Guateca: A Carbon Footprint Viability Analysis

A Senior Project

By

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1 Abstract

This report seeks to analyze the carbon footprint of the Guateca summer school program in 2011 run by Dr. Pete Schwartz. Through use of the listed carbon footprints of various substances in a Materials Engineering database, the CO_2 emissions associated with various technologies and practices to be implemented by Guateca in the village of San Pablo, Guatemala are calculated and compared to estimated emissions of alternative standard practices that are currently in use or might be in the near future. The results are varied, and while many are heavily reliant on how well they can be implemented, most of them show promising amounts of emissions reductions. Guateca may succeed at least in some of its goals regarding emissions reductions and will serve as a good learning experience for all those involved, as well as a stepping stone to further similar activities.

2 Introduction

Guateca is an alternative technology collaborative field school that will be initiated in the summer of 2011, whereby several Cal Poly students will enroll in three classes with participation from students and community members from the village of San Pablo, Guatemala, in San Pablo. San Pablo is a small, but growing village whose community is looking to improve their standard of living by increasing their use of technology, preferably in innovative ways that do not require them to use electricity off the Guatemalan grid. Currently they are in the last year or so of an eight year plan that is providing them with free electricity from the grid, which was recently extended to their location, but they are seeking to cut back on their electricity use once they start being charged for it, all the while supplementing their way of life with new, sustainable technology that they can implement on their own. Guateca seeks to aid the citizens of San Pablo

by providing them with simple, but effective and sustainable technologies, designed via cooperation between Cal Poly students and San Pablo community members, and instructing them in their operation and construction. One goal of Guateca is to help the community of San Pablo adapt these student-designed technologies permanently in a way that allows them to run a sustainable business through their production and dissemination within the community and possibly beyond.

In December of 2010 connections were made with the community and information was gathered on just what the villagers were looking for in terms of collaborative projects, when twelve Cal Poly students visited San Pablo for ten days. Since that trip, various student groups have been exploring projects to further explore over the two month trip this summer. The primary projects are: an alternative energy project focused on "microhydro" as a source of renewable energy; a housing improvement project focusing mainly on how to insulate San Pablo's dwellings cheaply, effectively, and in a sustainable manner; a project that is concerned with helping establish a small business opportunity in San Pablo by making and packaging small, healthy energy bars; a project in which a pottery wheel and kiln were designed out of everyday materials such as a trash can and an old car tire; a project that involves the design and creation of a small stove that can be fueled by burning less carbon intensive and more renewable fuels such as rice hulls; a project in which a simple "refrigerator" was designed to function without electricity and to keep its contents relatively cool; a water sanitation project focused on finding an alternative way to get clean water in San Pablo without needing to boil it; a solar water heating project in which an outdoor solar water heater was designed out of common materials such as old plastic water jugs; and a solar concentrator design project whose focus is to design and construct a simple and easily reproducible solar concentrator based on the Scheffler [1]

design concept. All of these projects were undertaken with a similar goal in mind: codeveloping safe, sustainable practices for the citizens of San Pablo to employ now and in the future.

With all of this in mind, it is critical to make sure that the work being done by Guateca in San Pablo is productive to the extent that it: 1) is able to be effectively implemented into the lives of San Pablo community members, 2) it is sustainable in the somewhat isolated environment of San Pablo, and 3) that it succeeds in not only improving the quality of living in San Pablo but also reducing their carbon emissions, especially by replacing technologies that they may have had to power with costly electricity – "costly" both in terms of its carbon footprint and the money required to pay for it. The primary focus of this analysis will be to determine whether or not the project can meet this last requirement regarding the overall carbon footprint of the Guateca Summer School and the technologies it implements. Before that, let us briefly delve into just what carbon footprints are and their significance.

An object or substance's carbon footprint is a measurement of, essentially, how much energy goes into the creation of that object or substance, expressed in terms of how much carbon is released in the process of supplying that energy. This can, of course, cover a wide variety of processes both in terms of the creation of the energy and the product itself. As a simple example, think of a plastic bottle:

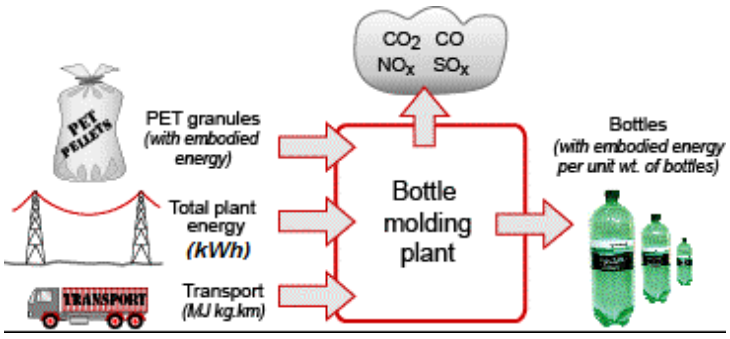

Fig. 1 [2]

