GAIA Competition Problem Statement 2022-23

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Electricity Access in Rural Peru

This problem statement is pending final review from WindAid, but is being released now to allow competitors to get started. If any specifications change, a new version will be released ASAP and competitors will be notified. Thanks for your patience.

Please direct questions to gaiacompetition@gmail.com.

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1. Problem Context

The seventh United Nations Sustainable Development Goal (UN SDG 7) calls for affordable, reliable, sustainable and modern energy for all by 2030. As of 2023, just over **15% of rural households in Peru lack electricity access**, leaving this segment of the population without power for lighting or device charging [bnamericas].

The fraction of rural Peruvians without electricity access has decreased from 68% in 2004 [World Bank]. The progress in the last two decades has been largely driven by the World Bank's 2005-2017 Rural Electrification Project (REP) and the Peruvian government's 2013-2022 National Rural Electrification Plan (PNER). Both programs directed hundreds of millions of dollars toward rural electricity systems, primarily off-grid solar photovoltaic panels to power indoor lighting. For more information on rural electrification in Peru, including the economic and social benefits of electricity access, lessons learned from prior program implementation, and statistics on electricity end use and generator repair, teams are encouraged to consult the REP Project Performance Assessment Report [World Bank].

The remaining 15% of un-electrified Peru households are the most difficult to reach, and currently get their energy from fuelwood, diesel, or kerosene. Electrifying these households is expected to increase quality of life and economic prosperity. Due to the remoteness of rural areas in Peru and the difficulty of setting up grid transmission lines throughout the diverse geography, **off-grid/microgrid solutions are more appealing than national grid connection** as an electrification strategy for these remaining unelectrified homes. While the Peruvian government has focused on solar photovoltaic and hydro power, strong sources of wind exist in both the coastal and mountainous regions of Peru. This makes Small Wind Turbines (SWTs) an appealing possibility.

SWTs used for rural electrification in developing countries should be manufactured and maintained locally to decrease cost and improve lifetime and user acceptance. These are often referred to as **LMSWTs (locally manufactured small wind turbines)**.

2. WindAid Program

The WindAid Institute is a non-governmental organization (NGO) that installs wind turbines in remote communities around northern Peru not connected to the national grid. They function both as a service organization, installing and maintaining wind turbines in rural communities at no charge, and as an educational organization, running trips for students to gain hands-on experience manufacturing and installing the turbines.

WindAid uses a LMSWT design described in section 3. **GAIA teams are challenged to improve aspects of the WindAid turbine design** (see section 4) and will receive the **opportunity to manufacture their design in Peru on a GAIA-funded WindAid student trip**.

A total of 8 students from across the highest-performing GAIA teams will be selected to attend WindAid's Summer 2023 trip. GAIA will provide the funds for everything included in the WindAid trip, which includes lodging, meals, local travel within Peru, and wind turbine build materials. Teams will be financially responsible for their flight to and from Peru. The 2023 trip is expected to run **approximately the last week of July and the first three weeks of August**, but can be adjusted slightly depending on students' academic schedules.

On the trip, students will install the standard WindAid turbine design at the partner community / rural village, as well as build a prototype of their proposed improved design at the WindAid development and testing facility.

3. WindAid Turbine Design

Here are some documents from WindAid describing their current turbine design:

1. Blade outline / Blade
2. Generator
3. Installation of the base and turbine
4. Turbine Assembly Drawing
5. Fabrication Process
6. Turbine User's Manual

The table below shows a technical data sheet for the WindAid turbine specification.

Table 1: Technical Data Sheet of the WindAid Turbine

Nominal Mechanical Power	500 W
Nominal Voltage	12 V
Nominal Current	20 A
Rotor Diameter	1.7 m

Swept Area	2.27 m^2
Rotational direction	Anti-clockwise
Cut In Wind Speed	3 m/s
Cut Out Wind Speed	12 m/s
Rotor speed	120 - 600 rpm
Number of blades	2
Hub Height	7 m

Note that the cut-in speed of WindAid's turbine, 3 m/s, is higher than the average wind speed in some parts of rural Northern Peru, so the turbine would not produce electricity effectively in these areas.

WindAid has been working recently with a major aerodynamics company to redesign their blades and rotor. In their partnership with GAIA, they are especially hoping to improve the design of their electronic system such as controls, inverters, storage, and sensors, but are open to innovations on any subsystem.

