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Development of the energy hub GEDERlab at Universitat Politècnica de València for encouraging the integration of renewable energy resources

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Abstract. Renewable energies stand out as fundamental solutions to address climate change, providing environmental benefits and promoting energy independence. However, renewable plants face challenges such as intermittency, initial costs, and visual effects on the surroundings. The GEDERlab is an innovative energy hub developed at the Universitat Politècnica de València (UPV) that integrates four renewable energies (solar, wind, biogas, and hydraulic) to tackle these challenges. The main objective is only to optimize complementarity among energies but also to develop strategies for efficient storage and optimal management. This project goes beyond research and it aims to become a replicable model at the municipal level. Therefore, the results are extrapolated to a rural municipality in the Valencian Community, to improve energy efficiency, promote circular economy principles and utilize waste as resources. So, in this paper, the components of the energy hub GEDERlab, their integration, and the control system are described to encourage the integration of renewable energy resources.

Key words. Renewable energies, energy hub, efficient management, sustainability.

1. Introduction

Climate change has emerged as one of the most urgent and complex challenges of our era. The rise in carbon dioxide (CO_2) levels and other greenhouse gases has triggered devastating impacts on our planet. From extreme weather events to the disruption of vital ecosystems, its effects are felt globally, impacting communities, economies, and environmental stability [1].

In response to this crisis, renewable energies emerge as a powerful tool to mitigate climate change [2]. Solar, wind, hydraulic, and biomass energy sources represent clean and sustainable alternatives to fossil fuels. Solar energy, captured through photovoltaic panels, harnesses solar radiation for electricity generation. Wind energy, obtained through turbines, converts the force of the wind into electricity. Hydropower utilizes the energy of water and, finally, biomass uses organic matter for energy generation. It has to be taken into account that theses renewable energies present a series of advantages and disadvantages that must be considered [3].

Among the advantages of these renewable sources are:

- Lower environmental impact: They significantly reduce CO_2 emissions and other atmospheric pollutants, decreasing the environmental footprint and contributing to the fight against global warming.
- Abundance and availability: Unlike limited fossil resources, renewable energies are naturally unlimited resources and widely available in many regions in the world.
- Energy independence: By diversifying energy sources, dependence on imported fuels is reduced, promoting energy security.

However, there are also challenges and drawbacks on the path to widespread adoption of renewable energies:

- Intermittency: The intermittent nature of solar and wind energy (dependent on sunlight and weather) requires solutions for efficient energy storage or integration with other sources to ensure a constant supply.
- Infrastructure and initial costs: Installing infrastructure to exploit these energies can be costly initially, although costs are gradually decreasing with technological advances and economies of scale.
- Landscape impact: The implementation of large-scale wind farms or solar panels may generate controversies due to their visual impact and effects on the natural environment.

In this context, the integration of these renewable energies has emerged as a crucial path to mitigate the impacts of climate change and minimize the drawbacks presented by each technology individually [4]. To materialize this vision, the energy hub GEDERlab initiative is developed, aimed at combining and managing photovoltaic, wind, hydraulic, and biomass energies in a energy hub at the Universitat Politècnica de València (UPV). This facility not only seeks to explore technological aspects but also addresses management challenges, thus deploying a comprehensive model for the development of an efficient and sustainable power network.

GEDERlab, developed by a multidisciplinary team (www.geder.es), headed by Ph.D. Guillermo Escrivá Escrivá, stands as a crucial testing environment to analyze the technical and economic feasibility of these technologies. Experiments are conducted to explore complementarity among different energy sources and leveraging their strengths to counteract the intermittency that characterizes some of them [5]. The optimization of storage systems, efficient management of energy production and distribution, and the assessment of their impact on the surrounding environment are key aspects addressed in this energy hub [6]. Beyond being an isolated research environment, GEDERlab positions itself as a precursor to change, providing fertile ground for the development of technologies and management strategies that could be replicated and scaled at municipal or regional levels. Specifically, the scope of this research extends beyond the experimental realm, as the goal is to extrapolate the results obtained to a specific application context. In particular, attention is directed towards a rural municipality in the Valencian Community that, due to its significant electricity supply problems and the growing depopulation, faces both substantial techno-economic challenges and sustainable development issues in the INASOLAR project [7]. The implementation of a microgrid in this area not only aims to generate energy more efficiently but also to promote circular economy principles and utilize livestock waste as energy resources.

