit to UPRM

During the Fall of 2016, two students continued working in El Coquí under the guidance of Prof. Marcel Castro. Actual consumer data from residents of El Coquí to establish real energy use patterns in the community. They used the data in the simulations developed at UPRM [15] They also performed an economic analysis using the Homer program.

VI. Second Capstone Design Course

During the Spring of 2017 two additional capstone design projects provided continuity to Coquí Solar. The main objective of the second phase of capstone projects was to establish design principles for use in the solar community. These projects picked up where the first capstone course left off. Actual consumption information was now available, and further work on solar community organization and structure was done. The four students (co-authors of the paper) interacted with El Coquí's Board on February, March and May 2017. On February 2017 the students re-examined the electrical infrastructure on the streets around the community center building, updated system information and corrected the number of houses to 238. Some of the schematics developed are shown in Figs. 6 to 8. The work performed in 2017 will be used by El Coquí in future negotiations with the utility regarding the operation of their solar community and in applying for further grants. This work can also be used to propose policies and regulations that facilitate solar communities. The capstone projects also provided information that was used to organize two Colloquia on Solar Communities in April 2017.

A. Solar Community Management

Two undergraduate students worked on the solar community management options discussed below. These options would entail the re-design of the utility distribution system and street lighting. The existing overhead distribution lines would be converted to an underground distribution system.

1) A Non-Profit Model

In the non-profit model, an entity would be in charge of the procurement and management of the solar community. This entity would engage a third party that would be responsible for designing, permitting, installation and maintenance of the photovoltaic system in the community. To finance the project, the community would work with a local financial cooperative. In this scenario the photovoltaic system would be distributed on the rooftops that meet the necessary requirements for the installation. A storage system would be distributed among the houses connected to a transformer. Consideration was given to the use of available land near the community center to equip recreational structures with PV panels on top.

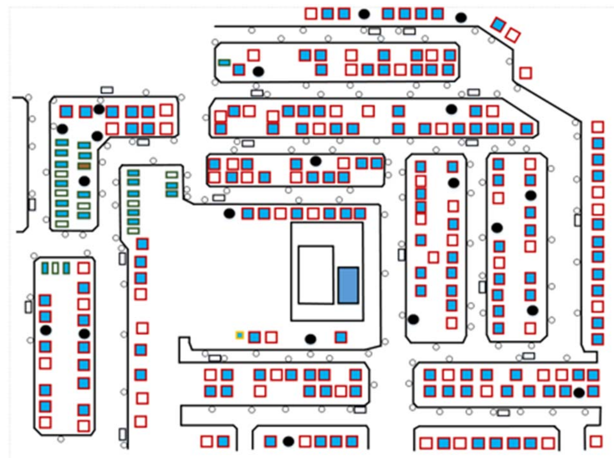

Fig. 6: Top view of streets and houses around the community center building

2) A Utility-Sponsored Project

The utility would install, maintain and manage the photovoltaic system. Not all households would have PV panels but all in the community would benefit equally from the systems. The energy used by the community will be measured by the utility and billed. The energy storage would be in the substation. It will charge from the grid during times when there is PV over-generation and discharge when PV energy is reduced (e.g., by clouds) and at night [12]. The Sacramento Municipal Utility District has an example of this type of arrangement.

3) A Special Purpose Entity

The community would join a nonprofit entity that mainly works with solar community projects. This entity would initiate, motivate, and support activities in and for the community to find donations to finance the project. This source of income is usually not constant and/or consistent enough for financing. The nonprofit entity and the community would have to seek third party participation to acquire the equipment and to be responsible for installation and maintenance. Afterwards, the community would agree with the third party on fixed monthly payments in exchange for the services and benefits of the system. The service from the third party would generate a profit and the residents would not own the equipment. In this scenario the PV systems are installed on the rooftops. As an example, Energy Solutions, an energy company in Washington, asked the Winthrop Community to join as a host for a solar community project; the ownership eventually passed to the community [12].

All alternatives were presented to the Community Board. The preferred option was the Non-Profit Model.

