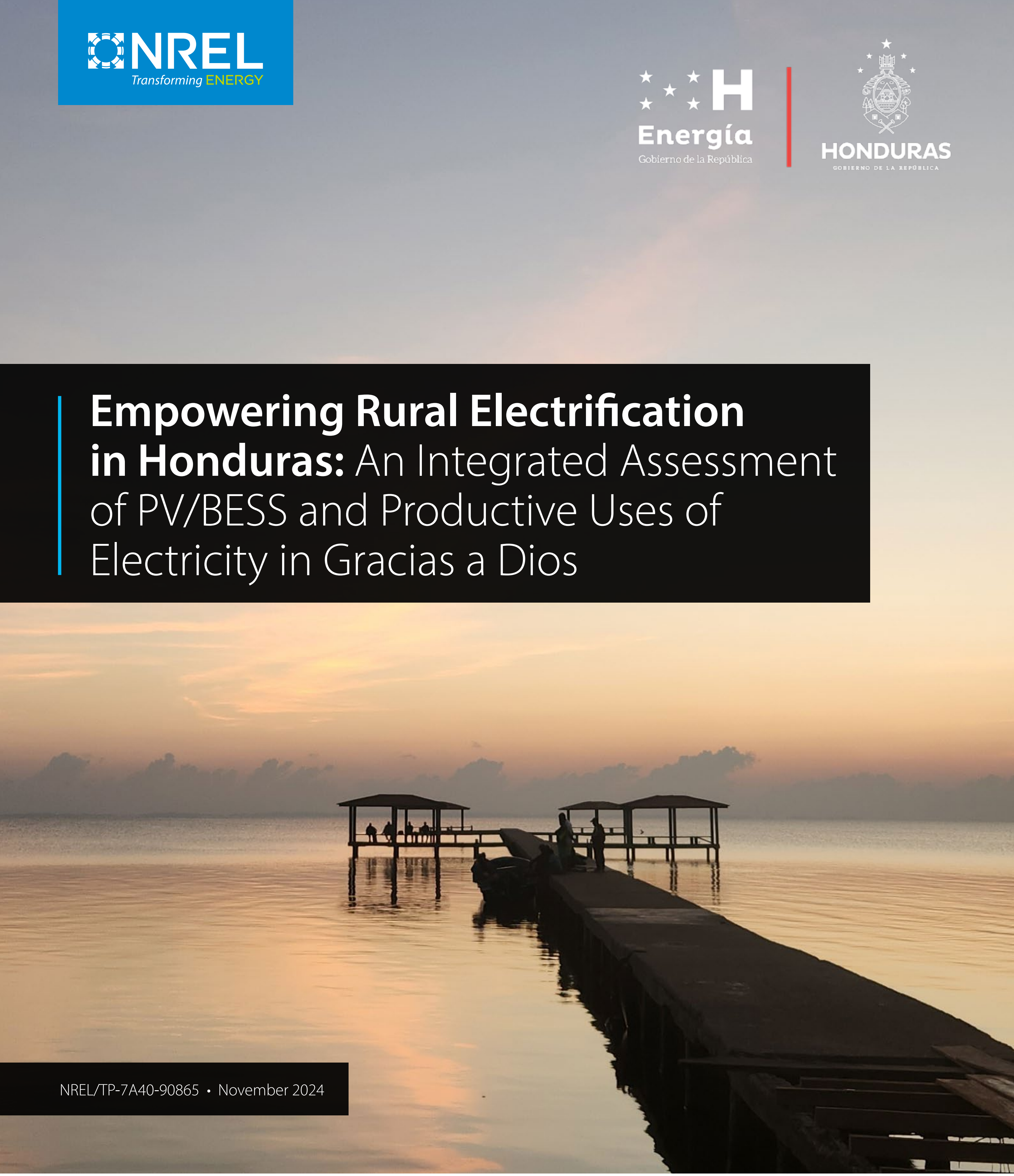

Empowering Rural Electrification in Honduras: An Integrated Assessment of PV/BESS and Productive Uses of Electricity in Gracias a Dios

NREL/TP-7A40-90865 • November 2024

Andrew Bilich, Byron Pullutasig, David Martinez Biro, and Daniel Bernal

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National Renewable Energy Laboratory

This report presents the work conducted by the National Renewable Energy Laboratory (NREL) on the rural electrification of Honduras, focusing particularly on schools and clinics and extending to support broader community development through productive uses of energy. The project was funded and directed by the U.S. Department of Energy and the U.S. Department of State and executed in close collaboration with the Government of Honduras.

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Front cover: *Laguna de Karataska, La Mosquitia, Honduras. Photo by Roberto Alfonso Zapata, SEN.*

List of Acronyms

BAU	business-as-usual
BESS	battery energy storage system
COOPESPCOL	La Cooperativa de Pescadores de Puerto Cortes
CO_2	carbon dioxide
HNL	Honduran lempira
LCOE	levelized cost of energy
NREL	National Renewable Energy Laboratory
PAUEH	Política de Acceso Universal a la Electricidad
PAUECEES	Plan de Acceso Universal a la Electricidad en Centros Educativos y Establecimientos de Salud
PUE	productive use of energy
PV	photovoltaic
REopt	Renewable Energy Optimization Tool
SEN	Honduras Secretary of Energy
USD	U.S. dollar

Executive Summary

Honduras faces significant challenges in its energy sector, particularly in rural areas where access to reliable, clean, and affordable electricity remains limited. The Honduras Secretary of Energy (SEN) manages the flagship rural electrification initiative (the Política de Acceso Universal a la Electricidad, or PAUEH [Universal Electricity Access Policy]). The PAUEH is key to addressing rural energy access, containing plans for deploying more than 170 distributed solar and hybrid mini-grid solutions (*La Gaceta* 2021).

In late 2023, as a first step toward supporting SEN's electrification efforts, the National Renewable Energy Laboratory (NREL) developed a literature review of SEN electrification policy documents and conducted a series of technical capacity-building workshops with SEN and other energy sector stakeholders in Honduras focused on using NREL's open-source REopt® tool[1] to conduct techno-economic assessments and develop least-cost optimizations for potential solar and storage mini-grid systems.

Following this initial capacity-building on mini-grid modeling, NREL worked with SEN to develop a detailed techno-economic assessment for electrifying two schools, a health care clinic, and a hospital in a hypothetical community in the department (region) of Gracias a Dios. The team analyzed this hypothetical scenario to provide broader insights that could be applicable to other similar rural communities in the region, helping inform scalable and adaptable strategies. The team used the analysis to also evaluate the business case for cold storage productive use of energy (PUE) applications for the fisheries value chain and how the incorporation of these PUE loads potentially impacts both the viability of a solar photovoltaic and battery energy storage system (PV+BESS) solutions, as well as local economic development.

Overall, the analysis highlighted the strong potential for both PV+BESS solutions and integrated PUE for supporting rural communities in Gracias a Dios. Key findings include:

- **Baseline electricity options are expensive and unreliable.** The model estimated a levelized cost of energy (LCOE) around \$0.64/kWh for small-scale gensets to provide power for the baseline schools, clinic, and hospital loads. This is still considered expensive power and comes with risks for power quality and potential damage to sensitive equipment from voltage spikes.
- **Small PV+BESS solutions can cost-effectively support baseline loads for the schools, clinic, and small hospital.** While there is an upfront cost for the development and deployment of the PV+BESS solution, operational savings from avoided generator fuel costs decrease the overall life cycle cost of the PV+BESS system compared to baseline individual small-scale gensets and result in a decrease in the LCOE by about \$0.04/kWh as well as avoided carbon emissions around 4.5 tons of carbon dioxide (CO_2)/year.
- **Adding PUE loads significantly reduces LCOE compared to the business-as-usual (BAU) baseline**. The optimized PV+BESS solution with PUE loads (Scenario 2A: 50%

[1] The REopt tool can be accessed at: https://reopt.nrel.gov/tool.

renewable energy) achieves an LCOE of $0.42/kWh, 34% lower than the $0.64/kWh of the generator-only baseline (Scenario 1).

- **Increasing the renewable energy fraction does not significantly impact costs initially, but achieving higher renewable targets requires careful consideration of trade-offs.** The cost-optimized renewable energy fraction for the PV+BESS solution + PUE load is around 50%, but increasing that fraction to 70% only increased LCOE by $0.02/kWh. However, pursuing higher renewable energy targets, such as 85% or 100%, involves more substantial capital investments, which lead to a slight increase in LCOE, as seen in Scenario 2C with 85% renewable energy ($0.47/kWh) and Scenario 2D with 100% renewable energy ($0.71/kWh). These scenarios illustrate that, while higher renewable energy generation reduces diesel reliance and emissions, it requires balancing the initial investment with long-term sustainability goals and operational benefits.
- **Electrifying schools, health care, and small PUEs can be a key anchor load for broader electrification solutions.** By deploying a "starter grid" system designed to serve specific essential services such as schools, health clinics, and businesses critical to the community's daily operations, this pilot project can cost-effectively lay the foundation for a more extensive mini-grid that could expand to include additional loads and users over time.
- **Cold storage PUE applications reduce post-harvest losses and open new market opportunities.** The ice-making and freezer PUEs can reduce post-harvest losses by almost 14% and help unlock downstream sales both to intermediaries as well as directly to secondary markets, which helps increase potential income from the same volume of fish catch. Further, ice-making itself provides a new income stream from the downstream selling of surplus ice.
- **Access to new markets and value streams can more than double income margins for fishing cooperatives.** Adding the cold storage PUE enables fish cooperatives to earn 50% more (average of 29.75 Honduran lempira [HNL]/lb. with cold storage compared to 19.5 HNL/lb. without cold storage) compared to the baseline for the same fish catch. Income is further increased through ice sales. There are added electricity costs and payments for the PUE equipment, but these are much smaller than the income growth. In total, net operating income more than doubled when cold storage was added.
- **Parallel training is a key need, as is a focus on inclusion to maximize the potential PUE applications.** It is critical to support deployment of PUE with focused programming on business/collaboration model development as well as training on both the operations and maintenance of the PUE appliances themselves (in this case, the freezer and the ice-maker) as well as the broader business model. In this case, this includes developing downstream market linkages, timing and pricing for fish catches, coordinating for utilization of ice-making and cold storage capacity, etc. This training is especially needed to bridge opportunity gaps for marginalized groups.
- **Pilot funding is needed, as well as work to bundle similar sites to create a more programmatic approach.** The modeled pilot deployment is small, so there is potential to couple the PV+BESS and PUE deployments and target concessional financing from development partners or integrate the programming into ongoing government initiatives;

however, more potential pathways may be unlocked by developing a portfolio of potential projects and accompanying PUEs.

By assessing the potential for deploying integrated PV+BESS systems to both support critical community services like education and health care, as well as the potential for downstream enterprise and economic development, this analysis represents a first step that can help inform specific strategies for the development of pilot PV+BESS projects aligned with national priorities and sector-level planning under PAUEH.

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1 Introduction

Honduras faces significant challenges in its energy sector, particularly in rural areas where access to reliable, clean, and affordable electricity remains limited. In fact, despite the country's abundant renewable energy resources, such as solar, wind, and hydroelectric power, the electrification rate stands at about 85%, with rural regions the most underserved (SEN 2022). The rugged terrain, dispersed populations, and financial constraints further complicate efforts to expand the electricity grid.

The Honduras Secretary of Energy (SEN) manages a flagship rural electrification initiative called the Política de Acceso Universal a la Electricidad (PAUEH, or Universal Electricity Access Policy), which addresses rural energy access by planning the deployment of more than 170 distributed solar and hybrid mini-grid solutions (*La Gaceta* 2021). Included in this effort is the "Plan de Acceso Universal a la Electricidad en Centros Educativos y Establecimientos de Salud" (PAUECEES, or Universal Electricity Access Plan for Education Centers and Health Establishments) as well as the Programa de Autosostenibilidad Mediante Usos Productivos de La Electricidad en la República de Honduras (Self-Sustainability Program Through Productive Uses of Electricity in the Republic of Honduras).[2] These plans develop specific targets, analyses, and a roadmap for electrifying rural health care facilities and schools using solar and hybrid solutions. The plans also highlight the opportunity to leverage the electrification of schools and health care facilities and new productive uses of energy (PUEs) to help ultimately expand mini-grid solutions to serve households and businesses in broader communities where grid expansion is not cost-effective.