Figure 1 illustrates just what factors might affect the carbon footprint of the bottles, ranging from the total energy supplied in their creation to the embodied energy in the PET (polyethylene terephthalate) used to create them and even the fuel used to transport the materials and bottles to their respective destinations. Embodied energy, as mentioned above, is essentially another way of looking at the same concept of a carbon footprint, only it is expressed purely in the units of energy that went into creating something. We can see in the figure that the carbon footprint of the bottles comes from three main factors. First of all, the manufacturing plant that creates the bottles needs electricity to function. The amount of carbon dioxide (CO_2) released by the power plant(s) generating electricity for the factory depends on how the plant is fueled (coal, natural gas, nuclear, hydro, etc.). Once the fuel source is identified, the calculation to find the approximate carbon emissions of that plant is relatively straightforward and depends upon the efficiency of the plant and a few other factors. One of those factors is the "carbon intensity" of the fuel, or the amount of carbon released per amount of heat released. The carbon intensity of most common fuels is readily available online and in reference books. The efficiency of the plant primarily depends upon the type of heat engine it uses to turn its turbines, whether it be Rankine cycle or Brayton cycle, the typical modern single cycle power plant has an efficiency of about 30-40% (that is, you can get out 30-40% of the heat energy you put in as electrical energy) [3]. Combined-cycle power plants, wherein the exhaust heat from one cycle can be used either as heat energy or as energy to power a second heat engine, can reach efficiencies of around 60-65% [3]. In addition to the emissions generated by the power plant, gas is burned by vehicles during the transport of raw materials to the bottle plant and the finished bottles to their final destination, whether they are delivered by jets, trucks, trains, or otherwise. Again, the carbon intensities of jet fuel, diesel, etc. are used to calculate the transportation portion of the footprint. Finally, the raw

materials themselves occasionally have their own carbon footprints depending on what processes where performed to refine, gather, or create them. These three different sources all factor into the final, total carbon footprint of our everyday drinking bottles, and in general, this method of analysis can be applied to find the carbon footprint of most anything you can think of, though obviously the more complex and varied something is in terms of its components and base materials, the more trails you must follow to calculate its carbon footprint.

Having thus established a "carbon footprint", we can move forward with discussing its significance to the project as a whole. San Pablo is at an important stage in its technological development where its citizens are, for the first time, living with readily available electricity. What Guateca aims to do is to not only reduce the impact of this shift in technology has on the community's coffers, but also on their CO_2 emissions, by supplying them with alternative technologies and sources of power that have minimal carbon footprints. This, of course, is desirable not only for the people of San Pablo, but also for the world as a whole. By implementing and testing small scale, sustainable technologies through Guateca, successful designs and business models for producing them efficiently can be discovered and thus encouraged elsewhere, even in more technologically advanced countries. The application in other locations of those projects and techniques found to be successful in San Pablo can therefore hopefully make an impact on carbon emissions worldwide. This is why analyzing the projects that are to be implemented this summer is essential to the success of the Guateca program, as we must be sure that they are actually reducing the carbon footprint of the village effectively.

Additionally, one of the other motivating factors behind this analysis is to determine if it would be economically viable for Guateca to enter into a carbon credit trading market, obtaining credits for the carbon abated through the collaborative efforts of the school and trading them to

other participants in the market for money which could then be used to fund further research, development, and implementation of sustainable technologies. Right now there are two main carbon markets in the world, a “voluntary market” comprised of a diverse group of organizations that certify individuals and businesses and then allow them to purchase and sell carbon credits through them, and the Clean Development Mechanism (CDM) established after the Kyoto Protocol [4], which is comprised of the countries who agreed to the protocol set forth by the UNFCCC (United Nations Framework Convention on Climate Change). An example of one of the organizations that works with the “voluntary market” is The Gold Standard [5], based in Switzerland.

3 Methods

The analysis of Guateca’s carbon footprint will be done primarily through Excel spreadsheets. There are two important sets of carbon footprints to examine for Guateca. One is, of course, the footprint of the technologies and sustainable procedures implemented through the school, but the other is the carbon emissions associated with simply travelling to San Pablo and back. These different emissions are calculated via spreadsheet in slightly different ways. For emissions produced via airline flight and road travel to and from the village of San Pablo, we need to know the approximate value of several things to calculate the share of CO_2 emissions incurred by the travelling students. First, we need to know approximately how many passengers are on the plane that takes them to Guatemala so that we may fairly calculate the students’ share of the emissions. Second, we need to know how many vehicles will be used to travel to San Pablo from Guatemala City, and if we want to know the individual shares of the emissions of each student travelling then we also need to know how many students will be in each vehicle.

