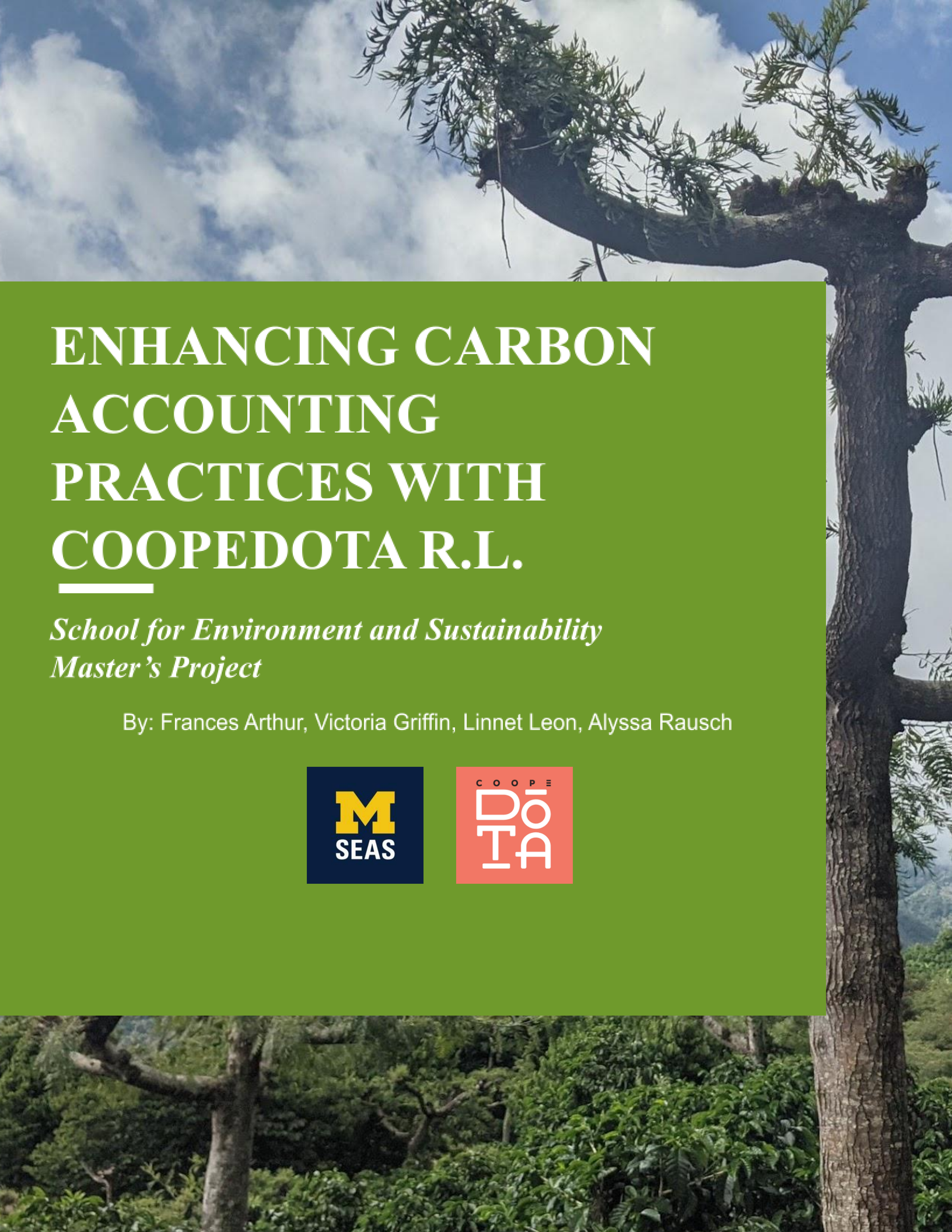


ENHANCING CARBON ACCOUNTING PRACTICES WITH COOPEDOTA R.L.

School for Environment and Sustainability Master's Project

By: Frances Arthur, Victoria Griffin, Linnet Leon, Alyssa Rausch

M SEAS

COOPE DOTA

Table of Contents

Abstract

This report presents research conducted in conjunction with Coopedota R.L., a coffee producing co-op based out of Santa Maria de Dota, Costa Rica. Within Coopedota's nearly 900 participating co-op members, this research focuses on the 69 Rainforest Alliance (RA) certified co-op farmers and their production area. The overarching goal of this work is to enhance the net-zero efforts of Coopedota by gaining a deeper understanding of the current carbon stored in their production area and making recommendations for future use of their entire production systems. The team approached the goal through three primary lenses: understanding farmers' perspectives on organic practices, calculating the carbon storage within the RA farmer production area, and evaluating alternatives to coffee cherry's end of life. To achieve this goal, the team: 1) carried out in-depth interviews with 34 RA famers concerning their thoughts on different certification processes and sustainable farming practices, 2) created 42 permanent plots within RA farmers' production area, collecting data to create a carbon inventory of the shade biomass, 3) created a life cycle assessment (LCA) of coffee production including gasification and biochar as an end of life alternative to composting for the treatment of coffee pulp.

Supporting the first objective, the research team interviewed 34 RA farmers on their sustainability and farming practices, opinions on the new Rainforest Alliance requirements, and the possibility of Coopedota starting an in-house certification process. Results found that RA farmers' main concerns regarding certification processes are having strong enough financial incentives and allowing minor use of chemicals when necessary. Supporting the second objective, the team collected carbon storage data from 34 RA farmers' production areas and 8 farms within Coopedota's private production area. Each plot was 34 x 34 m and collectively represented 1% of all RA farmers' production area. On average, each plot contained 194.35 tonnes of CO_2e. Total CO_2e in the 42 plots was 8162.94 tonnes of CO_2e, which was used to estimate the approximate CO_2e in all RA farmers' production areas to be 816,293.50 tonnes. The last objective required the creation of a simplified LCA, which involved coffee cultivation and production of greenhouse gas emissions following technical and agricultural recommendations to reduce greenhouse gas emissions. Upon review of the LCA, there is potential for carbon negative results as the process of gasification can be used to replace Coopedota's electrical needs and eliminate methane emissions produced during the end-of-life phase of the coffee production process. Gasification produces biochar as a byproduct, which is a substance that can be added to fertilizer as an enhancement and further aid farmers in the production of sustainable coffee with substantial growth.

Introduction

Coopedota is one of the largest coffee cooperatives in Costa Rica, located in the Santa Maria de Dota region, an area world-famous for its coffee as seen in Figure 1. In 2011, Coopedota became the world's first certified carbon-neutral coffee producer (*2020 Certification Program*, n.d.). Within Coopedota's nearly 900 participating co-op members, this research focuses on the 69 Rainforest Alliance certified co-op farmers and their production area. This year, the Rainforest Alliance (RA) released new regulations that they expect all farmers to adhere to, including becoming completely organic (*2020 Certification Program*, n.d.). The project's first objective required analyzing farmers' responses to these new regulations and considering the possibility of a new Coopedota Certification as an alternative to staying with the Rainforest Alliance.

Figure 1: Coopedota on the Map

Coopedota highly values its status as a carbon-neutral company and has previously invested time, effort, and money into calculating its carbon footprint. Coopedota purchased 1,100 tons of CO_2 credits in the Costa Rican market last year to maintain its carbon neutrality. (A. Cordero & J. Badilla, personal communication, September - October 2020). Previous calculations of their carbon storage did not consider shade biomass in their farms, which could significantly improve their understanding of their carbon budget. The second objective of this project was to create a detailed analysis of the average carbon stored in the shade trees of RA farmers to improve the organization's carbon accounting and sustainability practices in the future.

As one of the largest carbon-neutral coffee producers globally, Coopedota produces roughly 7,600 tons of coffee cherry pulp each year. Coopedota currently composts its coffee cherry pulp, which generates methane emissions and attracts stable flies, a non-endemic species that threatens regional cattle health. New regulations by the Costa Rican Ministry of Health regulations make

Coopedota responsible for the compost and any pests it attracts, even after farmers apply it as a soil amendment (A. Cordero & J. Badilla, personal communication, September - October 2020).

Gasification is based on the conversion of solid fuels (wood, agricultural residues, among others) to gasses. In other words, it is a thermochemical process that converts raw material, such as coffee pulp, into a combustible gas and generates a product known as biocarbon. By introducing gasification technology, Coopedota could (1) potentially create a carbon neutral electricity system to power its operations and cover power shortages encountered during harvest periods, (2) ameliorate stable fly concerns by repurposing compost material, and (3) utilize biochar, the gasifier's byproduct, as a soil amendment to improve retention of soil nutrients and coffee growth. Gasification allows the use of biomass residues to generate electricity and biochar which can be used as soil amendment, thus giving farmers the opportunity to use less or even zero other fertilizers, which is significantly better for the environment. The last objective of this report covers a simplified Life Cycle Assessment (LCA) of Coopedota's production system, while considering the future significance of implementing a gasifier on campus, in order to provide insights as to how Coopedota can best implement gasification into their processes.

