ESSPI as a Tool for STEM Education in Energy Backup System Design

Natanael Batista Alvarez
Department of Computer Science and Engineering
University of Puerto Rico
Mayaguez, PR
natanael.batista@upr.edu

Brian E. Vázquez Acosta
Department of Electrical and Computer Engineering
University of Puerto Rico
Mayaguez, PR
brian.vazquez6@upr.edu

Jesús F. Montalvo Nazario
Department of Electrical and Computer Engineering
University of Puerto Rico
Mayaguez, PR
jesus.montalvo@upr.edu

Guillermo Lopez Cardalda
Department of Electrical and Computer Engineering
University of Puerto Rico
Mayaguez, PR
eduardo.ortiz7@upr.edu

Eduardo Ortiz-Rivera, PhD
Department of Electrical and Computer Engineering
University of Puerto Rico
Mayaguez, PR
guillermo.lopez@upr.edu

Alanis M. Colón González
Department of Electrical and Computer Engineering
University of Puerto Rico
Mayaguez, PR
alanis.colon@upr.edu

***Abstract*—This research-to-practice full paper helps users prepare for blackouts and power outages by presenting a cutting-edge tool for STEM outreach. In an emergency, loads are prioritized according to the Energy Storage System Prioritization Index (ESSPI). It evaluates loads based on recovery time, power consumption, and ranking; it will soon be available as a web application. It provides a cost analysis and prioritizing index for building backup systems.**

By dividing loads into categories such as important, necessary, discretionary, non-essential, and disposable, the ESSPI tool is being used as an agile system design tool. Case studies show how adaptable it is to many environments, from homes to grid systems, improving energy management.

Furthermore, the application educates users about renewable energy by offering cost and size assessments, specifically for Photovoltaic (PV) installations. Based on user inputs such as location, number of hours of sunlight, and length of backup, the app estimates system costs and battery size and optimizes the size of the PV system by taking shading and panel efficiency into account.

To sum up, this creative tool and its intuitive online application emphasize STEM education and mark major advancements in backup system design and emergency preparedness. It helps users make cost-effective decisions by promoting knowledge of solar energy and battery technology, which is beneficial for researchers and aficionados of renewable energy sources.

Keywords—Load classification, Renewable Energy, Energy Storage

I. Introduction

This paper improves the Energy Storage System Prioritization Index (ESSPI) with a web application that provides detailed cost and size evaluations for photovoltaic (PV) systems and batteries. These enhancements facilitate strategic investments in energy systems that are not only reliable and resilient but also capable of rapid recovery. Additionally, the paper broadens the scope of the ESSPI's application, reinforcing its significance as an essential tool for optimized energy management within micro-grid systems [1], [2]. The focus of this web application is to function as a resource for both STEM education and practical, real-world applications in emergency readiness and renewable energy exploration with its uses in scenario-based learning [3]. The tool, designed to prioritize loads under emergency scenarios such as blackouts, uses a recovery-time index and the user's classification of loads across five categories: critical, essential, discretionary, non-essential, and expendable, providing the user with Short-Term or Mid-Term investment objectives where the loads are ordered by importance [2].

Furthermore, the tool has features that offer an in-depth analysis of the costs associated with constructing backup systems from short term to long term, focusing prominently on PV systems. This feature is specially designed to educate and engage users in the renewable energy domain, providing insights into the financial and physical aspects of system design, including the number of photovoltaic panels and batteries based on user-defined parameters such as location, sunlight availability, and desired backup duration [4], [5]. By integrating this tool into a user-friendly web application, the research aims to provide individuals and organizations with accessibility to sophisticated energy management and backup system design tools, making it a robust educational kit for STEM outreach and a practical guide for individuals and organizations aiming to enhance their energy resilience. This paper presents compelling case studies that demonstrate the tool's versatility and effectiveness across various settings—from individual households to grid-scale systems—highlighting its potential to significantly impact energy management practices and sustainability education.

