ISSN-e: 2737-6419

Athenea Journal
Vol.5, Issue 15, (pp. 16-28)

https://doi.org/10.47460/athenea.v5i15.71

Study of the location for the installation of a photovoltaic plant for the generation of electric power in Puerto Rico

Luz Elena Maldonado Alviarez
https://orcid.org/0009-0009-0246-9957
maldonadoluzelena20@gmail.com
Universidad Simón Bolívar
Programa Doctoral en Desarrollo Sustentable
Caracas-Venezuela

José Luciano Maldonado
https://orcid.org/0009-0004-9001-2917
jlmaldonaj@gmail.com
Universidad de Los Andes
Instituto de Computación y Estadística aplicada
Mérida-Venezuela

Received (26/09/2023), Accepted (15/02/2024)

Abstract. - The description of the geographical location study of a photovoltaic plant to be constructed in the coming years in Puerto Rico is presented as part of a major project the island has embarked upon to enhance its electrical service. This study entailed selecting the terrain based on its topography, as well as assessing the convenience of its location concerning its proximity to the national electrical interconnection system. Additionally, relevant consultations were conducted regarding the rights over the lands that will be affected by the construction of the photovoltaic plant (easements). As a result of this study, a plot of land spanning 131.56 hectares in the Juana Díaz sector, 1.59 kilometers from the electrical interconnected system, was identified as a suitable location, impacting only five easements.

Keywords: photovoltaic plants, renewable energies, sustainable development, global warming.

Estudio de ubicación para la instalación de una planta fotovoltaica para la generación de energía eléctrica en Puerto Rico

Resumen: En este proyecto se realizó un experimento de ingeniería utilizando mediciones para estimar la gravedad analítica y gráficamente. Este enfoque experimental pretende demostrar la utilidad de los principios de ingeniería para verificar los valores de la gravedad terrestre. Se emplearon métodos estadísticos para mejorar la comprensión de los conceptos subyacentes y garantizar una estimación precisa de los errores. Los principales resultados sugieren que esta práctica de ingeniería es una herramienta eficaz para evaluar la gravedad, en la que el análisis estadístico descriptivo desempeña un papel fundamental a la hora de presentar datos fiables y precisos.

Palabras clave: plantas fotovoltaicas, energías renovables, desarrollo sostenible, calentamiento global.

I. INTRODUCTION

A. Climate Change and the Need for Energy Transition

Our planet faces an urgent challenge: reducing uncontrolled greenhouse gas emissions to mitigate global warming. Ensuring a sustainable future for generations to come necessitates immediate action. The energy transition, a shift towards renewable energy sources, is a crucial objective for countries worldwide to lessen the catastrophic impact of climate change. Without concerted efforts to curb environmental pollution, this threat looms large. In this critical context, adopting concrete measures like transitioning to sustainable and renewable energy sources becomes imperative to halt the ongoing rise in global temperatures and safeguard environmental stability. Ultimately, the energy transition is a beacon of hope, guiding countries toward a more sustainable, resilient, and environmentally responsible path.

B. Case Study: Puerto Rico's Renewable Energy Ambitions

This paper presents a case study examining Puerto Rico's ambitious plans for renewable energy integration. The country aims to install and generate 3.750 MW of renewable energy capacity with an additional 1.500 MW of battery storage within the next four years [1][6]-[9]. To achieve this objective, the Puerto Rico Electric Power Authority (PREPA) will issue six Requests for Development Proposals by 2024. Fig. 1 schematically depicts these six tranches, specifying the targeted generation and storage capacity for each phase.

