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Implementation of an Algal-Voltaic Energy Center in the Fishing Port of Pachacutec City

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Abstract - This article explores the feasibility of a hypothetical project using algae-based solar panels to generate energy in Ventanilla, considering the associated technical, social, and environmental factors. The proposed design integrates modular "bioreactor" systems within traditional photovoltaic structures, optimizing the use of urban space and leveraging local resources such as treated wastewater and carbon dioxide emitted by nearby industrial sources. These algavoltaic panels not only produce electricity from sunlight; they also allow the cultivation of microalgal biomass, which can be transformed into biofuels, bioplastics, or fertilizers. This has a positive impact on the circular economy. Throughout the development of this theoretical project, multiple aspects are analyzed, from the selection of microalgae species adapted to Lima's desert climate to the implementation of automated monitoring systems to optimize photosynthetic productivity. The potential impact in terms of CO_2 emission reduction and energy supply to communities is also assessed. The study also addresses the importance of involving the local community in the design and management of the project; this ensures its social acceptance and long-term sustainability. In this regard, the implementation of educational programs on renewable energy is crucial.

***Keywords*:** Algavoltaics, photovoltaics, biopanels, environmental impacts, algae.

1. Introduction

In the current context of the climate crisis and the search for sustainable energy sources, hybrid technologies that integrate biological and photovoltaic elements are emerging as promising alternatives. Among them, algae-based solar panels represent an innovative solution [1]. These systems have the ability to harness the "photosynthesis" of microalgae to produce electricity, reduce carbon dioxide (CO_2) emissions, and generate usable biomass [2]. This approach not only responds to the growing energy demand in urban regions; it also contributes to mitigating the environmental impact associated with the consumption of fossil fuels.

In the specific case of Lima, the capital of Peru, the opportunities to implement sustainable technologies are significant. This is due to its high annual "solar radiation" index and the urgent need for energy solutions in areas with limited access to clean energy, such as Ventanilla. This district, located in the constitutional province of Callao, faces challenges arising from uncontrolled urban growth; inequality in access to basic services and environmental pollution are just some of them. These conditions make Ventanilla an ideal setting for implementing pilot projects that combine photovoltaic technology with biological systems such as algae, proposing a replicable model in other similar contexts.

Likewise, the project's role as a tool to promote the "energy transition" in Peru is emphasized; it highlights how the integration of hybrid technologies can aid the country in environmental innovation [3]. This approach is expected to inspire future research and practical applications that will allow the potential benefits of algavoltaic systems to be realized in Peru and around the world.

In summary, the objective of this technical proposal is to develop a renewable energy research and demonstration center focused on algae photovoltaic technologies, with the aim of promoting capacity building, awareness raising, and the development of technical skills in these areas. This center will allow not only training in the use of these technologies but also the implementation of applied research projects that respond to local energy needs, thus contributing to increasing the share of renewable energy in the national energy mix.

Regarding the socioeconomic status, the community is comprised entirely of poor families with incomes below the minimum wage of 700 to 900 soles.

Regarding the physical condition of their homes, since they are improvised and unplanned, the predominant material for exterior walls is wood (Poma, Tornillo, etc.) (70%), brick (20%), and plywood (10%) [4].

The roofing materials of the homes are 80% corrugated iron sheets, 20% wood, and 10% concrete.

In addition, the public water supply for the homes comes from a tanker truck. The homes' sewage system is connected to a cesspool or septic tank (116 homes) and a septic tank or biodigester (29 homes).

70% of the population has electricity through the public grid, and the remaining 30% does not.

This is why it is necessary to propose sustainable and sustainable economic alternatives such as the development of algal species cultivation projects.

1.1. Problem

Urban expansion and lack of basic services such as electrification: Use of algavoltaics to supply energy to homes in the Puerto Pachacútec AA.

1.2. Potential

The surrounding environmental conditions constitute potential sustainable development alternatives, as it is located in the Continental Marine Ecosystem. The landscape becomes a driving force for the construction of a sustainable collective habitat [5].

1.3. Objective

Propose a sustainable economic alternative, such as the development of a pilot project for the cultivation of green algae for energy.

2. Materials and methods

2.1. Study Area and Target Population

The Nuevo Pachacútec AA. HH population is 464. 66% of the population is economically active, and 50% have completed secondary and primary education.

2.2. Study Components

Biopanels

Biopanels are innovative systems that combine microalgae and technology to generate energy, oxygen, and biomass from photosynthesis, these panels have a triangular shape and a semi-transparent green color, allowing them to be integrated into architectural structures such as windows or walls. By capturing carbon dioxide and converting it into oxygen, biopanels contribute to reducing greenhouse gas emissions [6].

Cultivation System

The algae cultivation system for algavoltaic energy is an innovative solution that combines energy and food production, using algae as the primary source. This approach focuses on the development of biophotovoltaic panels that integrate algae to generate electricity, contributing to sustainability and energy efficiency in urban environments [7].

