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Dragonfly Hybrid Renewable Plant Design for Camella Subdivision

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Abstract - This study assesses the technical and economic viability of a Dragonfly-Inspired Hybrid Renewable Power Plant in Camella Groves Subdivision, Plaridel, Bulacan, Philippines, which includes solar photovoltaic (PV), wind turbine, and battery energy storage systems. To determine system performance and contribution to energy resiliency, a descriptive-analytical and engineering design approach was used, which included resource evaluation, system modeling, cost calculation, and techno economic analysis. The hybrid system was designed to meet a community demand of 1,800 kWh/day, with a 430 kW PV array, 130 kW wind turbines, 5,000 kWh battery storage, and a 150 kW inverter, resulting in a net available energy of 1,764 kWh/day and up to 2.8 days of full-load autonomy. The economic study shows a baseline capital cost of PHP 120.71 million, yearly operational and maintenance expenditures of PHP 1.81 million, and a simple payback period of 22.3 years. The integration of ICT, SCADA, and AI ensures intelligent, adaptive, and dependable operation, improving the system's ability to provide uninterrupted power amid grid outages, extreme weather, or disaster occurrences. These findings show that the planned hybrid power plant is technically and economically feasible, and it considerably improves local energy resiliency.

Index Terms **- Hybrid Renewable Power Plant, Dragonfly-Inspired Design, Solar PV, Wind Turbine, Battery Energy Storage System, Energy Resiliency.**

I. INTRODUCTION

Background of the Study

Modern power production systems operate in a fast changing environment marked by rising electricity demand, shifting decarbonization regulations, aging infrastructure, and increased susceptibility to extreme weather events. As a result, energy resiliency an energy system's ability to foresee, absorb, adapt to, and recover from disruptions has become an important design factor. Power systems that use intermittent renewable energy sources and have complex interconnections are especially vulnerable to extreme weather, operational uncertainties, and cyber threats [2].

Power plant engineering designs have traditionally prioritized efficiency, cost-effectiveness, and dependability under predictable operating conditions. However, contemporary circumstances highlight resilience as an equally important criteria Power plants must not only perform well under normal conditions, but also show flexibility, redundancy, and the ability to recover swiftly when disturbances [8].

Typhoons, flooding, fuel supply delays, and system failures are common causes of power outages in the Philippines, particularly in island and coastal locations like Bulacan. Camella Subdivision in Plaridel is similarly vulnerable, with key infrastructure like telecommunications requiring consistent power.

The proposed Dragonfly-Inspired Hybrid Renewable Power Plant overcomes these issues with a bio-inspired, modular architecture. The metaphorical "wings" represent various renewable energy sources, such as solar photovoltaic (PV) and wind power, which lessen the likelihood of single-point failures. The "thorax" indicates energy storage via battery or hydrogen systems for short- and long-term backup, while a segmented modular design allows for fast repair and staged recovery. Aerodynamic and flood-resistant civil designs improve survivability, while the "compound eye" is an ICT-based monitoring system that integrates SCADA, IoT sensors, and predictive analytics to provide real-time situational awareness. These design aspects are consistent with the Philippine Energy Plan's emphasis on a diverse energy mix, distributed generation, climate-proofing, and digitalization [1–4].

From a technical standpoint, complementing solar and wind generating provides energy availability at all times of day, while energy storage smooths output and supports black start capability. Micro grid capabilities enable the subdivision to operate independently during grid failures, while redundant conversion and protection systems maintain local stability and protect important loads such as telecommunications. Civil works and balance-of-plant siting reduce flooding and typhoon hazards, lowering recovery times and increasing local energy resilience [3].

Finally, implementation must take into account national and local regulatory, institutional, and financial frameworks. The Philippine Energy Plan and related power development policies emphasize incentives for grid upgrading, battery storage deployment, and distributed generation, as well as the deployment of resilient hybrid plants at the community level [1], [20]. Despite these policies, local implementation of energy resiliency measures is patchy, making communities like Plaridel vulnerable. This study fills a research gap by combining bio-inspired design, renewable energy diversity, and digital resiliency into a context-specific framework that encourages localized, disaster-ready energy systems.

Statement of the Problem

Bulacan communities, especially Plaridel and surrounding areas, frequently face power outages as a result of typhoons, flooding, and other weather-related calamities. These disruptions highlight the vulnerability of centralized power systems, emphasizing the importance of decentralized, resilient, and adaptive energy solutions. Despite governmental attempts to encourage renewable energy, there is a paucity of integrated hybrid systems at the community level that incorporate solar, wind, and energy storage within a climate-proof, digitally enabled design framework.