With this data in hand, we must also know the approximate miles per gallon (mpg) of the various vehicles used. A safe estimate is about 20 mpg for the automobiles [6] and about .2 mpg for a common airliner [7] (that is, a typical airliner uses 5 gallons of fuel to fly for 1 mile, so the mileage is .2 mpg). We can calculate the total gallons of fuel used simply by dividing the total distance travelled by automobile and by airliner by their respective mileage. As an example, take the calculation for gallons of jet fuel used during the round trip from LAX to San Pablo and back:

$$Gallons\ of\ fuel = \frac{Distance\ (mi)}{mpg} \tag{1}$$

$$\frac{4400\ mi}{.2\ mpg} \approx 22000\ gal\ of\ fuel \tag{2}$$

From the total gallons of fuel used we can now calculate the actual approximate carbon emissions of burning that fuel by taking the carbon intensity (in this case kg CO_2/gal of fuel) of jet fuel (9.57 kg CO_2/gal [8]) and multiplying it by our total gallons used, which gives us:

$$9.57\ \frac{kg\ CO_2}{gal} * 22000\ gal \approx 2.1 \times 10^5\ kg\ CO_2 \tag{3}$$

Now to find any individual on the plane's share of this CO_2 we just divide it by the number of passengers onboard. This process then repeated in a similar fashion for travel by automobile, but the actual emissions are significantly less due to the much smaller distance travelled.

The carbon footprint of the various technologies and sustainable practices implemented by Guateca must be calculated in a slightly different manner. Using the techniques for calculating the carbon footprint of various material components described in the previous section, a small database can be compiled for many types of common materials and used to calculate the approximate footprint of any device constructed from those materials. For this project, the approximate carbon footprints of a handful of common materials were gathered from a Materials Engineering database [2] and input into a spreadsheet. These footprints are given in

lbs. of CO_2 per lbs. of material (or for the sake of this analysis, kg CO_2 per kg material), so it is a simple calculation to find the total carbon footprint of some technology that is comprised of any number of them:

$$kg\ CO_2 = \sum_{i=0}^{Number\ of\ Materials} \left(Footprint\ of\ material\ \frac{kg\ CO_2}{kg\ material}\right) * (kg\ of\ material) \quad (4)$$

This equation does not necessarily apply to everything implemented through Guateca, as some practices will not involve using materials and some technologies will involve some degree of electricity use or burning of fuels. To account for this, an additional value can be added into the calculation that accounts for the amount of CO_2 produced yearly by supplying electricity or burning fuels. This process of analysis is called life cycle analysis (LCA). LCA is referred to as a "cradle to grave" analysis, in that it follows the development and implementation of a certain object or device all the way from the gathering of the raw source materials from which it is constructed, through all the various processes associated with its construction and use by humans, and finally ends with the object's final effects on the environment when it is either recycled somehow or left to deteriorate [9].

Calculating the total carbon emissions of everything related to Guateca is only half of the analysis we need to conduct. The other half involves taking those emissions and comparing them to what the emissions would be if Guateca was not established. This part of the analysis is critical, since it is the entire basis on which any conclusions regarding the success or shortcomings of Guateca's CO_2 impact lies. This portion of the analysis is two-fold. The estimated carbon emissions of the students must be calculated in the hypothetical situation that they were to stay at home instead of travelling to San Pablo. We have two alternatives regarding the acquisition of this data: we can either have the individual students travelling to San Pablo estimate their own carbon footprint using one of the many online tools available, or for the sake

of a rough approximation, we can use data based on the activities of an “average” American. It is recommended that the former choice is implemented for accuracy in all possible future cases, though for the sake of this project we will simply estimate. This total footprint can then be compared to the carbon footprint we already calculated for travelling to San Pablo and back and while living in Guatemala.

The carbon footprint of whatever activities the San Pablo community is currently engaging in that would be replaced, eliminated, or modified by introduced technologies must be examined in a similar fashion. This total footprint can then be compared to the total footprint of the various practices and technologies implemented by Guateca, but additionally the individual footprints can be compared on a case by case basis to determine which activities or technologies abate the most CO_2 emissions.

The actual Excel spreadsheets used to do the analysis described above are relatively simple to create and manage. The spreadsheet that handles the footprints of the various technologies consists of one sheet for the calculations and another that functions as a database of materials along with their associated carbon footprints. This database can be added to as necessary and instructions are included in the spreadsheet to facilitate such additions. The spreadsheet that calculates the CO_2 emitted during travel to and from Guateca uses one spreadsheet to calculate the estimated carbon footprint of the average student at home for two months and another to calculate their approximate footprint if they were to travel to Guateca. Emissions as a result of purchasing goods such as clothing, packaged or processed food, or common household devices that require electricity are omitted since in San Pablo there will be little to no opportunity to engage in such activities. Figure 2 on the next page shows sample

spreadsheet used to calculate the carbon footprint of the "microhydro" project group. All carbon footprint analysis for other groups was done in a similar fashion using this spreadsheet.

Static CO2 Emissions:					
Material	**CO2 (kg CO2/kg material)**	**kg material**	**kg CO2**		
PVC*	4.9	1	4.9		
Natural Rubber* (ex. Tires, tubing, etc.)	2.9	41	118.9		
Silicon	3.985	2	7.97		
ABS*	6.2	1.5	9.3		
	#N/A		0		
	#N/A		0		
	#N/A		0		
	#N/A		0		
	#N/A		0		
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	#N/A		0		
	#N/A		0		
	#N/A		0		
	#N/A		0		
Total	141.07	kg CO2			
Ongoing CO2 Cmissions:					
	0	kg(CO2)/year			
Abated CO2 Emissions:					
	49.5	kg(CO2)/year			
Total Carbon Footprint:					
141.07	**kg(CO2)**				
Minus		**This device will compensate for its initial footprint in…**			
49.5	**kg(CO2)/year**			**2.849899**	**years.**