2.3. Data Collection

Data was collected using primary and secondary sources.

Primary Data

To collect primary data, a survey was conducted with 14 representatives of various artisanal fishermen's associations dedicated to the extraction of green algae in the Pachacútec City area, Peru, as well as representatives of the Puerto Chico Artisanal Fishermen and Aquaculturists Association, which specializes in mariculture. A questionnaire was prepared in accordance with the study's objectives.

In addition, various professionals and project collaborators will be interviewed to obtain exclusive data on the laboratory's implementation. Private investment will be sought for the research.

Secondary Data

Likewise, secondary data was collected through access to journals, books, previous research, and certified websites related to the topic of study.

Likewise, the PRODUCE platform provides maps of the National Aquaculture Cadastre, where information can be found on the Mariculture field in Ventanilla authorized by the Regional Economic Development Office of the Callao Regional Government.

2.4. Infrastructure and Equipment

Implementation of the algae cultivation laboratory

The rental or acquisition of a facility that at least meets the conditions established in Table 1 should be considered [8]:

Table 1: Distribution and determined area of the algae cultivation laboratory environments

ROOMS	APPROXIMATE AREAS
Receiving, cleaning, and sorting area for algae. Space for freezers.	6 m2 (3x2)
Area for parameter taking and spore broth preparation. Space for containers, microscopes, and work table.	24 m2 (6x4)
Area for static vats, for the pre-incubation process	21 m2 (7x3)
Area for tubs with recirculation system	35 m2 (7x5)
Packing area	4 m2 (2x2)
Restrooms (2)	8 m2 (2x2) x2
Work/meeting room	20 m2 (5x4)
Store	6 m2(3x2)
Total minimum area to implement laboratory	124 m2

Minimum Equipment for an Algae Culture Laboratory

The minimum investment in equipment for an algae culture laboratory is presented in Table 2:

Table 2: Investment in equipment for the algae cultivation laboratory

LABORATORY EQUIPMENT	UNIT COST	AMOUNT	TOTAL COST WITH VAT	TOTAL COST WITHOUT VAT
2HP electric pump	S/ 3,500.00	1	S/ 3,500.00	S/ 2,870.00
1HP electric pump	S/ 2,000.00	1	S/ 2,000.00	S/ 1,640.00
Compound microscope	S/ 2,500.00	1	S/ 2,500.00	S/ 2,050.00
Stereoscope	S/ 1,500.00	1	S/ 1,500.00	S/ 1,230.00
250 liter refrigerator	S/ 1,200.00	1	S/ 1,200.00	S/ 984.00
Blower 2HP	S/ 3,500.00	2	S/ 7,000.00	S/ 5,740.00
Submersible pumps E3304	S/ 95.00	1	S/ 95.00	S/ 77.90
Total			S/ 17,795.00	S/ 14,591.90

Calculation by beneficiary user profile
Determining energy consumption per household in the Puerto Pachacútec settlement.

Consumption characteristics:
Basic equipment: Lighting with low-consumption bulbs (LED or compact fluorescent), use of a small or low-power television.

Mobile device charging, possible use of a small fan or radio. Absence of high-consumption equipment: They typically do not have air conditioners, washing machines, microwaves, electric ovens, or large refrigerators.

Estimated monthly consumption ranges: In households that meet the characteristics described, monthly consumption can be between 30 kWh and 60 kWh.

Average monthly consumption starting from this range: 45 kWh per household.

Calculation of solar panel implementation (connected to the grid)
Consumption of 150 households, 45 kWh each.
TOTAL MONTHLY CONSUMPTION: 150 homes x 45 kWh = 6,750 kWh
DAILY CONSUMPTION: 6,750 kWh/30 days = 225 kWh/day
CALLAO IRRADIATION (SENAHMI): Minimum 4 HPS - Maximum 5.5 HPS

Daily production = 610 Wp x 4 HPS = 2.44 kWh/day
Number of panels = 225 kWh/day / 2.44 kWh/day = 92.2 (93 panels)
Loss due to inverters and cables (20%) = 93 x 1.2 = 111.6 (112 panels) Without batteries, savings between 30% and 50% in price.
Solar panel investment: 112 panels x S/. 698.37 = S/. 78,217.44

Photovoltaic System Components

Accordig to the investigation [9] the average cost per installed Wp for each major component of the solar panel system was determined as shown in Table 3:

Table 3: Cost of the components of the proposed photovoltaic system

COMPONENT	AVERAGE RANK PER WP INSTALLED (DOLLARS)	AVERAGE COST PER WP INSTALLED (DOLLARS)	COST IN SOLES (PERUVIAN CURRENCY)
Investor	0.20 - 0.50	0.35	S/ 1.33
Mounting structure	0.10 - 0.30	0.2	S/ 0.76
Wiring and connectors	0.05 -0.15	0.1	S/ 0.38
Installation labor	0.10 - 0.20	0.15	S/ 0.57
Total value per installed Wp		0.8	S/ 3.04