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Although bio-inspired engineering principles have demonstrated potential for improving system efficiency and resilience, their application in the Philippine context particularly in suburban or semi-urban areas such as Plaridel has yet to be explored. The lack of such localized models restricts prospects for self-sufficiency and energy security during calamities or power outages.

This study fills these gaps by proposing a Dragonfly-Inspired Hybrid Renewable Power Plant for Camella Subdivision in Plaridel, Bulacan, which combines solar PV, wind turbines, and battery energy storage systems (BESS) via a modular, ICT-based control network. Specifically, the study aims to address the following:

1. What is the technical feasibility of integrating solar, wind, and storage components within a dragonfly-inspired hybrid power plant design suited for the local environment of Plaridel, Bulacan?
2. What are the estimated capital, operational, and maintenance costs, and what is the overall economic viability of implementing such a hybrid system at the subdivision scale?
3. How can the proposed design enhance energy resiliency, particularly in maintaining power supply for critical infrastructure such as telecommunications during disasters or grid failures?
4. To what extent can digital technologies such as ICT, SCADA, and AI monitoring can improve system reliability, maintenance efficiency, and response time during operational disturbances?

Hypotheses

Null Hypothesis (H_0):

The proposed Dragonfly-Inspired Hybrid Renewable Power Plant for Camella Subdivision in Plaridel, Bulacan is not expected to produce a significant improvement in energy resiliency, and its overall design may prove technically or economically unviable under existing environmental and market conditions.

Alternative Hypothesis (H_1):

The proposed Dragonfly-Inspired Hybrid Renewable Power Plant for Camella Subdivision in Plaridel, Bulacan is anticipated to significantly strengthen energy resiliency and demonstrate technical and economic viability within the present environmental and market context.

Objectives of the Study

General Objective

This study aims to evaluate the technical and economic feasibility of developing a Dragonfly-Inspired Hybrid Renewable Power Plant that integrates solar, wind, and energy storage technologies for Camella Groves Subdivision, Plaridel, Bulacan, as a strategic model for enhancing energy resiliency, reliability, and disaster preparedness at the community level.

Specific Objectives:

1. To analyze the technical potential and system design requirements for integrating solar photovoltaic, wind turbine, and battery energy storage components into a modular, dragonfly-inspired hybrid power plant.

2. To estimate the capital investment, operational, and maintenance costs associated with implementing the proposed hybrid renewable power system and determine its overall economic viability.

3. To assess the contribution of the hybrid system to local energy resiliency, particularly in maintaining continuous power supply during grid disturbances, disasters, or extreme weather events.

Significance of the Study

The study investigates the possibility of a Dragonfly-Inspired Hybrid Renewable Power Plant as a paradigm for energy resilience and sustainability in suburban communities such as Camella Subdivision, Plaridel, Bulacan. By incorporating solar, wind, and battery storage technologies into a flexible and digitally enabled architecture, the study sheds light on how bio-inspired engineering may fulfill the growing demand for dependable and disaster-resistant power solutions.

Beneficiaries:

- **Academics and Engineers** = Provides a framework for designing hybrid renewable systems that combine technical innovation, sustainability, and digital intelligence.
- **Residents** = Demonstrates localized hybrid power systems that reduce reliance on the national grid, ensure electricity during emergencies, and promote community awareness of renewable energy.
- **Future Researchers** = Contributes knowledge on hybrid renewable energy design and energy resiliency, providing a reference for future feasibility studies and policy development.
- **Local Government Units (LGUs)** = Guides energy planning, infrastructure development, and climate adaptation strategies, supporting micro grid initiatives at the community level.

Scope and Delimitations

Scope:

The study focuses on the conceptual design and feasibility assessment of a Dragonfly-Inspired Hybrid Renewable Power Plant for the Camella Subdivision in Plaridel, Bulacan. It comprises scientific assessments of solar and wind resources, economic evaluations, community viewpoints, and design creation for the energy landscape through 2025.

Limitations:

1. Conceptual and techno economic design only meaning no field implementations.
2. Focused solely on solar, wind, and BESS.
3. Digital and control features discussed conceptually.
4. Environmental impact assessments acknowledged but not declined.
5. Design assumes reliably secondary data for solar, wind and local demand.

Assumptions of the Study

1. National and local policies as the Renewable Energy act of 2008 and Philippines Energy Plan 2023-2025 continue to support renewable energy and resiliency projects.
2. Meteorological data for Plaridel accurately represent renewable potential.
3. Economic, financial, and technical parameters reflect realistic market conditions in 2025.
4. Community respondents provide honest and informed feedback.