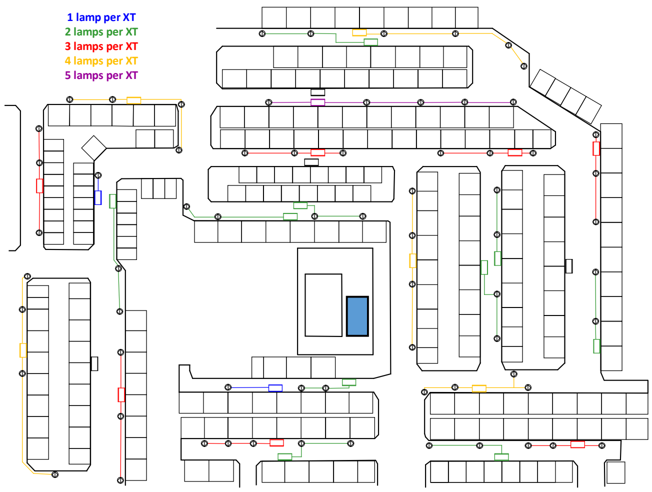

Fig. 7: Street lighting layout

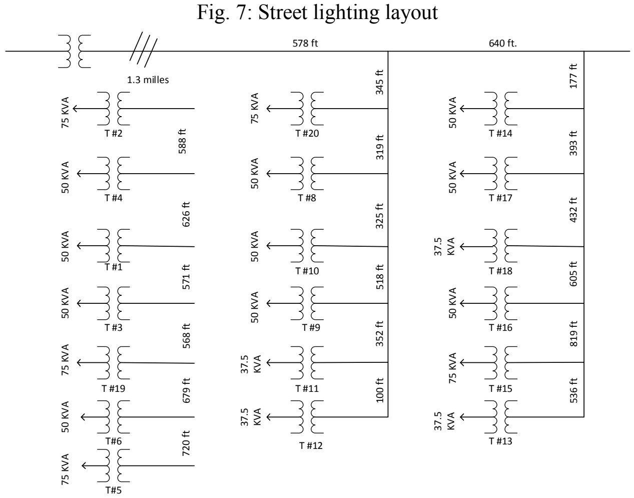

Fig. 8: The main power line (1.3 miles) and distribution transformers

B. *A DC solar community*

The other two students worked on the evaluation of a DC architecture for the solar community. One of them, Javier Rentas, is co-author of this paper and was part of the Fall 2016 project in El Coquí (presented earlier). A DC distribution system may reduce costs and losses associated with AC/DC conversion because the PV units and battery are DC connected and most of the current energy-saving appliances operate on DC. The system does not require long distribution lines to share solar power because the PV units are located nearby. Power sources and loads are closely located to each other in a community. A key advantage of DC systems is that there is no reactive power which increases losses in AC systems due to larger currents.

The DC architecture reduces the size of inverters required to export excess PV energy, thereby mitigating the potential impact of PV variability on the grid. Furthermore, DC based battery storage can be much more efficiently connected to a DC microgrid, enabling a more cost-effective way to smooth solar power intermittency. It also supplies power to loads via regular distribution lines (not exclusive lines for emergency) even during a blackout. A DC system has a smaller footprint, avoids most transmission and distribution losses. It also eliminates the waste of energy associated with the conversion of AC to DC, which is required for so many of the electrical loads.

VII. Students' Educational Experience

UPRM's electrical engineering capstone experience occurs during a one-semester course entitled "Design Project in Electrical Engineering." During the first two weeks students work on a project proposal that is presented orally in class. All oral presentations are evaluated in three main areas: organization, content and communication skills. Based on the professor's feedback, students fine-tune their work and hand in the written proposal which must include: problem definition, objectives (specific, measurable, and realistic), proposed design approach (possible solutions, preliminary calculations, applicable codes and standards), project schedule and distribution of tasks. During the semester, two progress reports are presented orally and latter submitted in written form. Both written progress reports are aligned with the proposal, but the emphasis is on the technical progress: design alternatives, analysis criteria, justification of all the choices (calculations, simulations), technical diagrams, blueprints and preliminary estimates for the selected design option. These reports also include the refined and final problem statement and objectives, and an updated project schedule (explaining and justifying any changes in or departures from the original plan). For the final report (presented at the end of the semester), students are evaluated both as a group and individually. The final report includes all work done during the semester, with more emphasis on clearly explained and strongly justified methods, specifications, design criteria and approach to the solution; specific changes that would improve the design; an engineering economic analysis; ethical analysis; and three of the following design constraints: environmental, social, political, manufacturability, sustainability, health and safety. Confidential peer evaluations are also used during the course.

1) *In-Class Seminars*

In-class seminars complemented knowledge of specific topics (e.g., ethics in design, distributed generation, photovoltaic systems, social issues, environmental considerations). Students worked on an ethics case related to power systems using a deliberation framework [16]. This experience helped them later in the ethical analysis of their designs.

During one of the seminars (delivered in 2015 and 2017), the professor discussed the connections between the capstone design work and the social sciences and humanities (SSH). In an anonymous exercise, students were asked to list the SSH courses they had taken, what topics they liked the most, and what topics they felt were relevant to electrical engineering. Afterwards, the professor asked the students to explain the reason for SSH electives in the engineering curriculum, and how those courses might help them complete an electrical engineering design. Very diverse and interesting perspectives emerged, especially after a presentation about liberal arts and engineering [11]. At the end of that learning module, the initial exercise was repeated to determine what additional insights the students had developed.