Fig. 2

4 Analysis

Below are the analyses for the various projects that will be implemented through Guateca in no particular order:

Alternative Energy ("Microhydro"):

Fig. 3 [10]

The alternative energy group designed what is commonly referred to as a "power bucket", which is simply a bucket (the larger plastic ones that you find at hardware stores for use as containers or for mixing paint) with a small "Pelton wheel" underneath the top of the bucket made of a grinder disk and ten 45 degree elbows of PVC piping. Water is fed in through four holes in the side of the bucket so that it powers the wheel which turns a DC motor on top of the bucket to produce power. The components are as follows:

Ten 45 degree PVC elbows, each weighing approximately .1 kg = ~1 kg PVC

Four Rubber Hoses (1 inch diameter, several feet in length) = ~7 kg Rubber

One Rubber Hose (2 inch diameter, possibly 100 ft. or longer) = ~34 kg Rubber

One Grinder Disk = ~2 kg Silicon Carbide

One Large Bucket = ~1.5 kg ABS plastic

The DC generator or "stater" (an alternator with a permanent magnet, used in motorcycles) that will be used is not included in this carbon footprint as whatever generator is decided upon will, due to price concerns, undoubtedly be found used and thus be recycled, likely preventing or at least delaying any emissions related to its deterioration if left in a landfill or simply left out to rust. We know Guatemala uses primarily hydro electricity and oil [11]. Since San Pablo is on the grid, whatever electrical power the "power bucket" design can produce is abated CO_2 emissions that would have been produced by burning oil at a plant because oil plants are the marginal electricity. Using the fact that oil contains about 20 kg C/MMBtu [12], we can calculate the approximate carbon intensity in kg CO_2 per kWh.

$$20\,\frac{kg\ C}{MBTU} * \left(\frac{1\ MMBtu}{1\times10^6\ MMBtu}\right) * \left(\frac{44\ kg\ CO_2}{12\ kg\ C}\right) * \left(\frac{1\ Btu}{1\ kJ}\right) * \left(\frac{3600\ kJ}{1\ kWh}\right) * \frac{1}{.3}\ (efficiency) = 0.88\ kg\ CO_2\ \ per\ kWh \quad (5)$$

In their experiments, the group designing the "power bucket" measured 3.77 W produced from simply using a kitchen faucet to turn their Pelton wheel. This is likely lower than what would be produced from a stream, especially considering the DC motor used was not functioning entirely properly. However, let's just assume that the bucket puts out about 4 W, and that the citizens of San Pablo can keep it running about a quarter of every day. This gives…

$$4\ W * 2190\ h = 8.76\ kWh \quad (6)$$

The bucket therefore produces 8.76 kWh of energy per year that would otherwise be produced via burning oil. Assuming a loss of about 6.5% [13] in transmission, this therefore abates an amount of carbon equal to…

$$\frac{8.76kWh}{.935\%} = 9.37\ kWh * .88\,\frac{kg\ CO_2}{kWh} = \ 8.25\ kg\ CO_2 \quad (7)$$

Thus the power bucket at what is likely the lowest estimate will abate about 8.25 kg of CO_2 per year. Entering the previously stated weights into the spreadsheet gives the initial footprint of construction at about 141 kg of CO_2. Given the amount abated per year, this means it will pay itself off in about 17 years. However, let's assume that the design can be improved such that it produces ten times the wattage it could originally produce, and that it can be kept running approximately half of every day on average.

$$40\ W * 4380\ h = 175.2\ kWh \tag{8}$$

$$\frac{175.2kWh}{.935\%} = 187.4\ kWh * .88\frac{kg\ CO_2}{kWh} = \ 165\ kg\ CO_2 \tag{9}$$

Under these circumstances, the power bucket abates 165 kg CO_2 per year and thus pays itself off in just under a year.

Refrigeration:

The group that was working on a simple form of refrigeration designed an underground refrigerator made with the following materials:

One Styrofoam container = ~1 kg of Styrofoam

One Black ABS 2.5" pipe = ~2 kg ABS

One Black Rubber Pipe = ~1 kg rubber

Fig. 4 [14]

The group illustrated via experimentation [14] that this small box, when buried a foot or more underground, could maintain a slightly cooler temperature than the outside air for a period of several days, though not by much. Nonetheless, if just one person were to use this design – which could likely be further perfected with little extra material – rather than a small refrigerator, then this device would be abating CO_2. A small refrigerator uses around 300 kWh/year of electricity [15]. Again, we can calculate the amount of CO_2 emitted by a power plant in supplying this electricity as follows…

$$\frac{300\ kWh}{.935\%} = 321\ kWh * .264 \frac{kg\ CO_2}{kWh} = \ 84.3\ kg\ CO_2 \tag{10}$$

Equation 10 gives us that if even just one person decides to employ this natural refrigerator instead of purchasing one, 84.3 kg of CO_2 are abated yearly. Given that the initial carbon footprint of the refrigerator is only about 20 kg, it will take only 3 months for this device to compensate itself. For the sake of comparison, we can calculate, using our spreadsheet, the carbon footprint of a normal "mini-fridge", which would be a likely alternative to this refrigerator design. Assuming the whole thing weighs about 27 lbs. [16] (about 12 kg) and about half of that is steel, we then have 6 kg of steel, assume about 2 kg or so of copper tubing, about 1 kg of aluminum, and about 3 kg of plastic. Entering this into our emissions calculator gives a carbon footprint of about 102.6 kg CO_2, which then increases over time as it uses electricity.