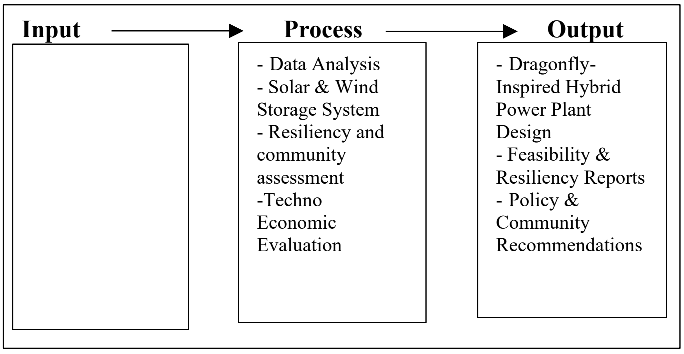
Theoretical Framework

This study is grounded in **Energy Resiliency Theory**, emphasizing system capacity to anticipate, absorb, adapt, and recover from disruptions [2]. **Renewable Energy Integration Theory** provides a framework for optimal coordination of multiple renewable sources [21]. **Biomimicry Theory** informs the bio-inspired dragonfly design, supporting adaptability, modularity, and efficient energy capture [22]. The integration of these theories ensures a holistic approach to technical feasibility, economic viability, and community-centered energy resiliency.

Conceptual Framework

The conceptual framework depicts the flow of inputs, processes, and outputs for the Dragonfly-Inspired Hybrid Renewable Power Plant. Inputs include technological, economic, and community information, as well as theoretical principles. Data analysis, system modeling, resilience assessment, and technoeconomic evaluation are all part of the processes. Outputs include hybrid power plant design, feasibility reports, resiliency assessment, and policy recommendations.

Figure 1: Input-Process-Output Conceptual Framework



This study employs a descriptive-analytical and engineering

design approach to evaluate the technical and economic feasibility of a Dragonfly-Inspired Hybrid Renewable Power Plant at Camella Groves Subdivision, Plaridel, Bulacan. Quantitative analyses are conducted for resource assessment, system modeling, and cost evaluation, while conceptual design techniques guide the hybrid system configuration. The methodology integrates techno-economic feasibility assessment, considering renewable energy supply, technical performance, costs, and contributions to local energy resiliency in accordance with the Philippine Energy Plan [1]. Combining engineering design with economic evaluation allows for a comprehensive analysis of hybrid solar, wind, and energy storage systems, including social acceptability and resilience under disruptive conditions [5].

B. Research Locale

Camella Groves Subdivision, located in Plaridel, Bulacan, Central Luzon, Philippines, is the study site. The area experiences rapid residential and commercial growth, rising electricity demand, and periodic power interruptions due to extreme weather events. The locale offers suitable solar irradiance is **4.5–5.1 kWh/m²** per day and exploitable wind conditions, making it ideal for hybrid renewable energy development. The subdivision's infrastructure, open spaces, and proximity to existing electrical networks further support system deployment. The location provides a representative case for assessing localized energy resiliency and informs potential community-scale hybrid energy projects aligned with national renewable energy goals [1, 23, 24].

C. Research Respondents

The study engages homeowners, community leaders, technical personnel from Streamtech Telecommunications, and local LGU representatives. Fifty respondents were purposively selected to ensure relevant knowledge and experience regarding local energy reliability. Table 1 summarizes the respondent distribution.

Group of Respondents	2025 Population	Percentage	Number of Respondents
Homeowners	180	60%	30
Community Leaders or Representative	10	20%	10
StreamTech Agents of Staff	20	10%	5
Baranggay Officials and Local LGU	10	10%	5
Total	220	100%	50

Table I: *Research Respondents*

D. Research Instrument

Data were gathered using structured questionnaires, semi-structured interviews, and environmental/technical measures. Surveys collected demographic information, perceptions of hybrid renewable systems, willingness to participate, and power outages. Interviews with stakeholders yielded qualitative insights into technological requirements, operational limits, and maintenance issues. Subject matter experts vetted and pilot-tested the questionnaires to verify their reliability and intelligibility. Observation and measurement sheets recorded sun irradiance, wind speed, ambient conditions, and electricity usage trends. Secondary data were gathered from DOE, PAGASA, MERALCO, and NAMRIA to supplement primary observations.

E. Simplified Hybrid Energy Output Estimation

Energy output from the proposed hybrid system was estimated using first law thermodynamic principles and simplified power equations.