The overarching goal behind each of the three objectives is to enhance the netzero efforts of Coopedota by gaining a deeper understanding of their current carbon stored in their production area and by making recommendations for future use of their entire production systems.

Methods

RA Farmer Interview Approach

Due to time constraints and the availability of farmers, the team decided not to randomize who was chosen to interview. Instead, Coopedota employee, Esteban Arguedas, facilitated the selection of the 34 RA farmers who participated in this study based on RA farmer availability and the availability of the translator, Krystal Barrantes. As the Cooperative's agronomic engineer, Esteban's main role is to help farmers with problems they may be having such as pest and fungicide issues. The interviews took place in Spanish, typically either at the farmer's house, the production area, or at the Coopedota Cafe. Upon arrival, the interviewer explained the purpose of the interviews and asked for the RA farmer's consent to be recorded. The interviewer also worked with the farmer to find a time and date to visit their production area to perform the carbon storage data collection.

Over the course of the interviews, the research team realized there were some questions that they thought were necessary to add, remove, or change. Therefore, they changed to a new interview template after extensive review and approval from the client. See Appendix 1 for the different interview scripts. The interviews focused on gaining an understanding of the farmer's use of chemicals, opinions on the changes in the Rainforest Alliance requirements, and thoughts on the creation of a new Coopedota Certification Program. The team also took this opportunity to explain to them the process of gasification with the objective of understanding if they would be open to using biochar for their soils.

Once the information was transferred, cleaned, and categorized, the research team used Tableau to visualize the interview findings. The team applied various visualization techniques including pie graphs, bar charts, and treemaps. The data was segmented into three categories: (1) general farmer background (e.g., size of the farm, types of trees in farms, presence of fungus, among others), (2) plans for continuing with Rainforest Alliance Certification, and (3) interest in pursuing an in-house Coopedota certification.

Carbon Storage Assessment

The team used the Instituto de Investigación y Servicios Forestales' Protocol for the Establishment and Measurement of Permanent Sampling Plots in Natural Forests throughout the project as guidance for establishing the carbon storage plots (Sánches-Monge, 2011). These IPCC-approved guidelines state that at least 1 percent of the land should be surveyed in order to receive an accurate representation of CO_2e stored in a given area. Appendix XX shows the breakdown of this 1% and how the research team determined plot size and number of plots. 34

RA farmers' production areas and 8 production segments within Coopedota's private production area were visited for the installation of permanent plots and data collection.

Since the team was creating 42 plots in just as many different locations, the protocol was not able to be perfectly followed as it was intended for significantly fewer plots all in the same area. Instead, the team created their own protocol for the placement of plots, influenced by randomization, avoiding edge effect, and safety constraints. Upon the team's arrival at a farmer's production area, the team and RA farmer would discuss where the plot could be placed without disrupting farming operations. Randomization was done when possible in order to deter any biases of consciously selecting certain farmland conditions such as topography and tree quantity. Areas that were too small, too steep, under pesticide application, or had large paths going through them were not applicable for the study. Once deciding on an applicable location within the production area, the team members walked directly 5 meters into a section of land to avoid edge effect affecting the data within the study. Edge effect is the effect of an abrupt transition between different adjoining ecological communities (Porensky & Young, 2013). They then used a phone application called Random Number Generator (*Random Number Generator Plus*, n.d.) to decide the angle from 0°-180° at which the team would walk an additional 5 meters. From "Point 1", team members walked 35 meters to create "Point 2", and so on to complete the square. A Garmin GPS InReach Explorer was used to dictate exactly where 35 meters was in order to stop and record the following corner points of a given plot. Once these procedures were achieved, a 35m x 35m square plot was completed.

The research team then began recording information for each shade tree within the plot which include the following: tree ID number, farmers' name, plot number, condition codes, axis quantity, GPS location, tree species, circumference (which was measured at 1.3 meters above the ground), and height. A Garmin GPS InReach Explorer was used to collect the GPS coordinates of every tree. A custom 1.3-meter metal pole was used during Diameter at Breast Height (DBH) measurements as a standard marking of 'breast height'. A standard tape measure was then used to measure the circumference while the Arboreal Tree phone application was used to measure tree height (*Arboreal - Tree Height*, n.d.). The circumference was then used to calculate the DBH in meters, the same unit used in tree height as well. Once the tree data was recorded in a Samsung tablet, a silver plaque containing an ID number was nailed to the tree. This was done in order to keep track of individual carbon information for each tree for future research.

It is important to note that shade trees had to meet specific protocol requirements before being considered for carbon storage. Therefore, only shade trees at least 1.3 meters tall and 10 cm in diameter were considered in the data collection. When a tree had multiple axes above the 1.3m, each axis was measured and recorded starting from left to right. The circumference values of these trees' axes were then combined in order to have the overall circumference value for the tree.

The allometric equation used to calculate CO_2e biomass came from the 2021 report published by Nature journal. The following allometric equation was used to calculate CO_2e in each tree:

$$CO_2e = DBH^2 * (\pi/4) * h * FF * CF * BSW * BEFa * BEFg * 3.67$$

Descriptions of each variable can be found in Table 1 below. The data was used to better understand how much CO_2e was stored in each tree, plot, and RA farmers' production areas. Three scatter plots were created to better understand if DBH, height, and tree quantity influenced carbon storage. Additionally, two maps were created using ArcGIS Pro to show the differences of carbon storage and tree quantity between plots.

Table 1. Description of the variables within the allometric equation chosen to measure CO_2e.

Abbreviation	*Meaning*	*Notes*
CO_2e	Estimated amount of greenhouse gasses captured	
DBH2 * (π/4)	Basal area	
h	Tree height	
FF	"Form-fitting" factor	Takes into consideration the change in diameter in relation to height, measuring from where the ground meets the tree to it's top leaves, as required by the protocol (Sánches-Monge, 2011)
CF	Carbon Fraction	Represents the volume of carbon stored in the trunk
BSW	Basic specific weight	Refers to the weight of the dry wood in a tree
BEFa, BEFg	Volume of the branches and leaves (BEFa) and roots (BEFg)	Above-ground biomass, the estimate for both was 1.2 of the trunk volume, calculated by the basal area times height
3.67	Ratio of the weight of carbon in carbon dioxide	One tonne of carbon is equivalent to 3.67 tonnes of CO_2

Coopedota's Greenhouse Gas Production

Coopedota's scope 1 and 2 carbon emissions cover their production phases, which entails emissions from owned and controlled sources and indirect emissions from energy production used in the coffee production phases. Coffee cultivation and production were separated into various stages: growing, milling, exporting, and production. Within these four categories exist subcategories that are factored into scope 1 and 2 emissions: agrochemicals and pesticides, fossil fuels, electrical and thermal energy, land transportation, and waste and recycling, all shown in Figure 2 below. Current and up-to-date use of fertilizers, farming practices, and coffee maintenance, cultivation, and production was provided by Adrian Cordero, Coopedota's Environmental Management and Occupational Health Coordinator (2021).

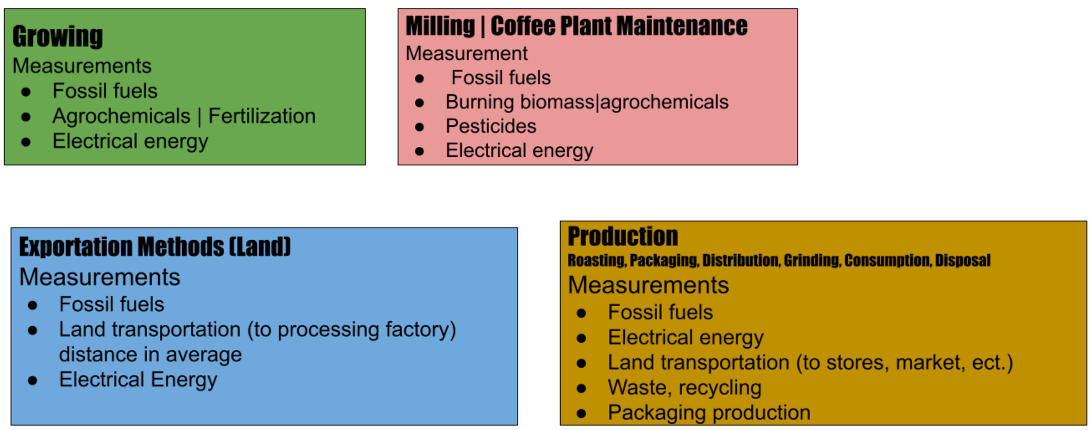


Figure 2: Categories Considered within the LCA Analysis

The categories were separated into the phases of coffee production to produce a simplified life cycle assessment of Coopedota's roasted coffee production from cradle to gate of the coffee bean. The method used by the team was inspired by previous LCA analyses from Giraldi-Díaz et al. (2018) and Wang et al. (2013) in their study of the environmental impact assoicated with the supply chain and production of coffee through life cycle analysis. The phases include cradle, cultivation, and final production. The calculations of CO2 emissions from each category were produced in reference to the IPCC Guidelines of National Greenhouse Inventories (2019).