One of the main areas of discussion was the integration of realistic constraints such as social, political, ethical, health and safety, and sustainability condiderations in their capstone designs. The need to understand the impact of engineering solutions in a global, economic, environmental, and societal context is also pondered.

2) Assessment of Learning Outcomes

The educational process envisioned by the professor was to provide students with an actual, practical challenge for students to: 1) apply engineering knowledge, 2) improve social awareness, and 3) feel part of a community partnership. Rubrics were applied to student work to determine if this vision was achieved, and also to assess whether each student achieved the learning outcomes expected from the capstone course. Table I summarizes these assessment results.

TABLE I. LEARNING OUTCOMES RESULTS (5 IS THE HIGHEST)

Learning outcome	Results
Identifies a problem, formulates the problem and proposes plausible solutions	4.31
Applies math, science, and engineering	4.27
Selects and uses techniques, skills, and modern engineering tools relevant to the project	4.91
Understands the need for, and an ability to engage in lifelong learning (e.g., uses library resources, and professional databases for references, proper citations in reports, uses engineering standards with little or no supervision)	5
Designs a system to meet needs, analyzes alternative solutions, follows and documents a logical and orderly design procedure to meet specifications within realistic constraints	4.81
Recognizes the impact of engineering in a global, economic, environmental and societal context	4.46
Recognizes an ethical issue, evaluates the ethical problem through the harm, publicity and reversibility tests, anticipates possible ethical conflicts and proposes alternatives to reduce the possible ethical problems	4.28
Able to identify and discuss contemporary issues related to the project	4.78
Communicates using schematics, tables, graphics or mathematical equations. Proper use of the language (Spanish or English). Delivers well organized public presentations, shows ability to relate to the audience, and answers questions related to his/her work. Creates a well-organized written report.	4.63

The results shown in Table I confirm that the educational objectives were achieved as well as each of the student learning outcomes. The first five outcomes in the table are related to the "apply engineering knowledge" objective of the vision. The last four rows confirm progress in students' social awareness. The fifth outcome provides information for the first two objectives of the vision. The third objective "Feeling part of a community partnership" is a more subjective one, and was studied through student reflections. The student reflections also provided qualitative data to conclude that the first two objectives of the vision were achieved.

3) Assessment of Student Reflections

The students were asked to reflect on their learning experience towards the end of the course. Of special interest to them was the emphasis community leaders placed on the unity of the residents. The students were able to internalize the importance of the community center building as a space that benefits the whole community by creating a sense of belonging. The needs of residents and the Community Board feedback were of utmost importance for the students. They clearly understood their roles as partners of the community. Some of the student comments that show they felt as part of a community partnership are: "I will never forget how nice it felt working with the community, trying to improve their standards of living. It just felt like we were doing something bigger than ourselves and I was really glad to be a part of it." "I contributed and worked with the people of the community, and this type of project would transform power generation and use in Puerto Rico." "… the community felt involved, and in the driver's seat" "…we can cooperate with them to achieve their goals."

Students' reflections (and demeanor throughout the semester) showed their awareness of the socio-economic circumstances of the community; their concern was very much present in their design decisions (e.g., when optimizing reliability, safety and cost regarding options for the equipment suggested). The use of the facilities by children was also mentioned in their reflections: The help kids would get with their homework, and also a way to entertain them during summer camps, or after emergencies (e.g., hurricanes).

When faced with the issue of the community's energy independence, students suggested it was a difficult proposition because of the cost of energy storage, and likely resistance from the utility to allow for independent operation of whole communities (e.g., microgrids). Societal acceptance of the solar communities concept in general was also part of their reflection, pointing to energy policy issues that need to be resolved in order to advance a more distributed energy future in Puerto Rico. The recommended strategy was to install a handful of rooftop PV systems, so that residents could understand the technology and the benefits of jointly owning the systems. These systems would initially participate in the existing net metering program for individual clients, but with a community agreement that would ensure benefits are shared among participants of the solar community. The students concluded that this particular approach requires consensus building, and constant communication and involvement, the very traits the community affirms in its principles.

