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Dragonfly-Inspired Hybrid Renewable Power Plant Design for Camella Subdivision:

A Case Study in Plaridel, Bulacan, Philippines

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INTRODUCTION

Background of the Study

Modern power generation systems function within a rapidly changing environment marked by rising demand, changing decarbonization policies, aging infrastructure, and increased susceptibility to extreme weather events. Consequently, the concept of energy resilience defined as the ability of an energy system to foresee, absorb, adapt to, and quickly recover from disruptions has become crucial. Recent academic research suggests that power systems that incorporate significant amounts of intermittent renewable energy sources and have complex interconnections are particularly vulnerable to the increased risks posed by extreme weather, cyber threats, and operational uncertainties [2].

Simultaneously, the field of power plant engineering, which encompasses the design, construction, and management of large-scale generation facilities, must adapt to address these challenges. Historically, designs focused on efficiency, cost-effectiveness, and reliability under predictable operating conditions. However, in today's environment, resilience has emerged as a similarly vital design criterion. Power plants must not only operate effectively under standard conditions but also demonstrate flexibility, redundancy, and the ability to recover quickly during abnormal or disruptive situations [8].

In the context of the Philippines, and similarly in many island and coastal region systems, power systems are particularly at risk from extreme weather conditions such as typhoons, floods, fuel supply disruptions, grid failures, and growing demand.

The Dragonfly-inspired Hybrid Renewable Power Plant for Camella Subdivision at Plaridel, Bulacan applies this resilience framing to a concrete local problem which is supplying dependable power in an area exposed to typhoons, flooding and grid interruptions including critical telecom loads such as Streamtech.

The dragonfly metaphor maps neatly to resilience requirements. The multiple wings serve as diverse renewable sources such as PV or solar generation and wind generation will reduce single-point failure risk. A centralized thorax serves as the battery or hydrogen storage that provides short and long duration backup. A segmented modular layout enables rapid repair and staged recovery. Aerodynamic, and flood-resistant civil design increases survivability and stability under extreme weather. The compound eye for the ICT with SCADA or EMS with IoT sensors and predictive analytics that enables real-time situational awareness and faster restoration. These design elements directly reflect the PEP's emphasis on diversified energy mix, distributed generation, climate-proofing, and digitalization [1], [4].

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From a technical sizing and resilience perspective, the combined solar, and wind architecture offers complementary benefits such as daytime solar output, nocturnal or overcast wind generation, and energy storage for smoothing and black-start or backup services. Modularity such as micro grid capable units will enables the subdivision to island during grid outages, while redundant conversion and protection systems preserve local stability and protect critical loads such as telecommunications. Meanwhile, hardened civil works and appropriately sited balance of plant equipment reduce exposure to flooding and typhoon forces, shortening repair time after events a critical resilience metric emphasized in recent reviews of energy resilience strategies [3].

Implementing such a hybrid, bio-inspired design must be aligned with national permitting, institutional and financing frameworks. The Philippine Energy Plan and related power development planning documents already point toward incentives and infrastructure priorities including grid modernization, battery storage deployment, and distributed generation that can support deployment of resilient hybrid plants at community scale [1], [20].

The local implementation of energy resiliency remains uneven especially at the community level. Many urban and peril-urban areas in Bulacan Province, including Plaridel, that experiencing frequent power interruptions due to flooding, storm surges, and extreme weather events that results in affecting the communication through the internet. This study addresses an existing research gap by integrating bio-inspired design**,** renewable-energy diversification**,** and digital resiliency into a single, context-specific framework. It also contributes to the broader national goal of building localized, disaster-ready energy systems in vulnerable regions such as Bulacan.

Statement of the Problem

Communities in Bulacan, including Plaridel and nearby Cities, frequently experience power interruptions due to and during typhoons, flooding, and other climate related events. These disruptions expose the vulnerability of centralized power systems and underscore the urgent need for localized, resilient, and adaptive energy solutions. Despite national efforts to promote renewable energy, there remains a lack of integrated hybrid systems at the community level that combine solar, wind, and energy storage technologies within a climate proof and digitally enabled design framework.

While bio-inspired engineering concepts have shown promise in enhancing system efficiency and resilience, no feasibility or design studies have yet explored their application in the Philippine context particularly in suburban or semi-urban areas like Plaridel. The absence of such localized models limits opportunities for communities to achieve self-sufficiency and energy security during disasters or grid failures.

This study addresses these gaps by proposing a Dragonfly-Inspired Hybrid Renewable Power Plant for Camella Subdivision, Plaridel, Bulacan, which integrates solar photovoltaic, wind turbine, and battery energy storage systems or the BESS through a modular, ICT-based control network. Specifically, the study seeks to answer the following research questions:

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?

Hypothesis

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.

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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

This research explores the potential of a Dragonfly-Inspired Hybrid Renewable Power Plant as a model for enhancing energy resiliency and sustainability in suburban communities like the Camella Subdivision, Plaridel, Bulacan. By integrating solar, wind, and battery storage technologies into a modular and digitally enabled design, the study provides valuable insights into how bio-inspired engineering can address the growing demand for reliable and disaster-ready power systems in the Philippines. The findings of this study are expected to benefit the following sectors:

Academics and engineering sector:

For students and professionals in mechanical and electrical engineering, this research serves as a practical framework for designing hybrid renewable systems that combine technical innovation, sustainability, and digital intelligence. It encourages further exploration of biomimicry-inspired solutions for future energy systems aligned with national resiliency goals.

Homeowners Residents:

For residents of Plaridel and nearby municipalities, the project demonstrates how localized hybrid power systems can reduce dependence on the national grid, ensure continuous electricity during emergencies, and promote awareness of renewable and resilient energy solutions. The dragonfly-inspired model also highlights opportunities for community participation in sustainable power initiatives.

Future Researchers:

The study contributes new knowledge on hybrid renewable energy design and energy resiliency, addressing a research gap in localized applications of bio-inspired and ICT-integrated systems. It also provides a reference for future feasibility studies, energy policy development, and engineering innovation focused on climate-resilient power infrastructure.

Local Government Units:

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The results can guide local governments in energy planning, infrastructure development, and climate adaptation strategies. Insights from the study may support policy formulation for integrating hybrid renewable systems and micro grid initiatives into community-level disaster preparedness programs.

Scope and Delimitations

Scope

This study is centered on the conceptual design and feasibility evaluation of a Dragonfly-Inspired Hybrid Renewable Power Plant intended for Camella Subdivision in Plaridel, Bulacan. The project integrates solar photovoltaic panels, small-scale wind turbines, and energy storage systems within a bio-inspired dragonfly architectural framework to improve energy resiliency, sustainability, and disaster preparedness at the community level.

