Comparing Renewable Energy Sources in Rural Ecuador

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My research project aims to analyze low-cost renewable energy sources and their ability to displace conventional energy methods in a rural Ecuadorian community. Isolated communities, specifically in developing countries, not only have limited access to any energy infrastructure, but also lack the funds and technology needed to establish their own reliable sources of energy. My project will explore three low-cost renewable energy systems and their ability to sustain a community that would otherwise have limited energy capabilities. My research will determine which system is the most efficient, cost effective, and best suited for the given environment through a cost-benefit analysis, as well as ways to optimize each individual system. This project can ultimately help isolated communities utilize low-cost, renewable energy systems.

I will conduct my research at the La Hesperia Biological Station, located in the Pichincha province 90 kilometers from Quito, Ecuador. La Hesperia is primarily a biological conservatory that studies the ecosystem of the cloud forest, but also upholds a strict goal to maintain a sustainable facility. La Hesperia seeks to leave zero impact on the environment utilizing renewable resources to produce energy through three separate systems: solar panels, solar energy derived from plastic bottles and pipes, and a biogenerater. These systems allow La Hesperia to establish a closed energy grid to output clean energy and mitigate environmental and health effects. While these systems have already been constructed, they are fairly new designs providing the opportunity for improvement. La Hesperia has also put forth considerable efforts to extend their sustainable philosophy to the surrounding villages.

The biogenerater converts organic matter (cow manure), through anaerobic digestion, to produce liquid fertilizer and biofuel. The biofuel has been used for cooking and heating water. The solar panels, mounted on top of the main facility, are used to heat the shower water. The solar energy derived from the plastic bottles and pipes is a new technology that stores the water in a tank on the roof. This heated water can be used for cooking or showering.

La Hesperia currently has little research in regards to the savings and co-benefits of the three systems. Conducting a cost-benefit analysis is a common engineering tool used to compare different energy systems (Clark 2011). I will be able to utilize the existing research on solar cells, biogeneraters, and solar energy from plastic bottles to help improve and analyze the systems at La Hesperia. Research exists for each of the three systems, but they are all contingent upon the system's site (location, size, climate). Research on all three systems has shown their ability to displace conventional energy sources in low-income, rural communities. There is a need, however, for research that compares different renewable energy designs and their ability to sustain a community over other sources (wood, petroleum). My research at La Hesperia will provide guidance to other rural ecosystems determining how to optimize their energy supplies. La Hesperia's specific location (within a cloud forest) will provide a different angle when it comes to analyzing renewable energy in rural environments. The research gained from the systems optimization phase can also be utilized to improve energy designs elsewhere.

My research is separated into two separate methodologies: a cost-benefit analysis (CBA) and systems optimization. The first phase of my project will be spent gathering and analyzing data to conduct the CBA. The CBA must set boundaries for the costs and benefits of each system, consider how the value of money is accounted for, and how environmental and human health issues are valued (Eaton 2010). I will determine the monetary value of the energy, environmental, and health benefits over the conventional energy methods as well as their estimated payback period. This phase will also help determine which system is most efficient, the money saved per unit energy, and the energy output per unit dollar of each system. The second portion of my research will be spent conducting a systems optimization on the three renewable energy systems. The different variables to be factored into the optimization equation will be based on the reports gathered in my literature review. Other co-benefits not considered will be analyzed in this phase, including practicality. This phase will allow me to improve each system, but it will also help establish the adaptability of these systems to a certain environment. I will then reevaluate the outputs of each system to determine their net effect. My results will be consolidated into data tables, graphs, charts, and diagrams that help present my findings.

The first step of the cost-benefit analysis will be to conduct a life cycle assessment where all the costs of a 15-year period are determined (Appendix A). The next step will be to determine the energy input and output of each system. I will also assess any other energy displacements based on the use of each system. For a biogenerater, a gas meter will be utilized as well as the weighing of manure inputs. I will also estimate the energy gained from using the fertilizer for crop production. The solar cells energy calculations can be done through an electronic monitor, or calculations based on solar cell type and size (Eaton 2010). The energy output of the plastic bottle system can be determined through the thermodynamic equation $E = mc\Delta t$. The data will be collected repeatedly until a desired precision is obtained. From this data the monetary amount of conventional gas displaced can be determined. The health and environmental benefits associated with each system, cost per unit dollar of energy, efficiency, and the payback period through current market and valuation techniques (Appendix A) can also be calculated. The monetary values for these benefits will be drawn from literature review as well as in-field observations.

The next phase of my project will involve a systems optimization of each system. I will also take this time to reconsider any other calculations not already accounted for and additional co-benefits associated with each system, specifically the practicality of each system and the feasibility of implementation. The biogenerater's efficiency is determined by several factors, which influence the digestion of organic matter. Temperature, pH, and materials balance are all important factors to consider (An, *et al*., 1997). Although the solar panels provide minimum room for variable adjustment, the angle and location of the panels can be studied to increase energy absorption. The last system provides the most opportunity for a systems optimization because of the paucity of existing research on solar energy derived from plastic bottles and pipes. I will adjust the amount and type of bottles used, angle of system, places where energy is lost, and amount of water used to optimize the efficiency and productivity of the system (Zilli 2010). A co-benefit to be considered with this system is the amount of energy saved by not having to dispose of the plastic bottles. I will recommend the implementation of any adjustment that improves the effectiveness of these systems.