Appropriate Technology Stove:

The prototype stove that was built by this group was constructed entirely out of steel sheet metal. The stove is approximately two and a half feet tall, and about eight inches square, with some extra components attached at the side and bottom [17]. So in total, the amount of steel can be estimated to be about .076 ft^3, given that the sheet metal is about 2 mm thick. This gives a total

of .00215 m^3, which amounts to a mass of about 17.2 kg, given that the density of stainless steel is around 8000 kg/m^3. This gives an initial footprint of about 206.4 kg of CO_2. The stove is designed to burn rice hulls or other waste that would normally be incinerated if it wasn't used for the stove, so any CO_2 emitted during the burning does not contribute to its carbon footprint. In fact, if the use of the stove discourages the burning of firewood then that carbon that would have been released by that wood is abated. The carbon intensity of burning wood is about 1.69 kg CO_2/kg wood [2]. Therefore if a common fire uses about 20 kg (44 lbs) of wood, it produces about 33.8 kg of CO_2.

Fig. 5 [17]

$$20\ kg(wood) * 1.69\ \frac{kg\ CO_2}{kg\ wood} = 33.8\ kg\ CO_2 \tag{11}$$

If such is the case, the stove is reducing CO_2 emissions by about 33.8 kg every time it is used instead of a traditional wood fire, as long as the fuel was waste to be burned anyway. Thus is will compensate for its initial footprint in about 6 uses, which likely amounts to about a week.

Solar Water Heater:

The group handling the solar water heater design recommended one of two designs based on their experiments. The chosen design was a batch water heater consisting of three five-gallon water jugs. The components of the water heater consisted of a variety of things [18] for which weights or amounts were not given, nor was it clear if they were even used. In this case, estimation was difficult, but by figuring

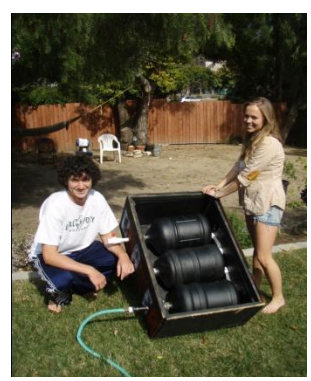

Fig. 6 [18]

the 3 water jugs amounted to about 5 kg of PET, that the piping added up to about 5 kg of PVC, that the Plexiglas cover was about 3 kg, the plywood about 10 kg, the polystyrene boards had about 5 kg of polystyrene in them, about 0.5 kg of epoxy was used, and there was about 1 kg of assorted steel clamps, one can calculate that it was likely in the neighborhood of about 114 kg of CO_2, as shown in figure 7 below.

Static CO2 Emissions:			
Material	**CO2 (kg CO2/kg material)**	**kg material**	**kg CO2**
PVC*	4.9	5	24.5
PET* (ex. Plastic bottles)	4.9	5	24.5
Plywood	0.75	10	7.5
Epoxies*	6.3	0.5	3.15
Polymethyl methacrylate* (ex. Acrylic, Plexiglas, etc.)	6.3	3	18.9
Polystyrene*	5.4	5	27
Steel* (ex. Ranges from paperclips to high quality tools)	8.2	1	8.2
Total	113.75	kg CO2	

Fig. 7

Hot running water is not widely available in San Pablo, so it's likely that this would be a luxury for those who could implement it, but assuming even one person implements this system rather than paying to heat their water with electricity, then they would be reducing the emissions of CO_2 from the electricity it took to run their water heater. Assume a typical hot shower uses water at about 38°C (311 K) with a flow rate of 2.5 gallons per minute for about 10 minutes. We know that therefore we need to heat 25 gallons of water to around 38°C. Let's assume the water starts around 10°C (283 K). Thus we can calculate the amount of energy needed to heat the water:

$$Q = m * c_v * \Delta T = \left(25\ gal * 3785 \frac{cm^3}{gal} * 1 \frac{g}{cm^3}\right) * 4.18 \frac{J}{g*K} * 18K = 7.12\ MJ \qquad (12)$$

We know there are 3.6 MJ in 1 kWh, so we can convert our result to 1.98 kWh. Thus assuming 100% efficiency and taking into account transmission loss again we find:

$$\frac{1.98\ kWh}{.935\%} = 2.11\ kWh * .264\frac{kg\ CO_2}{kWh} = \ .56\ kg\ CO_2 \tag{13}$$

Of course this amount is *per shower*, so given that someone showers at least once a day and that perhaps two or more share a shower, this adds up quite quickly within just a year.

$$.55\frac{kg}{day} * 365\frac{days}{year} * 2\frac{people}{shower} = 408\ kg\ CO_2\ per\ shower\ per\ year \tag{14}$$

Under these assumptions, the water heater will compensate for its initial footprint in just less than 4 months.