The scope of the study includes:

- Technical assessment of solar irradiance and wind potential in the selected area, including estimation of optimal system configuration and energy output.
- Economic evaluation for covering capital investment, operational and maintenance costs, and determination of the system's financial viability.
- Exploration of community perspectives that emphasizing awareness, acceptance, and perceived benefits of hybrid renewable power systems.
- Design development that focuses on the dragonfly-inspired concept, energy flow integration, and aesthetic-functional balance of the hybrid system.
- The study focuses on the current and near-future energy landscape within 2025 onward**,** considering local environmental conditions and the government's renewable energy goals.

Limitations

1. The study is limited to the conceptual and techno-economic design phase and does not involve full-scale implementation or field testing of the proposed hybrid system.
2. The analysis focuses solely on solar, wind, and battery storage technologies**,** excluding other renewable sources such as hydro, biomass, or wave energy.
3. The system's digital and control features such as smart monitoring and automation are conceptually discussed but not tested through hardware or software prototyping.
4. Environmental impact assessments are recognized but not included in detail, as the focus is on technical feasibility and energy resiliency modeling.
5. The study assumes the use of reliable secondary data on solar irradiation, wind patterns, and local energy demand for design estimation and simulation purposes.

Assumptions of the Study

1. The research presumes that national and local policies such as the Renewable Energy Act of 2008 or the Republic Act No. 9513 and the Philippine Energy Plan 2023–2050 will continue to promote and support renewable energy development and resiliency-focused projects**.**
2. The meteorological data on solar irradiance, wind speed, and temperature patterns in Plaridel, Bulacan are assumed to accurately represent the site's renewable energy potential and provide a reliable basis for system design and simulation.
3. It is assumed that the economic, financial, and technical parameters used in cost estimation and system evaluation reflect realistic market conditions for renewable energy technologies in the year 2025 and the near future.
4. The research presumes that national and local policies such as the Renewable Energy Act of 2008 known as the Republic Act No. 9513 and the Philippine Energy Plan 2023–2050 will continue to promote and support renewable energy development and resiliency-focused projects**.**
5. The study assumes that respondents from the local community will provide honest and informed feedback regarding their awareness, acceptance, and perceived benefits of adopting a hybrid renewable power system.

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Theoretical Framework

This study is grounded in the Energy Resiliency Theory, which emphasizes the ability of energy systems to anticipate, absorb, adapt to, and recover from disruptions caused by natural disasters, technical failures, or supply instabilities [2]. The theory underscores the importance of diversification, redundancy, and adaptability in power infrastructure to minimize vulnerability and maintain energy reliability in both normal and emergency conditions.

In the context of this study, energy resiliency theory serves as the guiding foundation for the development of a Dragonfly-Inspired Hybrid Renewable Power Plant, designed to integrate solar photovoltaic, wind turbine, and energy storage systems. By combining multiple renewable sources, the design aims to enhance redundancy and flexibility, ensuring continuous energy supply even when one component experiences failure or reduced efficiency.

Furthermore, the research draws upon the Renewable Energy Integration Theory, which focuses on the optimal combination and coordination of various renewable sources within a single energy system [21]. This theory provides the framework for balancing power generation, storage, and consumption to achieve system stability, efficiency, and sustainability. It emphasizes intermittency management, load balancing, and grid resilience, which are key considerations in the hybrid system's design and operation.

Lastly, the concept of Biomimicry Theory supports the study's innovative design approach. Biomimicry involves drawing inspiration from natural forms, processes, and systems to develop sustainable and efficient technologies. In this study, the dragonfly-inspired structure symbolizes adaptability and aerodynamic efficiency qualities mirrored in the hybrid system's energy capture and flow optimization [22]. By integrating Energy Resiliency Theory, Renewable Energy Integration Theory, and Biomimicry Theory, the study establishes a holistic theoretical foundation. This framework supports the evaluation of the technical and economic feasibility of the proposed hybrid renewable system while emphasizing its role in enhancing local energy resiliency, sustainability, and disaster preparedness in Plaridel, Bulacan.

Conceptual Framework (IPO Framework)