In late 2023, as a first step toward supporting these plans, the National Renewable Energy Laboratory (NREL) conducted a series of technical capacity-building workshops with SEN and other energy sector stakeholders in Honduras focused on using NREL's open-source REopt tool[3] to conduct techno-economic assessments and develop least-cost optimizations for potential solar + storage mini-grid systems.[4]

Building on this, NREL worked to develop a techno-economic assessment of integrating photovoltaic (PV) systems and battery energy storage systems (BESS) into communities specifically for schools and clinics. However, this effort mirrored SEN's published report, *Centros Educativos Priorizados, 2023* (Prioritized Education Centers),[5] which already provided a high-level analysis of electrification needs across prioritized rural communities in Honduras. Following discussions with SEN's Dirección General de Electricidad y Mercados, the assessment shifted to focus on integrating PUE loads alongside the PV+BESS systems for school and health care electrification.

Specifically, with this analysis, we developed a detailed techno-economic assessment for electrifying two schools, a health care clinic, and a hospital in a hypothetical community within

[2] For more information, see https://sen.hn/wp-content/uploads/2023/05/7.5.2-Informe-Socializacion-PAMUPE.pdf.
[3] See https://reopt.nrel.gov/tool.
[4] For more information about the workshops, see https://www.nrel.gov/docs/fy24osti/89643.pdf.
[5] Not publicly available but shared directly with NREL for background for this report.

the department (region) of Gracias a Dios, which has the lowest electrification rate in Honduras (*La Gaceta* 2021). We also evaluated the business case for cold storage PUE applications for the fisheries value chain and how the incorporation of these PUE loads potentially impacts both the viability of the PV+BESS solutions as well as local economic development. This aspect of the analysis is particularly relevant for coastal communities in Gracias a Dios, where fishing is a significant activity within the local economy, and the lack of cold-chains is a critical barrier for local economic development for fisheries.

While focusing on technical and economic factors, we also recognize the importance of considering local traditions, community values, and cultural practices in the design and implementation of electrification efforts. We acknowledge the need for local input and equitable participation of all community members, including women, Indigenous populations, and native peoples. Integrating these considerations into both the technical solutions and the roles, responsibilities, and decision-making processes can contribute to stronger community ownership and long-term success of electrification projects.

By assessing the deployment of PV systems integrated with BESS, with this analysis, we aim to ultimately develop projects that ensure a consistent power supply and support local needs from a school, a clinic, and PUE applications for economic development. This analysis represents a first step that can help inform specific strategies for developing a pilot PV+BESS project aligned with national priorities and sector-level planning under PAUEH.

1.1 Structure of the Report

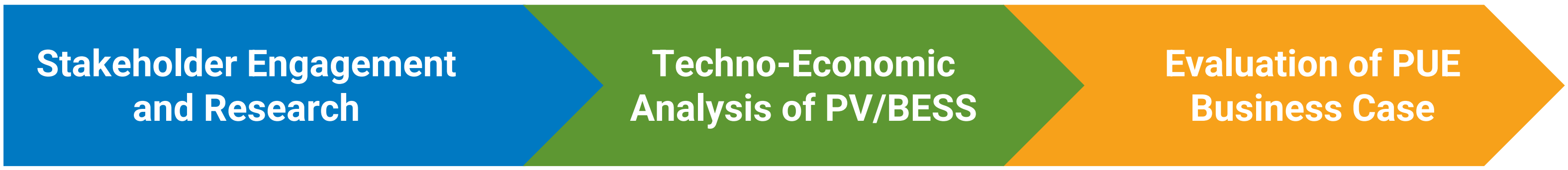
The report is structured as follows:

- **Approach**: Overview of the multi-step approach for the techno-economic assessment, including stakeholder engagement, analysis of PV+BESS systems, and evaluation of the PUE business case.
- **PV+BESS Systems for Schools, Clinics, and PUE Load**: Details the methodology, key assumptions and inputs, results, and key considerations for the high-level techno-economic analysis of potential PV + storage mini-grids to support both baseline loads for the schools, clinic, and hospital, as well as estimated loads for potential cold storage needs to support fishing production in the hypothetical community in Gracias a Dios.
- **PUE Business Case for Fisheries Cold Storage**: This section provides a high-level analysis of a potential cold storage PUE business case for the cold storage deployment to support fishing groups in the Gracias a Dios cooperative, including methodology and assumptions, results, key limitations, and considerations.
- **Financing Pathways**: High-level discussion of potential financing pathways for the initial PV+BESS mini-grid and PUE equipment.
- **Key Findings and Discussion**: Synthesis of key considerations and findings from the solar and PUE analyses above.

- **Next Steps**: An overview of potential next steps for follow-on analysis and support to advance and scale potential pilot projects for integrated electrification and PUE in Honduras.

2 Approach

The project followed a three-step approach to develop the overall techno-economic assessment of the school and health care electrification and parallel potential PUE applications for cold storage in the fisheries value chain (Figure 1).



Engagement with local stakeholders from the Gracias a Dios Department, facilitated by SEN to better understand the power needs of the schools, clinic, and hospital as well as key assumptions, operating constraints, and opportunities related to deploying cold storage to support the fisheries value chain. This was augmented heavily by the existing stakeholder engagement and research as part of ongoing efforts from SEN related to electrification for schools and health care.

Development of a high-level techno-economic analysis of potential PV + storage mini-grids to support both baseline loads for the schools, clinic, and hospital as well as estimated loads for potential cold storage needs to support fishing production in the hypothetical community in Gracias a Dios using NREL's REopt tool. Analysis includes a comparison of different PV+BESS configurations against the baseline small genset usage across key metrics like capital cost, LCOE, and carbon.

Evaluation of the business case for ice-making and cold storage for the fisheries value chain including impact on post-harvest losses, market development, costs and revenue for fishing cooperatives, and other enabling factors like training, business model development, and integration of marginalized groups.

Figure 1. Overview of three-step approach

Given the level of detail for both the techno-economic analysis of PV+BESS and the evaluation of the PUE business case, each section details its own specific methodologies, assumptions, results, limitations, and key considerations, which are then synthesized in the discussion section at the end. The details and learnings of the stakeholder engagement and research step (particularly key inputs and assumptions on health care and education electrification needs from the ongoing SEN processes and the fisheries value chain data from the conversation with stakeholders in Gracias a Dios) are outlined in the methodologies for the individual sections.

3 PV+BESS Systems for Schools, Clinics, and PUE Load

This section presents a techno-economic analysis of potential PV+BESS with diesel generators to support both baseline and PUE loads in a hypothetical community in Gracias a Dios. Our analysis focuses on meeting the energy needs of schools, including a small school (4–6 multipurpose rooms such as classrooms, kitchens, and office spaces) and a medium school (7–10 multipurpose rooms), as well as health care facilities such as the Unidades de Atención Primaria en Salud Clinic and the Centro Integral de Salud Hospital. These facilities make up the mini-grid that would provide refrigeration for local fisherfolk. The sections below detail the methodology, key assumptions and inputs, results, and key considerations.

3.1 Methodology and Assumptions

We incorporated data from local experts, research studies, and scenario modeling in the analysis using the NREL REopt tool. Key assumptions include the size and energy consumption patterns of various community facilities and the requirements for ice and refrigeration based on local fish production.

3.1.1 Estimation of Fish Production, Ice-Making, and Refrigeration Requirements for PUE

Based on the example case study for the Honduran fishing cooperative La Cooperativa de pescadores de Puerto Cortes (COOPESPCOL) (MiPesca 2020), in this study, we assumed an average of 200 members of the fishing cooperative in the hypothetical community. Further, we assumed the weekly fish catch to be approximately 1,530 pounds (lbs.), equivalent to 79,561 lbs. per year. This served as the basis for calculating the required ice and refrigeration systems.

We approximated the density of fish to that of water, at 62.4 lbs. per ft^3, allowing the calculation of the volume of fish caught annually as follows in Equation 1:

Equation 1. Annual Volume of Fish Catch

$$\textbf{Weekly fish catch} = 1{,}530\ lbs$$

$$\textbf{Annual fish catch} = \frac{1{,}530}{week} * 52\frac{weeks}{year} = 79{,}561\ lbs/year$$

$$\textbf{Daily fish catch} = \frac{1{,}530}{7\ days} = 218.57\ lbs/day$$

$$\textbf{Daily volume }(\mathbf{ft^3}) = \frac{218.57\frac{lbs}{day}}{62.4\frac{lbs}{ft^3}} = 3.5\frac{ft^3}{day}$$

$$\textbf{Annual volume (ft}^3\textbf{)} = \frac{79{,}561\ \frac{lbs}{day}}{62.4\frac{lbs}{ft^3}} = 1{,}275\frac{ft^3}{year}$$

Peak fishing occurs from August to January, which is 6 months or approximately 182 days. During this period, it is assumed that 80% of the annual catch is harvested. The remaining 20% is caught during the off-peak period (February to July).[6] This adjustment impacts the daily fish catch calculations and is used to size the need for cold storage (Equation 2):

Equation 2. Daily Peak Season Catch

$$\textbf{Annual peak season catch} = 0.80 \times 79{,}561\ lbs = 63{,}648\ lbs$$

$$\textbf{Daily peak season catch} = \frac{63{,}648\ \text{lbs}}{182\ days} \approx 350\ lbs \text{ per day}$$

The daily ice production requirement is determined based on the average daily fish catch and a typical 1:1 ice-to-fish ratio for tropical fish (1 pound of ice per 1 pound of fish) (Hanjabam and Raj, 2017).[7] This ice is used by fishers to keep the fish cool while they are fishing and transporting them back to the community. The corresponding daily ice requirement is shown in Equation 3.

Equation 3. Daily Ice Requirement

$$\textbf{Daily ice requirement} = 350 \text{ lbs. of fish per day} * \frac{1\ lb.of\ ice}{1\ lb.of\ fish} = 350 \text{ lbs. of ice per day}$$

To determine the required capacity of the ice maker, we assume that the device operates continuously over 24 hours, using the Euhomy commercial ice maker (Ubuy n.d.) with the capacity to produce 99 lbs. of ice in 24 hours (Equation 4).

Equation 4. Ice Makers To Meet Production Need

$$\textbf{Production rate needed} = \frac{350\ lbs.\ of\ ice\ per\ day}{99 \text{ lbs. of ice per day}} \approx 3.5 \text{ ice makers}$$

$$\textbf{Number of Ice Makers Needed} = 4$$

Fishers who venture out to sea for extended periods or transport fish to downstream markets need sufficient ice to preserve their catch and prevent spoilage. It is crucial that the ice remains available throughout the fishing and market trips to maintain the quality of the fish. To meet this need, continuous ice production is essential, and the ice must be stored properly to ensure a steady supply. Assuming the ice has a density of about 57.2 lbs. per ft^3. (based on typical ice density), the volume of ice produced daily is shown in Equation 5.

[6] Based on conversations with local stakeholders in Gracias a Dios.

Equation 5. Volume of Ice Produced Daily

$$\textbf{Volume of ice produced daily} = \frac{350\ l\ bs}{57.2\ ft^3} \approx 6.1\ ft^3$$

To accommodate at least one day's production and provide a buffer for any contingencies, ice storage units (e.g., coolers or ice boxes) should be able to store at least 6.1 ft^3 of ice. This ensures that fishers have a reliable supply of ice to preserve their catch during long hours at sea, thereby maintaining the fish's quality and market value.

For fish refrigeration, we assume that each day's catch needs to be stored for 3 days before it is sold. This means that on any given day, there will be 3 days' worth of fish in storage. We assume the use of a freezer with a capacity of 27 ft^3 (GRS n. d.). The number of freezers required is calculated as follows (Equation 6).

Equation 6. Freezers To Meet Cold Storage Need

$$\textbf{Daily cold storage requirement (peak)} = 350\ lbs\ of\ fish\ per\ day\ \times 3\ days = 1{,}048.35\ lbs \text{ of fish}$$

$$\textbf{Cold storage volume (peak)} = \frac{1{,}048.35\ lbs}{62.4\ lbs\ per\ ft^3} \approx 16.8 ft^3$$

$$\textbf{Number of freezers (peak)} = \frac{16.8\ lbs\ per\ ft^3}{27\ ft^3\ per\ freezer} = 1 \text{ freezers}$$

This ensures that at any given time, there is enough storage capacity to handle the fish caught over 3 days, allowing the community to manage their fish stores effectively.

3.1.2 Description of Mini-Grid Loads

As described above, with this analysis, we evaluated potential PV+BESS with diesel generators mini-grids for four end users: a small school (4–6 classrooms), a large school (7–10 classrooms), a health care clinic, and a hospital. Appliance usage data, including power consumption, operational hours, and start time variability, are used to model realistic load profiles.

We determined the baseline loads for these facilities using a bottom-up approach. This involved estimating the electrical loads of available appliances, as guided by PAUECEES and consultations with local fishing groups in Gracias a Dios. The parameters for each appliance include:

- **Power consumption:** The average power draw (in watts) when the appliance is in use.
- **Quantity:** The number of each type of appliance present.
- **Days of operation per week:** How many days per week the appliances are typically used.
- **Hours of operation per day:** The average number of hours the appliances are active each day.
- **Maximum daily load:** The peak load recorded during the operational hours.