II. Background Of the Energy Crisis

Puerto Rico's electrical grid has faced immense challenges. In 2017, Hurricanes Irma and Maria caused a near-total collapse, leaving some residents without power for nearly a year. This disaster highlighted the fragility of the island's infrastructure and the devastating consequences of widespread blackouts [6].

Investing in STEM education is crucial to ensure Puerto Rico is better prepared for future electrical disasters. By equipping students with knowledge in science, technology, engineering, and math, we can empower them to develop solutions for a more resilient grid. This could involve designing stronger infrastructure, exploring alternative energy sources, or creating better communication systems during outages. Puerto Rico is committed to meeting its electricity needs with 100% renewable energy by 2050 [7], as established in Puerto Rico Energy Public Policy Act (Act 17) [8]. By fostering a generation of STEM-literate citizens, Puerto Rico can build a stronger and more secure electrical future.

III. ENERGY STORAGE SYSTEM

Energy storage involves capturing and storing energy for later use. This process is crucial for balancing the intermittent nature of certain renewable energy sources, managing energy demand, and ensuring a reliable and stable power supply. Various technologies are employed for energy storage, each with its own characteristics and applications [4]. Here is presented several energy storage technologies that could be implemented for renewable projects:

1. Battery Energy Storage [9]:

- Description: Batteries store electrical energy in chemical form and release it as electric power when needed.
- Applications: Used in electric vehicles, grid stabilization, backup power systems, and residential energy storage.

2. Pumped Hydro Storage [10]:

- Description: Involves pumping water from a lower reservoir to an upper reservoir when excess electricity is available. The stored energy is then released by allowing the water to flow downhill through turbines to generate electricity.
- Applications: Large-scale grid energy storage.

3. Flywheel Energy Storage [11]:

- Description: Kinetic energy is stored in a rotating mass (flywheel) and released when needed.
- Applications: Used for short-duration energy storage, frequency regulation, and grid stabilization.

4. Compressed Air Energy Storage (CAES) [11]:

- Description: Involves compressing air and storing it in underground caverns. The stored air is then expanded through turbines to generate electricity when needed.
- Applications: Grid energy storage and stabilization.

The technologies discussed are currently available in the market and can be utilized as energy storage systems (ESS). This research primarily focuses on battery energy storage systems (BESS), although it is pertinent to acknowledge other energy storage technologies which include Pumped Hydroelectric Storage, Mechanical Energy Storage, Hydrogen Energy Storage, Thermal Energy Storage, Compressed Air Energy Storage, and Supercapacitors [12],[13]. In Figure 1 is shown a graph that summarizes the applications of these ESS technologies, their time durations and compares the energy storage capacity vs power output of each of them [14].

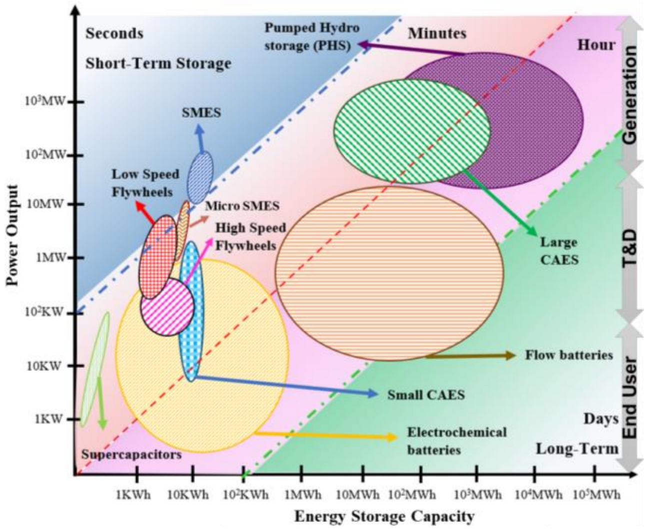

Fig. 1: Energy Storage Capacity vs Power Output graph with common duration applications and application usage.