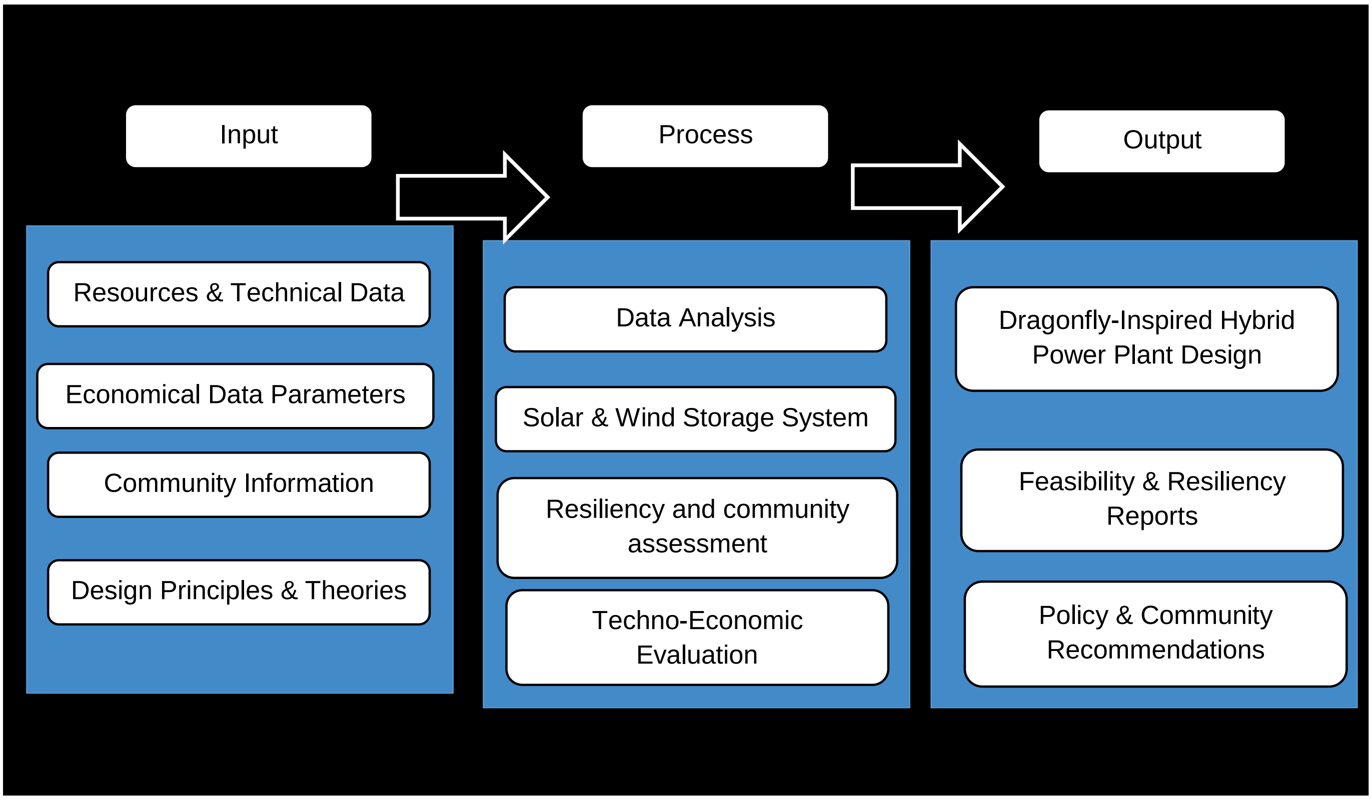

FIGURE 1. Conceptual Framework

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Figure 1 illustrates that the conceptual framework illustrates the input phase provides the foundational elements required for the design and analysis of the proposed Dragonfly-Inspired Hybrid Renewable Power Plant. These inputs include technical and environmental data such as solar irradiance, wind speed, and local energy demand and economic data related to capital, operation, and maintenance costs, theoretical foundations including Energy Resiliency Theory, Renewable Energy Integration Theory, and Biomimicry Principles, and community-related factors such as awareness and acceptance of renewable energy technologies.

The process phase encompasses the core activities that transform the gathered inputs into meaningful outcomes. This involves the collection and analysis of resource and demand data, conceptual and structural design of the hybrid solar–wind–storage system, techno-economic evaluation to assess performance and cost-efficiency, resiliency assessment to determine system reliability under disaster scenarios, and community evaluation to gauge social feasibility.

The output phase represents the tangible and analytical results of the study. These include the conceptual design of the Dragonfly-Inspired Hybrid Renewable Power Plant tailored for Camella Subdivision in Plaridel, Bulacan; the corresponding techno-economic feasibility report; an energy resiliency improvement framework that integrates renewable diversification and digital monitoring systems; and policy and implementation recommendations for enhancing local energy resilience.

The overall framework demonstrates how diverse technical, environmental, and social inputs are systematically processed to produce a resilient, efficient, and community-centered renewable power plant design that supports the Philippine Energy Plan [1].

Definition of Terms

1. **Energy Resiliency -** The ability of an energy system to predict, absorb, adapt to, and recover quickly from disruptions caused by natural disasters, technical breakdowns, or external shocks [2]. This study focuses on the planned hybrid renewable power plant's ability to sustain a consistent supply of electricity in the face of adversity.
2. **Hybrid Renewable Power Plant –** An establishment that generates electricity by combining two or more renewable energy sources, like solar, wind, and energy storage technologies, in order to create steady and sustainable electricity. With the help of battery storage, the dragonfly-inspired plant integrates wind and photovoltaic technology.
3. **Dragonfly Inspired Design –** A biomimetic engineering technique based on the structure and behavior of dragonflies. In this study, it represents a system that is flexible, adaptable, and balanced, reflecting the integration of different renewable energy wherein it serves as the wings and a stable energy storage called core.
4. **Biomimicry –** The procedure of using natural shapes, processes, and ecosystems as inspiration to address problems in human design. The dragonfly design concept creates a robust and effective renewable energy structure through biomimicry.
5. **Solar Generation System or PV System –** Utilizing semiconductor materials to directly convert sunlight into electrical power. It is one of the key components of the proposed hybrid power plant.
6. **Wind Generation System or Turbine System –** A device that transfers kinetic energy from wind into electrical power. It supplements the solar PV system by generating electricity during low-light or nighttime conditions.
7. **Energy Storage System -** An electrochemical device that is capable of being used later to store excess energy generated from renewable sources. It keeps supply steady when demand is high or the grid is down.
8. **ICT or Smart Grid Integration –** The use of information and communication technology (ICT) for real-time monitoring, control, and optimization of energy generation and delivery. This study considers the use of sensors, predictive analytics, and automated controls to improve reliability.
9. **Energy Diversification –** The intentional integration of numerous energy sources into a single system to reduce reliance on a single fuel or technology. It helps to improve resiliency and energy security.
10. **Resilient Infrastructure –** The physical systems have been constructed and intended to endure severe weather conditions and quickly recover from disruptions. As part of its robust design, the planned power plant has raised structures, aerodynamic designs, and long-lasting materials.
11. **Philippine Energy Plan (2023-2050) –** The Department of Energy (DOE) established a national framework that outlines methods for utilizing decentralized and diverse energy systems to achieve energy security, sustainability, and resilience.
12. **Techno-Economic Feasibility –** An analytical evaluation of a proposed project's technical performance and economic viability. This study employs techno-economic analysis to establish the viability of the dragonfly-inspired hybrid design.
13. **Micro Grid –** A localized network of distributed energy resources that can function in conjunction with or independently of the main power grid. The suggested system can be used as a microgrid for Camella Subdivision.

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14. Renewable Energy Integration – The coordinated integration of many renewable technologies into a single energy system enhances its overall effectiveness, reliability, and sustainability.

15. Community Acceptance - the degree of awareness, confidence, and readiness of locals to embrace and support renewable energy technologies. This component is important to the effective execution of the proposed power plant at Plaridel, Bulacan.

METHODS

Research Design

This study combines a descriptive-analytical and engineering design approach to assess the technical and economic viability of the planned Dragonfly-Inspired Hybrid Renewable Power Plant in Camella Groves Subdivision, Plaridel, Bulacan. The study combines quantitative analysis that is for resource and cost evaluation with conceptual design technique for system modeling and configuration.

The study employs a techno-economic feasibility approach that includes evaluating renewable energy supplies, identifying technical performance characteristics, predicting costs, and examining the system's contribution to energy resilience in accordance with the Philippine Energy Plan [1].

The integration of engineering design methods and techno-economic evaluation is essential in this study because assessing a hybrid renewable system combining solar, wind and storage requires not only a grasp of the site’s resource potential and technical configuration but also analysis of cost-effectiveness and social acceptability. A resilient energy system is understood as one that can prepare for, endure and recover quickly from disruptions [5].

Applying this combined approach, this research is structured to evaluate the feasibility of a dragonfly-inspired hybrid power plant at Camella Subdivision through data-driven resource analysis, engineering simulation, cost modelling, and stakeholder assessment thereby offering a comprehensive framework for determining its contribution to local energy resiliency and disaster-preparedness in a Philippine context [5].