Appliance tables for end uses are included in Appendix A.

3.1.3 Modeling Human Behavior in Load Variability

To accurately represent real-world conditions, we incorporated random variations in appliance start times. This variability reflects the unpredictable nature of human behavior, recognizing that activities do not adhere strictly to a fixed schedule. The start time variation introduced randomness to simulate this behavior. Local experts provided feedback on the start time and variation based on local knowledge of how those sites normally operate.

The defined parameters are:

- **Start time**: The typical start time for the appliance usage.
- **Start time variation**: The potential deviation from the typical start time, introducing randomness to simulate actual usage patterns. For instance, a microwave expected to start at 12 p.m. with a variation of ±1 hour could realistically start any time between 11 a.m. and 1 p.m.

Figure 2 presents weekly energy load profiles for various devices (*La Gaceta*. 2021), generated using custom modeling code based on input from local experts about the potential start time variation of each device. The total load includes randomized start times and maximum wattage constraints to reflect realistic device usage patterns.

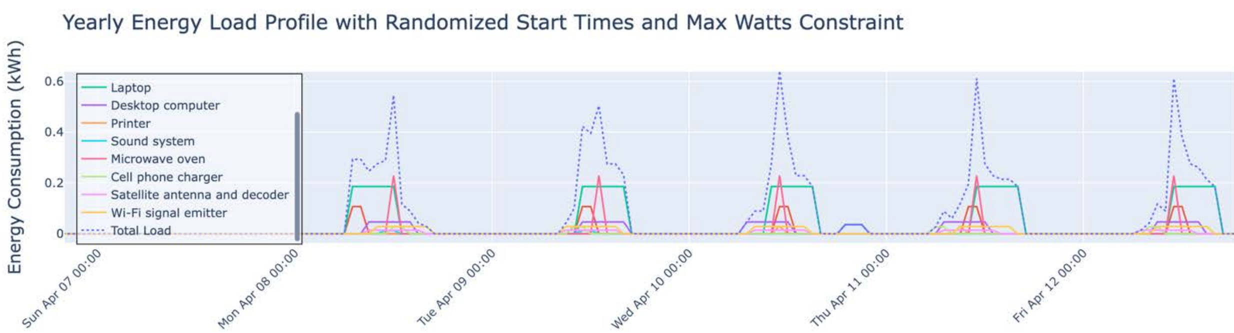


Figure 2. Example of load variation modeling for school with 7–10 classrooms

The custom modeling approach, developed with the guidance of local experts, ensures that the energy usage patterns accurately reflect local conditions and behaviors. This information is crucial for designing and optimizing energy systems, such as microgrids, to ensure they can meet the community's needs efficiently. The use of randomized start times and wattage constraints helps capture the variability in daily usage, providing a more comprehensive understanding of the potential challenges and requirements for energy system planning.

3.1.4 PUE Loads

For PUE loads, we included one freezer (250 W) and four ice makers (total of 1,150 W) in the analysis, assumed to operate continuously throughout the year. During peak fishing seasons, these are primarily used for fish refrigeration, while during off-peak times they may support other uses such as storing lake/river fish, meat, or agricultural products. The PUE loads are aggregated into the overall load for the four sites.

The resulting load profiles for the individual end users and PUEs are illustrated in Figure 3 and Figure 4. Figure 3 presents a stacked area chart showing 1 week of electrical loads across different facilities and the constant load from the PUE appliances. Figure 4 compares the baseline loads with PUE-adjusted loads, illustrating the impact of PUE integration on the mini-grid's overall energy demand.

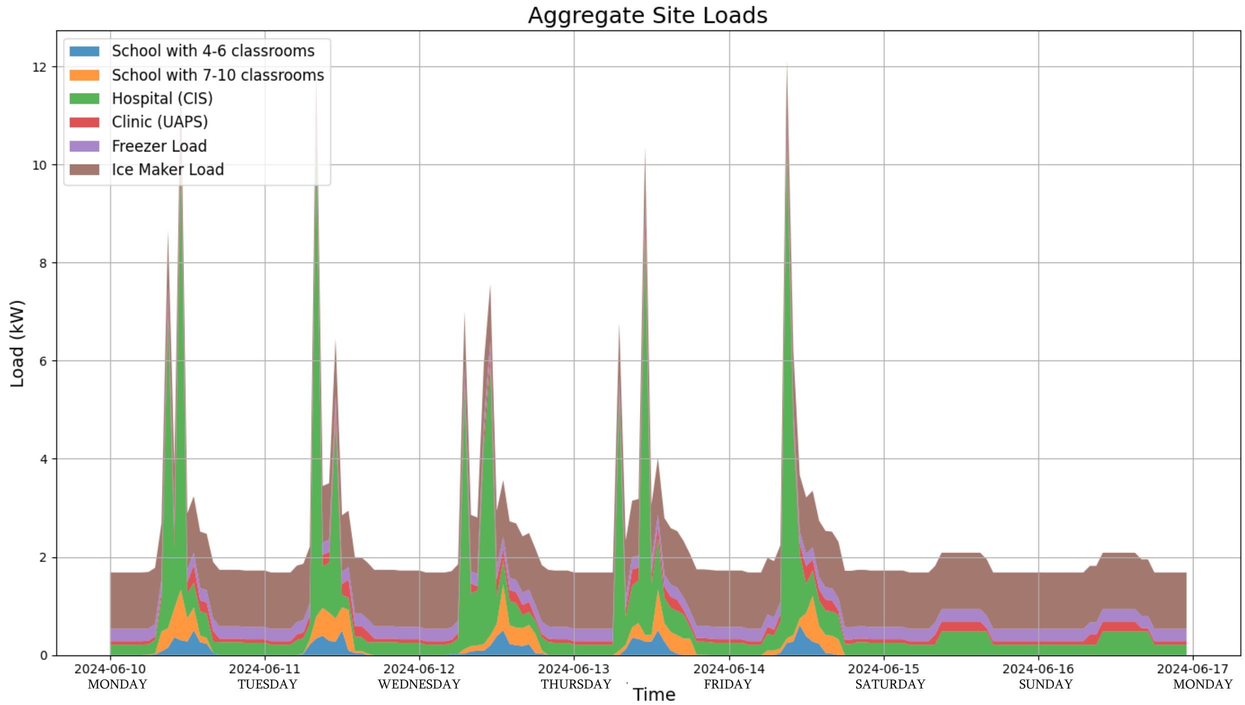


Figure 4. Baseline and PUE-adjusted electrical loads over a week (Monday – Sunday)

3.1.5 Scenario Descriptions

In this analysis, we explore several scenarios to address the energy needs of schools, a clinic, a hospital, and PUE loads in the community. There are two scenario groups (business-as-usual [BAU] load served by small gensets or a renewable mini-grid, and BAU+PUE load served by a renewable mini-grid). For the two mini-grid scenario groups, we also considered four different mini-grid configurations for different levels of renewable energy (pure cost-optimized solution, minimum 70% renewable, minimum 85% renewable, and 100% renewable) to allow for a deeper exploration of trade-offs between carbon and cost objectives. The scenarios are detailed below.

- **Scenario 1: Small-Scale Gensets (BAU Load)**
    - This baseline scenario uses individual small-scale diesel generators to meet the energy demands of a small school (4–6 classrooms), a large school (7–10 classrooms), a health care clinic, and a hospital. This scenario represents the BAU approach without incorporating renewable energy sources.
- **Scenario 1A: PV+BESS + Generator Mini-Grid (BAU Load)**
    - A hybrid mini-grid system combining PV panels, BESS, and diesel generators. This configuration aims to balance the use of renewable energy with diesel generation, thus reducing fuel consumption and associated emissions while ensuring a reliable energy supply.

- **Scenario 1B: PV+BESS + Generator Mini-Grid (BAU Load, 70% Renewable Energy)**
    - Similar to Scenario 1A, this scenario includes a constraint to achieve at least 70% renewable energy generation. It involves additional PV and BESS capacity to meet this target, reducing reliance on diesel fuel and lowering emissions.
- **Scenario 1C: PV+BESS + Generator Mini-Grid (BAU Load, 85% Renewable Energy)**
    - Building on Scenario 1B, this scenario increases the renewable energy generation to 85%. The configuration includes additional PV and BESS capacity to achieve this higher renewable energy generation, further minimizing diesel usage and emissions while slightly increasing capital costs and LCOE.
- **Scenario 1D: PV+BESS + Generator Mini-Grid (BAU Load, 100% Renewable Energy)**
    - This scenario pushes the renewable energy generation to 100%, eliminating reliance on diesel generators entirely. It involves the largest PV and BESS capacities to meet all energy demands, reflecting a significant capital investment and higher LCOE but with the benefit of zero emissions from diesel generators.
- **Scenario 2A: PV+BESS + Generator Mini-Grid (BAU + PUE Load)**
    - This scenario expands on the BAU load by integrating additional PUE loads, including refrigeration and ice-making facilities, which increase the overall energy demand. The scenario assesses the impact of these additional loads on system configuration, costs, and environmental metrics.
- **Scenario 2B: PV+BESS + Generator Mini-Grid (BAU + PUE Load, 70% Renewable Energy)**
    - Building on Scenario 2A, this scenario requires that 70% of the energy needs be met through renewable sources. The inclusion of PUE loads, coupled with a high renewable energy fraction, aims to maximize renewable energy utilization and reduce reliance on diesel generators.
- **Scenario 2C: PV+BESS + Generator Mini-Grid (BAU + PUE Load, 85% Renewable Energy)**
    - This scenario increases the renewable energy target to 85% for the BAU + PUE load. The system configuration includes additional PV and BESS capacities to achieve this higher renewable generation goal, further reducing diesel dependence and carbon dioxide (CO_2) emissions while slightly increasing LCOE.
- **Scenario 2D: PV+BESS + Generator Mini-Grid (BAU + PUE Load, 100% Renewable Energy)**
    - This scenario achieves a 100% renewable energy generation target for the BAU + PUE load, eliminating diesel fuel use. It involves the highest investment in PV and BESS capacities, resulting in zero emissions from diesel generators but with the highest capital costs and LCOE among the scenarios.

Table 1 presents the key assumptions used across all scenarios, including location-specific data and financial parameters. These assumptions are critical for ensuring accurate and consistent comparisons across different system configurations.

Table 1. Key Assumptions for REopt Scenario Modeling

Category	Details	Values	Source
Location	Latitude	15.806481	Latitude for Gracias a Dios, Honduras
	Longitude	-84.298769	Longitude for Gracias a Dios, Honduras
Financial	Operations and Maintenance Cost Escalation Rate	3%	Expected annual rate of inflation
	Electricity Cost Escalation Rate	4.8%	Regional average
	Generator Fuel Cost Escalation Rate	4%	Regional average
	Tax Rate	25%	Regional commercial average tax rate (PWC 2024)
	Discount Rate	12%	Regional average
	Analysis Years	25	PV life cycle
PV	Installed Cost Per kW (U.S. dollar [USD])	2,500	Wood Mackenzie's LATAM and Canada Solar PV System Cost Model, 2024
BESS	Installed Cost Per kW (USD)	775	NREL Annual Technology Baseline, 2024 (NREL n.d.)
	Installed Cost Per kWh (USD)	388	NREL Annual Technology Baseline, 2024 (NREL n.d.)
	Replacement Cost per kW (USD) at Year 10	440	NREL Annual Technology Baseline, 2024 (NREL n.d.)
	Replacement Cost per kWh (USD) at Year 10	220	NREL Annual Technology Baseline, 2024 (NREL n.d.)
Generator	Fuel Cost Per Gallon (USD)	3.76	Local Pricing for Juticalpa: 92.18 HNL per gallon
	Installed Cost Per kW (USD)	1,200	Wood Mackenzie Energy Storage Monitor 2024
	Replacement Cost per kW (USD) at Year 10	1,000	Wood Mackenzie Energy Storage Monitor 2024

While a specific fuel cost ($3.76 per gallon) is used in this analysis, diesel fuel prices in Honduras can vary dramatically by region and even daily, especially in remote areas like La Mosquitia in Gracias a Dios. This region, primarily accessible by water and air, often experiences significant price fluctuations due to factors such as lack of consistent regulation, high transportation costs, and local market dynamics. The diesel fuel cost used here should be considered as a snapshot, with the understanding that actual costs could fluctuate considerably. In future analyses, when specific communities are selected, it will be important to consider these factors and account for logistical challenges, such as fuel transport and storage. In addition, this price instability underscores the potential benefits of renewable energy solutions in such remote areas where diesel-dependent systems may face unpredictable operational costs.