IV. ESSPI TOOL IN STEM EDUCATION

The Energy Storage System Prioritization Index (ESSPI) tool offers an immersive learning environment tailored for STEM students interested in exploring the complexities of renewable energy and Energy Storage System (ESS) design. By incorporating multiple aspects of project management, cost analysis, and system optimization, the tool could enhance students' understanding of sustainable energy solutions. Through its user-friendly interface, students can adjust project parameters in real time and observe the possible effects on overall performance, cost-effectiveness, and system efficiency. Experimenting with variables such as duration, peak sun hours, and battery types may help students gain insights into how different decisions could influence the design and viability of renewable energy systems.

The ESSPI tool is not merely a teaching aid but could serve as a critical educational resource, preparing students for real-world challenges in the field of sustainable energy. By providing the skills, knowledge, and resources necessary to navigate the complexities of renewable energy and energy storage system design, the program may position students to make meaningful contributions to the advancement of sustainable energy technologies.

The application includes educational modal windows that are positioned strategically throughout the user interface to aid in learning. These modals function as digestible educational bite-sized pieces, providing concise, intelligible definitions and insights into technical terms such as "Max Critical Recovery Time" and "Complete Recovery Time." It covers relevant topics such as renewable energy, energy storage systems and about ESS priority index. The modals accommodate users with various levels of expertise by decomposing complex concepts into manageable chunks, thereby guaranteeing accessibility for all.

The application's interactive functionality, which enables users to actively engage in the learning process, is one of its primary features. Figure 2 shows one of the learning modals about ESSPI. Not only about ESSPI, but also it has other dynamic explanations about renewable energy and other interesting topics. After learning about the technical part, users can enter data for new calculations, like power consumption and recovery times, using simple input forms, and see directly how these factors affect ESSPI values.

The Project Dashboard component is designed to offer students an educational experience focused on the financial aspects of energy storage systems (ESS). By enabling users to create different projects with specific budgets, it provides visuals that may help students understand the process of designing a backup system. For example, constructing a backup system for a home could involve components like household appliances. Users enter details for each appliance, such as power consumption and maximum critical recovery time, which could lead to the calculation of an ESS priority index and the cost of batteries and a Photovoltaic (PV) system to maintain them.

Figure 3 illustrates the process of the user entering multiple elements, each with its own set of characteristics such as power consumption and maximum critical recovery time. The team collected data from several STEM students in person. Table 1 includes a test case from one of the STEM students that participated. Each appliance has distinct characteristics that the program evaluates while delivering results. Table 2 and example of how the user inputs in formation economic analysis of the photovoltaic system.

Visual aids such as progress bars and charts could enhance the learning experience by offering a clearer understanding of cost data, potentially helping students grasp complex concepts more easily and facilitating comparisons between different cost scenarios. Dynamic cost estimation, which recalculates in real-time as new elements are added or parameters are changed, might transform project budgeting from a static figure into an interactive teaching tool. This approach could enable students to see the potential impact of their decisions on the project's budget, offering a more engaging and informative learning experience.

As students experiment with different scenarios, the system continuously recalculates the total cost, potentially serving as a dedicated financial calculator for the project. This real-time feedback may give students quick insights into how their choices affect the budget, deepening their understanding of cost dynamics. Through dynamic visual aids, students could estimate the cost to maintain their system and compare it to their initial budget.

By providing step-by-step explanations, interactive activities, and real-world examples, the ESSPI tool could empower students to engage with sustainable energy solutions, potentially bridging the gap between academic knowledge and practical application. This experience may equip students with the skills and insights needed to manage projects effectively in a dynamic and ever-changing world, positioning them to contribute positively to global energy challenges.

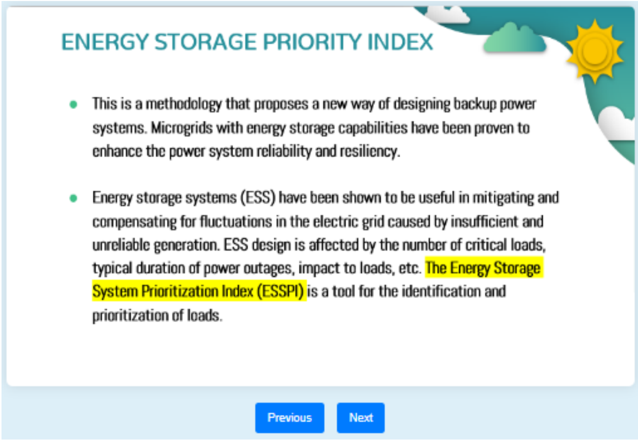

Fig. 2: Dynamic slideshows with explanations about ESSPI.