Research Locale

The area was chosen because of its rich on renewable energy farm such as solar and wind. The area is also in rapid growth of residential and commercial expansion, rising electricity use, and susceptibility to power outages during extreme weather

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occurrences. Its location near open fields and existing electrical infrastructure makes it ideal for hybrid solar-wind power generating. Camella Groves Subdivision, Plaridel, Bulacan, Central Luzon, Philippines, is where the study is being conducted.

Camella Groves Subdivision in Plaridel, Bulacan, is situated within a rapidly developing urban area that experiences periodic power interruptions due to increasing energy demand and occasional weather related disturbances. The community's growing residential population and reliance on centralized grid systems highlight its vulnerability to supply disruptions particularly during typhoons, flooding, or other extreme weather events common in Bulacan Province. These conditions make the subdivision an appropriate model for evaluating energy resiliency through localized renewable energy integration.

Plaridel's geographical and climatic characteristics offer favorable conditions for solar and wind resource utilization. According to the Department of Energy [1] the Bulacan Province has moderate to high solar irradiance levels ranging from 4.5 to 5.1 kWh/m² per day and intermittent but exploitable wind speeds suitable for hybrid system development. Similar hybrid renewable studies conducted in Central Luzon [23, 24] have demonstrated that combining photovoltaic, wind, and storage technologies can substantially enhance system reliability while reducing dependency on conventional grid power.

Furthermore, the national government's Renewable Energy Roadmap [1] and the Philippine Energy Plan 2023–2050 [1] emphasize decentralized, community-based generation systems as key strategies for achieving climate resilience and energy security. This policy framework supports initiatives such as the proposed dragonfly-inspired hybrid power plant, which aims to provide sustainable, adaptive, and disaster-resilient electricity to residential developments like Camella Subdivision.

By focusing on this location, the study seeks to produce context-specific findings that can inform both local and regional renewable energy planning. The results are expected to guide future community level hybrid energy projects and contribute to broader national goals of achieving energy resiliency, sustainability, and technological innovation.

Research Respondents

The primary respondents of this study are the home owner's residents, community leaders, and technical personnel from Streamtech Telecommunications located within Camella Subdivision, Plaridel, Bulacan**.** This area is a fast-developing residential community that relies heavily on continuous electricity for both household consumption and telecommunication operations. However, the subdivision occasionally experiences power interruptions, particularly during heavy rainfall, localized flooding, and storm-related events**,** which disrupt essential services and daily activities. These recurring issues make the site appropriate for assessing the feasibility of implementing a dragonfly-inspired hybrid renewable energy system aimed at improving local power reliability and resilience.

The respondents will provide essential insights into their awareness, acceptance, and support for hybrid renewable technologies, particularly systems integrating solar, wind, and battery storage. Understanding community perception is crucial, as local participation and acceptance often determine the long-term success and sustainability of renewable energy projects [5, 25].

A total of 50 respondents will be selected using purposive sampling to ensure that individuals with relevant experiences and knowledge are included. The participants will consist of homeowners, homeowners' association or HOA leaders, Streamtech technical staff, and local barangay or LGU representatives**.** This sampling method is appropriate for gathering targeted insights from those directly affected by power instability or involved in maintaining local infrastructure. As Creswell and Creswell [26] emphasize, purposive sampling allows researchers to obtain meaningful data from participants who possess specific characteristics aligned with the research objectives.

All participants will be fully informed about the purpose of the study, their voluntary participation, and their right to withdraw at any time. The researcher will ensure confidentiality and anonymity of responses. Prior coordination will be made with Camella Subdivision management and Streamtech administration to secure permission and uphold ethical and procedural standards during data collection.

Distribution of Research Respondents

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Group of Responents	2025 Population	Percentage	Number of Respondents
Home Owners	180	60%	30
Community Leaders or Representative	10	20%	10
Streamtech Agents or Staff	20	10%	5
Barangay Officials and Local LGU	10	10%	5
Total	220	100%	50

Respondents	Description
Home owners	Residents of Camela Groves Subdivision affected by recurring power interruptions.
Community Leaders or Representative	Officials that responsible for managing the subdivision operations and public services.
Streamtech Agents or Staff	Technicians and operators that is working dependent to uninterrupted electricity.
Barangay Officials and Local LGU	Responsible for monitoring and overseeing the energy and infrastructure within the area.

Table 1. Research Respondents

Research Instrument

This study will employ both quantitative and qualitative research instruments to obtain comprehensive data concerning the technical, environmental, and social dimensions of deploying a dragonfly-inspired hybrid renewable power system within Camella Subdivision, Plaridel, Bulacan.

A structured survey questionnaire will serve as the primary data-gathering tool, administered to selected residents, community leaders, and Streamtech Telecommunications staff. The survey is designed to collect essential information about:

A. Respondents' demographic profiles.
B. Respondent's perspectives for the potential benefits and limitations of hybrid renewable energy systems integrating solar, wind, and battery storage.
C. Their level of awareness, support, and willingness to adopt local renewable energy initiatives.
D. Their experiences with power interruptions, energy reliability, and local environmental conditions such as flooding or strong winds that may influence and affects the system's design and acceptance.

To complement the survey, the study will also include semi-structured interviews with subdivision officials and Streamtech engineers to gain qualitative insights into operational needs, technical challenges, and maintenance considerations. This combination of quantitative and qualitative approaches ensures that both measurable data and contextual perspectives are integrated into the feasibility evaluation, aligning with the mixed-method approach described by Creswell and Plano Clark [27].

The questionnaire will undergo content validation by three subject matter experts in renewable energy, engineering design, and research methodology before its distribution. A pilot test will be conducted among a small sample of respondents from nearby subdivisions in Plaridel to ensure clarity, reliability, and appropriateness of survey items.

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Survey Questionnaire:

Part A – Demographic Profile

Occupation:

Years of Residence:

Household size:

Electricity Power consumption:

Part B – Hybrid renewable energy systems: perceived 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.					

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Table 1: 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 do 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 2. Research Questionnaire adapted from Rogers et al. [28].

Environmental and Technical Assessment Tools

To support the technical and environmental evaluation**,** the study will employ observation and measurement sheets to document data relevant to hybrid renewable energy feasibility within the subdivision. The following parameters will be recorded and analyzed:

- Solar irradiance levels daily average in kWh/m².
- Wind speed and direction patterns in m/s.
- Ambient temperature and humidity levels.
- Power consumption patterns within the Streamtech facility and nearby residences.
- Grid reliability indicators, including voltage fluctuations and outage durations.

Data collection will be based on the standard renewable energy assessment protocols of the Department of Energy [1, 7, 20] and the Philippine Atmospheric, Geophysical and Astronomical Services Administration [11, 14]. Secondary data will also be obtained from NAMRIA [29] and DOE's Renewable Energy Information System (REIS) to ensure accurate estimation of resource potential for solar and wind integration.

