Engineering Principles 1 – Project 3

Design Solution

Design Challenge

Student Name: Aisha Siddiqui

UUN: [redacted]

Group No. 65

Date : 27/11/2023

Contents

Executive Statement

This document addresses the challenges faced by households without reliable access to electricity. They currently bear the daily burden of collecting firewood and seek a sustainable energy source. Our one-time solution introduces "Make your own Solar-powered Anaerobic Digester at home" kits, each capable of serving two households. These kits are crafted from recycled materials and utilize organic waste to produce a stable supply of natural gas for cooking. By reducing their dependence on electricity, this innovative approach not only simplifies their cooking process but also contributes to a carbon emission reduction of approximately 99%. It also provides 28 employment opportunities and achieves breakeven in 10 years.

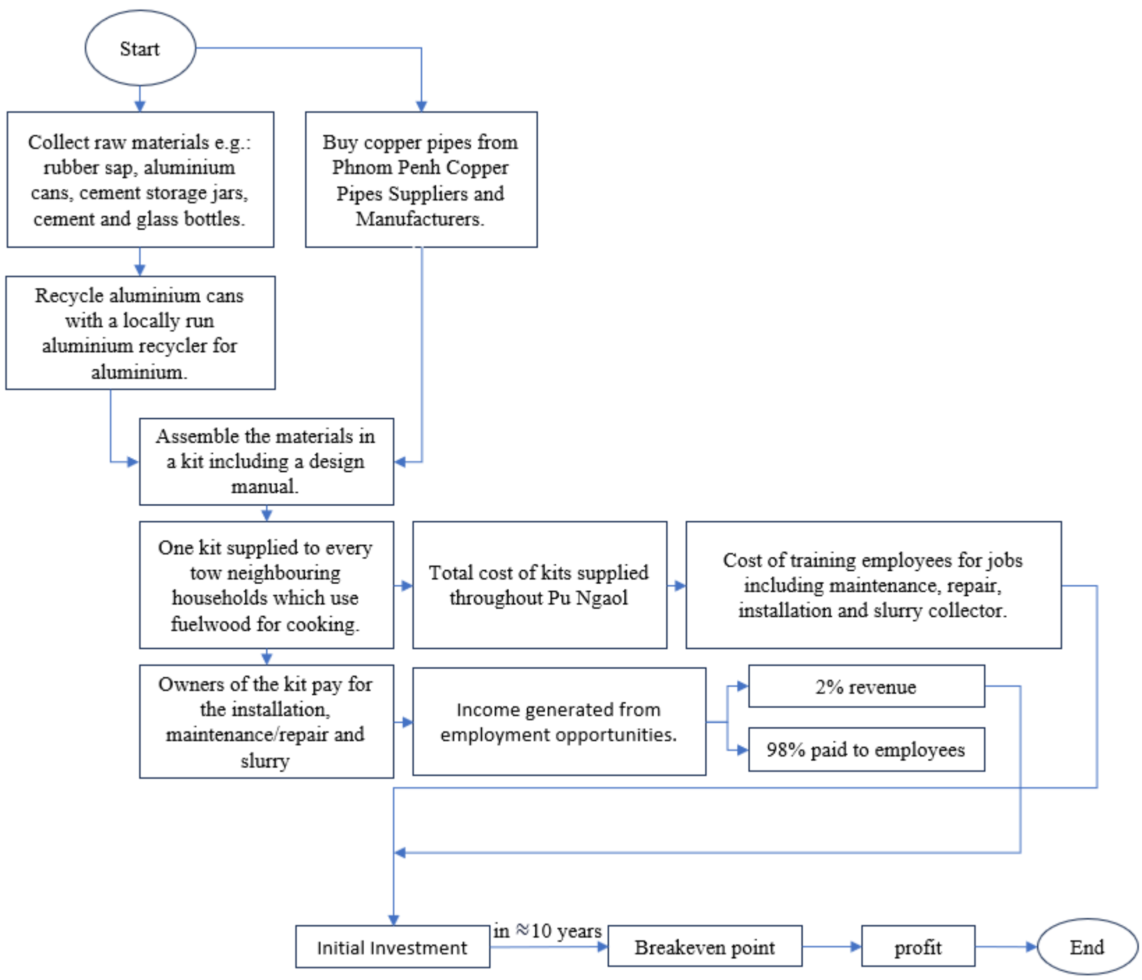
Problem Statement

Currently households without reliable access to electricity are trying to cook using cleaner fuels so that they can reduce carbon emissions as well as simplifying their cooking process because these households currently face the challenge of collecting firewood daily for their cooking needs, which is both time-consuming and environmentally taxing. But they are without a sustainable source of energy which leaves them feeling frustrated, so they end up searching for practical solutions.