Hybrid Energy balance:

$$P_{generated} = P_{solar} + P_{wind}$$

Where:
$P_{generated}$ = total energy output from the hybrid system in kWH per day.
P_{solar} = energy from solar panels in kWH per day.
P_{wind} = energy from wind turbines in kWH per day.

Solar PV output:

$$P_{solar} = I_{solar} \times A_{solar\ array} \times \eta_{PV}$$

Where:
I_{solar} = average daily solar irradiance in kWH/m^2 per day.
$A_{solar\ array}$ = total effective area of the photovoltaic array in m^2.
η_{PV} = photovoltaic system efficiency or the module efficiency and performance ratio.

Wind Energy Output:

$$P_{wind} = \frac{1}{2} \times \rho_{air} \times A_{rotor\ Swept} \times V_{wind} \times \eta_{wind\ turbine}$$

Where:
ρ_{air} = air density at 1.225 kg/m^3.
$A_{rotor\ swept}$ = turbine rotor swept area.
V_{wind} = wind velocity in m/s.
$\eta_{wind\ turbine}$ = efficiency of the wind turbine

F. Data Gathering Procedure

A mixed-methods approach was used to assess the technical, economic, and social feasibility of the Dragonfly-Inspired Hybrid Renewable Power Plant for Camella Groves Subdivision, Plaridel, Bulacan. This included quantitative surveys, qualitative interviews, and secondary technical data analysis. The data gathering procedure

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was divided into three primary phases: preparation, data collection, and data processing.

1. **Preparation Phase**

Prior to data collection, official cooperation was carried out with the Camella Subdivision Homeowners Association (HOA), Streamtech Telecommunications management, and Plaridel Municipal Engineering and Planning Office in Bulacan. Permissions and endorsements were obtained for conducting surveys, interviews, and on-site inspections.

Subject matter experts in renewable energy and engineering design approved the study instruments, which included a structured survey questionnaire and an interview guide, to ensure their relevance, correctness, and dependability. A pilot test was undertaken in a nearby subdivision to ensure the clarity and appropriateness of survey items, and revisions were made as needed.

2. **Data Collection Phase**

- **Primary Data**

- **Survey Questionnaires:** Data on demographics, energy usage trends, awareness and support for hybrid renewable systems, and experiences with power outages were collected through surveys given to homeowners, community leaders, Streamtech technical staff, and local government representatives.

Part A: Demographic Profile

Occupation:

Years of Residence:

Household size:

Electricity Power consumption:

Part B: Hybrid Renewable Energy System's Benefits and Risks

Indicators	1	2	3	4	5
The use of hybrid renewable systems (solar, wind, and battery storage) can reduce pollution and promote cleaner energy.					
Hybrid power systems can provide more stable and reliable electricity for residential and telecommunication use.					
The installation of renewable energy devices in our subdivision may cause noise or aesthetic concerns.					
Strong typhoons or extreme weather events may affect the safety and performance of hybrid renewable systems.					
Renewable energy projects can create local employment, maintenance, and business opportunities within the community.					
Hybrid renewable power plants can help reduce dependency on the main electrical grid.					
Incorporating renewable energy into subdivisions can help communities prepare for power outages and crises.					

Part C: Willingness to Support and Participate

I favor the use of hybrid renewable energy technologies in our subdivision.					
I am eager to take part in discussions or consultations regarding local renewable energy projects.					
I am confident that the subdivision management and the local government would correctly install renewable energy systems.					
I am willing to fund pilot initiatives or research aimed at increasing our community's energy resiliency.					
I consider adopting renewable energy is essential to our community's future.					

Table IIA: *Research Survey Questionnaire*

Legend:
5 – Strongly Agree
4 – Agree
3 – Neutral
2 – Disagree
1 – Strongly Disagree

Part D: Experience with Power Interruptions and Environmental Conditions

1.	How frequently does your community face power outages?
2.	What is the average duration of power outages?
3.	How many times has the weather or strong rains disrupted the electrical supply for your household in the last year?
4.	How significant an effect these incidents have on your ability to access electricity and carry out regular activities?
5.	How prepared do you believe your community is to deal with energy disruptions caused by severe weather or grid failures?

Table IIB: *Research Questionnaire adapted from Rogers et al. [28].*

- **Key Informant Interviews:** Interviews were conducted with subdivision engineers, Streamtech workers, and barangay officials to gain qualitative insights into operating requirements, technical obstacles, and maintenance issues.
- **On-site Observations and Measurements:** Environmental and technological criteria have been documented, including available roof and open-space areas for solar panels, wind exposure, and existing electrical infrastructure.