Estimation of Gasification Impact on GHG Accounting

In 2020, Coopedota produced 7,600 metric tons of coffee cherry pulp. The pulp has been traditionally composted and sold as a fertilizer additive to interested co-op members (A. Cordero & J. Badilla, personal communication, September - October 2020). Since composting generates greenhouse gas emissions and attracts stable flies, Coopedota is looking into alternative solutions to their cherry pulp's end-of-life. Gasification presents the possibility of mitigating the negative effects of composting while also producing energy and improving soil quality.

Parajuli et al. (2020) analyzed the capacity of plant biomass to create syngas during the process of gasification. Coopedota's yearly 7,600 tons of coffee cherry pulp presents an opportunity for extensive plant material to be converted into syngas. The first step of preparing the coffee pulp for gasification requires the pulp to be pre-dried. Coopedota uses two drying methods for their coffee production: sun-drying and fermentation, depending on the desired product. Limousy (2014) and *Silva et al.* (2014) confirm that coffee left out in the sun to dry reduces the moisture content of coffee cherry pulp significantly. Pre-drying the pulp increases its density and therefore increases the syngas created (*Dal-Bo et al.,* 2019).

Dal-Bo et al. (2019) and *Komilis et al.* (2000) used the calculations below to estimate the amount of syngas produced by gasification.

1 ton of coffee pulp has the potential to produce 190 m^3 of biogas
Syngas
1.8 kg/syngas per 1 kg of pulp

Appendix G shows the calculations of syngas and electrical energy used for this project.

Results & Discussion

RA Farmer Interviews Findings

The research team conducted 34 interviews with RA farmers. The data is aggregated for all farmers to protect the opinions and sentiments of individual farmers. Table 2 shows the data segmentation approach based on the type of questions covered.

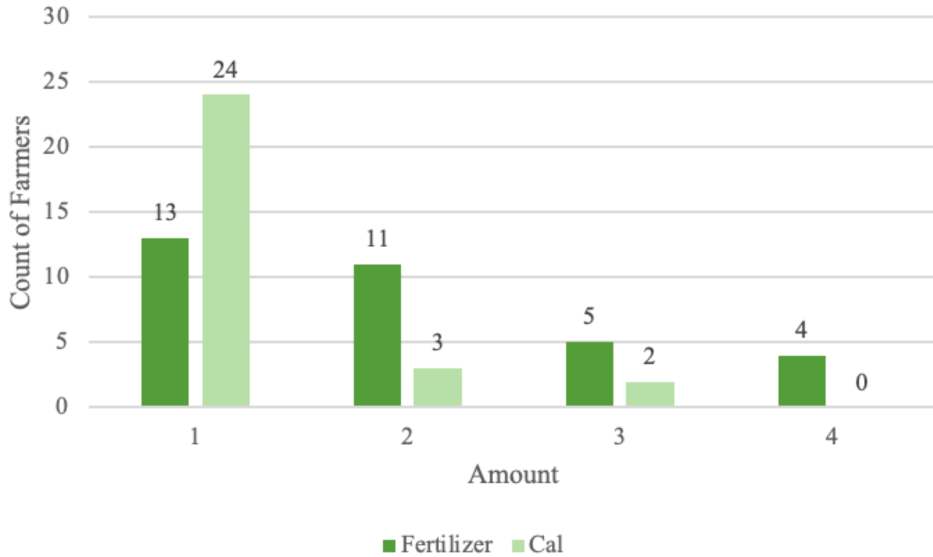
Table 2: Data Segmentation Approach

General Background	Rainforest Alliance Certification	Coopedota Certification
• Hectares • Farm Shade • Tree Type • Coffee Type • Presence of Fungus • Number of Fertilizers Used	• Plans to continue with certification • Challenges with certification	• Interest in adopting an in-house Coopedota Certification • Desired incentives from Coopedota's certification program

General Background

Collectively, the RA farmers own 323 hectares of land, 90% of which is attributed to actual coffee production. Roughly half of the farmers indicated having 100% of their production area covered with some shade, and 25% had at least 50-70% shade. Therefore, 75% of member farmers have a significant amount of shade throughout their conservation area.

Another key insight the team collected was the use of fertilizer, cal (lime), herbicide, and pesticide within the RA farmers' production area. RA farmers rely on fertilizer and cal to improve soil conditions. Graph 1 shows the distribution of RA members using a different number of fertilizers and cal products. The data indicates that the majority of RA members use at least one product of fertilizer and cal, while some use as many as four different products.



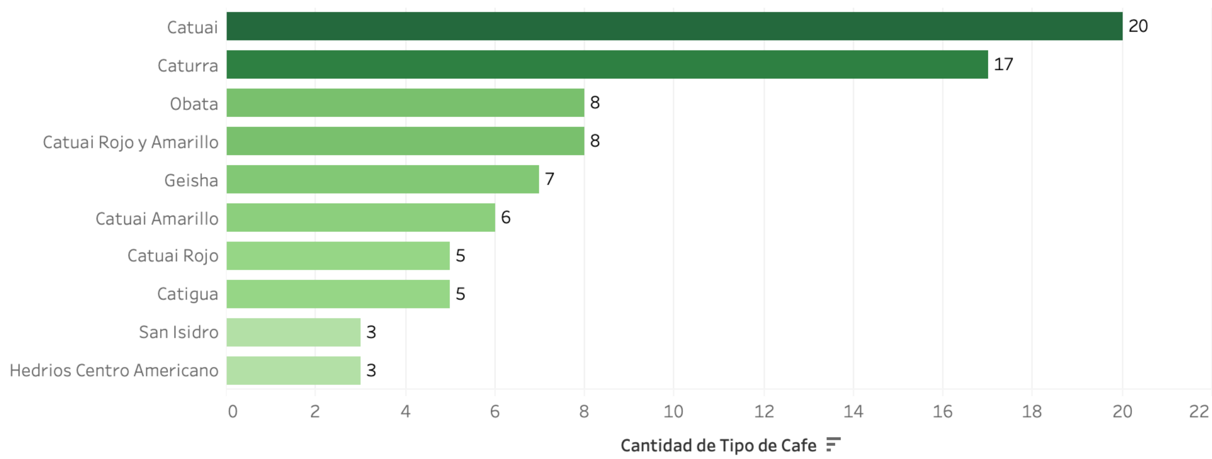
Graph 1 - Number of Fertilizers and Calcium Application

Another component in RA farmers' land management practices is the use of herbicides and pesticides. The list below shows the percentage of RA farmers dealing with different funguses on their farms.

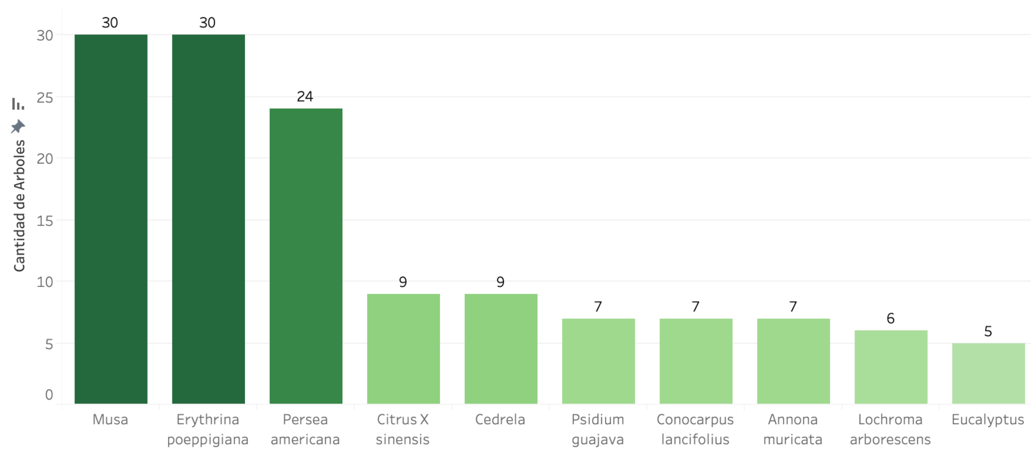
- Hemileia vastatrix (present in 68% of farmers' farms)
- Mycena citricolor (present in 68% of farmers' farms)
- Anthracnose (present in 43% of farmers' farms)
- Cercospora (present in 9% of farmers' farms)

Only four RA farmers (11%) did not experience any fungus on their farms. The other 89% of farmers used an array of fungicides. Furthermore, 82% used at least one herbicide and 79% used at least one pesticide, indicating that the use of chemicals is common practice among most RA farmers. However, many RA members try to limit their use of chemicals and resort to natural remedies for treating fungus and pests. Appendix B lists the natural remedies RA farmers deploy on their farms.