This approach is not only envisioned as a local solution but also as a replicable and scalable model with the potential to revitalize rural communities in various regions. The ultimate purpose is to bridge the gap between technological innovation and sustainability, aiming to build a more resilient and equitable energy future.

The paper is organized as follows. Section 2 presents the description of the GEDERlab energy hub. Section 3 shows the study case in which a resource allocation of energy resources in a rural municipality has been carried out. Then, Section 4 describes the application in GEDERlab. Finally, in Section 5, some conclusions of the presented work are drawn.

2. Description of the GEDERlab energy hub

This section provides an overview of the GEDERLab, a facility at UPV, describing the installed equipment and their technical specifications. Additionally, key features of its control system are also detailed. This coordinated system optimizes the production, distribution, and storage of electrical energy, ensuring efficient and adaptable operation in the system.

A. Technical Features

There are specialized devices and equipment representing various renewable energy sources:

1) Photovoltaic installation:

The photovoltaic installation comprises three key elements: solar panels, charge controller, and inverter.

Strategically positioned on the roof of the laboratory building, the photovoltaic solar panels are designed to capture solar radiation and directly transform it into electricity. Specifically, a total of 9 SERAPHIM SRP-310-E11B solar panels with a capacity of 310W STC (230W NOCT) each are deployed, providing and effective total power of around 2,1 kW peak for solar generation. Figure 1 illustrates the photovoltaic panels installed on the roof of the Building 5E in the UPV where GEDERLab is located.

Fig. 1. GEDERlab photovoltaic panels.

The charge controller regulates the battery charge state to ensure optimal charging based on the energy provided by the panels, thus extending the lifespan of the batteries. Specifically, the laboratory is equipped with the Schneider Conext MPPT 60 150 solar charge controller. On the other hand, the solar inverter is an essential device that plays a crucial role in converting the direct current (DC) generated by the solar panels into alternating current (AC). To achieve this, the laboratory is equipped with the Schneider Conext XW+ inverter.

2) Wind installation:

The wind installation consists basically of a wind turbine, a charge controller and an inverter. The wind turbine is situated on the roof of the building, near the PV panels.. In this case, a vertical-axis wind turbine GV-1kW is employed. This wind turbine delivers a power output of 1 kW. The wind turbine can operate at wind speeds ranging from 3-25 m/s, equipped with an automatic shutdown system if the wind speed exceeds 50 m/s. Similar to the PV installation, this setup includes a charge controller and a 1 kW inverter. Figure 2 illustrates the wind turbine.

Fig. 2. GEDERlab wind turbine.

3) Biomass installation:

Due to the difficulty of having a digester in the premises of the UPV, a diesel generator with a synchronous generator is installed, playing a crucial role in simulating the behavior of a biogas power plant in the context of renewable energies. This generator set is located on the roof of the building 5E.

The diesel generator, configured to simulate biogas generator, enables for a realistic study of the generation, storage, and use of this renewable energy source. This includes the assessment of its efficiency, the optimization of storage and distribution strategies, as well as its effective integration within the energy microgrid.

Specifically, the GEDERlab is equipped with a Raywin 4D24G motor and a Stamford 10 kVA alternator, as depicted in Figure 3 (left). For remote control of the generator and parallel operation to the grid, a control panel is available. This control panel is shown in Figure 3 (right).

Fig.3. Diesel Generator for Biogas Simulation (Left) and Control Panel (Right).

4) Micro-hydraulic installation:

There is a hydraulic installation designed to simulate and analyze electricity generation from water. This installation consists of two tanks, and two pumps and two turbines.

The upper tank, located on the roof of the building 5E, acts as an energy storage system. From this tank, water descends to the lower tank located in the GEDERlab control room, thus representing a controlled moving water system. Each tank has a capacity of 500 L. The strategic arrangement of these tanks simulates a controlled hydraulic reversible power plant.

Using pumps, water is lifted to the upper tank to recreate potential energy storage. Two AstraPool 200M pumps are used for this purpose, each with a power of 1.5 kW, a flow rate of 26 m^3/h, and a head of 10 meters of water column.