The scenarios are evaluated against several metrics, including PV size (kW-DC), battery size (kW), battery capacity (kWh), additional generator capacity (kW), initial capital cost ($), renewable energy generation (%), annual CO_2 emissions (tons), life cycle CO_2 emissions (tons), annual load (kWh), total life cycle cost ($), and mini-grid LCOE ($/kWh).

3.2 Site-Specific REopt Results

This section presents an evaluation of the technical and economic performance of various mini-grid configurations for an aggregate community load, including two schools (one with 4–6 rooms and another with 7–10 rooms), a health clinic, and a hospital in the northeast region of Honduras. Given the community's reliance on fishing, the integration of PUEs, such as fish refrigeration and ice-making, is crucial to supporting local economic activities.

3.2.1 Results and Analysis

Our analysis of the mini-grid scenarios reveals key insights into the technical and economic performance of different configurations. The primary objective is to identify the most cost-effective and sustainable clean energy solution for an off-grid community with a distinct economic activity, such as fishing, that requires reliable power for PUE applications. The REopt modeling results for these scenarios are summarized in Table 2 (baseline data) and Table 3 (baseline + PUE data) and visualized in Figure 5 (baseline scenarios) and Figure 6 (baseline + PUE scenarios), detailing:

- **System sizing**: Includes the installed capacities for PV, battery storage, and diesel generators across different scenarios.
- **Mini-grid LCOE**: LCOE for each scenario, highlighting the cost benefits of integrating renewable energy.
- **Capital cost**: Initial investment required for each scenario, with higher upfront costs observed in scenarios with greater renewable energy generation percentages and PUE integration.

Table 2. Baseline Mini-Grid Scenario Modeling Comparison

Scenario	1. Baseline: GENERATOR Only	1A. Baseline: GENERATOR + PV+BESS	1B. Baseline: 70% Renewable Energy - GENERATOR + PV+BESS	1C. Baseline: 85% Renewable Energy - GENERATOR + PV+BESS	1D. Baseline: 100% Renewable Energy - GENERATOR + PV+BESS
PV Size (kW-DC)	-	5	5	7	11
Battery Size (kW)	-	14	14	13	14
Battery Capacity (kWh)	-	18	18	17	41
Add-On Gen. Capacity (kW)	15	3	2	2	1

Scenario	1. Baseline: GENERATOR Only	1A. Baseline: GENERATOR + PV+BESS	1B. Baseline: 70% Renewable Energy - GENERATOR + PV+BESS	1C. Baseline: 85% Renewable Energy - GENERATOR + PV+BESS	1D. Baseline: 100% Renewable Energy - GENERATOR + PV+BESS
Net Capital Cost (USD)[8]	$21,240	$32,090	$33,700	$37,110	$54,270
Annual Operations and Maintenance Cost (USD)	$300.00	$99.08	$109.13	$139.41	$190.38
Annual Generator Fuel Cost (USD)	$2,660	$995.60	$797.26	$405.75	$26.37
Renewable Energy Generation (%) of Total	-	63	70	85	99
Annual CO_2 Emissions (Tons)	7.25	2.71	2.17	1.11	0.07
Life Cycle CO_2 Emissions (Tons)	181.25	67.8	54.29	27.63	1.8
Annual Microgrid Load (kWh)	9,276.6	9,276.6	9,276.6	9,276.6	9,276.6
Total Life Cycle Cost (USD)	$42,800	$40,060	$40,290	$41,030	$55,740
Microgrid LCOE (USD/kWh)	0.64	0.60	0.60	0.62	0.85

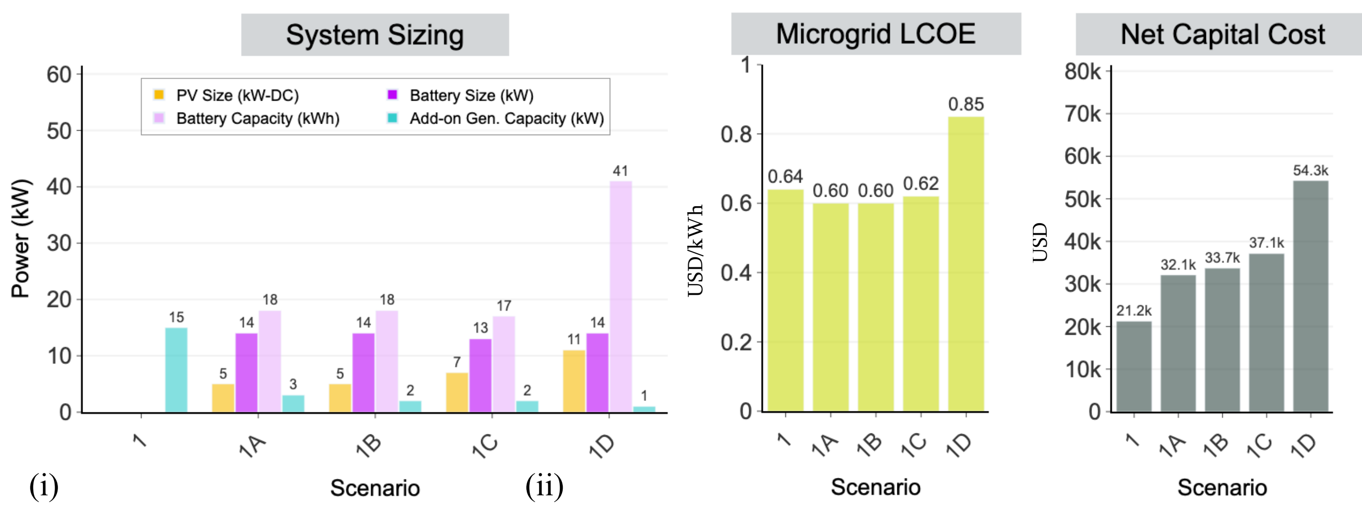


Figure 5. REopt baseline scenario comparison for (i) system sizing; (ii) mini-grid LCOE; (iii) capital cost

Scenario 1: Small-Scale Gensets (BAU Load) serves as the baseline with reliance on diesel generators. This scenario has no renewable energy generation, resulting in an LCOE of $0.64/kWh with significant generator fuel costs of $2,660 annually and 7.25 tons of annual CO_2 emissions. The total life cycle cost is $42,800 with a net capital cost of $21,240, highlighting the financial and environmental burdens associated with diesel dependency.

[8] Net capital cost does not include the acquisition, installation, or operations and maintenance of fuel storage tanks. This assumes existing fuel storage infrastructure is available, and only fuel supply to the generator is considered in operational costs.

Scenario 1A: PV+BESS + Generator Mini-Grid (BAU Load) introduces a hybrid system with 5 kW of PV, 14 kW/18 kWh of BESS, and a 3-kW diesel generator. This configuration achieves a renewable energy generation of 63%, reducing generator fuel costs to $995.60 annually and CO_2 emissions to 2.71 tons. The LCOE decreases to $0.60/kWh, and the total life cycle cost is $40,060, with a net capital cost of $32,090, reflecting the benefits of integrating renewables.

Scenario 1B: PV+BESS + Generator Mini-Grid (BAU Load, 70% Renewable Energy) targets 70% renewable energy generation by maintaining the PV capacity at 5 kW and adjusting the BESS to 14 kW/18 kWh, while reducing the diesel generator capacity to 2 kW. This scenario maintains an LCOE of $0.60/kWh, with further reductions in generator fuel costs to $797.26 annually and CO_2 emissions to 2.17 tons. The total life cycle cost is $40,290, and the net capital cost is $33,700, showing that higher renewable energy generation can be achieved with a modest increase in initial costs.

Scenario 1C: PV+BESS + Generator Mini-Grid (BAU Load, 85% Renewable Energy) increases the PV capacity to 7 kW and adjusts the BESS to 13 kW/17 kWh. This scenario achieves an 85% renewable energy generation target, reducing the LCOE to $0.62/kWh. The diesel generator fuel costs drop significantly to $405.75 annually, with annual CO_2 emissions decreasing to 1.11 tons. The total life cycle cost is $41,030, with a net capital cost of $37,110, indicating a balanced approach between cost and emissions reduction.

Scenario 1D: PV+BESS + Generator Mini-Grid (BAU Load, 100% Renewable Energy)[9] represents a 100% renewable energy generation scenario with 11 kW of PV and 14 kW/41 kWh of BESS. This configuration almost eliminates generator fuel costs ($26.37 annually) and CO_2 emissions (0.07 tons). However, the LCOE rises to $0.85/kWh due to higher capital investments, with the total life cycle cost reaching $55,740 and a net capital cost of $54,270, reflecting the trade-offs for achieving complete renewable reliance.

Table 3. Baseline + PUE: Mini-Grid Scenario Modeling Comparison

Scenario	1. Baseline: GEN Only	2A. Baseline + PUE: GEN + PV+BESS	2B. Baseline + PUE: 70% Renewable Energy - GEN + PV+BESS	2C. Baseline + PUE: 85% Renewable Energy - GEN + PV+BESS	2D. Baseline + PUE: 100% Renewable Energy - GEN + PV+BESS
PV Size (kW-DC)	-	8	12	15	22
Battery Size (kW)	-	12	13	13	12
Battery Capacity (kWh)	-	15	21	32	82
Add-On Gen. Capacity (kW)	15	5	3	2	1
Net Capital Cost (USD)	$21,240	$40,230	$49,970	$60,940	$99,670
Annual Operations and Maintenance Cost (USD)	$300.00	$177.24	$222.79	$272.82	$403.45
Annual Generator Fuel Cost (USD)	$2,660	$2,980	$1,780	$897.27	$56.04
Renewable Energy Generation (%)	-	50	70	85	99

[9] Although Scenario 1D aims for 100% renewable energy, the target was adjusted to 99% in REopt to avoid infeasible results. The generator remains in the system, but its fuel use and size are minimal enough to be disregarded.

Scenario	1. Baseline: GEN Only	2A. Baseline + PUE: GEN + PV+BESS	2B. Baseline + PUE: 70% Renewable Energy - GEN + PV+BESS	2C. Baseline + PUE: 85% Renewable Energy - GEN + PV+BESS	2D. Baseline + PUE: 100% Renewable Energy - GEN + PV+BESS
Annual CO_2 Emissions (Tons)	7.25	8.12	4.85	2.44	0.15
Life Cycle CO_2 Emissions (Tons)	181.25	202.91	121.36	61.1	3.82
Annual Microgrid Load (kWh)	9,276.6	20,620.8	20,620.8	20,620.8	20,620.8
Total Life Cycle Cost (USD)	$42,800	$63,300	$64,560	$69,370	$102,790
Microgrid LCOE (USD/kWh)	0.64	0.42	0.44	0.47	0.71

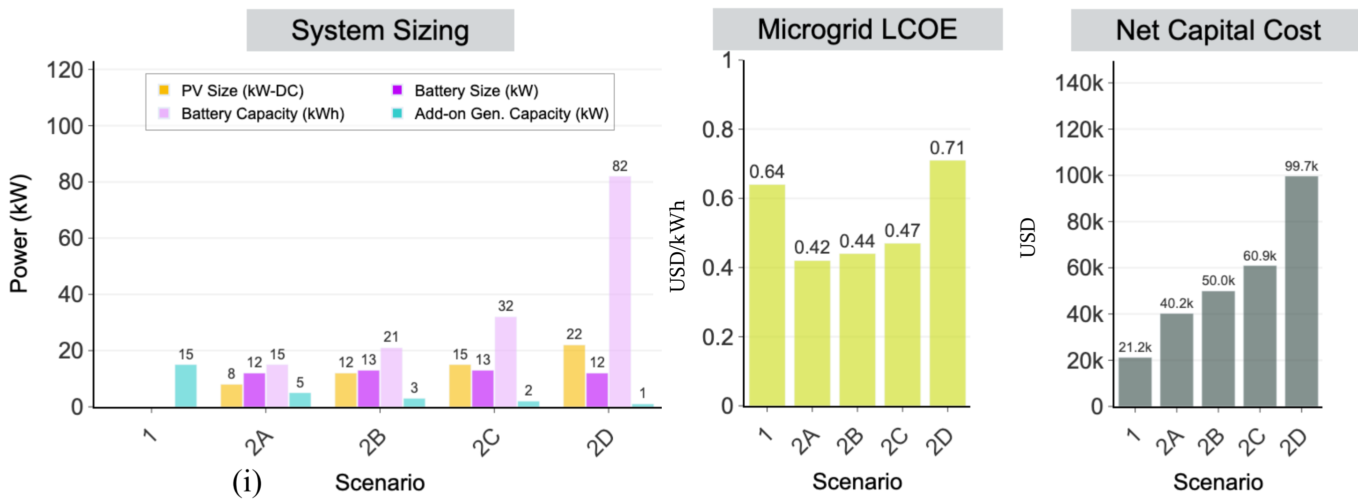


Figure 6. REopt baseline + PUE scenario comparison for (i) system sizing; (ii) mini-grid LCOE; (iii) capital cost

Scenario 2A: PV+BESS + Generator Mini-Grid (BAU + PUE Load) introduces a hybrid system with 8 kW of PV, 12 kW/15 kWh of BESS, and a 5-kW diesel generator to support additional PUE loads. This scenario achieves 50% renewable energy generation, resulting in an LCOE of $0.42/kWh. The generator fuel costs increase to $2,980 annually due to the higher load, and CO_2 emissions rise to 8.12 tons annually. The total life cycle cost is $63,300, with a net capital cost of $40,230, reflecting the added costs of PUE integration.