Lastly, Graphs 2 and 3 show the most common types of trees and coffee grown across the farms, respectively. Poro, Aguacate (Avocado), and Banana are the most abundant trees found throughout the farms, providing shade to the coffee trees. The most popular coffee species grown on RA farms were Catuai, Caturra, and Obata.



Graph 2 - Count of coffee variety in RA farms



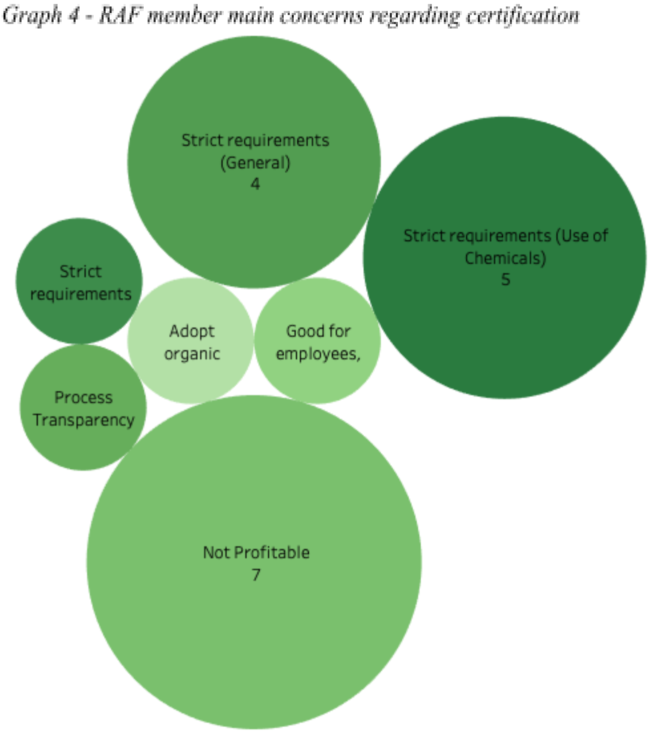
Graph 3 - Count of tree variety in RA farmer's production area

Rainforest Alliance Certification

Rainforest Alliance is an international non-profit organization responsible for protecting forests, improving the livelihoods of farmers and forest communities, promoting their human rights, and helping them mitigate and adapt to the climate crisis (*About the Rainforest Alliance*, n.d.). Approximately 10% of all Coopedota co-op farmers participated in the certification process two years ago.

The Rainforest Alliance came out with new requirements for certification in 2020. Notably, the 2020 certification requires farmers to

Graph 4 - RAF member main concerns regarding certification



eliminate the use of pesticides on their farms (*2020 Certification Program*, n.d.). Of the 34 RA farmers interviewed, 40% plan to continue with the Rainforest Alliance, 30% are undecided, and the remaining 30% will not. Graph 4 summarizes the main concerns for farmers in continuing with the certification. The size of the bubbles represents the count of farmers indicating the same concern. That the main problems farmers have with the new requirements include chemical requirements being too strict and financial incentives being too weak. Due to these concerns and a large number of farmers not interested in moving forward with RA, Coopedota is exploring creating its own certification program that incorporates members' financial, environmental, and social considerations

Coopedota Certification

The last interview segment consisted of a set of questions aimed at gaining a deeper understanding of RA farmers' willingness to participate in an in-house certification program with Coopedota. The team collected three main data points:

- Requirements member farmers would like to see Coopedorta establish
- Incentives member farmers expect from an in-house certification
- Sentiments on price point for premium

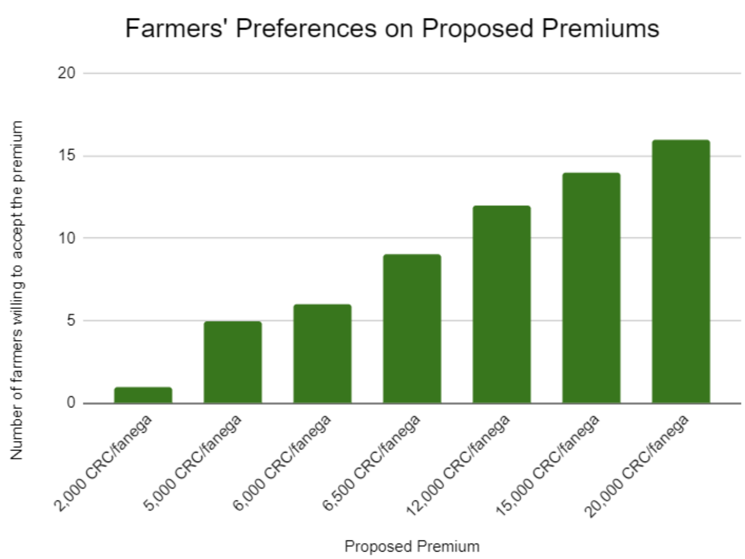
Table 3 shows all of the requirements captured during the interviews. The data indicates that technical assistance, chemical restrictions, and environmental factors play a significant role in the decision-making process for RA farmers. Similarly, incentives are closely aligned to these requirements. Table 3 provides a detailed description of the incentives member farmers' would prioritize. Out of five suggested incentives, financials and training were the most commonly mentioned incentives across all farmers. Several farmers also noted that they would like to see Coopedota provide more technical assistance around chemical use, inspection preparation, and good pesticide management. Farmers also indicated an interest in Coopedota performing occasional farm visits as they believe these visits help foster a sense of community and better understand current management challenges.

Table 3. RA farmers' feedback for new Coopedota certification

Better Administration	Reduce Paperwork	1
	Personalized Advice	1
	Equitable Distribution And Quality Cooperation	1
	Clear Meeting Protocols And Expectations	1
Financial	Financial	18
	Better Premium (Financial)	2
	Producers Need Bigger Cut	1
	Payment Credits	1
	Need Premium	1
	Have Set Price	1
Helpful Visits	Helpful Visits	2
Implement Natural Growing Methods	Prioritize Environment	1
	Introduce More Natural Maintenance Solutions	1
Other	Requirement Guidance	1
	Less Requirements	1
	Dont Mix Certified Coffee With Non Certified Coffee	1
	Better Labels For Customers	1
	Alternative Fungicide Supply	1
Reputation	Global Scale Recognition	1
Technical Assisstance	Technical Assisstance	7
	Subject Experts On Requirements	2
	More Inspection Preparation Training	1

Note: Numbers on the right indicate the count of RA farmers that mentioned the same category of feedback

Graph 5 shows the different financial incentives that RA farmers consider appropriate to receive for participating in an in-house certification premium. The data indicates a premium range of member farmers would be willing to accept, starting at 5,000 CRC/fanega to 15,000 CRC/fanega. Other farmers provided more qualitative feedback, such as the premium should be based on coffee quality, be 20% more per fanega, or be a fixed price.



Graph 5: *Count of RA farmers' feedback on certification premium*

Overall, survey responses show that members highly value their involvement with the cooperative. Periodic workshops could crowdsource effective coffee management practices and encourage collaboration across all farmers. These workshops could vary in topic, including sharing natural pest management practices, implementing organic land management practices, and discussing effective social treatment among farmers and cooperatives. Overall, Coopedota should support member farmers interested in keeping their Rainforest Alliance certification as well as those hoping to embark on a new Coopedota certification. In either scenario, Coopedota and its farmers will benefit from more substantial environmental standards, higher coffee premiums, and improved well-being for both farmers and customers.

Carbon Storage Assessment

Objective 2 entailed completing the data collection and calculations of carbon storage within the coffee production area. Figure 3 below shows that each plot averaged 194.35 tonnes of CO_2e per plot. The total CO_2e stored by shade trees in all 42 plots (1% of all RA production area) was approximately 8,162.93 tonnes. This number can be extrapolated to estimate the CO_2e stored in all RA production areas, which is 816,293.50 tonnes. Figure 3 also shows that Coopedota plots had a higher average CO_2e per plot at 394.70 tonnes/plot than the average RA farmer plot at 147.21 tonnes/plot. This difference in CO_2e could be attributed to contrasting tree heights and tree quantities between the areas. Generally speaking, taller trees can carry more carbon (Mildrexler *et al.,* 2020). Coopedota averages 10 more trees per plot than RA farmers' plots. Coopedota's average tree height was 12.40 meters tall, while RA farmers' average tree height was 5.94 meters tall. It is likely that since Coopedota plots had a higher tree quantity and tree height compared to RA farmers' plots, Coopedota had higher amounts of stored CO_2e overall.