The turbines, connected to the lower tank, harness the kinetic energy of the moving water from the upper to the lower tank to drive a generator and produce electricity. This generated electricity can be integrated into the electrical grid. Two Saloria TF-600 micro-hydraulic turbines, each with a capacity of 300 W, are employed for this purpose. Figure 4 illustrates both turbines.

As a summary, the power capacities of each renewable resource are indicated in Table I.

Table I. – Power Capacities of Each Renewable Resource

Renewable resource	Power	Units
Photovoltaic	2.1	kW
Wind	1.0	kW
Biomass	10.0	kVA
Hydraulic turbines	0.6	kW
Hydraulic pumps	3.0	kW

Fig.4. Micro-hydraulic turbines.

5) Batteries:

The facility is equipped with batteries a necessary component for the connection of the selected inverter.

The battery system not only stores excess energy produced by renewable sources during periods of high generation but also supplies energy when demand exceeds instantaneous generation.

Moreover, the battery system integrates with the laboratory's control system, enabling intelligent and efficient management. This involves continuous monitoring of the state of charge, discharge capacity, and efficiency of the batteries, allowing for precise adjustments to maximize their performance and lifespan.

The battery array consists of a total of 8 high-performance AGM batteries, Vision EVL16-400A-AM 6V 400Ah each, providing a total energy storage capacity of 19.20 kWh. Figure 5 displays the batteries located in the GEDERLab.

Fig.5. Batteries installed at GEDERlab.

6) Load banks:

In addition to the specific elements for the generation and storage of renewable energy, the GEDERlab is equipped with two load banks. These load banks play a crucial role in simulating the energy demand curve, representing energy consumption patterns over time.

The load banks enable for the accurate reproduction of variability in energy demand, a critical aspect for evaluating the efficiency and response of the renewable energy system to different consumption scenarios. By adjusting the load, scenarios ranging from low demand to peak demand can be emulated, enabling the analysis and design of more effective and efficient energy management strategies. This enables the design of more robust and adaptable systems capable of efficiently and sustainably meeting changing energy needs. On one hand, there is a standard load bank based on RLC loads that must be configured manually. On the other hand, to better adjust the values of the consumption curves, a programmable electronic load is available. Specifically, the ITECH IT8617, which enables simulating up to 5.4 kVA of power with a power step resolution of 0.4 W.

7) Meteorological monitoring:

The meteorological station installed on the roof of the building 5E is a sophisticated system designed to monitor and record climatic data.
Among the parameters, wind speed and direction, incident solar radiation, ambient temperature, relative humidity, and precipitation are measured. These data are collected at regular intervals and stored for subsequent analysis and correlation with the energy production from the renewable sources. The Davis Vantage Pro2 meteorological station is employed for obtaining these variables.

8) Data collection and measurements:

All data generated by renewable energy sources, and meteorological variables are recorded in a database. This logging system captures detailed information every minute, creating an extensive and accurate history of energy and climatic variables.
Additionally, this continuous logging facilitates the correlation between energy generation, simulated demand, and weather conditions.
This database becomes an essential tool for the study and analysis of long-term trends, enabling informed decision-making for the optimization and continuous improvement of energy efficiency within the system and its extrapolation to real-world environments.

B. Control system

In the formulation of the energy sources for the laboratory, a meticulous consideration of source management becomes imperative to enhance operational efficiency. This necessitates the implementation of a control diagram, overseen by a system that incessantly assesses conditions and orchestrates the energy output from diverse renewable sources, as shown in Figure 6.
Given the inherent inability of solar and wind generation to directly store energy, a nuanced equilibrium must be established between the output of these sources and hourly consumption. This intricacy gives rise to two scenarios contingent upon the existence or absence of an energy surplus.
Scenario 1 – Surplus Exists: In the event of an energy surplus, efforts will be directed towards utilizing this excess energy. Initially, it will be employed to pump as much water as feasible from the lower reservoir to the upper reservoir in the hydraulic power station. If a surplus persists, it will be channeled towards charging the batteries if required, and ultimately, if no alternative is viable, the surplus energy will be injected into the grid.
Scenario 2 – No Surplus Exists: In this scenario, priority will be given to utilizing biogas as the primary energy source. The rationale behind this decision lies in the constant production of biogas by the biogas plant. Failure to utilize this gas would necessitate its subsequent combustion in the flare, resulting in the forfeiture of potential energy utilization. This is particularly relevant given that the biogas plant is designed to operate in rural settings where the consistent processing of livestock waste is imperative. Subsequently, if demand persists, energy stored in the hydraulic power station will be employed. If necessary, stored energy in batteries (specifically for the laboratory) will be utilized, or as a last resort, energy will be procured from the grid.