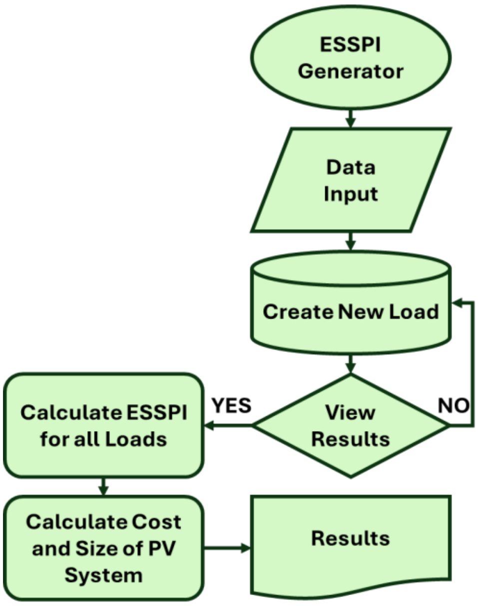

Fig. 3: Flow Chart for the app functions.

Table 1: Appliances category and classification

Appliances	Stove	House lighting	Cellphone (charge)	Refrigerator
Power consumption	7.2 kW	0.740 kW	0.10 kW	0.230 kW
Category	Non-essential	Essential	Discretionary	Critical
Max critical recovery time	1 day	1 day	1 day	1 day
Complete recovery time	1 day	1 day	1 day	1 day

Table 2: Data for cost analysis input by user

User Input	
Budget	$10,000
Peak Sun Hours	1
Battery Type	Lead
Duration (hr)	1

Project budgeting is given vitality by dynamic cost estimation, which could turn it from a static figure into an interactive teaching tool. This real-time feedback method has the potential to enable students to see the direct impact of their decisions on the project's budget, resulting in a more interesting and informative learning experience.

As new elements are added or parameters are changed, the system continuously recalculates the total cost in real-time, serving as a dedicated financial calculator for the project. The user can get the amount estimated to maintain their system and see how the cost obtained for each case relates with their initial budget with dynamic visual aids. Using the data from the test case. Figure 4 demonstrates how the progress bar is depicted in the tool; to keep track of the budget and how much it is going to cost to give energy to the appliances.

V. Scenario Based Learning

Scenario-based learning is a pedagogical approach in STEM [3] education that immerses students in realistic situations. Unlike traditional methods that focus on rote memorization, scenario-based learning challenges students to apply their scientific, technological, engineering, and mathematical knowledge to solve problems encountered in these scenarios. Through this active approach, students develop critical thinking, problem-solving, and collaboration skills – essential for success in STEM fields.

To get an idea of which appliances STEM students would prioritize in a blackout situation, the team conducted an online survey given to 32 STEM students. The survey participants ranged from 18 to 24 years old, graduated or pursued an engineering or STEM major.

The scenario relatable to a real-world situation that STEM students might encounter. Ranking the appliances forces them to draw upon various STEM concepts. For example, they need to consider the science behind how each appliance functions (think heat generation or providing light). They grapple with the technology aspect by recognizing how reliant each appliance is on electricity. Engineering principles come into play when evaluating what's most critical during a blackout – light, communication, or sanitation? Some students might even consider the math side of things, comparing appliance power consumption when making their rankings. This scenario pushes students to critically analyze these factors and prioritize appliances based on their importance for well-being. Figure 5 provides a graphical representation of various student selections as they analyze survey data. It helps identify areas where students might need further explanation, for example, the importance of refrigeration. Allowing the team to tailor future lessons or activities around similar scenarios to solidify their understanding. It actively engages students, promotes critical thinking, and reinforces the relevance of STEM knowledge in real-world situations.