4. Design Requirements

GAIA teams are tasked to improve the design of the WindAid off-grid small wind energy system to make it more reliable, economical, practical, sustainable, and otherwise impactful. The challenge is as follows:

1. Choose one subsystem of a wind turbine:
    a. Blades and rotor
    b. Foundation and tower
    c. Generator and drivetrain
    d. Electronics and battery
2. Redesign the subsystem with any/all of the following objectives in mind:
    a. Increase average power output at wind speeds typical of Peru wind climate
    b. Lower system cost (capital and operating)
    c. Increase reliability (time between failures) and system lifetime
    d. Improve local manufacturability and local maintainability, including safety
    e. Improve life-cycle environmental sustainability
    f. Any other changes that will allow the system to effectively provide electricity to as many houses as possible in the rural areas of Peru
3. Ensure compatibility with the following functional requirements:
    a. Electricity should be available to support residential household lighting and device charging loads. Example design requirement: electricity should be

available for a minimum of 12 hours each day in the evening, night, and early morning hours.

b. The system should function at the sites of WindAid's existing community partnerships (Luz del Sol, Nueva California, and El Chorro, Peru), WindAid's development and testing facility (Trujillo, Peru), and nearby locations in northern Peru.
c. Materials must be locally sourced in Northern Peru.
d. When estimating overall system performance and determining interface requirements, you may assume that the three subsystems you are not redesigning will use the default WindAid design, unless a specific change is necessary.

Teams should assess the wind resources, expected demand load, economics, reliability, manufacturability, maintainability, and sustainability of their design **in the context of rural Peruvian communities**, which may require different analyses than what teams are used to for design for the developed world.

As an example of the wind resource assessment, in Figure 1 below we show the average monthly wind speed in El Chorro, Peru at 10 meter height. Note that except in the summer months, the wind speed is below the 3 m/s cut-in speed of the WindAid design.

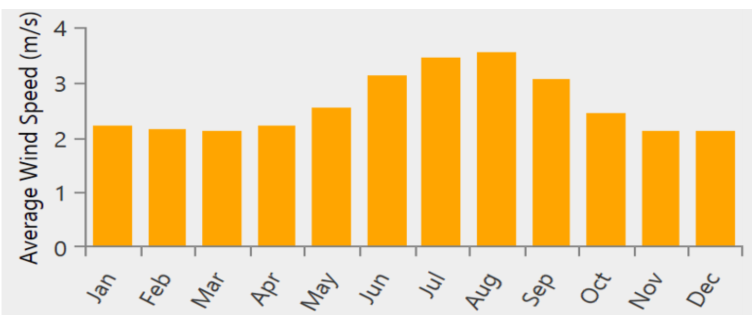

Figure 1 Current Wind Speed/Energy Analysis in El Chorro at 10 meter height.

Additionally, because wind patterns are expected to change as a result of global climate change, rising sea levels, and large storms, we recommend that teams consider future wind patterns in their design.

5. Suggested Design Considerations

The following list is to help you get started in thinking about what components you will need to source/design and what types of analysis you need to do, depending on the chosen subsystem.

Battery

1) Cell chemistry (lithium ion, lithium iron phosphate, lead acid)

2) Form factor (cylindrical cell, pouch cell)
3) s and p count (number of cells in series and parallel, determining voltage and capacity)
4) C-rate (charge and discharge rating)
5) Prevention of overcharging and overdischarging

Electronics

6) Power electronics (inverter, rectifier) efficiency, fault tolerance, and control
7) Cables, wiring, and connectors
8) Sensors

Blade and rotor

1) Prevailing wind direction and wind speed distribution
2) Basic specifications: rotor diameter, number of blades
3) Aerodynamics: angular momentum, pitch angle, angle of attack, tip speed ratio
4) Cut in and cut out wind speed
5) Calculate the torque and power curve
6) Blade manufacturing material and manufacturing process
7) Analyze blade erosion based on climate

Towers and Foundation

1) Determine extreme wind speed and corresponding load
2) Calculate stresses associated with lift and drag, dead load, extreme load, seismic load
3) Determine type of tower and foundation
4) Dynamic behavior (determine frequency of natural modes)

Drivetrain

1) Type of shaft (parallel shaft, planetary)
2) Torque, speed, and corresponding gear ratio
3) Load and fatigue stress analysis
4) Noise, lubrication, and reliability analysis

Generator

1) Operating speed and efficiency
2) Type of machine (AC / DC, induction / synchronous, trapezoidal / sinusoidal back EMF)
3) Type of insulation and windings
4) Amount of permanent magnets used
5) Control strategy
6) Frame size and generator weight
7) Torque ripple

6. Suggested Team Resources

- WindAid Institute - our NGO partner - GAIA will arrange zoom meetings, stay tuned!
- GAIA mentors - GAIA will provide mentor contact information, stay tuned!
- Wind Empowerment - global organization that WindAid is a member of, with resources on locally manufactured small wind turbines
- International energy organizations: Alliance for Rural Electrification, Latin American + Caribbean Energy Hub
- Academic journal papers about rural electrification and small wind turbines (ie example, example, example, example)
- Books by Hugh Piggot: Small wind systems for rural energy services, Wind turbine recipe book
- Small wind guidebooks (Engineers Without Borders, Wessex Institute of Technology, US Department of Energy)