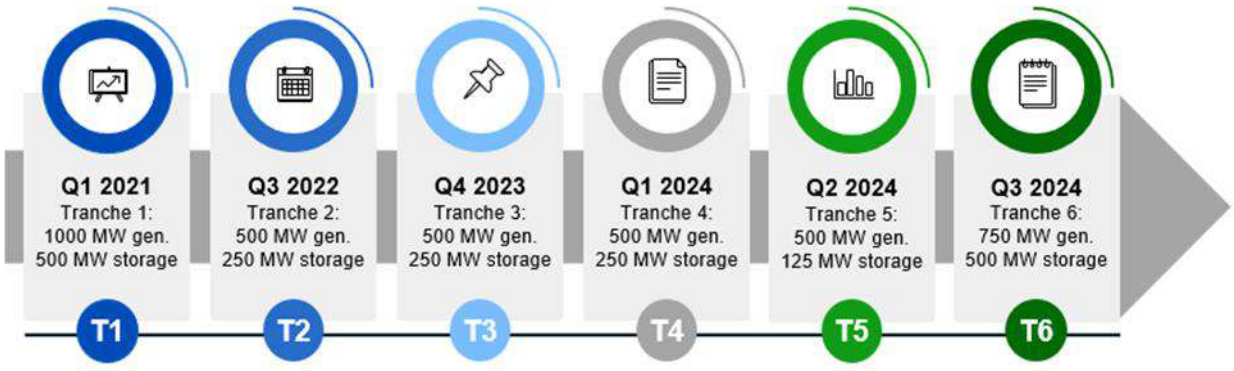

Fig. 1. PREPA Auction Plan involving the 6 tranches
Source: own.

Accion Strategic Energy Group, a Massachusetts-based energy consulting firm with over four decades of experience, has been supporting Puerto Rico's utility industry and government regulators since 2022. The company, along with its island-wide subsidiaries, is currently managing the bidding, review, and award process for Tranche 2, as illustrated in Figure 1. This process aims to select multiple projects that collectively contribute 500 MW of renewable generation and 250 MW of energy storage. Accion established a proposal submission deadline of December 5, 2022. One proposal submitted by Engineering, Procura y Construcción, a Panamanian and Puerto Rican company, focuses on a 25-year Power Purchase Agreement (PPA) to generate 30 MW in the Juana Díaz area. This project entails constructing a 30 MW photovoltaic plant utilizing bifacial panels mounted on fixed structures. Additionally, it includes a 34.5/115 kV step-up substation and a 1.59 km overhead transmission line connecting to the PREPA's TC Canas substation in Ponce (southern Puerto Rico). This paper focuses on the proposed plant's location characteristics.

The paper is structured into the following sections: Introduction, the 30 MW Generation Project for 25 Years, Management of the Photovoltaic Plant, Site Selection for the Photovoltaic Plant, Land Topography, Juana Díaz Land Boundary and Associated Data, Digital Terrain Models (DTMs) of Juana Díaz, Terrain Analysis, Easements and Results Related to the Photovoltaic Plant, and Conclusions.

II. 30 MW GENERATION PROJECT FOR 25 YEARS

This work contributes to a broader effort to establish a comprehensive, 25-year operational management plan for an electric power generation plant in Puerto Rico. Specifically, it details the design and implementation plan for the Juana Díaz 30 MW photovoltaic project. The design process incorporated a sustainability assessment, evaluating the project's environmental, economic, and social impacts. The design plan considered a review of the Puerto Rico Electric System's Administrative Management [3]. Since 1941, the Puerto Rico Electric Power Authority (PREPA) has managed the island's electricity generation, transmission, distribution, and service. The review identified deficiencies in the current system, including infrastructure deterioration, lack of environmental controls, and heavy reliance on fossil fuels (nearly 98%) [3]. Fossil fuel dependence contributes to soil degradation, water pollution, air emissions, and global warming.

On August 24, 2020, the Puerto Rico Energy Bureau issued the Final Resolution and Order on the Integrated Resource Plan of PREPA (Case No. CEPR-AP-2018-0001). This plan mandates the issuance of Requests for Proposals (RFP) tranches to procure renewable energy resources. Tranche 1 seeks at least 3,750 MW of solar PV or other renewables with 1,500 MW of battery storage, while Tranche 2 targets at least 500 MW of solar PV or renewable equivalents with 250 MW of battery storage (1,000 MWh or equivalent) [5]. The proposal described in this article falls under Tranche 2 and focuses on a 25-year Power Purchase Agreement (PPA) to generate 30 MW using photovoltaic technology in the Juana Díaz area [6, 7].