The survey also explored student opinions on renewable energy, just 30% of them use solar power for their house currently. It also delved into their thoughts on how combining energy storage (ESSPI) and solar power, potentially with other renewables, could contribute to a sustainable future. By examining both parts of the survey, it helped understand the students' STEM knowledge and views on renewable energy. The scenario-based learning approach assesses their ability to apply STEM concepts, while the renewable energy section provides insights into their understanding of these critical technologies and their potential benefits. This data can be used to tailor future learning experiences, addressing any knowledge gaps in renewable energy or scenario-based problem-solving.

The goal is to develop a tool that helps the students understand the rationale behind their decisions and propose backup system designs tailored to the prioritized loads. Potentially it could refine the students' understanding of emergency preparedness and the role of renewable energy solutions, such as Photovoltaic (PV) systems, in mitigating the impact of blackout.

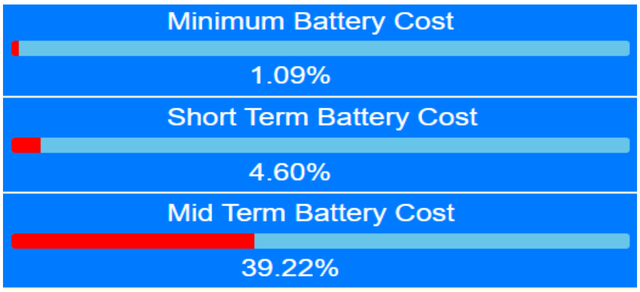

Fig. 4: Dynamic progress bar related to the project's budget and the cost of each section.

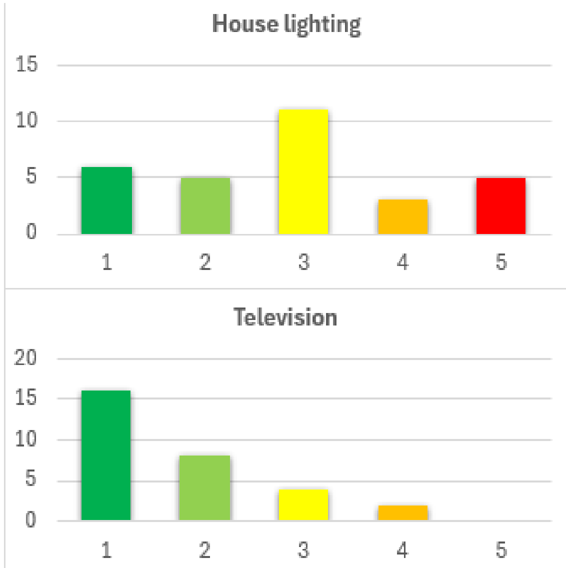

Fig. 5: Graphic representation of STEM student's selections on house lighting and television appliances.

VI. Impact In Stem Education

The ESSPI tool could be considered as a vital educational platform for STEM students, focusing primarily on renewable energy technologies and emergency preparedness. By integrating critical data such as solar irradiance, backup duration, and power consumption needs, the tool can calculate the requisite size and cost of photovoltaic (PV) systems and batteries.

This feature not only introduces students to the practical aspects of renewable energy solutions but also immerses them in detailed cost analyses. Such analyses provide a comprehensive understanding of the economic factors influencing the deployment of backup systems, thereby equipping students with valuable insights into the sustainability and financial viability of solar energy solutions.

The ESSPI tool's learning experience also emphasizes critical thinking and problem-solving skills. Students are asked to prioritize elements using a set of criteria that include power consumption rates, recovery time, and the subjective significance of keeping specific systems operating during power outages. This practice fosters a proactive perspective among pupils, helping them to think critically about energy management and catastrophe preparedness. Furthermore, the tool's position in STEM outreach and engagement makes it an excellent resource for young scholars interested in renewable energy technology and sustainability, as well as encouraging future inventions and environmental stewardship.