Solar Concentrator:

Fig. 8 [19]

Due to a lack of general information from the work that this group was pursuing, there is little that can be done to analyze the solar concentrator. There has only been one built to date and it was comprised of expensive and difficult to work with materials (such as aluminum). However, the group debated the possibility of making the dish for the solar concentrator out of aluminum, fiberglass, or ceramic, though ceramic was not recommended due to its weight. Within our database of materials [2], we can see that the footprint of aluminum is significantly higher per kilogram (16 kg CO_2/kg) than fiberglass (7.9 kg CO_2/kg) as well, so this is certainly a consideration for future design. Figure 8 shows fiberglass being molded around a wok. The group was not sure if they would recommend using reflective tape or Mylar to create the reflective dish for the concentrator, but we can make a quick estimate of just what the footprint

of the concentrator might be by assuming they used Mylar and fiberglass, both of which are light, cheap, and easier to work with than the alternatives. Mylar is primarily PET, and we can assume they use enough to cover the dish which is about 1.5 m in diameter, so you could probably cover it with about .5 kg of Mylar, considering how light it is, and if you were to construct the dish out of fiberglass (assuming it's around 1 in. thick) and the rest of the device out of steel, you would probably use about 40 kg of fiberglass (the density of fiberglass is about 110 lbs/ft^3 [2]) and around the same weight in steel for the support structure. Therefore, your approximate carbon footprint is about 646 kg CO_2. Assuming the dish can collect about 2 m^2 of sunlight a day, and given that there is about 5 kWh/m^2 of heat energy incident on the earth from the sun, the dish can collect about 10 kWh per day, or 36 MJ. The energy density of dry wood is about 20 MJ/kg [20], so per day the concentrator can collect the equivalent of about 2 kg of wood. Therefore this abates about $2\ kg \times 1.69\ \frac{kg\ CO_2}{kg\ wood} = 3.4\ kg\ of\ CO_2$ of per day. Thus, in a year the concentrator abates about $365 \times 3.4\ kg = 1241\ kg\ CO_2$, and so it should compensate for itself in about 6 months.

Pottery:

Fig. 9 [21]

The group handling the pottery wheel and kiln constructed their designs almost entirely out of leftover materials: an old care tire was placed on a stand made of wood for the wheel and an old metal trashcan or barrel was fitted with an air duct pipe to serve as the kiln. These designs essentially have no footprint besides the pipe that was used, which is negligible compared to the emissions produced simply by firing the kiln once or twice. Ceramic and glass both have fairly low carbon footprints (around 1.5 - 1.65 kg CO_2/kg), so common kitchenware is not incredibly carbon intensive, however one must consider that the plates were likely shipped to the market at which they were bought. Assuming they originated from Guatemala City, the plates would need to travel about 100 miles by truck to get to San Pablo. We can estimate it gets around 18 mpg, so it uses around 5.55 gal of gas, and gas has a carbon intensity of 8.91 kg CO_2/gal [8], so therefore the emissions of the truck amount to $8.91 \frac{kgCO_2}{gal} * 5.55\ gal = 49.5\ kg\ CO_2$. The plates being shipped are probably about $\frac{1}{100th}$ of the truck's cargo, meaning their share of the CO_2 is about .495 kg. On the other side of the spectrum, if the plates were imported from the US and shipped by boat, you might assume the carbon footprint would be significantly higher, however calculating this out shows that this is not so. Common cargo ship fuel (residual fuel oil or bunker fuel) has a carbon intensity of 11.79 kg CO_2/gal [8] and a good estimate for cargo ship fuel efficiency can be garnered from that of a cruise ship, which gets around 50 feet to the gallon, or about .009 mpg [22]. A ship going from California to South America would be travelling around 2500 miles and thus it would use about 277000 gallons of fuel. At 11.79 kg CO_2/gal, this is 3.3×10^6 kg of CO_2. However, a package of plates is likely to only be about a millionth or so of the total weight of the cargo in the ship, so at most its share of the emissions is about 3.3 kg.

Insulation:

The group working on new, low-impact insulation for Guatemala recommended the use of slip-straw in housing. Slip-straw was found to have an incredibly low carbon footprint (see figure 8) as it is made entirely of straw with some clay mixed in. The citizens of San Pablo often do not have any insulation in their homes, so this would not really replace any particular carbon intensive product. However keeping homes warmer on colder days might reduce the amount of wood burned to keep warm.