Simplified Hybrid Energy Output Estimation

The energy accounting for the proposed dragonfly-inspired hybrid system is founded on the first law of thermodynamics, which states that energy cannot be created or destroyed, only converted from one form to another [30].

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Basic computational model is applied to estimate potential energy output from the hybrid system using simplified solar and wind power equations:

$$P_{IN} = P_{out}$$
$$P_{in} = P_{solar} + P_{wind} = P_{gen}$$
$$P_{out} = P_{load} + P_{stored} + P_{delivered}$$
$$P_{solar} = G \times A \times \eta pv$$
$$P_{wind} = 0.5 \times \rho \times At \times v3 \times \eta wt$$

Where:

- P_{total} = total estimated hybrid energy output (kWh/day).
- P_{solar} = energy from solar panels. Estimated using Psolar = G×A×η_{pv}.
- P_{wind} = energy from wind turbines. Estimated using Pwind=0.5×ρ×At×v3×ηwt
- P_{losses} = total system losses include inverter, transmission, storage losses.
- G = average solar irradiance (kWh/m^2/day)
- A = area of solar array (m^2)
- η_{pv} = photovoltaic efficiency
- ρ = air density (1.225 kg/m^3)
- A_t = rotor swept area (m^2)
- v = average wind speed (m/s)
- η_{wt} = wind turbine efficiency

Data Gathering Procedure

To comprehensively evaluate the social, technical, and economic feasibility of the proposed dragonfly-inspired hybrid renewable power plant for Streamtech Telecommunications in Camella Subdivision, Plaridel, Bulacan, the data collection process will use a mixed-methods approach, incorporating quantitative surveys, qualitative interviews, and secondary technical data analysis. The approach will be executed in three major phases: preparation, data collecting, and processing.

Preparation

Before the data collection phase, the researcher will formally coordinate with the Camella Subdivision Homeowners' Association or HOA, Streamtech Telecommunications management, and the Municipal Engineering and Planning and Development Office of Plaridel, Bulacan. This coordination aims to secure the necessary permissions and endorsements to conduct surveys, interviews, and on-site inspections.

Research instruments includes the structured survey questionnaire and interview guide that will be validated by subject matter experts in renewable energy and engineering design to ensure relevance, accuracy, and reliability. A pilot test will also be conducted in a nearby subdivision to check the clarity and validity of survey items. Adjustments will be made as needed prior to final administration.

Data Collection

All data collection will follow ethical research guidelines. Participants will be informed about the study's objectives and their right to withdraw at any time. Confidentiality and anonymity of all responses will be maintained.

Primary Data

- Survey Questionnaires will be distributed to **r**esidents, Streamtech personnel, and subdivision representatives to gather quantitative data on demographics, energy usage patterns, perceptions of renewable energy, and willingness to support hybrid power systems.
- Key Informant Interviews will be conducted with selected stakeholders such as subdivision engineers, Streamtech technicians, and barangay officials to collect qualitative insights on energy reliability, system requirements, and operational constraints.
- On-site Observations and Measurements will be performed to assess environmental and technical factors, such as available roof or open-space area for solar panels, wind exposure, and existing electrical infrastructure.

Secondary Data Collection

- Technical and environmental datasets will be obtained from the Department of Energy (DOE), PAGASA, and MERALCO distribution records, including average solar irradiance, wind speeds, and grid reliability indices for Plaridel, Bulacan.
- Local energy consumption data will be requested from Streamtech to assess typical load demand and peak-hour requirements.

Data Processing and Analysis

All survey responses will be encoded, tabulated, and analyzed using statistical tools such as SPSS or MS Excel for quantitative analysis. Descriptive statistics including frequency, mean, and percentage will summarize community perceptions and awareness. Qualitative data from interviews will be transcribed and subjected to thematic analysis to identify recurring insights related to energy resiliency and renewable system feasibility.

Technical and economic data will be integrated into simulation and costing tools such as HOMER Pro, RET Screen, or equivalent to estimate energy output, system efficiency, and cost-benefit ratios of the proposed hybrid design. Results will then be cross-analyzed to determine how social acceptability, technical capacity, and economic performance align with the overall objective of achieving energy resiliency for Streamtech and the Camella community..

Economic Feasibility Analysis

The economic feasibility analysis in this paper is to assess the financial viability of building a dragonfly-inspired hybrid renewable power plant that combines solar photovoltaic, wind, and battery energy storage system. The objective is to see if the suggested design can provide a cost-effective, sustainable, and robust energy source for Streamtech Telecommunications and the Camella Subdivision neighborhood in Plaridel, Bulacan.

Financial Evaluation metrics

- Capital Expenditure or CAPEX includes costs of equipment, site preparation, installation, and system integration.
- Operational Expenditure or OPEX includes operation, maintenance, and replacement costs over the system's lifespan.
- Net Present Value or NPV measures the difference between discounted cash inflows and outflows over the project period to determine profitability.

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

where R_t = revenue or savings, C_t = cost at time t, r = discount rate, and n = project life expectancy.

- Internal Rate of Return calculates the discount rate that makes the NPV equal to zero, indicating the expected return on investment.
- Benefit–Cost Ratio compares total discounted benefits to total discounted costs to determine cost-effectiveness.
- Payback Period identifies how long it will take for the system's cumulative savings to cover the initial investment.
- Levelized Cost of Energy represents the average cost of generating electricity over the system's lifetime, computed as:

  LCOE = Total Lifetime Cost /Total Lifetime Energy Output (kWh)

Expected Output

The results of the economic feasibility analysis will provide:

- A comparative cost benefit profile of each system configuration.
- The optimal hybrid design that balances investment cost, reliability, and sustainability.
- Recommendations for local policy integration and potential public private partnerships to support renewable energy projects in residential subdivisions.

Payback Period

The Payback Period method will be used to determine how long it takes for the total savings generated by the hybrid renewable energy system to recover its initial investment cost. It measures the time required for the cumulative net cash inflows. It is the ratio of Initial Investment to annual net savings. The Initial investment or CAPEX represents the total upfront cost of installing the hybrid system such as solar and wind energy components, and storage units.

PBP = (Initial Investment or CAPEX) / (Annual net savings)

RESULT AND DISCUSSION

Background Data and Energy Demand Estimation

Camella Groves Phase 10 and Phase 11 in Plaridel, Bulacan were selected as the pilot area of the proposed hybrid renewable power system.