- **Secondary Data**

- DOE, PAGASA, NAMRIA, and MERALCO provided technical and environmental datasets, which included average solar irradiance, wind speeds, and grid dependability indices.
- Local energy usage and peak demand statistics were gathered from Streamtech Telecommunications to aid in system sizing and cost analysis.

3. **Data Processing and Analysis Phase**

All survey responses were encoded, tallied, and analyzed with Microsoft Excel and SPSS. The community's perceptions and awareness were summarized using descriptive statistics such as frequency, mean, and percentage. Qualitative interview data were transcribed and thematically examined to uncover common themes about energy resiliency and renewable energy viability.

Technical and economic data were combined with simulation and costing tools like HOMER Pro and RETScreen to evaluate the hybrid system's energy output, system efficiency, and cost-benefit ratios. A cross-analysis of social acceptability, technical performance, and economic viability confirmed congruence with the overall goal of increasing community energy resilience in Camella Groves Subdivision.

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G. Economic Feasibility Analysis and Financial Evaluation

The economic feasibility of the proposed Dragonfly-Inspired Hybrid Renewable Power Plant in Camella Subdivision, Plaridel, Bulacan, was assessed to determine whether the system integrating solar photovoltaic at **430 kW,** wind turbines at **130 kW**, and battery energy storage at **5,000 kWh** is cost-effective, sustainable, and financially viable for both Streamtech Telecommunications and the residential community.

Financial Evaluation Metrics:

- **CAPEX** includes costs for equipment procurement, site preparation, installation, and system integration. The baseline capital cost for the system is estimated at **PHP 120.71 million**.

- **OPEX** covers annual operations, maintenance, and replacement costs, calculated at approximately **PHP 1.81 million per year.**

- **Net Present Value (NPV)** measures the difference between discounted cash inflows and outflows over the project life.

$$\text{NPV} = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t}$$

Where:
R_t = revenue or savings.
C_t = is the cost at time t.
r = discount rate.
n = project life.

- **Internal Rate of Return (IRR)** is the discount rate that makes NPV equal to 0 while indicating expected return on investment.
- **Benefit-Cost Ratio** compares total discounted benefits to total discounted costs to assess cost-effectiveness.
- **Playback Period** is the time required for cumulative savings to cover the initial investment. Calculated as:

$$PBP = \frac{Initial\ Investment\ (CAPEX)}{Annual\ Net\ savings}$$

- **Levelized Cost of Energy** represents the average cost of generating electricity over the system's lifetime:

$$LCOE = \frac{Total\ Lifetime\ Cost}{Total\ Lifetime\ Energy\ Output\ in\ kWH}$$

Expected Output
The economic feasibility analysis provides:
- A comparative cost-benefit profile for each system Configuration.
- The optimal hybrid design balancing investment cost, reliability, and sustainability.
- Recommendations for local policy integration and potential public to private partnerships to support renewable energy deployment in residential subdivisions.

Utilizing these parameters for the proposed hybrid system, the baseline CAPEX is **PHP 120.71 million**, with an annual OPEX of **PHP 1.81 million**. At a household retail electricity pricing of PHP 11/kWh, the system saves **PHP 7.23 million per year** on electricity purchases, for a net yearly benefit of **PHP 5.42 million** and a simple payback period of **22.3 years**. The baseline LCOE is assessed at **PHP 21.5/kWh**. Sensitivity analysis shows that battery size and cost have a substantial impact on financial outcomes, and practical changes like as partial grid interconnection or concessional financing could enhance overall viability.

III. RESULTS AND DISCUSSIONS

A. Background Data and Energy Demand Estimation

The table below provides background data and expected energy consumption for Camella Groves Phases 10 and 11 in Plaridel, Bulacan, which will serve as the pilot site for the proposed Dragonfly-Inspired Hybrid Renewable Power Plant. The parameters are the number of households, population, per-household consumption, and design grid assumptions. These criteria serve as the foundation for sizing the solar photovoltaic, wind, and battery energy storage components to meet the community's energy requirements while maintaining technical feasibility and resiliency.