A. Photovoltaic plant management

Table 1 shows, in a general way, the activities involved in the management plan of the photovoltaic plant to be built, from the selection of the land where it will be located, to its design, construction, and commissioning for 25 years.

Table 1. Management activities of the proposed photovoltaic plant.

Nro.	Activity
1	On-site visits and development of topography studies of the selected implantation area.
2	Route from the easements of the 115 kV transmission line to its interconnection to the national energy grid.
3	Proposal for the implementation of the photovoltaic plant with an interconnection route.
4	Installation design of the photovoltaic plant with high-performance equipment.
5	Development of the management plan to manage the project for 25 years.

It's necessary to clarify the scope of this document. This work aimed to contribute to a broader project encompassing the Juana Díaz 30 MW photovoltaic plant. Here, the focus is specifically on the activities related to the land selection process management. Discussions of other project elements, such as plant design and implementation, will be addressed in separate phases of the research.

B. Selection of the site where the photovoltaic plant will be built

Following a comprehensive site analysis considering construction feasibility, the Juana Díaz sector, placed in south-central Puerto Rico, was selected to house the photovoltaic project [6, 7]. This site features irregularly distributed vegetation, including trees and herbaceous plants. Fig. 2. illustrates existing asphalt access roads suitable for transporting materials to the project location and surrounding areas. The land is currently unused for agriculture or livestock, further facilitating project development.

Photographs of the land where the plant will be developed are shown in Fig. 3.

C. Topography of the terrain

To support the initial project management plan, a topographic and photogrammetric survey was conducted in the Juana Díaz field on March 27, 2023. This survey utilized drone technology (specifically, the Mavic 2 Enterprise Advance) integrated with a Geographic Information System (GIS) to generate deliverables including contour lines, digital terrain models (DTMs), high-resolution orthomosaics, property boundaries, and land cover maps [6-9].

Through the Drone technology used, the data services specified in Table 2 were obtained.

Fig. 2. Access roads to the Juana Díaz Terrain.
Source: own.

Fig. 3. Photographs of the Juana Díaz Land where the plant will be developed.
Source: own.

Table 2. Data requested and obtained from the Drone service with their respective formats.

Aerial photographs (.JPG).
Georeferenced image (.GEOTIFF).
Records (.DXF)
3D mesh surface (.PLY and .OBJ)
Orthomosaic map (.JPG, .KLM and .PDF)

Source: own.

The location data of the Juana Díaz land where the photovoltaic plant will be installed and the data obtained from the topographic study are indicated in Tables 3 and 4.

Table 3. Location of the Juana Díaz 30 MW photovoltaic plant, Puerto Rico.

Characteristics of the location of the Photovoltaic Plant	
Municipality	Juana Díaz
Region	Juana Díaz
Country	Puerto Rico
Latitude	+18.05º
Longitude	-66.50º
Altitude	91.14 m a.m.s.l
Time zone	UTC -4

Source: own.

Table 4. Types of Files Obtained from the Topographic Survey.

Images for high-resolution mapping (.JPG).	
Videos (.MP4).	
3D models (.OBJ).	
Records (.DXF), (CAD surveying).	
Elevation models (.PDF, and .KLM)	
NVDI Vegetation Indices (.PDF)	
Orthomosaic	Ortho-mosaic (.JPG, .KLM and .PDF)
Point clouds	.CPR

Source: own.

The files indicated in Table 4 contain all the relevant information on the topography of the land where the plant will be located.