In terms of future work, the 2015 capstone course students acknowledged that their work was a first step. Actual consumption information and additional data from the utility were needed to achieve a more accurate analysis. Further work on how a solar community may work was also noted. These elements were picked up by the 2017 capstone students. Actual data was made available and different models or structures for the solar community were studied and presented to El Coquí's Board. Data from the utility remained difficult to obtain; an initial contact in the context of Act 133-2016 is required and remains as future work. The continuation of the work started in 2015 is evidence of the success of the initial capstone course. Two of the original participants later commented: "Very happy to know the project is moving forward, and it will affect positively people's lives." "After graduating I felt the project would be forgotten, but knowing that it continued rejoices me." Both groups, from 2015 and 2017 understood their contributions to an ambitious project such as Coquí Solar. Some sample comments on this regard: “Just giving that design will help others, in the future, not only to improve on it, but also make other recommendations or expand on it.” “… the project was feasible, even if we personally could not implement the design.”

An important question answered was about the educational value of a capstone that is based on an actual community need. The answers were inspiring and an assurance that the course’s vision was attained: “I had to apply what I learned on my engineering courses and I had to think critically on how to proceed to accomplish what was expected of me” “...a realistic experience in which your knowledge merge with real life constraints…” “Realizing we study to be able to help society” “We have a responsibility as professionals to give back to the community whenever we can even if it’s just a tiny bit” “...being aware that the knowledge being used actually affects people with different mindsets and ways of living” “It makes you understand that education can happen outside of a classroom…”

When asked how this capstone project was different from a more traditional course, or from other academic experiences, students unanimously agreed that the interaction with the community set this project apart. “It was a more human interaction, not just numbers. You could hear what they wanted, their dreams.” “…you do learn different things in an actual setting… it cannot be replicated through hypothetical situations” “Dealing with actual people presents interesting challenges and was a great learning opportunity. Seeing the emotion in the community members, the hope of a better community, was very motivating and satisfying” “The social and emotional aspects of this project really sets it apart from any other experiences”. Finally the answers on how this capstone experience can be repeated, or extended to other places focused on developing projects that strive to solve societal problems: “UPRM is a state university, other courses can focus their projects in solving actual problems the Puerto Rican society has”, “Always consider the impacts to communities, that should be a priority”, “Make capstone coursess linked to real contexts, where students can see the potential impact of their work on people.”

Based on the student reflections (from the 2015 and 2017 capstones courses), the professor concluded that the experience helped them grow as professionals and citizens. Students were deeply moved and grateful to El Coquí, for letting them be part of their solar community project. They mentioned the patience, understanding and amiability they sensed, and the family-like dynamic in the community. Both capstone courses represented important learning experiences for the students that added to their skill set and made a positive impact while contributing to the sustainable development of El Coquí. Thus, the learning experience successfully completed its objectives.

Lastly, a key element of the student assessment and overall collaboration came from one of the community’s main advisors, and co-author of this paper. The Coquí Solar community-university collaboration has served as an interdisciplinary learning exchange and simultaneously has promoted social integration. UPRM has the foremost engineering school in Puerto Rico, many of its graduates migrate to the mainland United States seeking better employment opportunities and/or advanced degrees. Although some UPRM students come from marginalized communities like El Coquí, many come from other backgrounds with limited opportunities for broader social experiences. Entrenched prevailing social paradigms promote upward mobility that steers students, particularly those in the STEM fields away from excluded communities. The Coquí Solar collaboration serves as an opportunity for students and academics to experience the merits of community organization and locally-based sustainable efforts while contributing valuable technical input through the capstone design projects. The community-university collaboration is a pathway for mutually beneficial alliances to promote social and sustainable development.

VIII. Conclusions

This paper presented a community-university collaboration currently underway to establish Puerto Rico's first solar community in the southern part of the Island. During the Spring of 2015 UPRM students from a capstone course completed the electrical design of an expanded community center building, and its photovoltaic (PV) system in El Coquí. They also studied different scenarios of penetration of rooftop PV systems in a subset of 225 houses around the community center building. The students interacted with community members on various occasions, and their project yielded documents and information that were used by the community to obtain the first grant towards the community building’s expansion and follow-up activities. In the Spring of 2017 two new capstone courses dealt with the design issues of solar communities, and will further the community’s knowledge and tools towards energy autonomy. Going beyond technology, the activism of communities, in partnership with universities can further local socio-economic initiatives such as solar communities to achieve social and environmental justice.

Using assessment results from the course’s learning outcomes, student reflections about their learning and observations of the students throughout the semester the professor concluded that the design experience was successful from an educational perspective. This was an unforgettable and transformative experience that helped the students grow as professionals and citizens. Furthermore, assessment comments from a key advisor of the community pointed out that the Coquí Solar community-university collaboration served as an interdisciplinary learning exchange that also promoted social integration. Entrenched prevailing social paradigms promote upward mobility that steers students, particularly those in the STEM fields away from excluded communities. The Coquí Solar collaboration served as an opportunity to experience the merits of community organization and locally-based sustainable efforts while contributing valuable technical input through the capstone design projects.

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