Scenario 2B: PV+BESS + Generator Mini-Grid (BAU + PUE Load, 70% Renewable Energy) targets 70% renewable energy generation with 12 kW of PV and 13 kW/21 kWh BESS, alongside a 3-kW diesel generator. The LCOE increases slightly to $0.44/kWh, but generator fuel costs decrease to $1,780 annually, and CO_2 emissions drop to 4.85 tons annually. The total life cycle cost is $64,560, with a net capital cost of $49,970, indicating the balance achieved between cost, load, and renewable integration.

Scenario 2C: PV+BESS + Generator Mini-Grid (BAU + PUE Load, 85% Renewable Energy) further increases the PV capacity to 15 kW and BESS to 13 kW/32 kWh. This scenario reaches 85% renewable energy generation, with an LCOE of $0.47/kWh. The generator fuel costs decrease further to $897.27 annually, with CO_2 emissions reduced to 2.44 tons annually. The total life cycle cost is $69,370, and the net capital cost is $60,940, reflecting the impact of higher renewable integration on costs and emissions.

Scenario 2D: PV+BESS + Generator Mini-Grid (BAU + PUE Load, 100% Renewable Energy)[10] represents a 100% renewable energy scenario with 22 kW of PV and 12 kW/82 kWh of BESS, eliminating the need for significant generator use. This results in the lowest generator fuel cost of $56.04 annually and CO_2 emissions of 0.15 tons annually. However, the LCOE increases to $0.71/kWh, with the total life cycle cost reaching $102,790 and a net capital cost of $99,670, illustrating the substantial investment required for complete renewable energy reliance while supporting PUE.

3.2.2 Discussion

The results demonstrate the economic and environmental benefits of integrating renewable energy with traditional diesel generation in mini-grids, particularly when considering PUE applications. These benefits are evident in the reductions in LCOE across scenarios that incorporate PV and BESS, especially when paired with PUE loads like refrigeration and ice-making.

While upfront costs are higher for systems with greater renewable energy generation and PUE capabilities, these configurations offer lower operational costs and environmental benefits that lead to significant reductions in the LCOE. For example, in the baseline scenarios, there is a noticeable decrease in LCOE from $0.64/kWh in Scenario 1 (diesel-only) to $0.60/kWh in Scenarios 1A and 1B, which integrate PV and BESS. The trend continues in the baseline + PUE scenarios: Scenario 2A achieves a low LCOE of $0.42/kWh, demonstrating the economic advantage of adding renewable energy even with increased energy demand due to PUE.

Comparing Scenario 1 to Scenario 2D illustrates that, while the integration of higher renewable energy generation and PUE requires a significantly higher initial capital investment, it still leads to a marginal increase in the LCOE in comparison to the baseline. Specifically, Scenario 2D, which represents a 100% renewable energy generation scenario with full PUE integration, results in a net capital cost of $99,670. This scenario sees a slight increase in LCOE to $0.71/kWh compared to the baseline LCOE of $0.64/kWh in the diesel-only scenario. However, this marginal increase in LCOE can be outweighed by the benefits of reducing reliance on diesel fuel, minimizing operational costs, and reduction in emissions. This supports the argument that the higher upfront costs associated with greater renewable energy generation and PUE integration are justified by the significant reduction in diesel dependency and the corresponding environmental and operational savings.

The findings highlight the potential for reducing energy costs through the integration of renewable technologies, particularly when combined with PUE. In addition to the economic

[10] Although Scenario 2D aims for 100% renewable energy, the target was adjusted to 99% in REopt to avoid infeasible results. The generator remains in the system, but its fuel use and size are minimal enough to be disregarded.

benefits, the environmental impact is also significantly reduced, as seen in the drastic reductions in CO_2 emissions across scenarios with higher renewable energy generation. The move from Scenario 1's 7.25 tons of annual CO_2 emissions to Scenario 2D's 0.15 tons of CO_2 underscores the environmental advantages of renewable energy integration.

The following sections will delve deeper into the broader socioeconomic benefits that PUE can offer, particularly in supporting local economic activities such as fishing by building a mini-grid that can support the energy required for refrigeration and ice-making. By providing reliable power for essential PUE loads, these systems can enhance productivity and have the potential to improve livelihoods and economic development.

3.3 Limitations

The analysis results demonstrate the significant cost-reduction potential of integrating PUE with renewable energy sources in off-grid mini-grid systems. However, several limitations and considerations warrant further analysis to obtain a comprehensive understanding of the benefits and challenges associated with these systems, including:

- **Exclusion of distribution grid development and upgrades costs**: The analysis does not account for potential costs associated with expanding and upgrading existing distribution and transmission infrastructure to support the new mini-grid systems, which can significantly impact the total deployment and operational costs, especially in remote regions.
- **Accuracy of load estimations:** The load data, based on appliance usage provided by PAUECEES, may not fully reflect seasonal variations in energy demand or future increases due to electrification, potentially affecting the accuracy of the modeled scenarios.
- **Uncertainty in technology cost data**: The cost data for PV panels, BESS, and generators can vary significantly depending on market conditions, including supply chain dynamics, tariffs, and local labor costs.

These limitations highlight the need for a more detailed and localized analysis to ensure that the proposed mini-grid systems are not only technically feasible but also economically viable for the community. Future work should consider these factors and involve stakeholders from the local community in the planning and implementation process to tailor solutions that best meet local needs and conditions.

3.4 Key Considerations

3.4.1 Starter Grid/Anchor Loads for Mini-Grids

The concept of a "starter grid" refers to the initial setup of a mini-grid system designed to serve specific anchor loads within a community. In this context, the anchor loads could include essential services such as schools, health clinics, and businesses critical to the community's daily operations. This practice focuses on establishing a reliable energy supply through distributed off-grid PV and BESS. The initial setup aims to provide consistent and affordable power, laying the foundation for a more extensive mini-grid that could be expanded to include additional loads and users over time.

For future potential integration, it is essential to clarify the design and operational strategies of the mini-grid. The system should be scalable, allowing for the addition of new loads as the community's energy needs grow. The integration of advanced energy management systems will be crucial to optimizing the operation of solar and storage assets, ensuring efficient energy distribution and minimizing waste.

3.4.2 Training for Sustainable Operations

A key element for the deployment of the PV+BESS hybrid systems is ensuring that parallel efforts are made to train local personnel in the operation and maintenance of these systems. This not only improves operational resiliency, but also enhances community buy-in and support, which improves the social sustainability of the project. Depending on how the program is financed, this could be a partnership with an existing workforce development program for solar technicians or direct training from a developer or local institution. For example, a combined training program could be envisioned, including both the PV+BESS and the PUE systems (as highlighted in the section below).

3.4.3 Incorporating Local Knowledge and Community Engagement

SEN has identified the integration of local knowledge, traditions, and community values as a top priority for the success of rural electrification projects. SEN has stressed the importance of ensuring that energy solutions not only meet technical requirements but are also deeply rooted in the cultural practices and governance structures of the communities they serve. This approach is critical for fostering long-term sustainability, as it promotes ownership and aligns energy projects with the unique social, economic, and environmental conditions of local populations.

In line with these priorities, this project has begun to take a community-centered approach by engaging local leaders, residents, and other stakeholders. To build upon this foundation and ensure comprehensive community engagement, further work is needed. Future efforts should focus on defining roles and responsibilities for system management in culturally appropriate ways, incorporating local inputs into decision-making and governance processes. Special attention should be given to enhancing the participation of all community members, including women, Indigenous populations, and native peoples who may have been underrepresented in initial consultations.

4 PUE Business Case for Fisheries Cold Storage

This section provides a high-level analysis of a potential cold storage PUE business case for cold storage deployment to support fishing groups in the Gracias a Dios cooperative. The sections below detail the methodology, key assumptions and inputs, results, and key considerations.

4.1 Methodology and Assumptions

For this initial analysis, we modeled two different cold storage appliances to support the Gracias a Dios fishing cooperative: (1) a chest freezer (27 ft^3); and (2) four ice makers (each 99 lbs./day capacity), as detailed above. All assumptions and inputs are included in Table 4, then discussed in detail with accompanying equations below. All inputs and assumptions are preliminary and based on conversations with a local group in Gracias a Dios, other case studies and research, and conservative benchmarks.

All parameters are meant to be flexible and can be adjusted in the accompanying Excel model.

Table 4. Key Assumptions and Inputs for Evaluation of Cold Storage and Fisheries Business Case

Metric	Value	Units	Source/Notes
Number of Fisherfolk	200	People	
Conversion Rate (HNL to USD)	24.769	HNL–USD	Xe.com Currency Converter (2024), pulled July 15, 2024
Discount Rate	12%	%	REopt analysis above
Fish Catch			
Annual Fish Catch	79,560	Lbs.	A profile on COOPESPCOL highlighted fish catch of 1,530 lbs. of fish every week, which translates to 79,560 lbs. per year if the cooperative in Gracias a Dios is similarly sized (MiPesca 2020).
BAU: Post-Harvest Losses	15%	%	Estimates for post-harvest loss in Honduran small-scale fisheries are estimated at 10%–20%.
Post-Project Post-Harvest Losses	3%	%	COOPESPCOL (MiPesca 2020)
Annual Decrease in Fish Catch	0.3	%	Conservative estimate based on fishery loss projections from climate change, overfishing, habitat degradation, and other factors
Price of Fish (Local)	15	HNL/lb.	Based on 15 HNL/lb. from conversations with local stakeholders in Gracias a Dios
Price of Fish (Intermediary)	30	HNL/lb.	Based on 30 HNL/lb. from conversations with local stakeholders in Gracias a Dios
Price of Fish (Secondary Market)	50	HNL/lb.	Based on 50 HNL/lb. from conversations with local stakeholders in Gracias a Dios
BAU: % of Catch Sold Locally	70%	%	Based on conversations with local stakeholders in Gracias a Dios and observations from other markets
BAU: % of Catch Sold to Intermediaries	30%	%	Based on conversations with local stakeholders in Gracias a Dios and observations from other markets

Metric	Value	Units	Source/Notes
BAU: % of Catch Sold to Secondary Markets	0%	%	Based on conversations with local stakeholders in Gracias a Dios and observations from other markets
Post-Project: % of Catch Sold Locally	35%	%	65%/35% split secondary vs. local sales for COOPESPCOL (assumes 35% still sold to intermediaries and 30% now sold directly to secondary markets following cold storage and ice-making) (MiPesca 2020)
Post-Project: % of Catch Sold to Intermediaries	40%	%	65%/35% split secondary vs. local sales for COOPESPCOL (assumes 40% still sold to intermediaries and 25% now sold directly to secondary markets following cold storage and ice-making) (MiPesca 2020)
Post-Project: % of Catch Sold to Secondary Markets	25%	%	65%/35% split secondary vs. local sales for COOPESPCOL (assumes 40% still sold to intermediaries and 25% now sold directly to secondary markets following cold storage and ice-making) (MiPesca 2020)
PUE/Solar Project Assumptions			
Investment Year	2025	Year	Assumes installation of solar and PUE equipment in 2025
Solar Project Lifetime	25	Years	Based on general distributed solar assumption for REopt
PUE Equipment Lifetime	7	Years	Assumed lifetime of PUE equipment
Number of Ice Makers	4	Units	Modeled need from ice assessment above
Capital Cost for Ice Maker	$500	USD	Ubuy (n.d.)
Number of Freezers	1	Units	Modeled need from cold storage assessment above
Capital Cost for Freezers	$1,200	USD	Typical freezer available in Central America (GRS n.d.)
Logistics/Customs Adder	50%	%	Conservative assumption based on other markets
Loan Tenor	3	Years	Based on sample capital loan for the COOPESPCOL Cooperative (MiPesca 2020)
Loan Interest (Annual)	24%	%	Based on sample capital loan for the COOPESPCOL Cooperative (MiPesca 2020)
Payments Per Year	12	Payments	Monthly loan payments
Annual Electricity Consumption for Cold Storage PUE	12,264	kWh	REopt calculations above
Electricity Tariff	0.65	USD/kWh	Assumed tariff for the planned solar + storage solution based on $0.60–$0.75/kwh tariff in Puerto Lempira
Fishing Costs	5.45	HNL/lb. of fish catch	Based on an estimated $0.5/kg for small-scale fisheries. Fishing costs include a variety of costs, such as equipment, boat/fleet maintenance, fuel, etc.
BAU Other Costs	$2,400	USD/Year	Simple estimate of $200 per month for factors not built into fishing costs above

Metric	Value	Units	Source/Notes
Post-Project Other Costs	$4,800	USD/Year	Simple estimate of 2x BAU to account for increased transportation costs and other costs with the expanded business model
Annual Increase in Costs	3%	%	Conservative assumption
Ice-Making			
Ice-to-Fish Ratio	1:1		Typical 1:1 ice-to-fish ratio for tropical fish (1 pound of ice per 1 pound of fish) (Hanjabam and Raj, 2017)
Ice Production Used for Fish Harvest/Transport	80%	%	Estimate based on calculated ice need; remainder of ice sold to local markets
Cost of Ice	$0.90	USD/lb.	Based on $2–$5 per bag estimate from conversations with local stakeholders in Gracias a Dios

We developed a simple annual model based on throughput for fish catch to estimate the potential impact of integrating cold storage and ice-making PUEs for the hypothetical 200-member fishing cooperative in Gracias a Dios. This model assumed 79,560 lbs. of fish catch per year for both the BAU and post-project cases. Raw fish catch was assumed to decline by a simplified rate of 0.3% per year due to a combination of factors including climate change, overfishing, etc.[11] We then applied post-harvest losses. For the BAU, post-harvest losses were assumed to be 15%, but with cold storage from the project, the losses were assumed to be reduced to 3%. Finally, 5% of the fish catch was then assumed to be consumed by the fishing cooperative itself and therefore not sold to market (Equation 7).