D. Boundaries of land boundaries in Juana Díaz and associated data

The area of interest was delineated using a Keyhole Markup Language (.KML) file [7]. Figure 4 depicts the territorial boundaries of the Juana Díaz sector land parcel.

Fig. 4. Boundaries of the terrain in the Juana Díaz sector.
Source: own.

A total of 4857 cartographic photographs were obtained, captured with a camera at 90 degrees concerning the ground surface in Juana Díaz. That data was acquired on two different trips, according to established flight plans. Figure 5 and Table 5 show the data for the flights executed, which were 155 minutes and 63 minutes respectively.

III. DIGITAL MODELS CREATED FROM THE JUANA DÍAZ TERRAIN

The data acquired digitally allowed the creation of different digital models of the Juana Díaz terrain, which are indicated below:

- **Point Cloud Model:** A model representing the information in the form of a point cloud was created, as shown in Fig. 6. In other words, the digitization of the Juana Díaz terrain made it possible to represent it from a file with 2 million points, showing all the existing, relevant objects on it such as roads, houses, trees, etc.

Fig. 5. Flight Plans in Juana Díaz
Source: own.

Table 5. Topographic survey flight data.

Project	Image Mapping	High Resolution	Low resolution	Flight Height	Area
Juana Díaz	4857	2 cm/px	10 cm/px	262 feet	160ha

Source: own.

Fig. 6. Juana Diaz's Point Cloud.
Source: own.

- **DXF or Contour Line Models:** From a .DXF file you could generate contour line modeling, as shown in Fig. 7, which facilitates the creation of engineering topographic plans for earthworks, slope management, roads, and other facilities. The DXF shows contour lines at a distance of 2 meters, considering that it was not prepared by traditional survey methods using theodolite or total station.

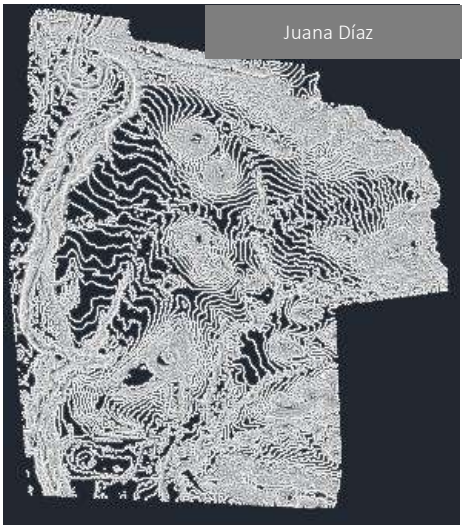

Fig. 7. Contour lines of Juana Díaz
Source: own.

Table 6. Orthomosaic accuracy in meters.

Project	X	And	Z
Juana Díaz	0.8 m	0.9 m	2.6 m

Source: own.

The files that make up the orthomosaic and elevation model are high- and low- resolution images in PDF, KLM, and TIFF formats. Fig. 8 shows the orthomosaics obtained for the project.

Fig. 8. Extension of Juana Díaz's orthomosaic at 10 cm/px.
Source: own.

- **Elevation model:** This model is the layout of a continuous area of the earth's surface, which makes it easier to understand as it represents the slope through a heat map. The accuracy of this data is based on a resolution of 2 cm/px in the high-quality file, while the low-resolution file corresponds to 10 cm/px. These files were obtained in PDF and KLM, both in high and low resolution in TIFF. Figure 9 shows the elevation model obtained for the project.

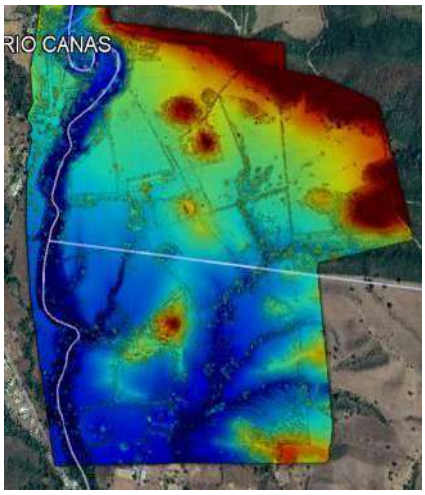

Fig. 9. Juana Díaz Elevation model.
Source: own.