Parameters	Value
Number of Houses	180units
Maximum number of persons per unit	5 persons/unit
Population	900persons
Power consumption per houses	10 kWH/day per unit
Design Grid	Off-grid Hybrid (solar, wind, and battery)

Power Consumption per day in the Philippines, according to a 2023-2025 source, per-capita electricity consumption in the Philippines is around 8–15 kWh/day depending on size and consumption habits.

Total energy consumption:
Number of houses x Power consumption per houses = 180units x 10kWH/day per unit
Total energy consumption = 1,800kWH/Day

Average Power Demand with peak factor of 1.5:

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Average load =1,800kWH/Day (1day/24hours) = 75kW
Peak load demand = 75kW (1.5) = 112.5kW peak demand
The dragonfly Inspired Hybrid Renewable Power Plant must have the capacity to provide a peak load of 110 to 120kW with safety margins for the peaking load demand for the subdivision.

Technical Feasibility of the Hybrid System

The design integrates solar panels, wind turbines and BESS. The solar energy generates at 70% and the wind energy will be at 30% to have the total of 100% of energy the system can generate to power the subdivision.

To improve reliability, I used a diversified generation mix of:

Solar contribution = 70% of daily energy

Wind contribution = 30% of daily energy

- **Computation for solar energy with 70% of contribution to the system:**

Conservative average sunlight for central Luzon is 4.5 peak sun hours/day and a buffer margins multiplier for losses at 20% over 100%.
Photovoltaic system performance ratio = 0.75
Over build factor for micro grid designs = 1.15
(1,800kWH/day) 0.7 = 1,260kWH/day of solar power target
Energy produced per 1kW of PV = 4.5 x 0.75 = 3.375 kWH/ 1kw per day
PV Capacity = (1,260kWH/day) / (3.375 kWH/ 1kw per day) = 373.33 KW
= (373.33 KW) 1.15 = **430kW**
The 430 kW PV with overbuild factor is the target installed PV capacity.

- **Computation for wind energy at 30% contribution to the system**:

Conservative wind capacity factor for small and urban turbines is **0.2.**
A rated turbine yields on average of 1kW (24H/day) (0.2) = 4.8kWH/day
Over build factor = 1.15
Target wind energy:
= (540kWH) / (4.8kWH/kW per day) = 112.5 kW
=1,800kWH/day x 0.3 = 540kWH/day
Installed wind capacity = 112.5kW x 1.15 = 130kW
Nominal energy Balancing:
System loss percent is 15%
Solar:
430kW (3.375kWH/kw per day) = 1451.25 kWH/day
Wind:
130kW (4.8kWH/kW per day) = 624 kWH/day
Combined nominal gross generation = 2075.25 kWH/day
Net available energy = 2,075.25kWH/day (1-0.15) = 1,764kWH/day

Comparing to demand loads:

The required 1,800 kWh/day is at shortfall of 1,800 to 1,764 = 36 kWh/day for about 2% short. This small deficit can be covered by slight operational adjustments such as demand side management, small additional PV, or a small increase in wind or use of battery charge strategy. Because we rounded installed capacities, engineering practice would either slightly increase PV to 440 kW or accept a negligible deficit covered by batteries during most days.

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Result and Solution:

Installed sizes 430 kW PV and 130 kW wind produce net of 1,764 kWh/day after losses very close to the target 1,800 kWh/day. The operational management and battery dispatch will bridge the small difference.

- **Computation sizing for battery energy storage system:**

Design decision is to provide 2 days of autonomy at full community load such as a defensible resiliency target. This is for emergency or disaster standard.

Depth of Discharge to extend battery life = 80% = 1.25 multiplier
Round trip efficiency for losses at charge and discharged = 90% = 1.11 multiplier
1,800kWH/day x 2 days = 3,600kWH = 3.6 MWH of battery systems
Nominal battery energy target = 3,600kWH x (1.11 x 1.25) = 5,000kWH = 5MW**H**

Conclusion (BESS):
The 5,000 kWh nominal battery capacity provides 2-day useful autonomy at full load with standard DoD and efficiency considerations.

- **Computation sizing for inverter:**

30% margin for startup loads and redundancy
Peak load = 112.5kW
Inverter Capacity = 112.5kW (1 + 0.3) = 146.25 kW

Conclusion and summary table for the technical feasibility of the hybrid powered power plant:

Based on a fixed demand product of 180 houses and 10 kWh/day is 1,800 kWh/day, the proposed dragonfly-inspired hybrid system was sized using conservative resource and loss assumptions. A 70 to 30 split for solar and wind yields daily targets of 1,260 kWh for solar and 540 kWh for wind. Using 4.5 peak sun hours and Performance Ratio of 0.75 gives a base PV requirement of 373 kW, increased by a 15% overbuild to 430 kW DC to compensate for variability and real-world losses. Wind sizing at CF is 0.20 yields at 112.5 kW, increased by 15% to 130 kW. Combined gross production from the installed capacities is 2,075 kWh/day then after a 15% BOS loss allowance the net available energy is to1,764 kWh/day within a small margin of the 1,800 kWh/day requirement. To provide two days of autonomous operation the BESS nominal capacity is calculated at 5,000 kWh or 5.0 MWh that accounting for 80% DoD and 90% round-trip efficiency. An inverter bank of 150 kW with 30% peak margin completes the system. These sizes demonstrate technical feasibility for a fully off-grid, resilient micro grid capable of serving Camella Groves for the Phases 10–11.

Parameters	Value	Note
Daily total demand	1,800 kWH/day	
Average load	75kW	
Peak load	112.5 kW	
Solar	430kW	DC, installed
Wind	130kW	
Nominal gross generation	2,075kWH/day	
Net power available	1,764kWH/day	With 15 balance of system losses
Nominal battery storage system	5MWH	
Inverter Capacity	150kW	

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Economic Viability of the Hybrid System
Estimated Costing:

Component	Notes	Estimated Cost
Solar PV Systems	installed	P60,000/kW
Small scale Wind Turbines	Installed	P75,000/kW
Battery Storage	installed	P11,200/kWH
Controls System, inverters & Wirings		P12,000/kW
SCADA/EMS/ICT/monitoring and communications		P1,000,000
Site and Civil Works		P2,000,000
Safety Systems	Fire suppression, HVAC,BMS	P1,500,000
Permitting, consulting fees		P500,000
Balance of the System	12% of the subtotal	
Contingency	10% of subtotal	
Total Capital Cost		P162.9M

Annual Electricity Cost of the total residents in the Camella Groves without the Hybrid

Power plant system:
Electrical power rate = P11kWH
1,800kWH/day x P11/kWH = P19,800/day (365days/year) = P7,227,000/year