Narrative Description

In response to the pressing issue faced by households without reliable access to electricity and the environmental challenges posed by daily firewood collection and burning, I present the "Build your own Solar-Powered Anaerobic Digester kit" as an innovative solution. This kit offers a sustainable approach to address these challenges, aligning with the specified design criteria and contributing significantly to several United Nations Sustainable Development Goals (SDGs).

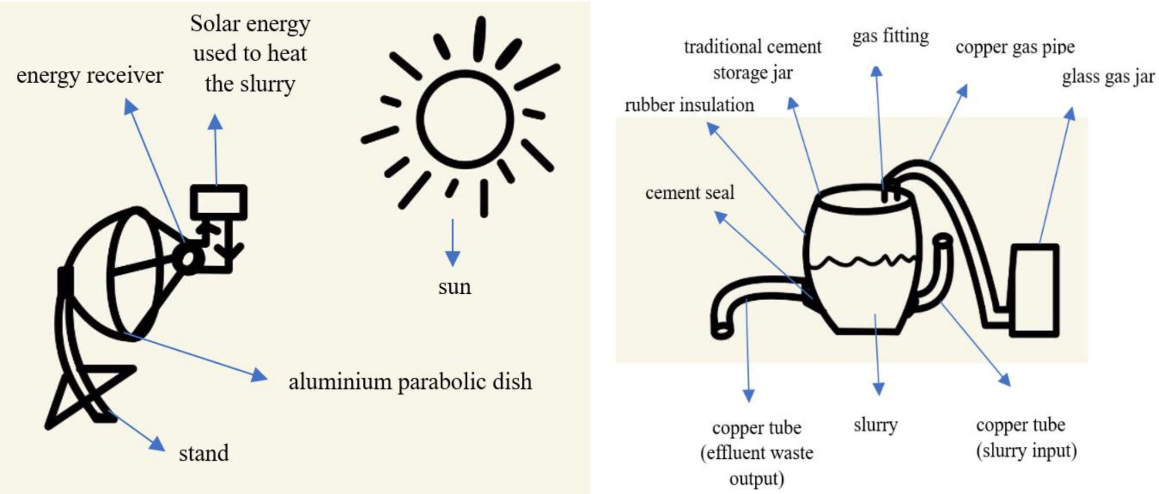
Flowchart of the Design Solution



Design Components and Functionality

The core components of this kit include traditional cement storage jars, gas fittings, flexible copper pipes sourced from local suppliers like Phnom Penh Copper Pipes Suppliers and Manufacturers (go4WorldBusiness), a rubber uni-seal derived from sustainable rubber sap (Engineers Without Borders UK, 2023), gas pipes, sealing cement, a glass gas jar, and a DIY crafted parabolic dish constructed from aluminium sheets obtained by recycling from aluminium cans (The Phnom Penh Post, 2022). These components work in harmony to facilitate the production of biogas through the anaerobic fermentation of a slurry consisting of agricultural residue, animal manure, and food waste. The parabolic dish plays a pivotal role by precisely maintaining the slurry's temperature at a constant 35 degrees Celsius for a period of 25-30 days, ensuring optimal biogas yield (Chae, Jang, Yim, & Kim, 2008).

Solar-Powered Anaerobic Digester Kit



“Trees are ‘tapped’ by making a small hole in the trunk and lighting a fire. The resin drips out of the tree like sap and is collected. The process does not kill the tree” (Engineers Without Borders UK, 2023)

Alignment with Design Criteria

- The kit offers a cleaner and healthier alternative to burning fuelwood for cooking and hence uplifts the quality of life for the residents of Pu Ngaol.
- The kit harnesses the power of renewable energy resources like biogas and solar energy, providing a sustainable and reliable energy solution
- Engineered as a one-time purchase, the kit ensures affordability, particularly when neighbouring households opt to share a single kit, further enhancing accessibility.
- The responsible integration of locally sourced materials, such as sustainably tapped rubber, traditional cement storage jars, glass jars crafted from recycled glass bottles, and aluminium sheets obtained through the recycling of aluminium cans, reflects our commitment to the responsible utilization of indigenous resources.
- The kit not only encourages sustainable practices but also contributes to environmental preservation. Measures, including synthetic rubber insulation and robust sealing mechanisms, mitigate the risk of undesirable gas odours, promoting an eco-friendly process.
- The solution provides several employment prospects within the local community, ranging from kit manufacturing and sales to assembly, installation, maintenance, repair services, and organic waste collection/slurry distributer.
- By yielding carbon-neutral biogas and responsibly utilizing waste materials, the kit combats environmental pollution and minimizes carbon emissions, contributing to land preservation.