Parameters	Value	Notes	References
Number of Houses	180 units	Phases 10 and 11	[1], [23]
Max person per house	5 persons / unit	*Assumed* based on local household size	Assumption
Population	900 persons	180 units x 5 persons	[1], [23]
Power Consumption per house	10kWH / day	Standard *estimation* average daily consumption	[1], [23], [5]
Total Energy Demand	1,800kWH/ day	180 units x 10 kWH	Author Calculation
Average Load	75kW	1,800kWH per day ÷ 24 Hours	Author Calculation
Peak Load	112.5kW	*Estimated* using 1.5 peak factor	Author Calculation
Design Grid	Off-grid hybrid	Solar, Wind, and Battery	Project Design

Table III: *Background Data and Energy Demand Estimation Camella Groves Phase 10 and 11, Plaridel, Bulacan, Philippines*

1. Technical Feasibility of the Hybrid System

The technological feasibility of the proposed Dragonfly-Inspired Hybrid Renewable Power Plant was assessed using previously known background characteristics. The hybrid system combines solar PV, small-scale wind turbines, and a battery energy storage system (BESS) to fulfill peak and average needs while being resilient to outages. Using conservative resource and loss assumptions, the PV and wind capacity were designed with a 70:30 energy contribution ratio. The BESS was designed to give two days of full-load autonomy, while the inverter was sized to handle peak demands with a 30% safety margin. Table 4 highlights the important system sizing and performance parameters obtained through these computations.

Parameters	Value	Notes	Source
Solar PV installed capacity	430kW	Includes 15% overbuild	Computed

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Wind Installed Capacity	130kW	Includes 15% overbuild	Computed
Nominal Gross Generation	2,075kWH / day	PV + wind	Computed
Net Energy Available	1,746kWH / day	After 15% losses	Computed
Nominal Battery Storage	5,000kWH	2-day autonomy with 80% DoD, and 90% round trip efficiency	Computed
Inverter Capacity	150kW	Has 30% margin for startups	Computed

Table IV: *Technical Feasibility Parameters of the Dragonfly-Inspired Hybrid Renewable Power Plant Camella Groves Phase 10 and 11, Plaridel, Bulacan, Philippines*

2. Economic Viability of the Hybrid System

The economic viability of the proposed Dragonfly-Inspired Hybrid Renewable Power Plant was assessed using the fixed technical configuration established in the technical feasibility analysis, which included a 430 kW solar PV array, 130 kW wind turbines, a 5,000 kWh battery energy storage system (BESS), and a 150 kW inverter capacity. The system sizes were kept constant to provide uniformity between technical and financial assessments. The research focuses on capital investment requirements, annual operating costs, avoided electricity expenditures, and traditional financial performance measures such as payback period and levelized cost of energy (LCOE). All cost assumptions are based on current Philippine market estimates for community-scale renewable energy systems, and they are consistent with recent national and international energy cost benchmarks [1], [13], [16], and [17].

Parameter	Value	Notes	Source
CAPEX	Php 120.71 million	Includes PV, wind, BESS, Inverter, BOS, civil Works, SCADA, and Contingency	Author's Computation; [13], [16]
OPEX	Php 1.81 million	*Assumed* 1.5% of the CAPEX	[13], [17]
Annual Energy Supply	657,000kWH / year	Based on 1,800kWH per day demand	Section III-A
Grid Electricity Tariff	Php 11 / kWH	Residential retail *assumption*	Section III-A
Annual Avoided Cost	Php 7.23 million / year	Grid cost offset by hybrid system	Author's Computation
Net Annual Benefit	Php 5.42 million / year	Avoided cost - OPEX	Author's Computation
Simple Playback Period	22.3 years	CAPEX divided by annual net benefit	Author's Computation
LCOE	Php 21.5 / kWH	8% discount rate and 20 year lifetime	[17]

Table V: *Economic Parameters and Financial Performance of the Proposed Hybrid System*

The findings show that the suggested off-grid hybrid system requires a significant initial expenditure, which is mostly driven by battery energy storage expenses. While the system saves roughly PHP 7.23 million in electricity each year, operating and maintenance costs limit the net annual benefit to PHP 5.42 million, resulting in a 22.3year easy payback period. The projected LCOE of PHP 21.5/kWh is higher than the existing home grid rate of PHP 11/kWh, indicating the premium associated with totally off-grid, high-resilience systems. Nonetheless, the economic results show that the system's value goes beyond cost competitiveness by improving energy security, disaster resilience, and operational independence. According to sensitivity analysis, battery cost reductions, partial grid connections, or concessional financing arrangements could greatly increase the financial viability of the proposed hybrid power plant.

3. Energy Resiliency Analysis

Energy resiliency is an energy system's ability to foresee, withstand, adapt to, and recover quickly from power disruptions such as grid breakdowns, extreme weather events, and extended outages. Using the fixed technical configuration established in the technical feasibility analysis namely a **430 kW** solar PV system, **130 kW** wind turbines, a **5,000 kWh** battery energy storage system (BESS), and a **150 kW** inverter the resiliency performance of the proposed Dragonfly-Inspired Hybrid Renewable Power Plant was quantitatively assessed for Camella Groves Phases 10 and 11. This study focuses on operational autonomy, renewable contribution, and critical-load survivability in islanded operations, which are important markers of community-scale energy resilience in disaster-prone areas like Central Luzon [2], [7].