Payback Period:
P72,000,000 / P7,227,000/year = 14.4years

- **Baseline CAPEX computation:**

Equipment item cost:
PV = 430kW x P60,000/kW = P 25,800,000
Wind = 130 kW x P75,000/kW = P 9,750,000
BESS = 5,000kWH x P11,200/kWH = P56,000,000
Inverter cost = 150kW x P12,000/kW = P1,800,000
BESS auxiliary = P1,500,000 lump sum
Subtotal = P94,850,000
Balance of System = 0.12 x P94,850,000 = P11,382,000
Civil = P2,000,000
SCADA = P1,000,000
Permits = P500,000
Subtotal = P109,732,000
Contingency = 0.10 x P109,732,000 = P10,973,200
Total CAPEX baseline = P10,973,200 + P109,732,000 = P120,705,200

- **Operating expenses and annual savings:**

Annual energy produced / avoided cost = (1,800kWH/day) (365days/year) = 657,000kWH/year
Annual avoided cost from P11/kWH grid
Net savings = 657,000kWH/year x P11/kWH = P7,227,000/year
Annual Operating and maintenance at 1.5% of CAPEX
0.015 x P120,705,200 = P1,810,578/year

Net annual benefit
= P7,227,000/year - P1,810,578/year = P 5,4164,22/year

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Payback Period
= P120,705,200 / P 5,416,422/year = 22.29years

- **Levelized Cost Estimate**

Standard capital recovery factor with discount rate 8% and lifetime 20 years
CRF = $r(1+r)^n / (1+r)^{n-1}$ = $0.08(1+0.08)^{20} / (1+0.08)^{20}-1$ = 0.10185
Annual CAPEX = CAPEX x CRF = P120,705,200 x 0.10185 = P12,293,824/year
LCOE = (Annual CAPEX + O&M) / annual energy
= (P12,293,824/year + P1,810,578/year) / 657,000kWH/year = P21.5/kWH

Conclusion:

LCOE at P21.5/kWh, which is twice the assumed grid tariff P11/kWh. Under baseline assumptions the off-grid system is more expensive per kWh than current retail electricity mainly because of the high installed battery cost.

Conclusions to the viability of the hybrid power plant system:

Economic analysis was performed using the fixed technical design of 430 kW for PV, a 130 kW wind, a 5,000 kWh BESS, a 150 kW inverter and conservative Philippine unit costs. The baseline capital cost is approximately at P120.71 million, with annual operations and maintenance of P1.81 million. At a domestic retail electricity rate of P11/kWh, the system avoids about P7.23 million/year in purchased electricity, yielding a net annual benefit of P5.42 million and a simple payback period of 22.3 years. The baseline LCOE is estimated at P21.5/kWh. Sensitivity scenarios illustrate that BESS cost and battery sizing critically affect economics. The strictly off-grid baseline design is expensive per kWh today, several practical adjustments such as smaller and cheaper storage, partial grid integration, and concessional financing would improve the financial attractiveness of the Dragonfly hybrid system for Camela Groves.

Energy Resiliency Analysis

This section quantifies how the proposed Dragonfly-inspired hybrid power plant improves local energy resiliency in Camella Groves Phase 10 and 11. Resiliency here is defined as the system's ability to anticipate, absorb, adapt to, and recover from power disruptions [2].

Key design assumptions used for the analysis:

- number of houses = 180
- Consumption per house = 10 kWh/day
- Total community demand = 1,800 kWh/day
- Solar PV = 430 kW DC
- Wind = 130 kW
- Nominal battery storage = 5,000 kWh
- Inverter capacity = 150 kW
- System loss and BOS allowance = 15%

All values above are design assumptions and will be validated in detailed engineering and site surveys.

Basic resiliency metrics

A. **Battery only autonomy.**

Battery nominal capacity = 5,000kWH

Daily demand = 1,800kWH/day

Autonomy in days = Battery capacity / daily demand = 5,000kWH/1,800kWH/day = 2.78 days of full load autonomy from the battery energy storage system alone.

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B. Battery only autonomy at 50% load demand

Autonomy in days = battery capacity / half load demand = 5,000kWH / (1,800kWH/day /2)

= 5.56days of full load autonomy at 50% load.

C. Battery at critical load at 5kW endurance

A conservative Streamtech critical load = 5 kW at continuous battery hours

5,000kWH / 5kW = 1,000H = 41.7 days of continues power for a 5kW critical load.

D. Renewable Generation Margin

PV generation = PV energy produced x PV yield per kW per day

= 430 kW x 3.375 kWH/kW day = 1,451.25 kWH/day

Wind generation = wind energy produced x wind energy yield per kW per day

= 130kW x 4.8 kWH/kW day = 624kWH/day

Gross renewable production = 2,075.25kWH/day

Apply the 15% balance of the system losses

Net energy Available = (2,075.25kWH/day) x (1-0.15) = 1,764kWH/day

Compared to the demand of 1,800kWH/day, Net daily production is within ~2% of the required demand; battery dispatch and short-term operational management will cover this small gap on typical days.

E. Renewable Fraction

Nominal renewable fraction = net energy available / demand load

= 1,764kWH/day / 1,800kWH/day = 0.98 or 98%

F. Descriptive resilience feature enabled by the design

Decentralization & islanding:

System can operate independently from the main grid due to grid-forming inverter and BESS. This reduces single-point failure risk from distant transmission lines.

Resource diversity solar and wind:

Complementary generation profiles improve the probability that at least one source is available during adverse conditions.

Large storage buffer

5 MWh BESS provides multi-day autonomous operation, critical for resilience during multi-day storms.

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Prioritization capability

EMS/SCADA can automatically shed non-critical loads and allocate energy to critical infrastructure to Streamtech for maximizing useful autonomy.

Modularity or the dragonfly-inspired

Distributed PV as the wings and segmented strings reduce single-point physical damage; modular BESS blocks allow staged replacement/repair.

Digital intelligence

SCADA and AI enable predictive maintenance, forecasting, and optimized dispatch shortening recovery time and preventing avoidable failures.

G. Quantitative data for Resilience indicators

Indicator	Result
Full load autonomy	2.78 days
Half load autonomy	5.56 days
Critical load at 5kW autonomy	41.7 days
Net daily renewable availability	1.764 kWH/day
Renewable fraction	98%

H. Limitations, risks, and assumptions

- **Resource variability**:

Severe, multi-day storms can reduce both solar and wind generation simultaneously and autonomy then depends solely on BESS.

- **Battery degradation:**

Nominal 5,000 kWh assumes initial capacity and usable capacity will decline with cycling and calendar aging include maintenance and replacement planning.

- **Physical damage risk:**

Extreme typhoon winds and flying debris can damage PV arrays, turbines, and BESS enclosures site hardening and elevated installation needed.