Table 4. A table breaking down the CO_2e values of Coopedota's lands, RA members' lands, and the Cooperative as a whole.

CO_2e Information of Coopedota Cooperative	
Approximate RA farmers' CO_2e in 42 plots (1% of RA production lands sampled)	8,162.93 tonnes
Approximate CO_2e in total RA farmer production lands	816,293.50 tonnes
Average CO_2e per Coopedota plot	394.70 tonnes/plot
Average CO_2e per RA farmer's plot	147.21 tonnes/ plot

Average CO_2e per plot (including all 42 plots)	194.35 tonnes/plot

A visual comparison of stored CO_2e and tree quantity between plots can be found in the choropleth maps below. The choropleth map in Figure 1 compares the total CO_2e stored by coffee shade trees among the 42 sampled plots. The Choropleth map in Figure 2 compares the number of trees among the 42 sampled plots. Both choropleth maps show where each plot is located in the Coopedota region.

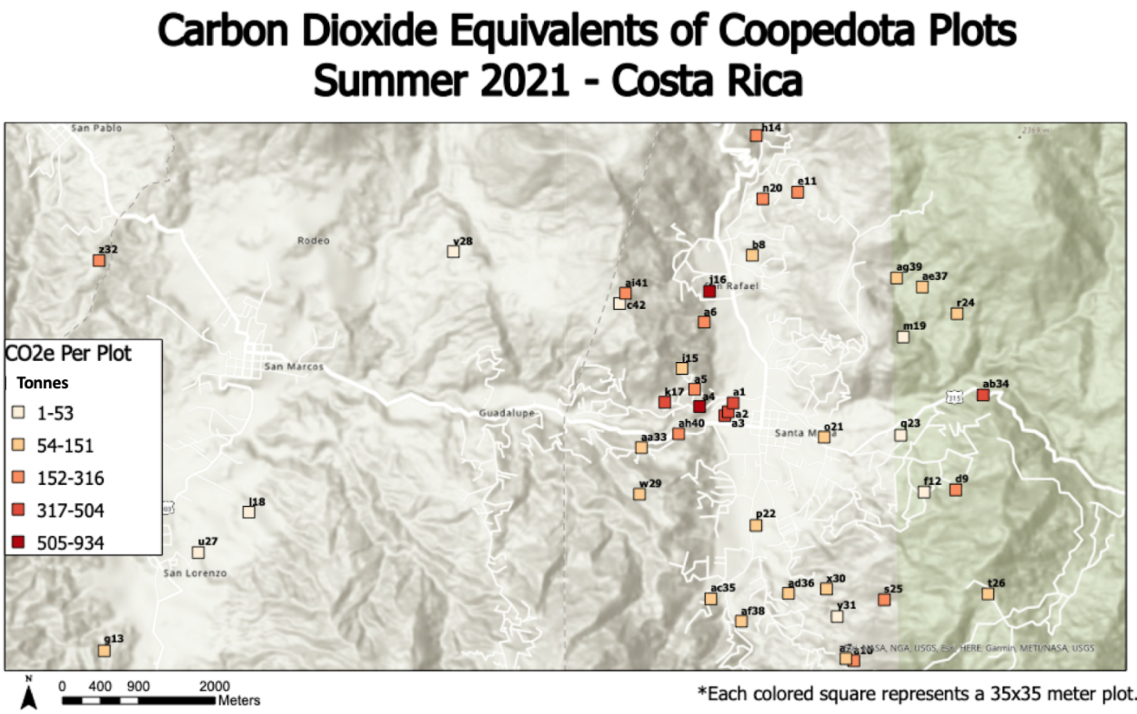


Figure 3. Choropleth map #1

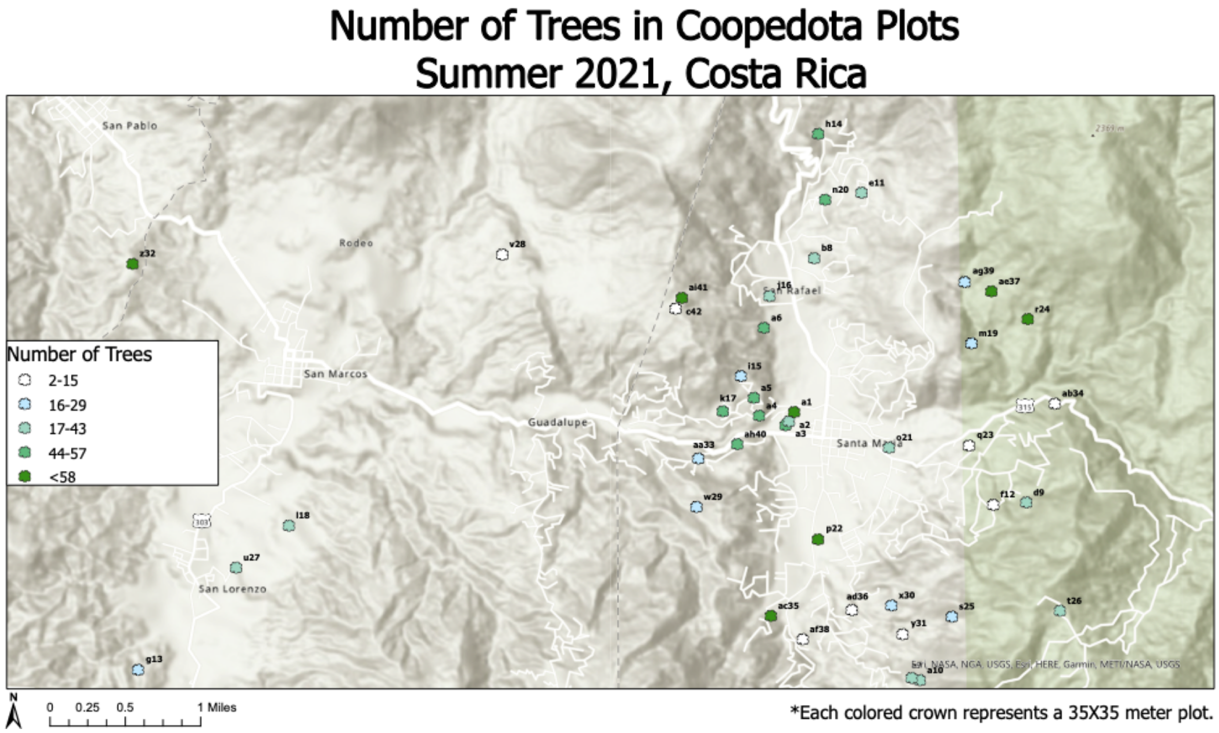


Figure 4. Choropleth map #2

Three research questions were considered to understand what variables affect CO_2e storage:

- What is the relationship between trees' DBHs and CO_2e storage?
- What is the relationship between trees' heights and CO_2e storage?
- What is the relationship between the quantity of trees within a plot, and that plot's CO_2e storage?

Figure 4 below shows the relationship between Shade Tree DBH and CO_2e storage. The R-squared value of this analysis was 0.32, indicating a weak correlation between the variables. In other words, a shade tree that has a higher DBH does not necessarily store more CO_2e than a shade tree with a lower DBH. The R-squared value between shade tree height and CO_2e storage was 0.03 (Figure 5 below), indicating no correlation between the variables. taller shade trees did not necessarily store more CO_2e than shorter shade trees. The weak or non-existent correlation in these graphs is likely due to most of the recorded trees being similar in height and DBH, making it nearly impossible to see if a statistical pattern exists.

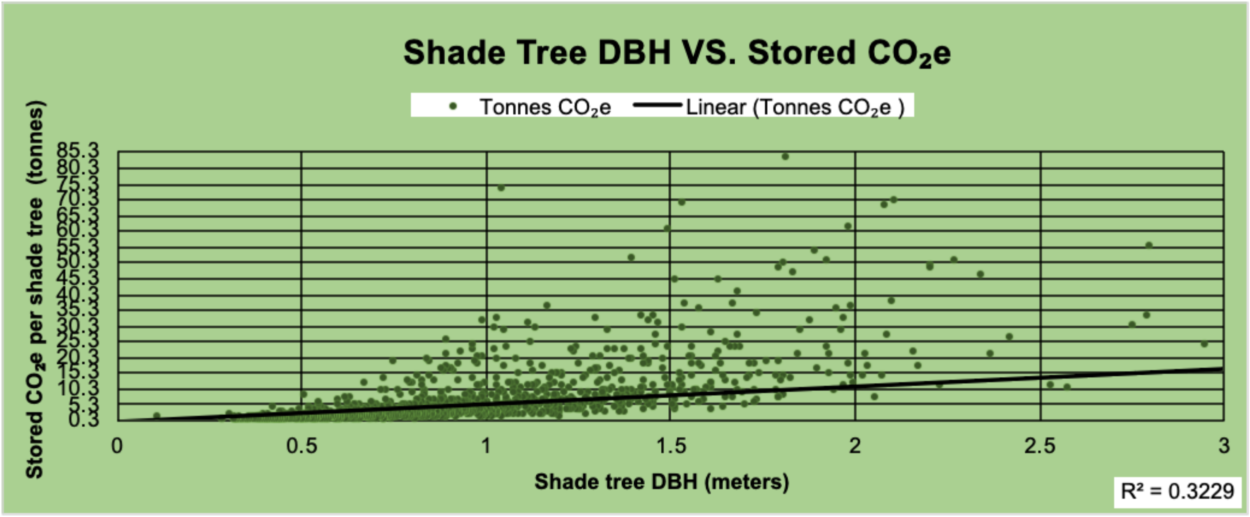


Figure 5. With an R-squared value of 0.32, there is a weak correlation between shade tree DBH and stored CO_2e.