- **OBJ Model:** This model provides three-dimensional (3D) terrain information through the Autodesk Online viewer. From this, data related to the dimensions and heights of the objects can be obtained. Figure 10 shows Juana Díaz's OBJ model.

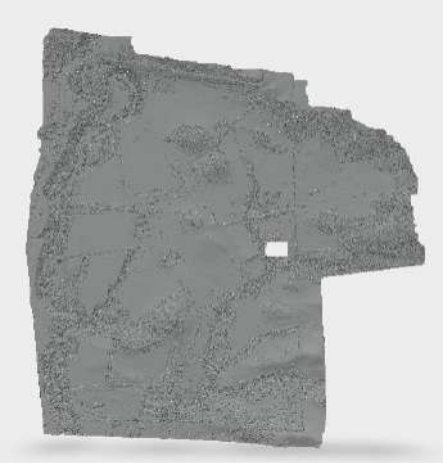

Fig. 10. OBJ Model by Juana Díaz.
Source: own.

- **NVDI Vegetation Model or Index:** Data processing revealed that 62.71 hectares of land in Juana Díaz are suitable for installing the photovoltaic plant, as shown in Figure 12. Digital technology studies confirmed the presence of hills and depressions observed during field visits, thus validating the chosen technology ([6]-[9]). Figure 13 further supports the existence of flat areas within the easement lands.

IV. ANALYSIS OF THE LAND, EASEMENTS AND RESULTS RELATED TO THE PHOTOVOLTAIC PLANT

Data processing revealed that 62.71 hectares of land in Juana Díaz are suitable for installing the photovoltaic plant, as shown in Fig. 12. Digital technology studies confirmed the presence of hills and depressions observed during field visits, thus validating the chosen technology [6]-[9]. Fig. 13 further supports the existence of flat areas within the easement lands.

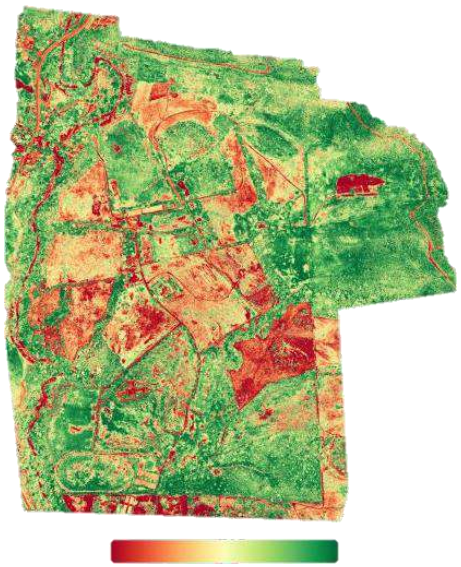

Fig. 11. Image obtained from the NDVI Vegetation Index of Juana Díaz.
Source: own.

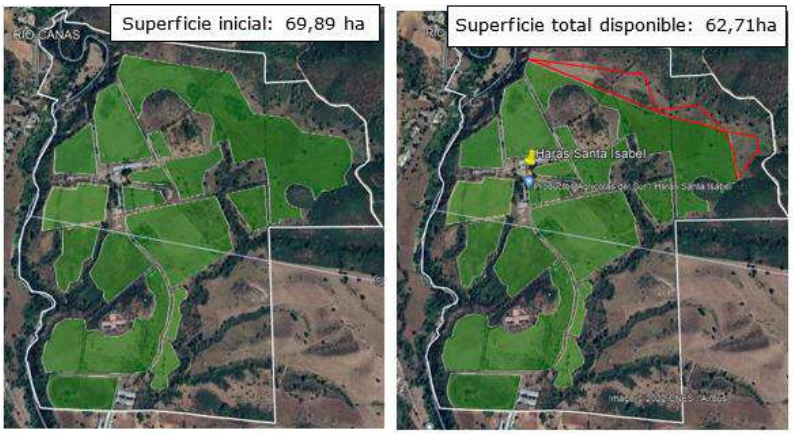

Fig. 12. Comparison of Juana Diaz's total area with the usable area.
Source: own.