The following benefits are based on ABET's list of student outcomes [15]:

A. Create awareness about possible electrical disasters and how to prepare for them with backup systems.

"An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts". By guiding users through the process of prioritizing loads and designing backup systems, the tool instills a proactive mindset regarding emergency preparedness. It may equip individuals and communities with the necessary knowledge to mitigate the impact of potential disasters, highlighting the importance of public health, safety, and welfare. Additionally, the tool provides STEM students with detailed insights into the size and cost of batteries and solar panels needed for a resilient and trustworthy backup system. It calculates these requirements based on total power consumption and the operational duration required, offering practical learning experience in designing energy solutions that are economically viable. This comprehensive educational method aims to prepare students to create systems that enhance community resilience and safety.

B. Introduce them to cost analysis and renewable energy to power their household appliances.

"An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions." The tool could serve as an educational platform for understanding photovoltaic (PV) energy. By integrating user inputs such as location, sunlight hours, and backup duration, the tool not only could teach the user to analyze and interpret data effectively but also encourages the development and conduct of appropriate experimentation. This interactive approach helps students apply engineering judgment to draw conclusions, optimize PV system sizes, and determine necessary battery capacities, thereby providing a hands-on learning experience in renewable energy technologies.

In addition to helping students design a backup system, the tool also could enhance their understanding of cost analysis. It guides students through performing a simple cost analysis, explaining the method of unit cancellation and other cost-related calculations. This feature equips students with general knowledge and practical skills necessary for economic evaluation in engineering projects.

C. Critical Thinking and Problem-Solving

"An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics." The tool not only helps students to think critically about load priority, considering elements like power consumption, recovery time, and subjective relevance, but it may also challenge them to discover, create, and solve complicated engineering issues. It pushes students to solve actual problems in emergency preparedness and energy resilience by applying engineering, physics, and mathematics principles. Furthermore, the tool's design requires students to continually acquire and apply new information, adapt to changing technical needs, and employ suitable learning methodologies.

D. STEM Outreach and Engagement

"An ability to communicate effectively with a range of audiences". The tool could be an excellent asset for STEM outreach activities, including students in meaningful projects connected to energy resilience and sustainability. It may be utilized in classrooms, STEM clubs, or outreach activities to pique students' interest in STEM subjects and spur future innovation in sustainable energy solutions. This dual emphasis not only enhances their comprehension of technical subjects, but it can also improve their communication skills, which are critical for communicating complicated ideas effectively and convincingly in a variety of situations.

E. Practical Application of STEM Concepts

"An ability to acquire and apply new knowledge as needed, using appropriate learning strategies". ESSPI provides a real-world application of STEM concepts, particularly in energy storage, power systems, and renewable energy technologies. It allows students to see how theoretical knowledge translates into practical solutions for emergency preparedness and energy management.

VII. FUTURE WORK

The ESSPI tool is being developed to improve students' understanding of the complex decision-making processes associated with the design of energy backup systems. Subsequent versions of the tool will aim to enhance users' comprehension of the underlying concepts of their decisions and optimize backup systems to efficiently handle prioritized loads. The team hopes to offer a more user-friendly and complete platform that supports a variety of instructional and real-world scenarios by improving the user interface and extending the tool's capabilities with continuous data collecting.

Additionally, enhancing the tool's instructional elements will be a priority. This entails creating interactive modules and more thorough educational materials that clarifies the underlying assumptions behind each decision-making process. These improvements will use the scenario-based learning framework to potentially increase students' comprehension of disaster preparedness.

VIII. CONCLUSION

In conclusion, the ESSPI tool emerges as a powerful resource for both STEM education and practical applications in emergency preparedness and renewable energy exploration. By providing a user-friendly platform for prioritizing electrical loads, designing backup systems, and analyzing the viability of renewable energy solutions, the ESSPI tool empowers users to take control of their energy security. This contrasts sharply with the traditional, lecture-based approach to STEM education. The ESSPI tool fosters a hands-on learning experience, akin to how a team of engineers would design a backup system in the real world. This practical approach cultivates critical thinking, problem-solving skills, and a deeper understanding of renewable energy technologies.