3. Study case: Resource allocation in a rural municipality

The purpose of the GEDERlab is to explore the technical and economic feasibility of implementing an energy hub based on distributed renewable energy resources.
To achieve this, it is useful to have electricity consumption records from an actual municipality. These records offer a detailed insight into consumption habits, unveiling critical demand patterns. This data serves as the foundational basis for designing an intelligent and efficient allocation strategy of resource allocation derived

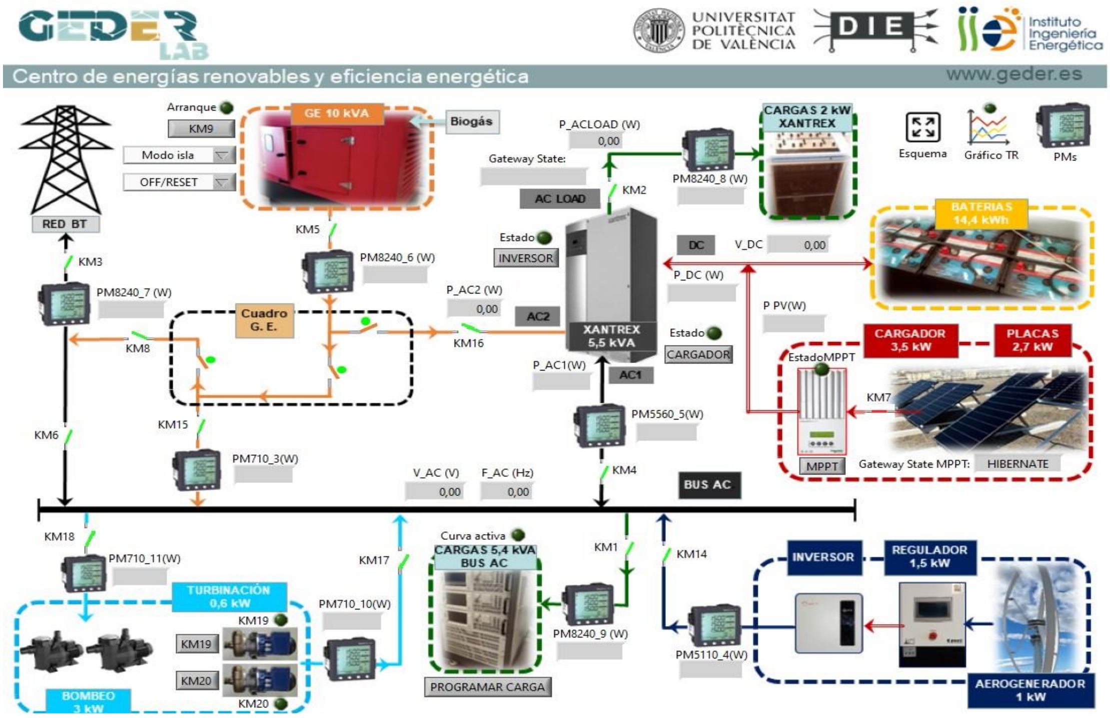

Fig.6. GEDERlab control system.

from renewable sources. Specifically, the study is conducted based on data obtained from the municipality of Aras de los Olmos. This municipality, situated in the northwest of the province of Valencia (Valencian Community, Spain), shares borders with the province of Teruel to the north (Aragon, Spain), and to the west with the province of Cuenca (Castilla La Mancha, Spain). The selection of Aras de los Olmos is justified by its location at the end of an electrical power line, leading to numerous electrical supply issues. Additionally, its geographical location renders it ideal for the implementation of renewable resources [8].

The weekly consumption curve serves as a benchmark for understanding variability in demand, pinpointing peak and off-peak energy periods. This information is crucial for determining the required capacity of renewable sources—solar, wind, hydro, or biomass—to meet energy demands at different times of the day and week. Figure 7 illustrates the consumption curve for a week in the municipality, with the gray line representing consumption.

Taking into account consumption patterns and analyzing years of electrical consumption records, the following capacities for each renewable resource have been deemed optimal.