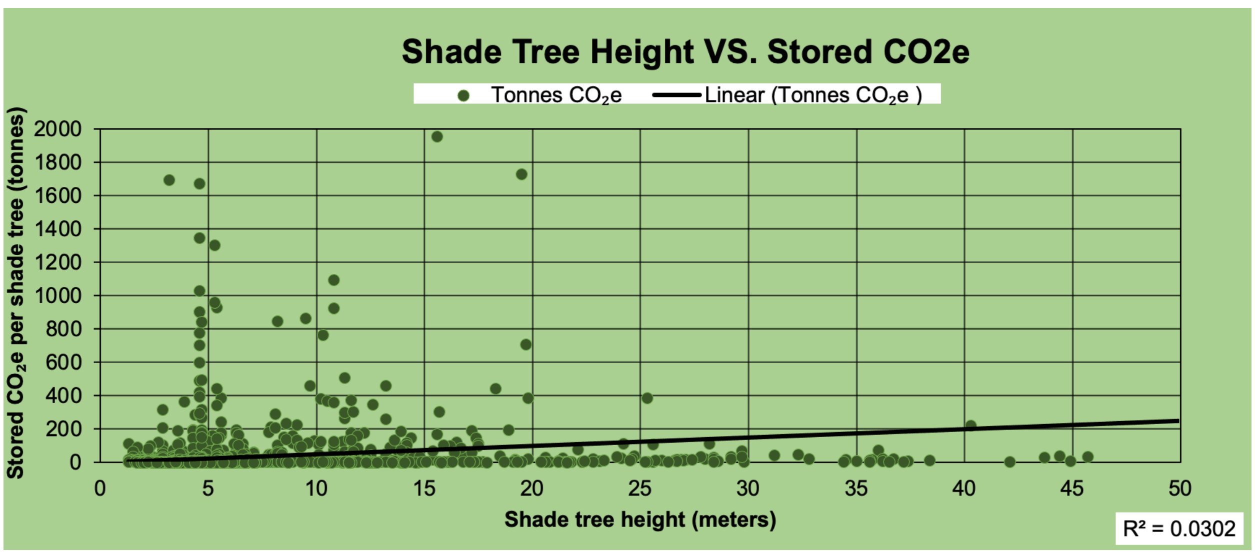


Figure 6. With an R-squared value of 0.03, there is no correlation between shade tree height and stored CO_2e.

Lastly, the R-squared value between shade tree quantity and CO_2e storage per plot was 0.52 (Figure 6 below), meaning there is a slight correlation between tree quantity per plot and CO_2e. Therefore, plots with more shade trees were more likely to hold more CO_2e than plots with fewer shade trees. If Coopedota would like to increase the carbon storage within its production area, they should consider expanding the shade tree quantity within its production area. Overall, it would be beneficial for Coopedota to continue monitoring height, DBH, and quantity variables to better understand what can increase carbon storage in their coffee shade trees.

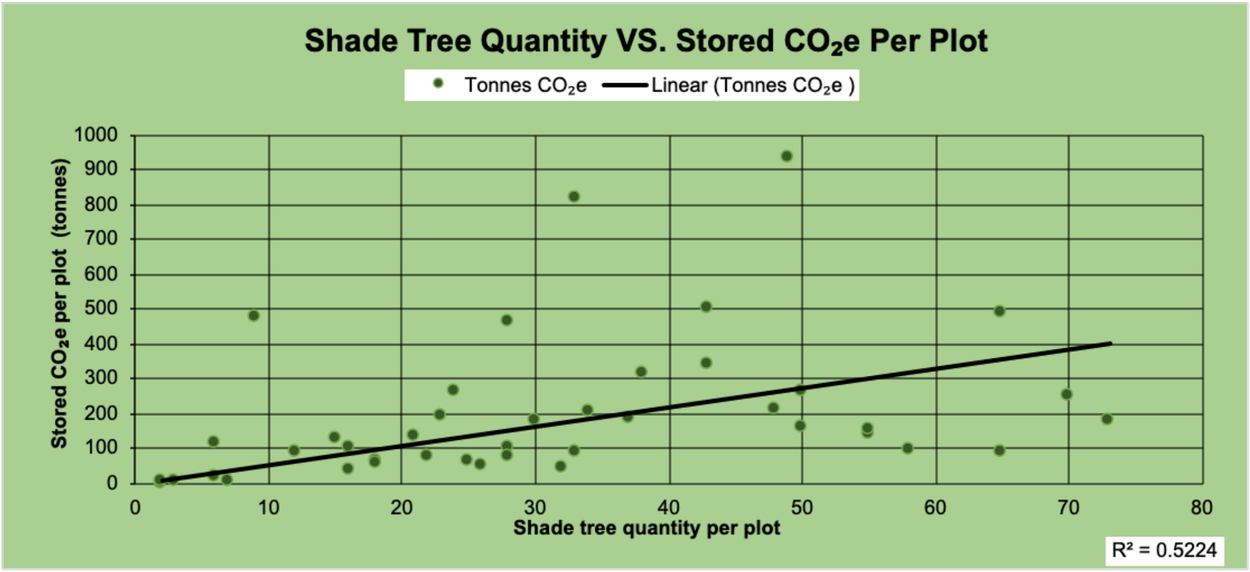


Figure 7. With an R-squared value of 0.52, there is a correlation between shade tree quantity and overall CO_2e *stored per RA plot.*

The team also collected data on the general condition of each tree, including variables like growing straight, being cut above 1.3 meters, and being dead or a stump. Figure 1 below shows the general conditions for all trees within the research. There were significantly more straight, healthy trees than trees cut about 1.3m and even more than dead trees or stumps.

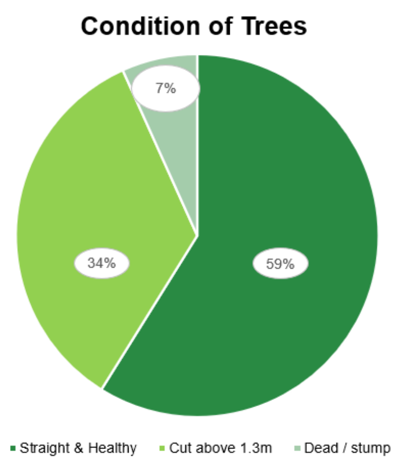


Figure 8: Condition of Trees

Generally, 74% of carbon in trees is stored in its trunk, branches, and leaves (Barbose, 2011), meaning that trees cut considerably above 1.3 meters will hold less carbon than mathematically predicted. Due to a lack of precedent research, the condition of trees could not be an influential factor in the team's carbon storage calculations. Because such a significant percentage of trees were majorly cut above 1.3m, the team's calculations may overestimate the amount of carbon stored as they generally assume trees have the makeup of a natural forest where trees are not anthropogenically cut or chopped down.

Crown shape and tree condition are additional factors that theoretically affect the carbon stored in shade trees. Figure 9 shows the Crown Shape of all Trees, indicating the density of leaves and branches of each tree. Figure 10 shows the Shade Rating of All Trees, indicating the amount of direct sunlight that the crown of each tree received due to its surroundings. Figure 9 indicates that there is a slight slope toward more sparse trees, while Figure 10 shows that significantly more trees received direct sun from all angles. The trend towards sparsity within the crown shape is likely due to the practice of chopping branches off shade trees to allow for sunlight to hit the soil and coffee trees. See Appendix E for detailed descriptions on conditions codes for all Coopedota Plots within each plot's drone shot.