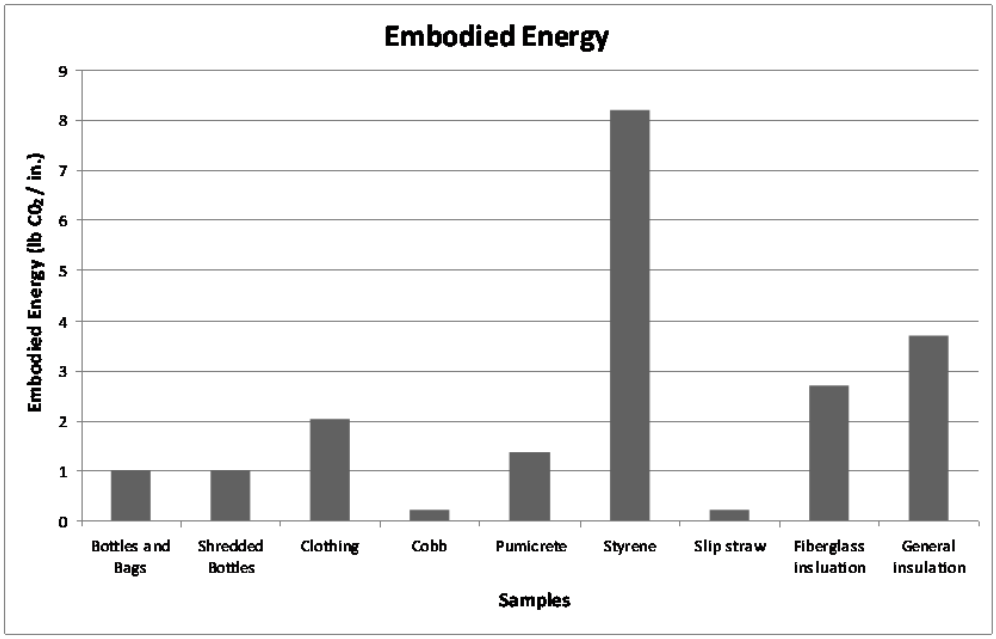

Fig. 10 [23]

Examining equation 11 again, we can get an idea for the kind of CO_2 an average fire produces burning 25 kg of wood. Needing to burn just half this amount would abate about 21 kg of CO_2 per day or so. Additionally, from our database [2] we know that fiberglass has a footprint of about 12.3 kg CO_2/kg and given the results from figure 9 a perfectly safe estimate for the footprint of slipstraw could be around 1 kg CO_2/kg, or likely less. It is likely that fiberglass insulation weighs slightly less than slipstraw, but not by much, and so we see that insulating with slipstraw produces 1/12th the CO_2 that insulating with fiberglass does. As an example, assume for

a very small, one room house (or just one room of a larger house) it takes about 20 kg of fiberglass insulation per wall, on all four walls and the roof, making 100 kg total. The footprint of this insulation is therefore about 1230 kg CO_2. If the house were insulated with 100 kg of slipstraw, the footprint would likely be around just 100 kg of CO_2 or less.

Water Sanitation:

For water sanitation, two directions were explored and both result in little to no CO_2 emissions. One consisted of filling a bucket (fig. 9) with rocks, pebbles, and fine grained sand that would be used to filter out and bacteria in a biosand filter. The other consisted of a clay filter fired with various types of dried biomass such as rice hulls, coffee grounds, and sawdust. Only firing the clay produces noticeable emissions between both designs. It takes about 5-10 minutes or so to boil about half a gallon of water on very high heat. Another rough estimation is that it takes around 3 hours to burn through about 25 kg of wood. Therefore about 1.25 kg of wood is consumed while boiling half a gallon of water, which corresponds to (using equation 11 with 1.25 kg instead of 25 kg) about 2.11 kg of CO_2. Therefore the filter could possibly abate about 2.11 kg of CO_2 per half gallon of water it filtered. Assuming even just 5 gallons were filtered daily, this amounts to something in the range of 7700 kg of CO_2 abated yearly.

Fig. 11 [24]

Additional Analysis:

The last portion of the analysis was concerned mainly with finding the difference in emissions between the students travelling to San Pablo and living sustainably there compared to what their emissions would be if they remained at home. The results are given below.

Flight:		
Airliner (Boeing 747) MPG:	0.2	mpg
Max Passengers	524	
Passenger Estimate	400	
Distance (Round Trip)	4400	mi
Gallons of fuel	22000	gallons
Carbon Intensity of Fuel	9.57	kg(CO2)/gal
Total CO2 Emission	210540	kg (CO2)
Share per student:	526.35	kg (CO2)
Number of students	20	
Share for all students:	10527	kg (CO2)
Drive:		
Estimated mpg	18	mpg
Distance (Round Trip)	300	mi
Gallons of gas	16.66667	gal
Carbon Intensity of Gas	8.91	kg(CO2)/gal
Total CO2 Emission from Driving	148.5	kg(CO2)
Total Vans	4	
Total CO2 Emissions from Driving	594	kg(CO2)
Total CO2 Emissions from Driving (per student)	29.7	kg(CO2)
Total CO2 Emissions from Travel	11121	kg(CO2)
Share per student	556.05	kg(CO2)

Fig. 12 [7, 8, 25]

Average Emissions for a Student at Home:		
Average Miles Driven Per Year	15000	mi
Average Miles Per Two Months	2500	mi
Average MPG (America)	22	mpg
Carbon Intensity of Gas	8.91	kg(CO2)/gal
Gallons of Gas Consumed in Two Months	113.6364	gal
Carbon Emissions From Driving	1012.5	kg/2 months
CO2 From Shopping/Assorted Necessities	8	Tons/year
	1.333333	Ton/2 months
	1333.333	kg/2 months
Total For 2 Months:	2345.833	kg (CO2)
Number of Students	20	
For All Students:	46916.67	kg (CO2)