The photovoltaic plant will be located on land in Juana Díaz, where the topographic study was carried out, but, additionally, the construction of a 115 kV transmission line that will be interconnected to the principal grid is required. This interconnection is guaranteed since PREPA, in the auction documents, indicates the capacity of its substations to receive energy, as shown in Table 7. It is important to note that most of these substations are located in the south of the island, highlighting a 115 kV transmission line coming from the TC Cañas substation, as shown in Table 7, which is the line to which the 30 MW Juana Díaz photovoltaic project will be interconnected, as described in this article, through a disconnecting switch using the "Breaker and a half" design, at the site shown in Fig. 14.

Fig. 13. Juana Díaz Land Easement.
Source: own.

Table 7. Available Capacity in Substations for Interconnection Renewable Energy Plants in Puerto Rico.

POI Station-Existing	POI Voltage (kV)	Maximum Size MW Solar PV Injection	Maximum Size MW Storage	Latitude	Longitude
Maunabo TC	38	10		18.0115	-65.9043
Veredas Sect.	38	10		18.2249	-66.0074
Manati Sect.	38	10		18.4424	-66.6378
Jobos TC	115	50		17.9615	-66.1395
CT Gray Hair	115	100	100	18.0128	-66.6392
Santa Isabel TC	38	10		18.022	-66.3697
Santa Isabel TC	115	10		18.022	-66.3697
Juana Díaz TC	115	150		18.0598	-66.5513

Source: PREPA.

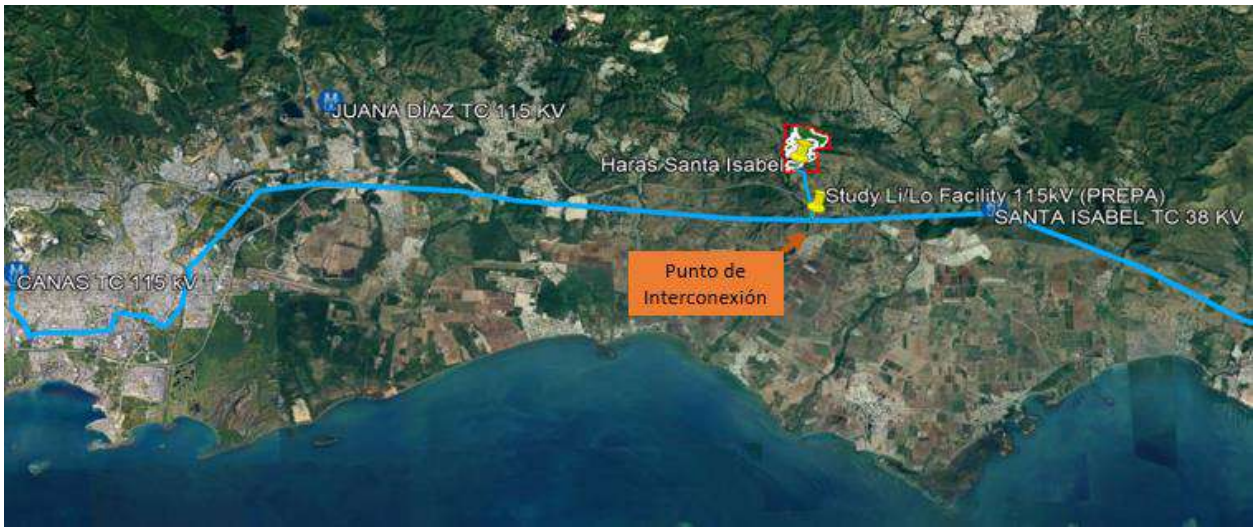

Fig. 14. Transmission Line where the interconnection will be made.
Source: own.