Total cost of implementing algaevoltaic energy infrastructure at Puerto Pachacutec

Accordig to the investigation [10] the approximate investment, considering the algae cultivation system and the photovoltaic system, is presented in Table 4:

Table 4: Total implementation cost

INSTALLATION TYPE	INVESTMENT EQUIPMENT	COMPLEMENTARY INVESTMENT	TOTAL INVESTMENT
Algae cultivation system	S/ 17,795.00		S/ 17,795.00
Solar panel system	S/. 78 217.44	S/. 207 692.8	S/. 285 910.2
TOTAL COST			S/. 303 705.2

Analysis by kWh cost at the window, Callao

The residential electricity rate was determined based on location, according to Table 5:
-Up to 30 kWh is S/. 0.58 per kWh
-From 31 to 100 kWh is S/. 0.81 per kWh
-More than 100 kWh is S/. 0.88 per kWh Source: Enel

ESTIMATED AVERAGE CONSUMPTION OF 45 kWh = S/. 0.81 per kWh

ESTIMATED MONTHLY PAYMENT PER HOME: S/. 0.81 per kWh X 45 kWh = S/. 36.45
MONTHLY DATA: S/. 0.81 per kWh X 45 kWh x 150 homes = S/. 5,467.5 ANNUAL DATA: S/. 5467.5 x 12 months = S/. 65,610
SOLAR PANEL SYSTEM INVESTMENT = S/. 285,910.2

Table 5: Financial analysis, cash flows of the proposal

UTILITY	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	…	YEAR 20
Income	S/ 65,610.00	S/ 65,610.00	S/ 65,610.00	S/ 65,610.00	S/ 65,610.00	S/ 65,610.00	S/ 65,610.00	…	S/ 65,610.00
Annual maintenance cost (- 5%) (expense)	S/ 62,329.50	S/ 62,329.50	S/ 62,329.50	S/ 62,329.50	S/ 62,329.50	S/ 62,329.50	S/ 62,329.50	…	S/ 62,329.50
Investment recovery	S/ 62,329.50	S/ 124,659.00	S/ 186,988.50	S/ 249,318.00	S/ 311,647.50	S/ 373,977.00	S/ 436,306.50	…	…

3. Results

The implementation of the algae cultivation laboratory requires a minimum space of 124 m2, distributed in specific areas to optimize the algae cultivation process. It is essential to ensure functional and well-distributed spaces to cover all stages of cultivation. Furthermore, the total equipment cost amounts to S/. 14,591.9 (excluding VAT), including key equipment such as microscopes, electric pumps, and refrigerators. This initial investment is reasonable and ensures the laboratory's basic operations. Regarding the viability of its implementation, the initial investment is recovered in the first year with a net profit of S/. 3,805. Beginning in the second year, the annual net income is S/. 25,920, demonstrating the high profitability of this system, as shown in Table 6.

Table 6: Profitability of the proposed system

YEAR	PRODUCTION (m)	INCOME (S/. 4.50/m)	EXPENDITURES (70%)	NET PROFIT (S/.)
YEAR 1	16,000	72,000	50,400	3,805
Year 2+	19,200	86,400	60,480	25,920

Installing a photovoltaic system requires a total investment of S/. 285,910.20, considering panels and complementary components. This project is viable to supply the average consumption of 45 kWh/month per household, generating long-term energy savings. The system recovers its initial investment in the fifth year. From that point on, it generates consistent net income, with low maintenance costs (5% annually), making it a sustainable and economically efficient solution, according to Table 7.

Table 7: Initial investment recovery analysis

YEAR	GROSS INCOME (S/.)	MAINTENANCE COST (5%)	NET PROFIT	ACCUMULATED RECOVERY (S/.)
YEAR 1	65,610	3,280.50	62,329.50	62,329.50
YEAR 5	65,610	3,280.50	62,329.50	311,647.50

4. Conclusion

The use of open-sea cultivation systems takes advantage of Ventanilla's favorable climatic conditions, such as high solar radiation and the availability of seawater. This maximizes the efficiency of both microalgae cultivation and photovoltaic energy generation, making the project a viable and sustainable solution.

The project combines electricity generated by solar panels with biomass obtained from microalgae cultivation. This biomass can be transformed into biofuels or biogas, diversifying clean energy sources and contributing to the reduction of greenhouse gas emissions.

The proposal to incorporate an algavoltaic energy center in the Puerto Pachacútec area is economically viable, as both the incorporation of an algae cultivation system and a solar panel system in the area meet the demanding needs. They also show a payback period of up to five years based on the initial investment, giving the project a 75% feasibility.

Biopanels represent an innovative solution for generating clean and sustainable energy by harnessing the photosynthetic properties of microalgae. With their ability to produce oxygen and energy while helping to clean the air, these devices have great potential for both residential and industrial applications in the future.

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