Fig. 13 [6, 8, 26, 27]

4 Discussion

The analysis of the various projects that Guateca will be involved with produced no real surprising results, but they are nonetheless helpful in answering the question of whether or not the endeavor as a whole will be viable or successful. Most of the technologies and practices to be implemented will have a clear impact on the CO_2 emissions of San Pablo if carried out properly and effectively. For example, even the power bucket design, despite its low power output, can be used to power a few small LEDs or charge batteries that can be used to power an array of small devices that might otherwise draw their power from disposable batteries or power from the grid. It is also likely that this technology can be improved further to provide a more respectable amount of power. While the refrigerator does not at first glance seem so significant a design, if it

can be used by just one or two families who would have otherwise bought a small refrigerator to keep their fruits and vegetables cool, then it not only saves those people money but also abates a significant amount of CO_2 every year. Encouraging the citizens of San Pablo to use slip-straw to insulate their homes will not only improve their quality of life, but also create much less emissions than if they were to use other common forms of insulation. The solar water heater can possibly have one of the largest contributions to emissions reductions of any of the designs, though it hinges on just how many people can use the water to shower and how many hot showers they may have taken otherwise. Finally, the biosand filter can abate thousands of kilograms of CO_2 yearly if used regularly and effectively.

However, this brings up one of the largest concerns about the program and one of the most glaring results of this analysis. Almost all of these benefits are entirely reliant on whether or not these technologies are effectively implemented and actually used for extended periods of time by more than just one or two people. If Guateca cannot reach out to San Pablo's community enough to convince them to use these technologies, or if they prove to be far more of a hassle to them than they are worth, then there are concerns with how much the community will be able to benefit from the school. Take the power bucket for example. The group responsible for its design actually recommended not implementing it due to its lack of real power output and the possible lack of any convenient streams or creeks near the village. Even if the device is implemented successfully, if it is not improved drastically in some way, it would take around seventeen years just to compensate for the footprint of the materials required to build it. It's highly unlikely that the device itself would be function effectively and be operated consistently for seventeen years. Similar problems plague many of the other devices as well: the batch water heater designers admitted to not having devised a way to actually reliably get water out of the tank, not to

mention the jugs burst when put under pressure from a normal water line [18]; the refrigerator is only useful for people who want to keep their fruits and vegetables at a constant temperature only a few degrees less than the outside air [14] and is not viable for anything else that spoils quickly, so it is unlikely to discourage people from buying a real refrigerator if they truly need one; the stove design would normally be useful in most other areas, but the citizens of San Pablo are known to harvest most of their wood sustainably and so any benefit from using rice hulls and other similar flammable waste is decreased. These are just some of the issues facing Guateca that must be resolved before we can be certain of success.

If nothing else, just travelling to Guatemala and living sustainably in San Pablo abates some CO_2 that would have otherwise been produced by normal activities at home, allows those who make the journey and those they meet in San Pablo to learn valuable life lessons from each other both in regards to living sustainably and about living in harmony with other cultures. The amount of CO_2 abated, of course, becomes less significant if not many students make the trip, but it is nonetheless readily apparent if we examine the spreadsheet data in figures 12 and 13 on the previous pages. In addition, some of the technologies, so long as they can be implemented, will definitely improve the quality of life in San Pablo while producing little to no CO_2 or actually abating a small amount. By illustrating that these sustainable practices and technologies can and do improve the quality of life in San Pablo via effective implementation and collaboration, the program can hopefully encourage more widespread implementation not only in San Pablo but in other similar regions in the future.

There is also the matter of carbon credits and trading to discuss. Given that the initial payment to even have an inspector to come your site and approve or deny you for accreditation through an organization like The Gold Standard is in the neighborhood of around $20000 [28],

this is likely not a viable path that can be taken by Guateca at this time. This is especially the case because at the moment we do not know just how widespread the use of the various technologies will be, if they can be implemented at all. However, if Guateca is able to sustain itself and sustainable businesses can be established, it may be an investment to consider in the future, when technologies are being implemented consistently and their effects are reliably measurable.

5 Conclusions

From the data gathered and analyzed in the preceding pages, it is clear that Guateca can and will likely make a difference in San Pablo. Whether this difference is minor or significant depends on a number of factors, most of which are outside the scope of this analysis, such as the level of collaboration and commitment to the project's goals shared between the San Pablo community and those visiting from Cal Poly. Still, no estimates made in this report were unreasonable, and many values, such as those for the solar water heater, were simply for a single device. If these devices were indeed distributed successfully throughout San Pablo, the results clearly illustrate that the amount of abated CO_2 emissions yearly will be significant. While it is not likely that Guateca will be able to fund itself via carbon credit trading currently and in the near future, should the project grow and spread successfully throughout San Pablo it is not unrealistic to conclude that credit trading may be a viable option further down the line.

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