Alignment with UN Sustainable Development Goals (SDGs)

SDG 7 (Affordable and Clean Energy): The kit empowers residents by offering access to cleaner cooking fuels and affordable energy solutions.

SDG 9 (Industry, Innovation, and Infrastructure): Our solution stimulates local business opportunities, nurtures skill development, and advances the cause of inclusive and sustainable industrialization.

SDG 12 (Responsible Consumption and Production): The utilization of carbon-neutral biogas and sustainable waste-to-energy conversion practices highlights our commitment to responsible consumption and production.

SDG 13 (Climate Action): By significantly reducing carbon emissions in comparison to conventional fuelwood burning, our kit plays a pivotal role in mitigating global warming and addressing the challenges posed by climate change.

Guesstimation Calculations

Technical

- **What is the amount of biogas produced by one kit in a day?**

$\boxed{1\,kg/m^3 \;=\; 1000\,l}$

A_G – amount of biogas produced by one kit in a day

V_S – volume of slurry

V_W – volume of water

V_D – volume of dry organic waste

n – percentage of organic waste converted into biogas

$$n_{min} \;=\; 40\%$$

$$n_{max} \;=\; 80\%$$

$$n_{avg} \;= \sqrt{(40 \times 80)} = \sqrt{(32 \times 10^4)} \approx 6 \times 10^2$$

$$A_G \;=\; V_S \;\times\; n \;= (V_W + V_D) \times n \;= (6+2) \times 0.06 \;=\; 4.8 \;\times 10^{-1}\,kg/m^3 \;\times\; 1000l \;=\; \mathbf{480}\; \boldsymbol{l}$$

- **What is the amount of solar energy required to produce a usable amount of biogas in the digester per day?**

$\boxed{1\,kWh \;=\; 3.6 \times 10^6}$

Q_S – amount of solar energy needed in a day

Q_T – energy needed to raise the temperature of slurry from 20-35°C over 25-30 days

m_S – mass of slurry

ρ – density of slurry

c_s – specific heat capacity of slurry

$\Delta\theta$ – change in temperature

n_d – number of days for anaerobic digestion to take place

$n_{d\,min} \;=\; 25$ days , $n_{d\,max} \;=\; 30$ days $\therefore n_{d\,avg} = \sqrt{(25 \times 30)} = \sqrt{750} \approx 27\; days$

$c_W \;=\; 4200\,J/kg°C$ where c_W is the specific heat capacity of water

$c_S \;<\; c_W$ since c_{DW}(specific heat capacity of dry waste) < c_W and slurry consists of water and dry waste

$c_{S\,\mathrm{min}} \;=\; 2000\,J/kg°C$, $c_{S\,\mathrm{max}} \;=\; 3000\,J/kg°C$ $\therefore$ $c_{S\,\mathrm{avg}} = \sqrt{(2 \times 10^3 \times 3 \times 10^3)} = \sqrt{(6 \times 10^6)} \approx 2.5 \;\times\; 10^3\,J/kg°C$

$$Q_S \;=\; Q_T \;\times\; \frac{1}{n_d}$$

$$= (\rho \times V_S) \times c_S \times \Delta\theta \times \frac{1}{n_d}$$

$$= (1250 \times 0.48) \times 2.5 \times 10^3 \times (35 - 20) \times \frac{1}{30}$$

$$= 1250 \times 48 \times 10^{-2} \times \frac{5}{2} \times 10^3 \times 15 \times \frac{1}{30}$$

$$\approx 1250 \times 600$$

$$\approx 7.5 \times 10^5 J$$

$$\therefore \; Q_S = \frac{7.5 \times 10^5}{3.6 \times 10^6} = \frac{5}{24} \approx \frac{5}{25} = \mathbf{0.20\, kWh}$$