Equation 7. Total Sellable Fish Catch in Year (Y)

$$\textbf{Total Sellable Fish Catch}_{(\mathbf{Y})} = Raw\ Fish\ Catch_{(Y-1)} * (1 - Fish\ Decline) * (1 - Post - Harvest\ Losses) * \ (1 - Self\ Consumption)$$

Total sellable fish catch was then allocated to different market segments each with different price points for fish (prices are based on the conversations with a local group in Gracias a Dios):

- **Local**: Fish sold directly to local consumers in the Gracias a Dios markets (price: 15 HNL/lb.; BAU: 60% of fish catch; post-project: 35% of fish catch)
- **Intermediaries**: Fish sold to market intermediaries for sale in other markets (price: 30 HNL/lb.; BAU: 40% of fish catch; post-project: 40% of fish catch)
- **Secondary markets**: Fish sold directly to higher-value secondary markets (price: 50 HNL/lb.; BAU: 0% of fish catch; post-project: 25% of fish catch).

Cold storage is assumed to enable local fishers to sell larger proportions of their fish catch to higher-value segments, including directly to secondary markets. Total gross income for selling the fish catch is estimated by multiplying the total sellable fish catch by the proportion of fish

[11] Actual fisheries loss is more likely to be a stepwise or cascading function as habitat thresholds or limits are reached.

catch sold to a given market segment by the price per kg for that market segment. The ice maker and freezer PUE was mostly designed to support the cold storage of fish catch (1:1 ice-to-fish weight ratio), but 80% of ice production was assumed to be used for fish catch transport and storage, leaving 20% of ice production to be sold at an assumed price of $0.90/lb. in local markets, thereby creating an additional income stream for the fish cooperative (Equation 8).

Equation 8. Total Gross Income

$$\boldsymbol{Total\ Gross\ Revenue_{(Y)}} = Total\ Sellable\ Fish\ Catch_{(Y)} * [\ (Prop\ Local\ Markets * Local\ Market\ Price) + (Prop\ Intermediaries * Intermediary\ Price) + (Prop\ Secondary\ Market * Secondary\ Market\ Price)] + \frac{ICE{:}Fish\ Ratio * Fish\ Catch}{Prop\ Ice\ for\ Fish\ Catch} * Ice\ Price$$

We calculated total costs by assuming a cost for fishing (including a variety of factors such as fuel, operations and maintenance, equipment, etc.) of $0.22/lb. of fish catch or about 5.45 HNL/lb. of fish catch as well as other fixed costs of $2,400 per year in the BAU case and $4,800 in the Post-Project case (accounting for higher transportation and other costs to support downstream business). Both fishing and fixed costs were assumed to grow by 3% per year. In the Post-Project scenario, we added additional costs for electricity consumption and repayment of the loan for PUE equipment. For electricity consumption, in the analysis, we used an annual consumption value of 12,264 kWh per year (see REopt analysis above) and assumed an average electricity tariff of $0.65/kWh. Electricity tariff was also assumed to grow by the same 3% per year.

A simple amortized loan was assumed for the purchase of the PUE equipment (one freezer, four ice makers) with a loan tenor of 3 years and an annual interest rate of 24% (Equation 9). The loan was assumed to be for the full capital cost of the PUE equipment plus a conservative 50% adder for logistics and customs. New loans were assumed to be needed to purchase new PUE equipment at the end of the assumed 7 years for PUE lifetime (Equation 10, Equation 11).

Equation 9. Total Annual Costs

$$\boldsymbol{Total\ Annual\ Costs_{(Y)}} = \ [Total\ Fish\ Catch_{(Y)} * Fishing\ Costs * (1 + Cost\ Increase)^{Y} + Other\ Fixed\ Costs * \ (1 + Cost\ Increase)^{Y} + \ Total\ Sellable\ Fish\ Catch_{(Y)} * PUE\ Electricity\ Consumption\ Rate * Electricity\ Tariff * \ (1 + Cost\ Increase)^{Y} + Loan\ Repayment]$$

Equation 10. Loan Principal

$$\boldsymbol{Loan\ Principal} = (\#\ of\ Ice\ Makers * Cost\ of\ Ice\ Maker + \#\ of\ Freezers * Cost\ of\ Freezer) * (1 + Logistics\ and\ Customs)$$

Equation 11. Annual Loan Payment

$$\boldsymbol{Loan\ Repayment_{(Y)}} = 12 * Loan\ Principal * \frac{Interest\ Rate * (1 + Interest\ Rate)^{Tenor*12}}{(1 + Interest\ Rate)^{Tenor*12} - 1}$$

For both the BAU and Post-Project scenarios, operating income was estimated by subtracting total costs from total gross income (Equation 12).

Equation 12. Total Annual Operating Income

$$\boldsymbol{Total\ Operating\ Income_{(Y)}} = Total\ Gross\ Revenue_{(Y)} - Total\ Costs_{(Y)}$$

Net present value for the operating income was calculated by discounting total operating income streams according to a 12% discount rate (Equation 13).

Equation 13. Net Present Value

$$\boldsymbol{Net\ Present\ Value} = \frac{Total\ Operating\ Income_{(Y)}}{(1+Discount\ Rate)^{t-1}}$$

Results are approximated to the nearest $5/5 HNL or 5 lbs. to improve clarity of discussion.

4.2 Results

In the BAU case for Year 1, total fish catch was estimated to be 79,560 lbs., of which ~11,935 lbs. were estimated to be lost post-harvest (over $7,225 of loss if valued at local market price) and 3,380 lbs. were consumed by the cooperative itself, leaving 64,245 lbs. of total sellable fish catch. 70% of the total sellable catch or 44,970 lbs. was estimated to be sold to local markets for a gross income of 674,570 HNL, and the remaining 30% (19,270 lbs.) was sold to intermediaries for a gross income of 578,200 HNL. Overall, fish was sold at 19.5 HNL/lb. Total gross income for Year 1 was estimated at 1,252,770 HNL, or around $50,580. Fishing costs were estimated at 446,540 HNL and other operating costs at 61,230 HNL for a total of 507,770 HNL, or about $20,500. Overall operating income for the cooperative was estimated at around 745,000 HNL, or about $30,080.

By comparison, the Post-Project Year 1 case had the same fish catch and self-consumption but only an estimated 2,385 lbs. are lost post-harvest (~$1,445 of losses if valued at local market price) which resulted in a much higher total sellable fish catch of around 73,315 lbs. Only 35% of the total sellable catch, or 25,560 lbs., was estimated to be sold to local markets for a lower gross income of 384,900 HNL. However, 40% of sellable catch (29,325 lbs.) was now sold to intermediaries for a gross income of 879,775 HNL and 25% (18,330 lbs.) was sold directly to secondary markets for a gross income of 916,430 HNL. Overall, with the secondary markets fish was sold on average 52% higher at 29.75 HNL/lb. Ice production was estimated at 99,450 lbs., of which 20% or about 19,890 lbs. was estimated to be sold for other uses, adding an additional income of 443,390 HNL. Total gross income for Year 1 nearly doubled at an estimated at 2,624,500 HNL, or around $105,960.

Fishing costs were again estimated at 446,540 HNL, but other costs increased to 122,460 HNL. The annual loan payment for the PUE solutions was estimated at 55,975 HNL, and 12,264 kWh of electricity was estimated to be consumed by the PUE appliances, with an estimated cost of 203,370 HNL. Total costs for Year 1 were estimated at 802,110 HNL, or about $32,385. For the Post-Project scenario, overall operating income for the cooperative more than doubled to around 1,822,390 HNL, or $73,575.

In Year 1 overall, the PUE project is estimated to increase total sellable fish catch by 14% or about 9,070 lbs., primarily by reducing post-harvest losses. The PUE project also enables the cooperative to sell that fish catch to higher value markets, while still providing fish to local markets. All of this helps to increase operating income by 145%, or about $43,500, and per-fisher operating income by $217. An overall comparison for Year 1 fish catch, flows to different market segments, and income for the cooperative is shown in Table 5.

Table 5. Year 1 Comparison of Fish Catch and Income Under BAU and Post-Project Cases

Metric	BAU	Post-Project	% Change From BAU
Total Fish Catch (lbs.)	79,560	79,560	0%
Post-Harvest Losses (lbs.)	11,935	2,385	-80%
Total Sellable Fish Catch (lbs.)	64,245	73,315	14%
Fish to Local Markets (lbs.)	44,970	25,660	-43%
Fish to Intermediaries (lbs.)	19,275	29,325	52%
Fish to Secondary Markets (lbs.)	-	18,330	N/A
Total Gross Income From Fish Sales (USD)	$50,580	$88,080	74%
Total Gross Income From Ice Sales (USD)	-	$17,900	N/A
Total Operating Income for Association (USD)	$30,080	$72,515	141%
Total Operating Income per Fisher (USD)	$150	$363	141%

Over time, catch values are expected to decline while costs are expected to increase, which makes for declining income for the cooperative over time, all else being equal, but the PUE shifts income significantly for the cooperative. The PUE also creates a stable income stream for the PV+BESS solution and helps reduce LCOE, as highlighted above. Table 6 highlights cumulative impacts of the Post-Project case.

Table 6. Comparison of Cumulative Impacts for Post-Project Case Year 1, Year 10, and Year 25

Metric	Year 1	Year 10	Full Solar Project Lifetime (25 years)
Increased Gross Income From Fish Sales (USD)	$37,480	$369,780	$904,025
Gross Income From Ice Sales (USD)	$17,900	$176,615	$431,780
Increase in Operating Income Over BAU (USD)	$42,440	$414,885	$925,980
Project Net Present Value (USD)	$72,515	$437,785	$567,540
Per-Fisher Net Present Value (USD)	$363	$2,190	$2,840
Reduction in Post-Harvest Losses (lbs.)	9,550	94,195	230,280
Reduction in Post-Harvest Losses (USD)	$5,780	$57,045	$139,460
Electricity Consumption From Solar (kWh)	12,265	122,640	306,600
Electricity Sales (USD)	$8,210	$94,130	$299,360

4.3 Limitations

The calculations above are meant to provide a preliminary high-level analysis of the cold storage PUE business model, but several factors must be refined in follow-on scoping and analysis, including but not limited to:

- **Limited primary data from Gracias a Dios**: Several key variables for the analysis were estimated based on other published fishery profiles or conservative values from the analysis team, including annual fish catch, market splits, fishing costs, other operating costs, etc., but more primary data from the local fishing cooperative would be valuable to improve these estimates, especially for operating costs.

- **Established market linkages and business models**: For the analysis, we assumed that the fishing cooperative could start selling ice to local markets and fish directly to downstream markets fully in Year 1, whereas it can take a few months to a year for a cooperative to be able to operate PUE business models fully and create the linkages to downstream markets.

- **Simplified business model**: For the initial analysis, we assumed a very simplified business model for the cooperative whereby total income and total costs were shared equally across the members, allowing for calculations to focus on overall financial flows and create a single point of payment for elements like the loan and electricity. However, many different structures for income and cost-sharing should be modeled.