Furthermore, the ESSPI tool offers a starting point for further STEM research endeavors. Integrating the tool into existing STEM curriculums could be a valuable step, allowing educators to assess its effectiveness in improving student learning outcomes in areas like renewable energy, energy management, and disaster preparedness. Additionally, the research could explore more into expanding the tool's functionalities to encompass a wider range of disaster scenarios beyond blackouts. By incorporating these advancements, the ESSPI tool can become an even more comprehensive resource for individuals and communities seeking to enhance their energy resilience and preparedness.

ACKNOWLEDGMENT

This work was sponsored in part by NASA Cooperative Agreement 80NSSC20M0052. Also, by the "Consortium for Hybrid Resilient Energy Systems (CHRES)" with grant number DE-NA0003982 and given by the National Nuclear Security Administration part of the US Department of Energy. Also, this work was sponsored in part by the Minds2CREATE Research Team from the University of Puerto Rico-Mayaguez. Finally, this project was sponsored in part by the "Universal Interoperability for Grid-Forming Inverters (UNIFI) Consortium" given by the US Department of Energy.

REFERENCES

[1] G. Lopez-Cardalda and E. I. Ortiz-Rivera, "Proposed Methodology Using the Energy Storage System Prioritization Index," 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC), Fort Lauderdale, FL, USA, 2021, pp. 2529-2533, doi: 10.1109/PVSC43889.2021.9518618.

[2] L. Colomba-Colon, N. Batista-Alvarez, G. Lopez-Cardalda and E. Ortiz-Rivera, "ESSPI as a Fast Tool for Load Prioritization on Microgrids Design," 2023 IEEE 50th Photovoltaic Specialists Conference (PVSC), San Juan, PR, USA, 2023, pp. 1-4, doi: 10.1109/PVSC48320.2023.10359955.

[3] IJCRSEE. "Scenario-Based eLearning and STEM Education: A Qualitative Study Exploring the Perspectives of Educators," International Journal of Cognitive Research in Science, Engineering and Education, https://www.ijcrsee.com/index.php/ijcrsee/article/view/270/346.

[4] ESA. "Why energy storage. Energy Storage Association," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/

[5] E. I. Ortiz-Rivera, "Economic Analysis for a PV Power System" Dept. Electrical and Computer Engineering, University of Puerto Rico, Mayagüez, PR, May 21, 2020.

[6] G. Lopez-Cardalda, M. Lugo-Alvarez, S. Mendez-Santacruz, E. O. Rivera and E. A. Bezares, "Learnings of the Complete Power Grid Destruction in Puerto Rico by Hurricane Maria," 2018 IEEE International Symposium on Technologies for Homeland Security (HST), Woburn, MA, USA, 2018, pp. 1-6, doi: 10.1109/THS.2018.8574120.

[7] DOE. "Puerto Rico Grid Resilience and Transitions to 100% Renewable Energy Study (PR100)," U.S. Department of Energy, https://www.energy.gov/gdo/puerto-rico-grid-resilience-and-transitions-100-renewable-energy-study-pr100.

[8] PR. "Act No. 17 of 2019," Commonwealth of Puerto Rico, https://bvirtualogp.pr.gov/ogp/Bvirtual/leyesreferencia/PDF/2-ingles/17-2019.pdf.

[9] ESA. "Solid electrode battery technology: Energy storage association," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/technologies/solid-electrode-batteries/

[10] ESA. "Pumped hydropower," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/technologies/pumped-hydropower/

[11] ESA. "Mechanical Electricity Storage Technology," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/technologies/mechanical-energy-storage/

[12] ESA. "Hydrogen Energy Storage," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/technologies/hydrogen-energy-storage/

[13] ESA. "Thermal Energy Storage Technology," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/technologies/thermal-energy-storage/

[14] ESA. "Advanced Energy Storage Technologies," Energy Storage Association, https://energystorageassociationarchive.org/why-energy-storage/technologies/

[15] ABET. "Criteria for Accrediting Engineering Programs, 2023-2024," Accreditation Board for Engineering and Technology, https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2023-2024/.