Business

- **What is the estimated cost of one kit?**

C_k – cost of one kit

C_J – cost of a cement jar

C_{GF} – cost of a gas fitting

C_{CW} – cost of flexible copper pipes

C_C – cost of cement for sealing purposes

C_{GP} – cost of a gas pipe

C_{GJ} – cost of a gas jar

C_{PD} – cost of aluminium foil used to make the parabolic dish

$$C_K = C_J + C_{GF} + C_{CW} + C_C + C_{GP} + C_{GJ} + C_{PD}$$

$$C_K = £30 + £2 + £10 + £5 + £5 + £15$$

$$C_K \approx 150{,}000 \text{ riels} + 10{,}000 \text{ riels} + 50{,}000 \text{ riels} + 25{,}000 \text{ riels} + 25{,}000 \text{ riels} + 75{,}000 \text{ riels}$$

$$C_K = \mathbf{3.35 \times 10^5}\ \boldsymbol{riels}$$

- **How long does it take to recover the initial investment (e.g. breakeven point) if selling the kits?**

> Assuming that 50% of the population already have access to electricity so the remaining 50% who use fuelwood will now use the kits where two neighbouring households will share the same kit (proved on page 7 by guesstimation)

T – time taken to cover the initial investment

C_I – total initial investment

C_E – money earned from employment opportunities per year

C_M – cost of maintenance/repair services per year

C_S – cost of slurry sold by the slurry distributer per year

C_T – cost of training

q - % of money earned from employment opportunities used to pay the employees (assume that it is 98%)

> 1 kit will require 8 kg/m^3 of slurry every day to produce the required amount of biogas where cost of 1 kg/m^3 slurry is £0.1 $\approx$ 510 *riels*. The kit requires maintenance 4 times a year and each maintenance service costs £2 $\approx$ 10,000 riels.

P – population of Pu Ngaol

N_P – average number of people in a household

N_H – average number of households

N_F – number of households using fuelwood

N_K – number of initial kits distributed

$$N_K = 0.5 \times 0.5 \times N_H \; where \; N_H = \frac{P}{N_P} \therefore N_K = 0.25 \times \frac{571}{3} \approx 0.25 \times \frac{570}{3} \approx 48 \; kits$$

$$C_I = C_T + (C_K \times N_K) = 5 \times 10^6 riels + (3.35 \times 10^5 \; riels \times 48$$

$$\approx (5 \times 10^6 riels) + (15 \times 10^6 riels) = 2 \times 10^7 \; riels$$

$$C_E = C_S + C_M = (8 \times 510 \times 48 \times 365) + (10{,}000 \times 4 \times 48)$$

$$\approx (10 \times 500 \times 50 \times 360) + (1{,}920{,}000) = (90 \times 10^6) + (1.92 \times 10^6)$$

$$\approx 9.2 \times 10^7 riels/yr$$

$$T = \frac{C_I}{q \times C_E} = \frac{2 \times 10^7}{(1 - 0.98) \times 9.2 \times 10^7 riels/yr} = \frac{2}{0.02 \times 9.2} \approx \frac{100}{9.2} \approx \boldsymbol{10\; yrs}$$

Environmental

- **How much carbon dioxide (CO2) is typically emitted by a house using firewood for cooking every day?**

A_C – amount of CO_2 emitted by burning fuelwood for cooking every day

m_F – mass of fuelwood consumed by a house for cooking every day

A_W – amount of CO_2 emitted per unit mass of fuelwood

Assuming that 1 kg of wood contains 50% carbon all of which is emitted as CO_2 when the wood is burned and we know from the equation : $C + O_2 = CO_2$ that carbon is $\frac{12}{12+2(16)} \times 100 = \frac{12}{44} \times 100 = \frac{3}{11} \times 100 \approx 30\%$ of CO_2 ∴ the amount of CO_2 emitted by 1 kg of fuelwood is $\frac{0.5}{0.30} = \frac{5}{3} \approx 2\,kg$

$1\,mole = 22.4\,l$ ∴ $No. of\ moles\ in\ 30\,kg\ of\ CO_2 \times 22.4 = \frac{30}{44\times10^{-3}} \times 22.4 \approx 15 \times 10^3 l$

$$m_{F\,min} = 12\,kg\,,\ m_{F\,max} = 20\,kg \therefore m_{F\,avg} = \sqrt{(12 \times 20)} = \sqrt{2.4 \times 10^2} \approx 1.5 \times 10 = 15\,kg$$

$$A_C = m_{F\,avg} \times A_W = 15 \times 2 = 30\,kg \approx \mathbf{15 \times 10^3} \boldsymbol{l}$$

- **What is the potential annual reduction in carbon emissions achieved by households that switch from using firewood to kits?**

R – % of annual reduction in carbon emissions

A_{CK} – amount of CO_2 emitted by the kit every day

A_G – amount of biogas produced by a kit in a day

r – % of CO_2 in biogas

$$r_{min} = 20\,\%\,,\ r_{max} = 40\,\% \therefore r_{avg} = \sqrt{(2 \times 10) \times (4 \times 10)} = \sqrt{8 \times 10^2} \approx 30\,\%$$

$$A_{CK} = A_G \times r_{avg} = 480 \times 0.30 = 144\,l$$

$$R = \frac{(15 - 0.144) \times 10^3 \times 365}{15 \times 10^3 \times 365} \times 100 \approx \frac{14.85}{15} \times 100 = \mathbf{99}\,\%$$

Social Impact

- **How many households can be served by one kit on average?**

Assuming that each person consumes 100 l of biogas for food every day.