- Solar Installation: 250 kW
- Biogas Installation: 300 kW
- Wind Installation: 100 kW
- Hydraulic Installation: 150 kW

It should be noted that, as of today, only the photovoltaic and biogas plants are close to be operational, so these are the only ones available for use. Therefore, simulations will be conducted solely with these two technologies for a closer resemblance to the current reality. In the future, when the other plants are constructed, this work will be expanded.

These capacities are strategically chosen to align with observed consumption patterns, ensuring that the renewable energy infrastructure meets the municipality's energy needs reliably throughout the week. The goal is to create a balanced and sustainable energy system that effectively caters to the dynamic energy demands of the community.

In Figure 7, resource allocation for a week is shown. It should be noted that despite the existence of surpluses, they will be used for pumping in the hydropower plant when available. The optimization of resource allocation is achieved by carefully considering the availability and variability inherent in each renewable source, depending on climatic and temporal conditions. For example, during periods of high demand, solar resources can be fully utilized, provided that meteorological conditions allow. On the other hand, more constant sources like biomass could offer a consistent contribution throughout the day. Figure 7 illustrates the outcome of the proposed resource allocation, showing the generation of the renewable sources. This representation demonstrates minimal energy exchange with the grid, potentially approaching total self-sufficiency for the municipality.

Once the hydroelectric and wind power plants are implemented into the municipality's energy mix, a more resilient system will be in place, increasing the reliability of the energy supply.

The proposed resource allocation through renewable resources not only aims to meet the current energy demand but also endeavors to establish a flexible and scalable energy infrastructure. This would enable adaptation to future changes in consumption patterns and promote sustainable growth, even in the face of a potential population increase in the municipality.

4. Application in GEDERLab

With the aim of analyzing the technical feasibility of the theoretically conducted resource allocation, the resources of GEDERlab are employed. Among all available equipment, the photovoltaic installation, the diesel generator set (simulating biogas), and the grid will be utilized. While the utilization of other renewable energies is feasible, the aim is to assess the technical feasibility of unit allocation for a day, using the resources available in the municipality of Aras de los Olmos in the near future.

For this study, the last day of Figure 7 (highlighted in green) has been selected as the trial day. To achieve this, the municipality's demand curve is scaled to a replicable power level in the laboratory. However, it is necessary to consider the limitation regarding power regulation of the generator group. Power regulation of the generator group is only possible in increments of 1 kW. In the future, this regulation will be enhanced to increments of 0.1 kW. With this limitation in mind and based on the demand curve of January 13, 2024 (Figure 7, highlighted in green), the unit allocation conducted in the laboratory is depicted in Figure 8.

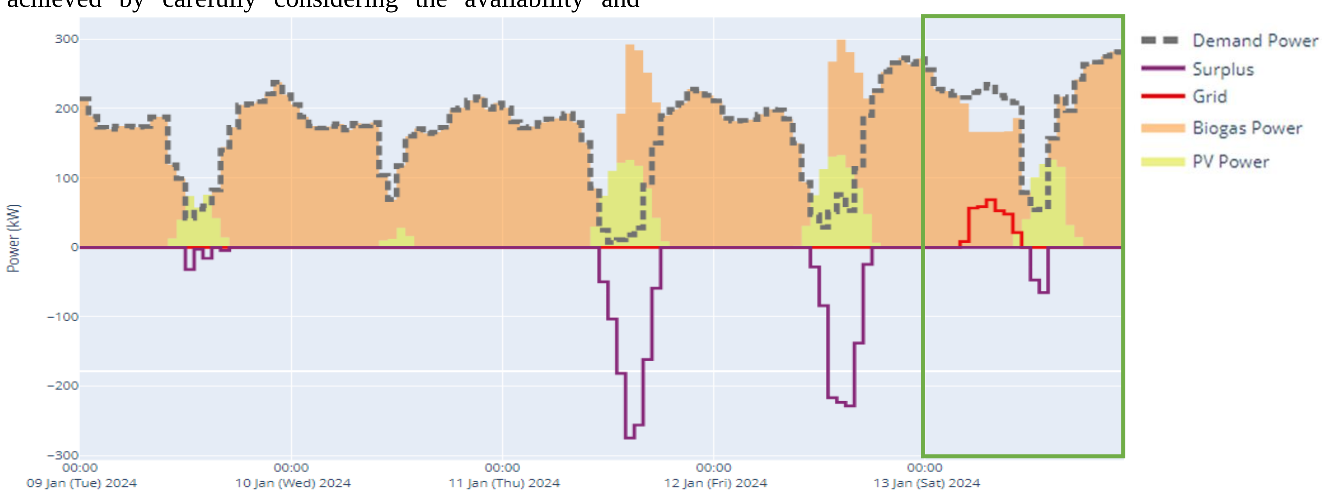

Fig. 7. Resource Allocation in Aras de los Olmos.