- **Cyber-physical risk:**

Reliance on SCADA and ICT requires cybersecurity, redundant control links, and offline fallback procedures.

- **Operational assumptions:**

Net daily generation used average yields; hour-by-hour time-series modelling such as HOMER, MATLAB, or RETScreen that is required for precise reliability statistics.

I. Practical recommendations for enhancing the resilience

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- **Prioritize loads in EMS:**

Predefine critical loads on Streamtech, emergency lighting, and water pumps and implement automatic islanding & load shedding rules.

- **Add small auxiliary gen set for extreme contingencies:**

A modest diesel or biofuel gen set ranging from 50 to100 kW and can extend autonomy beyond BESS limits without oversized CAPEX.

- **Segment PV and BESS physically:**

Distribute PV across multiple wings and rooftops and modularize BESS into smaller containers to avoid single-point failure.

- **Harden installations:**

Elevate BESS, storm proof mounting for PV, secure turbine towers, lightning protection, and flood-resistant siting.

- **Implement predictive maintenance & redundancy:**

Use SCADA and AI to predict failures and schedule preventive replacement and deploy N-1 redundancy for inverters.

- **Community protocols & drills:**

Coordinate with barangay & Streamtech for outage drills, prioritized resource lists, and community charging and communication centers.

J. Resilience Analysis Conclusion

The Dragonfly-inspired hybrid system with a 430 kW PV, 130 kW wind, 5,000 kWh BESS, and a 150 kW inverter materially strengthens energy resiliency for Camella Groves. Quantitatively, the system delivers roughly 2.8 days of full-load autonomy and over 41 days for a small critical telecom load at 5 kW when islanded. Net renewable generation meets approximately 98% of the daily demand under typical conditions. These metrics demonstrate the system's capacity to anticipate, absorb, adapt to, and recover from routine and multi-day power disruptions common to the Plaridel area. To address extreme or prolonged outages and to reduce residual risk, the design should incorporate load prioritization, physical hardening, modular redundancy, and contingency backup such as gen set as needed.

4. ICT, SCADA, & AI Analysis

This section assesses how Information and Communication Technology or ICT, Supervisory Control and Data Acquisition or SCADA, and Artificial Intelligence or AI to improve the reliability, efficiency, and resilience of the proposed Dragonfly-Inspired Hybrid Renewable Power Plant in Camella Groves, Plaridel, Bulacan.

A. **Role of ICT in the Hybrid Power System**

ICT functions as the communication backbone of the hybrid power system.

It interconnects the following parameters:

- Solar PV systems
- Wind turbines

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- Battery Energy Storage Systems
- Inverter and Control Panels
- Smart meters in the 180 unit houses
- Streamtech communication infrastructure
- Control room and monitoring stations

Functions of the ICT in the systems are:

- Real time data monitoring for power generation, battery charge and discharge level, power demand, system voltage and frequency.
- Control capability for turning off and on, switching between the grid connected and island or off grid modes, and activating load shedding when necessary.
- Communication during disaster for supporting streamtech devices and emergency signals systems, and maintains the coordination among engineers and local authorities.

Conclusion:

ICT ensures continuous communication between all components, enabling fast reaction to system disturbances and efficient system coordination**.**

B. SCADA System Performance Analysis

The Supervisory Control and Data Acquisition system is responsible for automatic control and supervision of power generation, storage, and distribution.

Main functions of the SCADA:

Function	Description	Impact
Data Acquisition	Collects data every second	Accurate monitoring
Alarm Generation	Sends warning during faults and errors	Prevents accidents and major costs
Load Prioritization	Allocates energy to critical loads	Improves resiliency
Automatic Islanding	Switches to batter energy storage system during the grid failure scenario	Prevents blackout

Response Time Calculation:

SCADA systems operated with an update interval of 1 to 5 seconds per cycle.

In 1 minute:

(60 sec)/ (5sec /cycle) = 12 data cycles per minute (60min/1hour) = 720 data cycles per hour

The system can check its condition 720 times per hour, allowing immediate response to voltage drops, overload, or battery depletion. This fast response minimizes damage and prevents system collapse, therefore increasing system reliability and resilience.

C. AI Integration for the SMART Energy Management

Artificial Intelligence provides decision-making capability based on historical and real-time data.

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The AI is used for:

Load Prediction to predicts daily and hourly demand of 180 houses.

Weather forecasting integration to predicts solar and wind availability.

Battery Optimization to prevent overcharging and deep discharge.

Predictive Maintenance for detects possible failures in the PV, wind, and BESS systems before major accidents.

D. AI Based Battery Management Improvement

Parameters:

- Solar capacity: 430 kW
- Wind capacity: 130 kW
- Battery storage (BESS): 5,000 kWh
- Inverter capacity: 150 kW
- Community load: 1,800 kWh/day
- Number of houses served: 180

Usable Battery energy percentage without AI is 85%, computing for the Battery energy without AI:

5,000kWH x 0.85 = 4,250kWH

Usable Batter energy with AI at 92% improved efficiency, computing for the battery energy with AI:

5,000kWH x 0.92 = 4,600kWH

Net Improvement: with AI – without AI

4,250kWH - 4,600kWH = 350kWH improvement or additional capacity

350kWH x (1 house /10kWH/day) = 35 houses per day

The battery can power 35 additional houses per day or extend system operation during outages.

This clearly shows that AI directly increases the effective capacity of the energy storage system and improves resilience.

E. AI Impact on the System Autonomy

Using AI optimized usable capacity at 4,600kWH:

4,600kWH / 1,800kWH/days = 2.56 days is the usable with renewable resistance.

AI also reduces wastage and improves dispatch, therefore effective autonomy increases real conditions because it minimized energy loss, manageable non critical loads, optimizable charging and discharging.

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F. Resiliency Improvement Summary of ICT, SCADA, and AI

ICT	Maintains communication during disasters.
SCADA	Detect defaults, errors, and problems before making any progress worse.
AI	Increase usable energy by 350kWH.
Smart Load Control	Protects critical loads.
Predictive Maintenance	Prevent Failures
Control Access	Faster repair and response

Conclusion:

The integration of ICT, SCADA, and AI significantly strengthens the system's ability to withstand, adapt to, and recover from power interruptions caused by typhoons, floods, and grid failures in Plaridel, Bulacan.

G. Conclusion:

The integration of ICT, SCADA, and AI transforms the proposed hybrid renewable power plant from a conventional energy system into an intelligent, adaptive, and self-managing infrastructure. Through real-time monitoring, automated control, predictive analytics, and optimized battery management, the system improves operational efficiency, reduces energy losses, and increases overall resilience. These digital technologies are essential in ensuring the reliability of power supply for Camella Groves, particularly during disasters and long-term grid disruptions.

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