- **Simplified loan structure**: For the analysis, we assumed a very simplified amortized loan would be available from local microfinance institutions to cover the PUE equipment, which would then be paid back over time by the cooperative. However, availability for appliance financing and ability to access that financing by local cooperatives can be a critical barrier for PUE deployment in emerging markets.

4.4 Key Considerations

While the above preliminary analysis does highlight strong potential for the cold storage PUE applications to support both livelihoods for fishers and improved viability for the PV+BESS solution, several considerations should be explored in future analyses.

4.4.1 Business/Collaboration Models

To successfully implement the modeled PUE applications, the supporting business and collaboration models must be established. These models could potentially function in many ways, from integrating into an existing cooperative structure (for example, expanding on a simple shared income/cost model) to establishing new structures or more complicated collaborations. Key parameters that must be determined in advance of the PUE deployment include:

- Governance/decision-making structure, including for elements like the utilization of the PUE assets and the quantity and timing of selling different fish catches to different market streams

- Approach to downstream market linkages and engagement
- Split and handling of PUE income and costs
- Roles and responsibilities, for example, operation and maintenance of the assets, paying for electricity and other costs, downstream markets, etc.

From initial conversations, it is likely that the planned PUE project could fit into existing associations and cooperatives, but exactly how would need to be determined with more detailed stakeholder engagement prior to deployment. If using existing associations, one key aspect will be understanding how those existing associations work, particularly with respect to inclusion and opportunities for women and other marginalized groups (see Section 4.4.5).

4.4.2 Technical Training

As highlighted above, PUE applications in communities with limited baseline access to power often require additional parallel training for local partners to be sustainable and successful over the longer term. This will need to include training on both the operations and maintenance of the PUE appliances themselves (in this case, the freezer and the ice maker) as well as the broader business model—including, in this case, developing downstream market linkages, timing and pricing for fish catches, coordination for using ice-making and cold storage capacity, etc. This training is especially needed to bridge opportunity gaps for marginalized groups, as discussed in Section 4.4.5. PUE or enterprise training should be built into the broader project deploying the PV+BESS solution and PUE equipment in Gracias a Dios.

4.4.3 Parallel PUE and Value Streams

For this initial analysis, only the two cold storage applications and the fish value stream were explored, but a variety of other value streams and applications are worth exploring to support socioeconomic development in Gracias a Dios, as well as the viability of the solar solution. First, given seasonality and seasonal restrictions for fishing, it is likely that the cold storage solutions will be able to (and may need to from a financial standpoint) consider supporting other value streams—for example, in agriculture during the shoulder months for fishing. Further, the cold storage applications can help prove out business and collaboration models for the community and for the owner of the PV+BESS asset, which can then be adapted to support other PUE models (for example, for commercial applications like agricultural production and processing [pumping, milling, grinding, drying, threshing, hulling, de-kerneling, pressing etc.], carpentry, welding, water pumping, telecommunications, and health care).

4.4.4 Community-Led Decision-Making and Governance

Alongside the focus on parallel value streams, as outlined in Section 4.4.3, it is crucial that the roles and responsibilities for managing the PUE systems are determined through a collaborative process with the community. It can be helpful for the community to take the lead in deciding how these roles will be assigned, ensuring that the project reflects local governance structures and cultural practices. This approach not only strengthens local ownership but also ensures that the PUE systems are sustainable and aligned with the community's long-term goals.

To support this, the project provides some initial considerations for how these roles could be structured. However, during actual project development, the community, with the support of government entities like SEN and technical assistance as needed, should evaluate and select the roles and responsibilities for their context. This participatory approach allows the community to take charge of the decision-making process, ensuring that local priorities are at the forefront while the community benefits from expert guidance and support when necessary. By empowering the community to shape the operational model, the project lays the groundwork for long-term success and self-sufficiency.

As highlighted above, this community decision-making and governance element would be a core component for any Phase 2 deployment efforts.

4.4.5 Marginalized Groups

Building on the importance of community-led decision-making outlined in the previous section, it is equally crucial to ensure that energy access interventions (especially for PUE projects) are designed to be aware of and sensitive to considerations for gender and other marginalized groups. This would help to avoid exacerbating existing inequalities and leverage the intervention to drive new opportunities.

Globally, although women make up half of the overall workforce throughout fishery value chains, they constitute a disproportionately large percentage of the people engaged in the informal, lowest-paid, least-stable, and least-skilled segments of the workforce. In fisheries, women account for 18% of the workforce in the primary sector and 50% across the pre- and post-harvest components of the value chain. Just as women are not a homogenous group, the different roles of women throughout the fisheries sector vary widely; however, women in the sector tend to:

- Have significantly higher work burdens
- Have heightened risk for gender-based violence
- Have limited access to information, extension and financial services, infrastructure, social protection, and decent employment
- Have limited access to physical and capital resources
- Be excluded from decision-making and leadership positions
- Receive fewer benefits from their activities and have fewer rights and privileges
- Have limited control over markets, how prices are set, and interactions within value chains (FAO 2022).

For a project like the one analyzed above, PUE and energy access assets represent a substantial change to the status quo, but also a risk of further exacerbating inequalities by concentrating benefits and decision-making power with those that already have it. Therefore, it will be important for the community to engage with local women active in the fisheries value chain to identify key challenges and opportunities to integrate them into the PUE business model—for example, on the operation/coordination of the cold storage PUE, governance for decision-making on fish catch, and the downstream market linkages for fish. This may require additional parallel trainings as highlighted above, particularly if moving from informal roles to more formalized market streams. This is likely to be important because traditional or existing roles in the informal selling or processing of fish in local markets may be impacted negatively by the project as less fish is sold locally.

This element of the project should be proactively explored in any future efforts.

5 Financing Pathways

As highlighted above, from a project development perspective, cost savings and expanded impact can be realized by combining the PV+BESS hybrid solution with the PUE development and associated business model and training. All combined, focusing on a single site would likely be a relatively small-ticket effort (<$100,000).

This, combined with the nature of a project focusing on schools and health care loads in unelectrified communities, suggests a need to focus on identifying partners for providing concessional or grant capital (e.g., development partners, philanthropies, corporate giving, etc.) and/or exploring the possibility of using some government funding (e.g., through the ongoing PAUEH or PAUECEES efforts). A private sector developer could also be interested in the opportunity, but to establish that partnership, a formal request for proposals and supporting incentives may need to be developed, given the difficulty in logistics and less-established markets in Gracias a Dios. It may also be difficult to develop interest in a single site application. A high-level overview of potential financing models for solar projects and developers can be found in Appendix B.

Regardless, the goal for initial partnerships would be to get support for a pilot project that could then ground-truth and prove out the business model so that a more combined programmatic approach could be developed for a portfolio of sites, which might be more attractive for private sector actors or for larger projects with development banks and philanthropic capital.

However, a more likely pathway for building partnerships may be to propose a more programmatic approach from the beginning. This could include, for example, feasibility studies, technical design, and procurement for multiple PV+BESS sites in Gracias a Dios and other departments, coupled with PUE stimulation and training for the fisheries value chain (as modeled here) and other important value chains like health care, agricultural production and processing (e.g., water pumping, milling, threshing, drying, pulping, etc.), water, and telecommunications. By doing this, both the total ticket size and the potential for impact and learning (especially on approaches for empowering livelihoods through integrated electrification) would increase, which might unlock pathways for collaboration with different development partners.

For example, further efforts could be made to align with existing country programming for energy, the blue economy, and rural economic development from partners like the U.S. Agency for International Development,[12] Inter-American Development Bank,[13] World Bank,[14] Global Energy Alliance for People and Planet[15], Central American Bank for Economic Integration,[16]

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[12] For more information about the U.S. Agency for International Development's work with Honduras, see https://www.usaid.gov/honduras.

[13] Information about the Inter-American Development Bank in Honduras is available at: https://www.iadb.org/en/who-we-are/country-offices/honduras.

[14] See https://www.worldbank.org/en/country/honduras/overview for an overview of the World Bank in Honduras.

[15] Information about the program is available at: https://energyalliance.org/latin-america-caribbean/.

[16] See https://www.bcie.org/en/member-countries/founders/republic-of-honduras for more information.

MiPesca (via the Nordic Development Fund),[17] FMO,[18] World Food Program,[19] GOAL Blue Economy,[20] and others.

This partnership-building effort is critical for the next steps following this analysis, as discussed in Section 6. Some additional analyses and discussions are also needed to help better scope and frame the opportunity and develop specific proposals for different potential financing pathways.

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[17] More information about the MiPesca Nordic Development Fund is available at: https://www.ndf.int/newsroom/mipesca-project-in-for-long-haul-in-honduras.html.

[18] Information about the FMO Access to Energy Fund: https://www.fmo.nl/l/en/library/download/urn:uuid:1ff382c3-0129-4445-aa07-0f74fdc98bbd/access_to_energy-fund-strategy.pdf.

[19] For more information about the World Food Program, see https://www.wfp.org/countries/honduras.

[20] More information about GOAL Resilience of the Blue Economy is available at: https://unctad.org/system/files/non-official-document/ditc-ted-31062022-UNOC-side-GOAL-brochure-v1.pdf.

6 Key Findings and Discussion

The analyses above highlight the strong potential for both PV+BESS solutions and integrated PUE for supporting electrification of rural communities in Gracias a Dios. Key findings include:

- **Baseline electricity options are expensive and unreliable.** The model estimated an LCOE around $0.64/kWh for small-scale gensets to provide power for the baseline schools, clinic, and hospital loads. This is still considered expensive power and comes with risks for power quality and potential damage to sensitive equipment from voltage spikes.
- **Small PV+BESS solutions can cost-effectively support baseline loads for the schools, clinic, and small hospital.** While there is an upfront cost for the development and deployment of the PV+BESS solution, operational savings from avoided generator fuel costs decrease the overall life cycle cost of the PV+BESS system compared to baseline individual small-scale gensets and result in a decrease in LCOE by about $0.04/kWh as well as avoided carbon emissions around 4.5 tons of CO_2/year.
- **Adding PUE loads reduces LCOE compared to the BAU baseline.** The optimized PV+BESS solution with PUE loads (including cold storage) achieves an LCOE of $0.42/kWh, significantly lower than the $0.64/kWh of the generator-only baseline.
- **Increasing the percentage of renewable energy generation does not significantly impact costs initially, but achieving higher renewable targets requires careful consideration of trade-offs.** The cost-optimized renewable energy fraction for the PV+BESS solution + PUE load is around 50%, but increasing that fraction to 70% only increased LCOE by $0.02/kWh. However, pursuing higher renewable energy targets, such as 85% or 100%, involves more substantial capital investments, which lead to a slight increase in LCOE, as seen in Scenario 2C with 85% renewable energy ($0.47/kWh) and Scenario 2D with 100% renewable energy ($0.71/kWh). These scenarios illustrate that, while higher renewable energy generation reduces diesel reliance and emissions, it requires balancing the initial investment with long-term sustainability goals and operational benefits.
- **Electrifying schools, health care, and small PUEs can be a key anchor load for broader electrification solutions.** By deploying a "starter grid" system designed to serve specific essential services such as schools, health clinics, and businesses critical to the community's daily operations, a pilot project could cost-effectively lay the foundation for a more extensive mini-grid that could expand to include additional loads and users over time.
- **Cold storage PUE applications can reduce post-harvest losses and open new market opportunities.** The ice-making and freezer PUE can reduce post-harvest losses by almost 14% and help unlock downstream sales to intermediaries and directly to secondary markets, which helps increase potential income from the same volume of fish catch. Further, ice-making itself provides a new income stream from the downstream selling of surplus ice.
- **Access to new markets and value streams can more than double income margins for fishing cooperatives.** Adding the cold storage PUE enables fish cooperatives to earn

50% more (average of 29.75 HNL/lb. with cold storage compared to 19.5 HNL/lb. without cold storage) compared to the baseline for the same fish catch. Incomes are further increased through the sale of ice. There are added electricity costs and payments for the PUE equipment, but these are much smaller than the income growth. In total, net operating income more than doubled when cold storage was added.

- **Parallel training is a key need, as is a focus on inclusion to maximize potential PUE applications.** The deployment of PUE appliances should be supported by focused programming on business/collaboration model development as well as training on the operation and maintenance of the PUE appliances themselves (in this case the freezer and the ice-maker) and the broader business model. In this case, that includes developing downstream market linkages, timing and pricing for fish catches, coordination for utilization of ice-making and cold storage capacity, and so on. This training is especially needed to bridge opportunity gaps for marginalized groups.
- **Pilot funding must be secured, and bundling similar sites could create a more programmatic approach.** The modeled pilot deployment is small, so there is potential to couple the PV+BESS and PUE deployments and target concessional financing from development partners or integrate the programming into ongoing government initiatives. However, more potential pathways may be unlocked by developing a portfolio of potential projects and accompanying PUEs.