N_{HK} – number of households that can be served by one kit on average

A_G – amount of biogas produced by one kit in a day

B_P – amount of biogas needed by per person

N_P – average number of people in a household

$$N_{HK} = \frac{A_G}{B_P \times N_P} = \frac{480}{100 \times 3} \approx \frac{500}{300} \approx \boldsymbol{2\ households}$$

- **How many jobs can be provided from this design solution?**

N_J – number of jobs

P_S – number of slurry distributers

P_R – number of people employed for maintenance/repair of kits

Assuming that one employee on average can repair 2 kits and given that there are 48 kits then $P_R = \frac{48}{2} = 24\ employees$.

Assuming that we need at least 4 slurry distributers located throughout the village so that people would not have to travel far to collect slurry every day ∴

$$N_J = P_R + P_S = 24 + 4 = \boldsymbol{28\ jobs}$$

References

Chae, K., Jang, A., Yim, S., & Kim, I. (2008). The effects of digestion temperature and temperature shock on the biogas yields from the mesophilic anaerobic digestion of swine manure. *Bioresource, 99*(1), 1-6.

Engineers Without Borders UK. (2023). *Engineering for People Design Brief Cambodia.* Retrieved from Engineers Without Borders UK: https://www.ewb-uk.org/wp-content/uploads/2023/09/2023-24-Engineering-for-People-Design_Brief_Cambodia.pdf

go4WorldBusiness. (n.d.). Phnom Penh Copper Pipes Suppliers and Manufacturers. Retrieved from go4WorldBusiness.

The Phnom Penh Post. (2022, September 18). *Local recycler processing up to 100 tonnes a day*. Retrieved from Phnom Penh Post: https://www.phnompenhpost.com/national-post-depth/local-recycler-processing-100-tonnes-day

Engineering Principles 1

SCEE08012

THE UNIVERSITY *of* EDINBURGH
School of Engineering

Project 3 – Engineering for People Design Challenge

Multiple-Criteria Decision Analysis

Your name ___________Aisha Siddiqui_____________________________________

Your group number __________________65_____________________________

Multiple-criteria decision analysis (MCDA) is a structured decision-making method used to evaluate and compare multiple alternatives based on a set of criteria. It is commonly used to make complex decisions where multiple objectives and trade-offs need to be considered, when there are conflicting objectives, multiple stakeholders with diverse interests, and limited resources. It provides a systematic and transparent approach to evaluating and comparing options, making it easier to make informed decisions that consider a wide range of factors and perspectives.

This tool will help you rank and select the best Design Solution for your Design Challenge group. This does not mean that there are technically better or worse Design Solutions by the different members of your group. It simply means that the selected design option is the one that fits with a larger share of Design Criteria for your group. The output would likely be different for a different set and different weights of the Design Criteria.

1. Write the initials of each of your group members or the nickname of the Individual Design Solution.

2. List the Design Criteria for your group and assign weights reflecting their relative importance. The tally of the weights should be 100%.

3. Score each Individual Design Solution on each criterion – we recommend using a scale of 1 to 5.

4. Calculate a total score for each alternative by aggregating the scores on the various Design Criteria, taking into account their weights.

5. Rank the alternatives based on the composite scores.

Design Criteria	**Weight**	**Initials of group members or Design Solution**					
		ALZ	**HX**	**LC**	**MZ**	**ZWC**	**ZY**
Improve the quality of life of Pu Ngaol's people	20	3	3	3	3	3	3
Produce and/make use of renewable energy	20	5	5	5	5	5	5
Must be affordable	15	2	3	3	3	2	2

Must make use of local resources	10	3	2	3	3	3	3
Should be sustainable and eco-friendly	10	4	3	4	3	4	3
Could provide employment opportunities	5	3	2	3	4	3	4
Won't generate environmental pollution and cause land degradation	20	3	3	4	4	4	4
TOTAL	100%	23/35	21/25	25/35	25/35	24/35	24/35