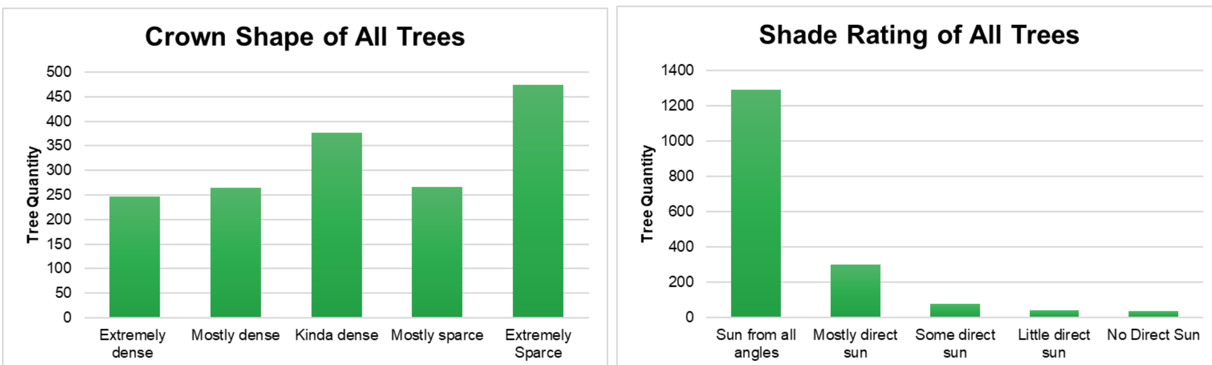


Figure 9: Crown Shape of All Trees; Figure 10: Shade Rating of All Trees

Figures 9 and 10 work together to indicate the likeness of gaps in the canopy where sunlight can reach the coffee trees and forest floor. Because the shade trees are mainly receiving full sunlight and are more likely to be more sparse, the coffee trees beneath likely only receive sunlight at certain times of the day. These variables indicate that it is very unlikely that the coffee trees do not receive any sunlight due to the shade trees and instead receive full or partial shade. Data from the RA farmer interviews shows that some farmers use a mixture of shade and direct sunlight to assist in the detriment of pests and diseases on their farms (Appendix B).

There are many areas for improvement within carbon accounting for production areas. Future research in this area should consider incorporating condition codes into carbon calculations to assess carbon stored in production areas more accurately. The equation used for calculating carbon could slightly overestimate the carbon stored within the plots because it assumes a random crown shape within forests, which are less likely to be sparse. Additionally, the calculations performed for carbon storage also use a generic allometric equation, representing the average carbon storage makeup of all tropical tree species. This research would greatly benefit from the creation of species-specific allometric equations which account for the carbon density and makeup of each individual species. This report does not consider these factors within the carbon calculations due to a lack of precedent research.

Coopedota's Scope 1 and 2 Greenhouse Gas Production

The LCA is an open-loop system in which some products such as water and fertilizers are recycled. Three processes were examined and calculated to give results of CO_2e emissions. The functional unit used to account for emissions from roasted coffee production processes is kilograms of CO_2e per kilogram of roasted coffee.

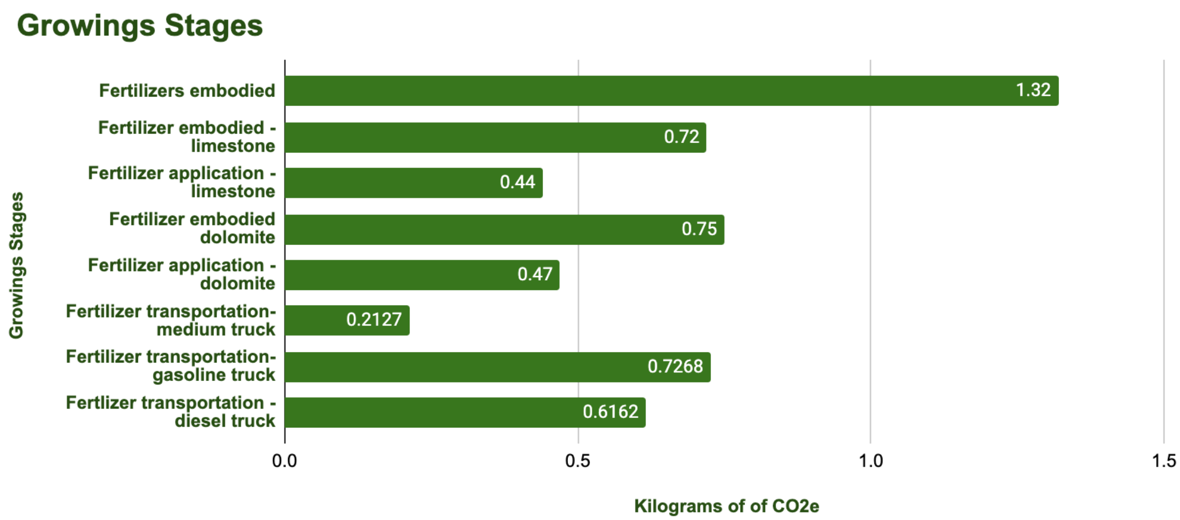


Figure 11: Cause of Emissions in Growing Stage per (what is the functional unit being used here)?

Figure 11: Causes of Emissions in Growing Stage above shows emissions of kilograms of CO_2e of product for each cause of emission in the growing stage of Coopedota's coffee per kilogram of roasted coffee. From the chart depicted above, the most significant factor of CO_2e emissions comes from embodied fertilizers with 1.32 kg of CO_2e per kilogram of roasted coffee outside of the use of lime and dolomite. Embodied fertilizers contain heavy amounts of phosphates and nitrates to aid in plant and agricultural growth. The interviews also found that several RA farmers use fertilizers not directly prescribed to them that may contain ammonium nitrate, phosphates, nitrates, and potassium. Traces of these elements can be found in farmers' soil and fertilizer profiles as examined by Coopedota's environmental engineers.

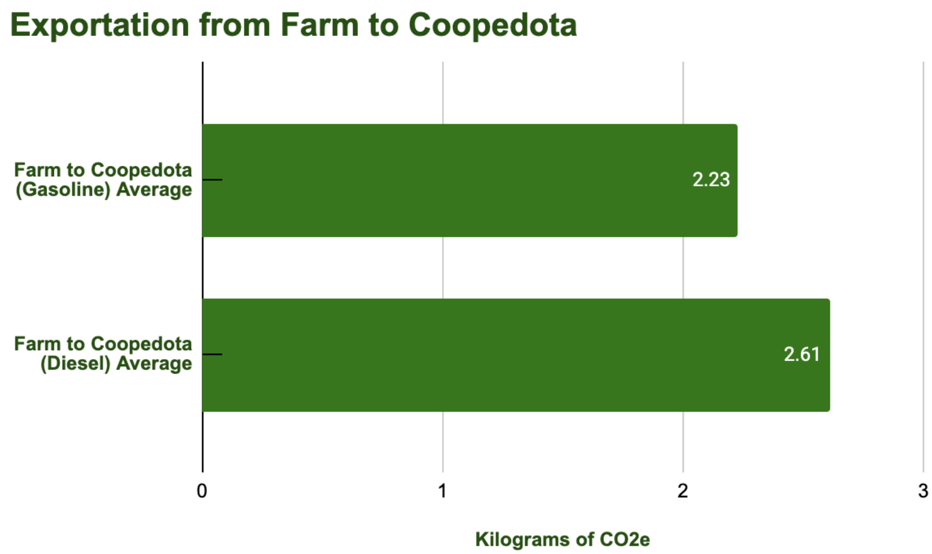


Figure 12: Cause of Emissions in Exportation of Green Bean

The measurements in Figure 12 above provide data on coffee beans' exportation to Coopedota's factory for processing. The farmers were asked about their coffee vehicle's make, year, model, and fuel type during the interview process. In some cases, farmers had several vehicles, which was also factored into the calculations. Adrian Cordero, Coopedota's Environmental Coordinator, provided further information on the entire cooperatives' vehicles and fuel types. These measurements work together to show that the most significant cause of major CO_2e emissions from exportation is vehicles that use diesel fuel type instead of gasoline (Figure 12 above).

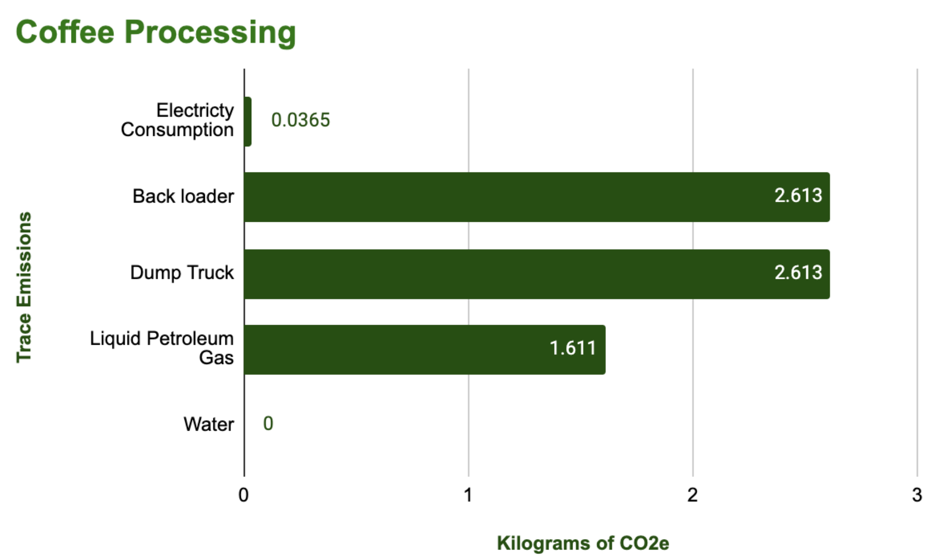


Figure 13: Cause of Emissions in Processing

During the processing stage, Coopedota uses the least electricity possible by incorporating manual and natural labor. Water used in the washing phase is recycled back into a local river, resulting in 0 kilograms of CO_2e. It is important to note that the energy being used in water transportation does not impact the gasification or composting process calculations. During the drying process, beans are sun-dried and then stored for processing inside the factory. The highest emissions of CO_2e are attributed to the back loaders and dump trucks used to load and dump coffee beans into the processing plant after they have been washed and dried, as seen in Figure 13 above.