Parameters	Value	Basis	Source
Full load battery autonomy	2.78 days	5,000kWH BESS supplying 1,800 kWH per day	Author's Computation
Half Load Battery Autonomy	5.56 days	Battery supplying 50% of daily demand	Author's Computation
Critical Load Autonomy	41.7 days	Continuous telecom critical load operation	Author's Computation
Daily net Renewable Availability	1,764kWH / Day	After 15% system losses	Section III-A
Daily Energy Demand	1,800kWH / day	Community Demand Baseline	Section III-A
Renewable Energy Fraction	98%	Net Renewable supply divided by demand	Author's Computation
Islanded Operation Capacity	Yes	Grid forming inverter and BESS enabled	Design Feature
Load Prioritization Capability	Yes	EMS and SCADA supported load shedding	Design Feature

Table VI: *Energy Resiliency Metrics of the Proposed Hybrid Power System*

The resiliency study reveals that the proposed hybrid system significantly improves Camella Groves' energy security. With over **2.8 days** of full-load autonomy and more than **41 days** of continuous operation for key telecom loads, the system provides a strong buffer against both short-term outages and long-term grid disruptions. Under normal operating conditions, the high renewable portion of about **98%** decreases dependence on external energy source even more. These findings demonstrate that the Dragonfly-inspired architecture, which incorporates modularity, diverse generating sources, and significant energy storage, effectively enables decentralized and resilient power distribution. While extreme multi-day weather events may continue to challenge renewable availability, the system's storage capacity, load prioritization, and digital energy management capabilities significantly reduce

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operational risk, making the design ideal for disaster-resistant residential micro grids in the Philippines.

4. ICT, SCADA, and AI Analysis

Performance Indicator	Without Digital Optimization	With ICT, SCADA, and AI	Impact	Source
SCADA monitoring cycle	Manual and delayed	1 to 5s update	Faster detection of faults and voltage deviations	[18]
System Condition checks	Limited	*Estimated* 720cycles per hour	Continuous system awareness	Author's Computation
Usable Battery Capacity	4,250 kWH	4,600 kWH	AI optimized charge and discharge control	Author's Computatin
Battery Utilization efficiency	85%	92%	Reduces overcharge and deep discharge	[19]
Additional usable energy	-	+350 kWH	Increased effective storage capacity	Author's Computation
Equivalent Households Powered	-	+35houses per day	*Based* on 10kWH / day per house	Author's Computation
Full load autonomy	2.36 days	2.56 days	Improved dispatch efficiency	Author's Computation
Predictive Maintenance Capability	none	yes	Failure prediction and prevention	[19]
Automatic Islanding Response	Manual	Automatic	Seamless transition during outages	[18]

Table VII: *Performance Improvements Enabled by ICT, SCADA, and AI*

The results show that combining ICT, SCADA, and AI considerably improves the operational intelligence and robustness of the proposed hybrid power system. SCADA allows for rapid fault detection and automated islanding with response times of seconds or less, eliminating cascade failures during grid disturbances. AI-driven battery management boosts usable storage capacity by about **350 kWh** enough to power **35 more houses** per day while also improving system autonomy through optimal dispatch and load prioritization. Predictive maintenance capabilities further reduce downtime by detecting component degradation before it occurs. Collectively, these digital innovations improve the system's ability to react to variable renewable supplies, manage key loads, and recover fast after disturbances. The findings demonstrate that ICT, SCADA, and AI are not just add-ons, but critical enablers of a resilient, community-scale hybrid renewable energy system ideal for disaster-prone residential areas like Camella Groves.

The proposed Dragonfly-Inspired Hybrid Renewable Power Plant is transformed from a conventional hybrid system to an intelligent, adaptive, and resilient micro grid by integrating information and communication technology (ICT), supervisory control and data acquisition (SCADA), and artificial intelligence (AI). Building on the existing technological setup having **430 kW** solar PV**, 130 kW** wind turbines, **5,000 kWh** BESS, and **150 kW** inverter, with this part assesses how digital technologies improve operational efficiency, response time, battery use, and overall system resilience. Rather than changing the physical design, ICT, SCADA, and AI improve system performance through real-time monitoring, automated control, predictive analytics, and optimized energy dispatch, all of which are critical for maintaining reliable power during grid failures and extreme weather events like those that occur in Plaridel, Bulacan [18] [19].