Fig. 15 shows in detail the most efficient route, from a technical and economic point of view, between the Juana Díaz land and the Point of Interconnection (POI) through a 1.59 km 115 kV transmission line.

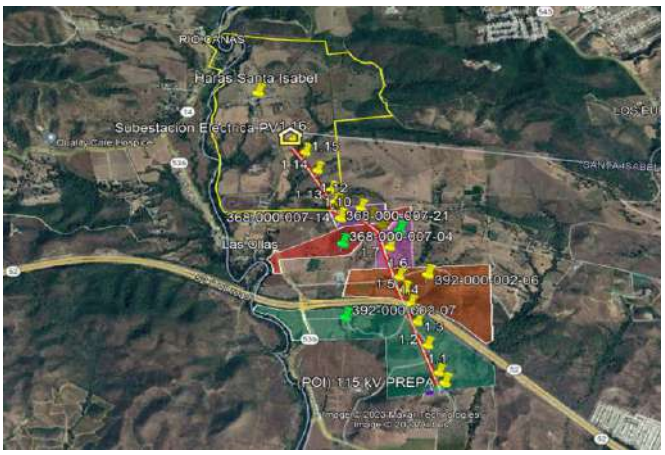

Fig. 15. Route of the 115 kV transmission line from the Juana Díaz land to the point of interconnection.
Source: own.

As can be seen in the image in Fig. 15, the transmission line will pass through five plots of land. These five lots are identified because they correspond to different owners, which were located through the CRIM (Municipal Tax Collection Center). The five affected easements are shown in Table 8.

Table 8. Number of easement parcel data on the 115 kV transmission.

Item	Parcel Number According to CRIM	Route of Power Line in Easements (m)	Surface Line Easement Area (Ha)
1	368-000-008-15	398	0.89
2	368-000-007-24	107	0.26
3	368-000-007-22	620	0.96
4	392-000-012-16	485	0.86
5	392-000-012-27	830	2.12
115 kV Power Line Easements		**2440.00**	**5.09**

Source: own.

Table 4 shows other statistical parameters. It can be noted that the dispersion given by the information is relatively small.

In these designated easements, transmission towers will be erected to support the overhead transmission line, measuring approximately 30 meters in height and 16 meters in width, until reaching the interconnection site where the interconnection disconnector will be additionally constructed.

The specific impacts on the easement lands are outlined as follows:

- **Easement 1**, 368-000-008-15: This easement necessitates the installation of 2 transmission towers.
- **Easement 2**, 368-000-007-24: Within easement 368-000-007-24. The installation of one transmission tower is mandated.
- **Easement 3**, 368-000-007-22: For easement 392-000-012-27, the installation of one transmission tower is required.
- **Easement 4**, 392-000-012-16: In easement 4, identified as 392-000-012-16, the installation of 1 transmission tower is needed.
- **Easement 5**, 392-000-012-27: Within easement 392-000-012-27, the installation of 4 transmission towers and a disconnector is necessary for grid interconnection.

CONCLUSIONS

In this study aimed at determining an optimal site for the proposed photovoltaic project, it was identified that the most suitable location is a parcel of land within the Juana Díaz sector, situated in the south-central region of Puerto Rico. This selection was made based on several key factors: the presence of tree and herbaceous vegetation, albeit not in abundance; the sufficiently flat terrain; the presence of asphalt roads providing access to surrounding lands and farms; and its proximity, at a distance of 1.59 km, to the interconnection point of the national electricity system.

Moreover, during the project's execution, only five plots of land, owned by different individuals, will be affected. Agreements were successfully negotiated with these landowners without encountering significant obstacles. The proposal for the Photovoltaic Plant's development on the identified land underwent rigorous review by PREPA, ultimately receiving approval. This endorsement not only validates the suitability of the chosen location but also underscores its potential to contribute significantly to Puerto Rico's energy supply over the next twenty-five years.