The findings presented in this report are meant to be initial indicative data points that can be used to inform discussions and more targeted follow-on analysis and pilot design. The project analysis was focused on a hypothetical community and therefore had key limitations for localized data specific to Gracias a Dios on both costs for the electrical equipment and labor, as well as the specific cost structure and operating dynamics for local fishing cooperatives. The use of a hypothetical community in this analysis allows for the generation of insights that are broadly applicable across similar rural communities in the region. This approach provides a foundation for discussions and potential solutions that can be adapted and refined for specific local contexts, including those in Gracias a Dios and beyond. Further, the initial analysis focused on capital cost for generation, but there are likely some broader dynamics that would need to be considered for deployment of effective PV+BESS systems even if operating as a starter grid.

Despite the limitations, this analysis highlights an important opportunity for deploying PV+BESS systems in rural communities to drive improved clean energy access for critical community services and catalyze opportunities for local economic development and livelihoods through tailored PUE applications supporting critical local value chains. The analysis also highlights an important pathway for rural electrification in line with national planned priorities in the PAUEH and Plan de Aceso Universal a la Electricidad en Centros Educativos y Establecimientos de Salud.

7 Next Steps

As highlighted above, by assessing the potential for deploying integrated PV+BESS systems to support critical community services like education and health care and the potential for downstream enterprise and economic development, this analysis represents the first of multiple phases that can help inform specific strategies for developing pilot PV+BESS projects aligned with national priorities and sector-level planning under PAUEH.

Potential next steps and follow-on needs for Phase 2 work include:

- **Identification of financing partners for potential pilot projects**: As highlighted above, it is essential to start identifying potential funding sources to support the continued development and implementation of potential electrification and PUE projects. This could include seeking grants, loans, and investments from international organizations, government agencies, and private sector partners.
- **More robust stakeholder engagement with local communities**: More focused and detailed discussions with potential communities and community leaders within Gracias a Dios are needed to evaluate potential electrification needs and opportunities for supporting local value streams through PUE. Such discussions can also evaluate the willingness, capacity, and readiness of these communities to participate in a project and provide valuable local insights and support.
- **More tailored and localized design and analysis**: More localized and granular data must be gathered (e.g., from stakeholder engagement) to better tailor the analysis of potential PV+BESS hybrid solutions as well as approaches for PUE and enterprise development.
- **Evaluation of other PUE value streams**: As highlighted above, evaluation of business cases for other PUE value streams like telecommunications, agricultural processing and production, carpentry/metalworking, printing and computer services, among others, can highlight the potential for supporting downstream economic development and improve potential economics for planned solar solutions. A wider menu of options and business cases for PUEs can help build community buy-in by tailoring support to local needs, expand learning potential, and potentially bringing in different partners and funders.
- **Develop an assessment for a full mini-grid**: The initial analyses presented above highlight a pathway for developing starter grids for anchor loads that could then be expanded to serve other households, businesses, and institutions in a target community. A potential next step would be to develop a full mini-grid assessment that considers a broader suite of technical, economic, and social implications of implementing a mini-grid, ensuring it meets the needs of all community members and maximizes the benefits of integrated energy systems.

Phase 2 work would lay the groundwork for scaling and replicating the approach under Phase 3 to support critical learning and project development for energy access across Honduras and the broader Latin America and Caribbean region.

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Appendix A. Bottom-Up Appliance Modeling

Table A- 1, Table A- 2, Table A- 3, and Table A- 4 show the bottom-up appliance details for each of the four end uses.

Table A- 1. Appliance Load Assumptions: Small School (4–6 Classrooms)

Appliance	Power (W)	Quantity	Days on per Week	Hours per Day	Max Watts per Day	Start Time	Start Time Variation	Weekday Use	Weekend Use
LED Lamps	9	12	1	3	46	18	1	TRUE	FALSE
40-Inch LED TV	75	2	5	2	214	10	4	TRUE	FALSE
Laptop Computer	65	4	5	6	1,114	9	4	TRUE	FALSE
Desktop Computer	65	1	5	6	279	9	3	TRUE	FALSE
Printer	350	1	3	0.2	30	10	2	TRUE	FALSE
Sound System	45	1	2	2	26	9	1	TRUE	FALSE
Microwave Oven	800	1	5	0.4	229	12	1	TRUE	FALSE
Cell Phone Charger	8	6	4	2	55	10	4	TRUE	FALSE
Satellite Antenna and Receiver	20	1	5	7	100	9	1	TRUE	FALSE
Wi-Fi Modem	20	2	5	7	200	9	1	TRUE	FALSE

Table A- 2. Appliance Load Assumptions: Large School (7–10 Classrooms)

Appliance	Power (W)	Quantity	Days on per Week	Hours per Day	Max Watts per Day	Start Time	Start Time Variation	Weekday Use	Weekend Use
LED Lamps	9	20	1	3	77	18	1	TRUE	FALSE
40-Inch LED TV	75	2	5	2	214	10	2	TRUE	FALSE
Laptop	65	7	5	6	1,950	9	4	TRUE	FALSE
Desktop Computer	65	2	5	6	557	9	3	TRUE	FALSE
Printer	350	2	3	0.2	60	10	2	TRUE	FALSE
Sound System	45	1	3	2	39	9	1	TRUE	FALSE
Microwave Oven	800	2	5	0.4	457	12	1	TRUE	FALSE
Cell Phone Charger	8	9	4	8	82	10	4	TRUE	FALSE
Satellite Antenna and Receiver	20	1	5	7	100	9	1	TRUE	FALSE
Wi-Fi Modem	20	2	5	7	200	9	1	TRUE	FALSE

Table A- 3. Appliance Load Assumptions: Unidades de Atención Primaria en Salud Clinic

Appliance	Power (W)	Quantity	Days on per Week	Hours per Day	Max Watts per Day	Start Time	Start Time Variation	Weekday Use	Weekend Use
LED Clinic Lamps	9	3	5	8	154	10	2	TRUE	FALSE
Outdoor LED Lamps	9	4	5	1	26	10	4	TRUE	FALSE
Laptop Computer	65	1	5	3	139	9	4	TRUE	FALSE
Printer	350	1	3	0.05	8	9	3	TRUE	FALSE
Microwave Oven	800	1	5	1	143	12	1	TRUE	FALSE
Cell Phone Charger	8	3	4	0.25	27	9	2	TRUE	FALSE
Nebulizer	40	1	5	1	57	8	1	TRUE	FALSE
Magnifying Glass With Lamp	10	1	2	8	1	10	4	TRUE	FALSE
Vaccine Refrigerator (110 liters)	72	1	7	24	671	0	0	TRUE	TRUE
Fan	250	1	7	8	1071	9	1	TRUE	TRUE

Table A- 4. Appliance Load Assumptions: Centro Integral de Salud Hospital

Appliance	Power (W)	Quantity	Days on per Week	Hours per Day	Max Watts per Day	Start Time	Start Time Variation	Weekday Use	Weekend Use
LED Clinic Lamps	9	6	5	8	309	8	2	TRUE	FALSE
Outdoor LED Lamps	9	6	5	1	39	10	4	TRUE	FALSE
Laptop Computer	65	2	5	3	279	9	4	TRUE	FALSE
Printer	350	1	3	0.05	8	10	2	TRUE	FALSE
Microwave Oven	800	1	5	0.25	143	13	1	TRUE	FALSE
Cell Phone Charger	8	5	4	2	46	9	1	TRUE	FALSE
Nebulizer	40	2	5	2	114	10	4	TRUE	FALSE
Magnifying Glass With Lamp	10	2	2	0.2	1	9	1	TRUE	FALSE
Anatomical Stretcher	350	2	5	0.5	250	9	1	TRUE	FALSE
Electrocardiograph	100	2	5	0.25	36	10	2	TRUE	FALSE
Vital Signs Monitor	20	1	5	12	171	9	1	TRUE	FALSE
Tube Shaker	10	2	5	1	14	10	1	TRUE	FALSE
Centrifuge	20	1	5	1	14	9	2	TRUE	FALSE
Hematocrit Centrifuge	250	1	5	1	179	10	1	TRUE	FALSE
Microcentrifuge	280	1	5	1	200	9	2	TRUE	FALSE
Spectrophotometer	120	1	5	1	86	10	1	TRUE	FALSE
Glass Washer	7,000	1	5	1	5,000	9	2	TRUE	FALSE
Medical Compressor	750	1	5	3	1,607	10	1	TRUE	FALSE
Autoclave 50–70 Liters	3,000	2	5	1	4,286	9	2	TRUE	FALSE
Sterilizer of 23–30 Liters of Water	2,000	2	5	1	2,857	10	1	TRUE	FALSE
Vaccine Refrigerator	28	1	7	24	671	0	0	TRUE	TRUE
Refrigerator for Special Areas	46	4	7	24	1,096	0	0	TRUE	TRUE
Fan	391	2	6	8	2,142	9	1	TRUE	TRUE

Appendix B. Overview of Financing Sources for Solar Projects

B.1 Conventional Finance Models

Equity finance: Equity finance involves the investment of funds in exchange for partial ownership of assets. This method allows for community ownership through contributions: local residents or stakeholders invest in the project and, in return, gain a share of the ownership. This model can enhance community engagement and ensure that the benefits of the project are shared among those who invest (Brealy et. al 2020).

Grants and prizes: Grants and prizes are awarded funds that do not need to be repaid. These can come from various sources, including government subsidies or climate and development aid programs. Grants are particularly useful for funding the initial stages of projects, including feasibility studies, pilot projects, and capacity-building activities. They provide a financial cushion that can help communities and developers take on innovative projects without the burden of repayment (IRENA, 2020).

Debt finance: Debt finance involves borrowing funds that are repaid with interest over time. This model does not impact ownership, making it a popular choice for projects that need significant upfront capital but want to retain ownership control. Common sources of debt finance include loans from banks and financial institutions, which can often be reduced with a down payment. This model is suitable for projects with predictable income streams that can ensure timely repayment.

B.2 Conventional Finance Providers

Equity providers: Equity financing can come from both public and private entities. Public entities might include government programs aimed at promoting renewable energy or community development. Private investors could be individuals or firms looking to invest in sustainable projects. These investors provide the necessary capital in exchange for a stake in the project's success (US Department of Energy).

Debt providers: Debt financing is typically provided by financial institutions such as banks, as well as development finance institutions and climate funds. These organizations lend money with the expectation of repayment with interest. They assess the project's risk and potential for success before providing the necessary funds (IEA, 2019).

Grant and prize providers: Grants and prizes can be awarded by a variety of entities, such as:

- **Governments and government agencies**: National and local governments often have programs to support renewable energy projects, particularly in underserved areas.
- **Development finance institutions and climate funds**: These organizations focus on funding projects that have a significant positive impact on climate and development goals.

- **Private nongovernmental organizations and foundations**: Many nongovernmental organizations and foundations offer grants for projects that align with their missions, such as improving energy access or promoting sustainable development.
- **Renewable energy project developers**: Some developers may offer grants or prizes as part of their corporate social responsibility initiatives or to support projects that align with their business interests.
- **Crowdfunding platforms**: These platforms allow for raising small amounts of money from many people, typically via the internet. Crowdfunding can be an effective way to gather community support and raise funds for specific project components.

B.3 Alternative Finance Models

Green revolving funds: Green revolving funds involve reinvesting cost savings from energy projects back into the fund. This model requires initial capital, which can come from government financial institutions, nongovernmental organizations, or community contributions. The fund is used to finance projects that generate cost savings, such as energy efficiency improvements or renewable energy installations. The savings are then used to repay the funds, creating a sustainable financing cycle.

Tax-equity loans: Tax-equity loans leverage tax incentives to make investments more attractive to private financiers. These incentives can come from national or local government programs designed to promote renewable energy. The guarantee of tax credits reduces the financial risk for investors, making it easier to attract private capital for projects.

Energy or utility energy service performance contracts: Energy or utility energy service performance contracts involve partnerships with energy service companies to finance energy projects. The savings generated from these projects are used to pay for the cost of implementation. Energy service performance contracts can bundle distributed energy projects with other energy efficiency measures, ensuring comprehensive energy solutions. Utility energy service contracts are similar but are typically limited-source contracts between an agency and a utility for energy and demand-reduction services. Both models ensure energy cost savings pay for the project over the contract term, providing financial sustainability without upfront costs.

These alternative finance models offer flexible and innovative ways to fund renewable energy projects, ensuring that communities can access the capital needed to improve their energy infrastructure and promote sustainable development.