While the engineers and owners on site all speak English, my fluency in Spanish will still be a vital tool. I have taken 9 years of Spanish, lived in Bolivia for 6 weeks, and will take an online accelerated course to acquaint myself with the local dialect. I have worked extensively on design projects, through Engineering Design and Communication and Design for America, where I gained valuable experience understanding the process of implementing a system. I have taken several classes where renewable energy sources were under investigation; from these classes I have learned about the important variables of renewable energy systems, how each system works, and other components of each design. My statistics class, Uncertainty Analysis in Civil Engineering has also provided me with the skills to retrieve and interpret data. My work in Professor Galliard's research lab reiterated the importance of sufficient data collection processes.

I hope to apply this research in many different ways upon my return. I plan on distributing my findings to NGOs and other international development organizations to promote the use of sustainable infrastructure. This research could also be utilized by student organizations such as Engineers for a Sustainable World to determine which renewable system would be most effective and cost efficient in other undeveloped areas of the world. Finally, I hope to present my findings at the undergraduate research symposia, and publish my work in the *Northwestern Research Journal*.

Appendix A: Equations Used

Equations 1-11 were obtained from (Eaton 2009). Discount rates will be based on researched valuation techniques and market trends. Additional equations may be used, if necessary.

Life-Cycle Assessment (LCA)

Equation 1

$LCC = C + M + E + R - S$

where:

C = capital cost (initial capital expenditures, system design, & installation)
M = sum of annual maintenance costs
E = sum of annual energy costs (e.g. fuel)
R = sum of all anticipated equipment repair and replacement costs
S = salvage value of system equipment at the end of the life cycle period

Equation 2: Calculate present worth of future inputs in LCA

$P = F/(1+I)^N$

where:

P = the single present worth of a future sum of money
F = the estimated future sum of money
N = year difference
I = discount (or interest) rate

Equation 3: Calculate present worth of annual costs

$P = A*[1-(1+I)^{-N}]/I$

where:

P = the uniform present worth of an annual sum of money
A = the annual sum of money (maintenance costs)
N = year difference
I = discount (or interest) rate

Payback/ Benefits (Energy, Health, Environment)

Equation 4: Payback for Energy Benefits

Payback = Total Cost/ Annual Cost of Benefits

Equation 5: Present worth of annual sums that have discount rate different than standard rate of other items

$P = A\{(1+E)/(I-E) *[1 -[(1+E)/(1+I)]^N]\}$

where:

P = the uniform present worth of an annual sum of money
A = the annual sum of money (energy benefits)
N = year difference
I = discount (or interest) rate
E = discount rate (relative to I) of energy benefit

Equation 6: Present value payback rate
$P= C / A\{(1+E)/(I-E) *[1 - [(1+E)/(1+I)]^{N}]\}$
where:
C = the total cost
A = the annual sum of money (energy benefits)
N = year at a given discount rate
I = discount (or interest) rate
E = discount rate (relative to I) of energy benefits

Equation 7: Payback for Reduced Health Risks
Payback = Cost / value of health benefits

Equation 8: Present value payback from annual health benefits
$P = C/A*[1-(1+I)^{-N}]/I$
where:
C = Total cost of system
A = the annual value of avoided health risks
N = year difference
I = discount (or interest) rate

Equation 9: Simply payback from emissions reduction benefits
Payback = Cost / value of emission reduction benefits

Equation 10:Present value payback rate of Emissions Reductions
$P= C / A\{(1+E)/(I-E) *[1 - [(1+E)/(1+I)]^{N}]\}$
where:
C = the total cost of the biodigester
A = the annual sum of money (emissions reduction benefits)
N = year difference
I = discount (or interest) rate
E = discount rate (relative to I) of emissions reduction benefits

Equation 11: Present value payback of combined benefits
$P = C / (EB + ER + HB)$
where:
C = Total Cost
EB = Present value of total energy benefits
ER = Present value of emissions reduction benefits
HB = Present Value of all Health Benefits

Additional Equations for Biogenerater
Equation 12: Methane % of biofuel
Methane % = 100% - carbon dioxide% (-3% other gases)

Additional Equations for Solar Panels
If electronic devices not available, refer to (Energy Matters, 2011).

Additional Equations for Plastic Bottle Solar Energy System

Equation 13: Energy Change of System

$E = mc\Delta t$

m=mass (kg)
c= specific heat of water (kj/kg*K)
t= temperature difference in K

Additional Equations

Equation 14: Efficiency

Efficiency (%) = Energy output/input

Equation 15: energy/ unit dollar

Energy/money = annual energy output of system/annual cost of system

Equation 16: Money saved per unit energy

Money/energy = Cost of conventional source displaced/joule * 1/Energy output of system