IV. CONCLUSIONS

This study assessed the technical feasibility, economic viability, and energy resiliency of a Dragonfly-Inspired Hybrid Renewable Power Plant proposed for Camella Groves Phases 10 and 11 in Plaridel, Bulacan, Philippines. Using a set community demand of **1,800 kWh/day** obtained from **180 houses** consuming **10 kWh/day** each, the system was sized using conservative resource assumptions, loss allowances, and engineering safety margins.

This study looked at the technical feasibility, economic viability, and energy resiliency of a Dragonfly-Inspired Hybrid Renewable Power Plant proposed for Camella Groves Phases 10 and 11 in Plaridel, Bulacan, Philippines. The system was sized using conservative resource assumptions, loss allowances, and engineering safety margins to meet a predetermined community demand of **1,800 kWh/day** generated by 180 homes consuming **10 kWh/day** each. This output falls within a **2%** margin of the goal demand and can be addressed with operational optimization, battery dispatch techniques, or modest capacity adjustments. The battery system offers roughly **2.8 days** of full-load autonomy and more than **41 days** of operation for a **5 kW** critical telecommunications load, demonstrating the system's potential to provide important services during extended outages.

According to the economic study, the proposed system requires a baseline capital investment of roughly **PHP 120.71 million**, with yearly running and maintenance costs of **PHP 1.81 million**. At the current household electricity pricing of **PHP 11/kWh**, the system saves over **PHP 7.23 million per year** in grid electricity purchases, for a net yearly benefit of **PHP 5.42 million** and a simple payback period of **22.3 years**. The calculated levelized cost of electricity (LCOE) is **PHP 21.5/kWh**, which is higher than existing grid prices, owing to the high initial cost of battery storage. While the off-grid arrangement is not instantly cost-competitive in the current market, sensitivity analysis shows that lower battery costs, partial grid connectivity, and concessional financing can dramatically improve financial performance.

In terms of energy resiliency, the Dragonfly-inspired design significantly improves the system's ability to predict, absorb, adapt, and recover from shocks. Decentralized generation, diverse renewable sources, extensive energy storage, and modular system architecture prevent single-point failures and improve survival during typhoons, flooding, and grid outages. Under usual conditions, the system has an estimated renewable portion of about 98%, indicating considerable independence from centralized power infrastructure.

Finally, the integration of ICT, SCADA, and AI converts the hybrid system into an intelligent and adaptable energy infrastructure. Real-time monitoring, automatic islanding, predictive maintenance, and AI-based battery optimization boost operating efficiency, increase usable battery capacity by about **350 kWh**, and extend system autonomy. These digital technologies considerably improve system dependability and resilience, especially during crisis scenarios and extended grid outages.

Overall, the data support the proposed Dragonfly-Inspired Hybrid Renewable Power Plant as technically possible, resilience enhancing, and conditionally economically viable. The design offers a viable framework for implementing community-scale, disaster-resistant renewable energy systems in residential subdivisions in the Philippines and other developing countries.

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V. RECOMMENDATIONS

Based on the results of this study, the following recommendations are proposed:

1. **Partial Grid Integration**
   Implementing a grid-connected or grid-assisted operating mode can minimize battery sizing, capital expenditures, and overall economic feasibility while maintaining resiliency benefits.

2. **Optimized Battery Saving and Phased Deployment**
   Implementing a grid-connected or grid-assisted operating mode can reduce battery size, capital costs, and overall economic feasibility while retaining resiliency benefits.

3. **Advanced Load Prioritization Strategies**
   Implementing a grid-connected or grid-assisted operating mode can reduce battery size, capital expenditures, and overall economic feasibility while maintaining resiliency advantages.

4. **Physical Hardening and Modular Layout**
   Implementing a grid-connected or grid-assisted operating mode can reduce battery size, capital costs, and overall economic feasibility while retaining resiliency benefits.

5. **Integration of Backup Generation for Extreme Events**
   A small auxiliary generator such as 50 to 100 kW diesel or biofuel that could be used as a backup plan for uncommon, long-term low-renewable conditions.

6. **Further Time Series and Simulation Studies**
   Detailed hourly simulations with tools like HOMER, MATLAB, or RET Screen are recommended to fine-tune reliability measures, battery degradation affects, and long-term performance.

7. **Policy and Financing Support**
   Government incentives, concessional funding, and public-private partnerships can considerably increase the viability of off-grid and hybrid renewable energy systems in residential communities.

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