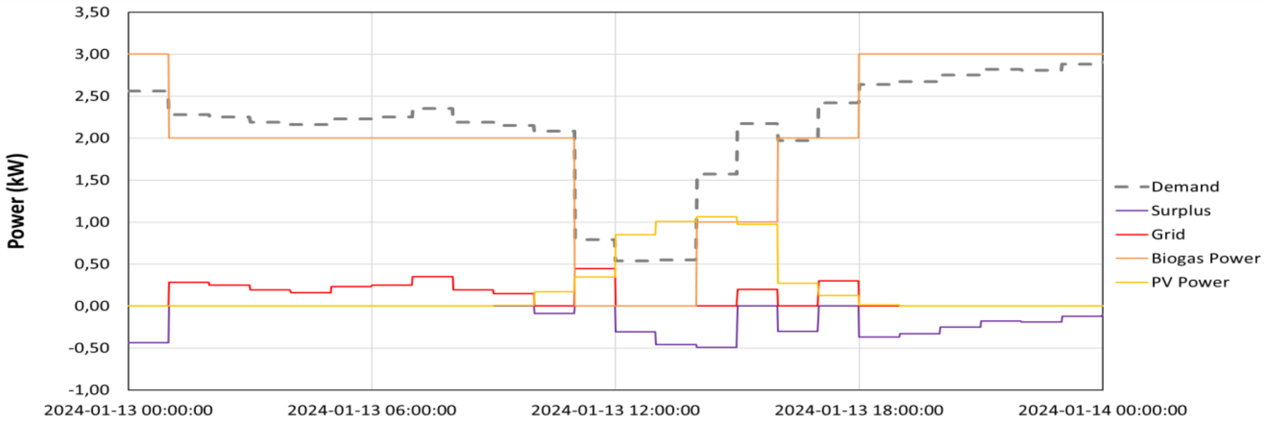

Fig. 8. Resource Allocation in GEDERlab.

The experiment conducted in the GEDERlab demonstrates the feasibility of implementing the unit allocation proposed for the municipality of Aras de los Olmos. However, it is important to consider the limitations in power regulation of the power plants, which would be available in actual generation plants. Furthermore, it is evident that there is a surplus for a significant portion of the hours. This surplus could be easily mitigated with a higher degree of biogas regulation or by utilizing the mini-hydropower plant to harness this energy for pumping purposes.

5. Conclusions

Climate change is recognized as an urgent and complex challenge with devastating global impacts. Renewable energies are emerging as powerful tools to address this issue, despite the challenges they present. In this context, GEDERlab has been developed at UPV, integrating renewable energies into an energy hub and serving as a crucial testing ground to analyze the technical and economic viability of these technologies. This facility faces technological and energy management challenges, deploying a comprehensive system for the development of an efficient and sustainable energy grid. Commercial equipment is used, and a scalable architecture has been implemented. The available energy hub consists of a 2.1kW photovoltaic installation, a 1kW wind installation, a 10kVA generator simulating a biomass power plant, and a hydraulic plant with a pumping capacity of 3kW and a turbine capacity of 0.6kW.

In this work, a theoretical allocation of units of demand for a municipality is used. With the aim of showcasing the possibilities offered by the GEDERlab energy hub, this allocation of units is scaled to the laboratory to study the management of energy resources. After the trial, it is verified that GEDERlab allows testing different scenarios, grid tied or isolated, and verify the viability of implementing such unit allocations. Furthermore, these types of trials enable the identification of possible deficiencies in the proposed system, as well as the examination of technical and economic viability before implementing large-scale generation plants in the municipality of Aras de los Olmos. Additionally, this approach is conceptualized not only as a local solution but also as a replicable and scalable model with the potential to revitalize rural communities in various regions.

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