The decision to select Juana Díaz as the site for the photovoltaic plant was informed by a comprehensive assessment that considered not only topographical and logistical factors but also prioritized effective collaboration with local landowners. The presence of vegetation, coupled with the flat terrain, suggests a balanced ecological environment that will minimize the project's environmental footprint. Accessible infrastructure, including asphalt roads, ensures seamless logistics during both the construction and operation phases.

The cooperative agreements with affected landowners demonstrate a proactive approach to managing easements, reflecting a positive synergy between project development and community interests. This collaborative spirit, coupled with PREPA's approval, underscores the strategic significance of Juana Díaz as a model for sustainable development that harmonizes technical, environmental, and social considerations, promising both increased energy capacity and long-term sustainability for Puerto Rico.

REFERENCES

[1] N. Singh. (2022). Así es el plan de Puerto Rico para impulsar 3700 MW renovables junto a almacenamiento [Online]. Available: https://www.energiaestrategica.com/asi-es-el-plan-de-puerto-rico-para-impulsar-3700-mw-renovables-junto-a-almacenamiento/

[2] N. Singh. (2022). Panorama 2022: Estas son las licitaciones de energía activas, interrumpidas y pendientes en Latinoamérica [Online]. Available: https://www.energiaestrategica.com/panorama-2022-licitaciones-de-energia-activas-interrumpidas-y-pendientes-en-latinoamerica/

[3] S. Caraballo. (2019). Comentarios sobre la nueva política pública y el marco regulatorio del sistema eléctrico de Puerto Rico. Revista Jurídica UPRRP [Online]. Available: https://derecho.uprrp.edu/inrev/2019/01/31/comentarios-sobre-la-nueva-politica-publica-y-marco-regulatorio-del-sistema-electrico-de-puerto-rico/

[4] Ley Núm. 120 de 20 de junio de 2018. (2018). Ley para transformar el sistema eléctrico de Puerto Rico [Online]. Available: https://energia.pr.gov/wp-content/uploads/sites/7/2019/05/120-2018.pdf

[5] Government of Puerto Rico Public Service Regulatory Board Puerto Rico Energy Bureau. (2022). Motion to reiterate the request for entry of resolution and order detailing PREPA's role in the Tranche 2 RFP process [Online]. Available: https://energia.pr.gov/wp-content/uploads/sites/7/2022/01/Motion-to-Reiterate-Request-For-Entry-Of-Resolution-And-Order-Detailing-PREPAs-Role-In-The-Tranche-2-RFP-Process-NEPR-MI-2020-0012.pdf

[6] Acama Solar. (2011). Declaración de Impacto Ambiental: Proyecto Parque Fotovoltaico Atacama Solar 250 MW [Online]. Available: https://www.caf.com/media/6752/declaracion-de-impacto-ambiental-dia.pdf

[7] Aresol Energías Renovables. (2020). PROYECTO DE PARQUE SOLAR FOTOVOLTAICO "JUMILLA" DE 9.74MWp EN JUMILLA (MURCIA) [Online]. Available: https://transparencia.carm.es/wres/transparencia/doc/Infoub/4E20ATE007264_PSFV_PROYECTO_PARQUE_SOLAR_JUMILLA.pdf

[8] Solar Power Europe. (2023). Global Market Outlook: For solar power 2023-2027. Focus on Southeast Asia [Online]. Available: https://gycxsolar.com/wp-content/uploads/2023/10/GYCX-SolarsolarPower_Europe_GlobalMarketOutlook_for_SolarPower_2023-2027.pdf

[9] Engr.dcet. (2023). Solar Power Plant Construction and Working. [Online]. Available: https://paktechpoint.com/solar-power-plant-construction-and-working-pdf/