Estimation of Gasification Impact on GHG Accounting

Appendix G - Calculations of Syngas and Electrical Energy shows the calculations of biogas to energy and syngas calculations. The team found that Coopedota's 7,600 tons of coffee cherry pulp can produce 24.8 kwh of syngas through gasification per kilogram of roasted coffee.

Identification of Greenhouse Gas

After further review of the LCA, the most significant greenhouse gasses involved in the cooperative's scope 1 and 2 emissions include methane, carbon dioxide, and nitrous oxide, with nitrous oxide persisting as the highest greenhouse gas produced. Nitrous oxide is highly present in the process of raw materials in the first stage of coffee cradle cultivation in fertilizers and the bacteria of soil and water. Both nitrous oxide and methane are results of composting as well. Cradle, cultivation, and processing of coffee beans produce 298 kg/m^3 of nitrous oxide, 25 kg/m^3 of methane, and 1 kg/m^3 of carbon dioxide. While Coopedota has carbon-neutral results for the cooperative, it is also imperative to remedy the remainder of greenhouse gas accounted for in the cooperative's coffee bean production.

Technical Recommendation

For a technical recommendation, a further study has been conducted to introduce gasification into the cooperative's processing of the coffee cherry pulp. Gasification is when biomass undergoes partial oxidation to "produce a mixture of gas called syngas composed of hydrogen, carbon monoxide" (Aristizábal-Marulanda, 2020). Gasification allows biomass to be converted into syngas fuel to generate electricity or heat. (Dal-Bo, 2019). However, it can also convert different types of organic material, such as compost. Coffee residues, particularly coffee husks, are a low-cost energy biomass option for gasification, thus very appealing to utilize in some form to reduce the coffee industry's ecological footprint (Dal-Bo, 2019). Syngas could be directly used from combustion to produce electricity but must first be filtered to remove ash and other particulates (Castillo-Benavides et al., 2018).

Greenhouse Gas Remediation and Biochar

Using gasification in substitution for composting, Coopedota can reduce their f CO_2e emissions even further. Coopedota's methane production from composting is 0.058 CH_4/kg with a f CO_2e equivalent of 1.5 f CO_2e/kg. Gasification burns down plant biomass, removing the methane and carbon dioxide in the system and leaving their total outputs net-zero (see Table 1).

Table 5: Greenhouse Gasses: Before and After Gasification

Composting	After Gasification
0.058 - CH_4/ kg	0 - CH_4/ kg
1.5 f CO_2e / kg	0 - f CO_2e / kg

Biochar, the by-product of gasification, contains elements such as carbon, hydrogen, sulfur, oxygen, and nitrogen, as well as minerals in the ash fraction (Wang, L. et al.). Plant biomass undergoes partial oxidation during the gasification of plant material, converting nitrous oxide into nitric oxide. Nitric oxide in soil plays a role in nitrification and the production of *nitroso bacteria,* which can benefit both soil retention and plant development (Aristizábal-Marulanda, Valentina, et al.).

The team suggests that Coopedota use biochar as an additive to fertilizer to enhance its benefits. Using a mixture of biochar and fertilizer rather than composted cherry pulp will reduce methane production while improving soil conditions (Aristizábal-Marulanda, Valentina, et al.). Biochar acts like a sponge, retaining nutrient-rich bacteria in the soil to stabilize plant health. Furthermore, biochar reduces soil runoff, increases soil fertility and retention, and improves plant health and yield overall.

Conclusion

As one of the largest carbon-neutral coffee producers globally, Coopedota is highly committed to further minimizing its carbon footprint. To improve these net-zero efforts, Coopedota partnered with the University of Michigan to explore three lenses: 1) opinions of RA farmers on different certification processes and sustainable farming practices, 2) carbon storage of shade trees within coffee production areas, 3) alternatives to coffee cherry pulp's end of life.

Starting with the RA farmer interviews, the team found that 40% of the farmers interviewed plan to continue with the Rainforest Alliance, 30% plan to detach, and the last 30% are undecided. The main concerns farmer's brought up during their interviews regard chemical requirements as being too strict and financial incentives as too small. As such, when asked about participating in an in-house Coopedota certification, most of the RA farmers stated they would be interested in participating. However, several RA farmers noted that they would like to see Coopedota provide more technical assistance around chemical use, inspection preparation, and good pesticide management before agreeing to participate in the new certification program. To deliver on these requirements, the research team recommends Coopedota hold periodic workshops to crowdsource effective coffee management practices and encourage collaboration across all RA farmers. Coopedota should support farmers interested in keeping their Rainforest Alliance certification as well as those hoping to embark on a new Coopedota certification. In either scenario, Coopedota and its farmers will benefit from stronger environmental standards, higher coffee premiums, and increased support for both farmers and customers.

Secondly, the team assessed the carbon biomass in Coopedota and its RA farmers' production areas. The findings revealed that all RA farmers' production land stored approximately 816,293.50 tonnes of CO_2e, which should be considered in their carbon accounting in the future. The team found that stored CO_2e is higher in Coopedota plots than in RA farmers' plots. This is likely because, on average, trees on Coopedota's land were more abundant and taller than RA farmers' shade trees. This research was limited by gaps in the industry standards, and would be significantly improved if allometric equations for each tree species existed as well as guidelines on how to calculate the carbon for trees missing a significant amount of branches or leaves. Overall, the research team recommends that Coopedota consider tracking these metrics as they can aid in land management efforts, further improve coffee quality, and deliver a competitive edge in the coffee industry.

Lastly, the team explored the use of gasification to lower emissions, strengthen agricultural yield, and improve soil quality with the help of biochar. Gasification presents itself as an opportunity for Coopedota to reduce its CO_2 emissions during the production stage and repurpose its coffee cherry pulp. Specifically, the use of gasification in the area of electrical production allows Coopedota to continue their carbon neutrality. Biochar can be mixed with fertilizer use to reduce the use of fertilizers, improve soil conditions, and store carbon. It also helps limit the emissions of nitrous oxide and methane from agricultural soils, especially those created during the composting of coffee cherry pulp (Rittl et al., 2021). Another attractive biochar quality is that it holds carbon in the soil over long periods, resulting in a net reduction of CO_2 in the atmosphere. When bringing these three lenses together, the research team believes that Coopedota is well positioned to remain one of the few carbon-neutral coffee producers globally and do so with its farmers' support, resilience, and hard work.

Acknowledgments

Esteban Arguedas, for providing guidance and assistance in interview and farmer visit logistics.

Krystal Barrantes, for her assistance as a translator during interviews and for her help during fieldwork data collection.

Alexandra Paniagua-Ramierez, for sharing her expertise and scientific protocols.

Jose Alfaro, director, and advisor of the Master's project, for providing guidance and logistical assistance.

Appendix A - Interview Templates

See here for the first Interview Script.
See here for the second Interview Script.

Appendix B - Natural Fungicide Interventions

Natural steps to avoid pesticide and/or fungicide
Control Shade And Cut Grass
Use Pesticide - No Major Problems
Tests Soil And Plants
Bioensumos
Stay Proactive
For Ojo De Gallo
No Pesticide
Natural Pesticide
Nothing Natural
Guacamaja (Plant From The Mountains)
Uses Tricoderma And Does Not Overclean The Soil
Antragnosis Better With Shade And Ojo De Gallo Better With Full Sun
Apply Cal
Trichoderma
Rice Shell
Use Fongcacida (Esfera)
Amistar
Use Of Beolis (A Natural Fungus) To Avoid The Fungicides
Uses Air Circulation
Care For Soil
Compost
Trims Coffee Plants
Criasoles
Atemi
Mixes With Natural Fungus
Roundup
Makes Ground Unlevel
Only Chemicals In Areas Needed
Bioles
Aloe Vera

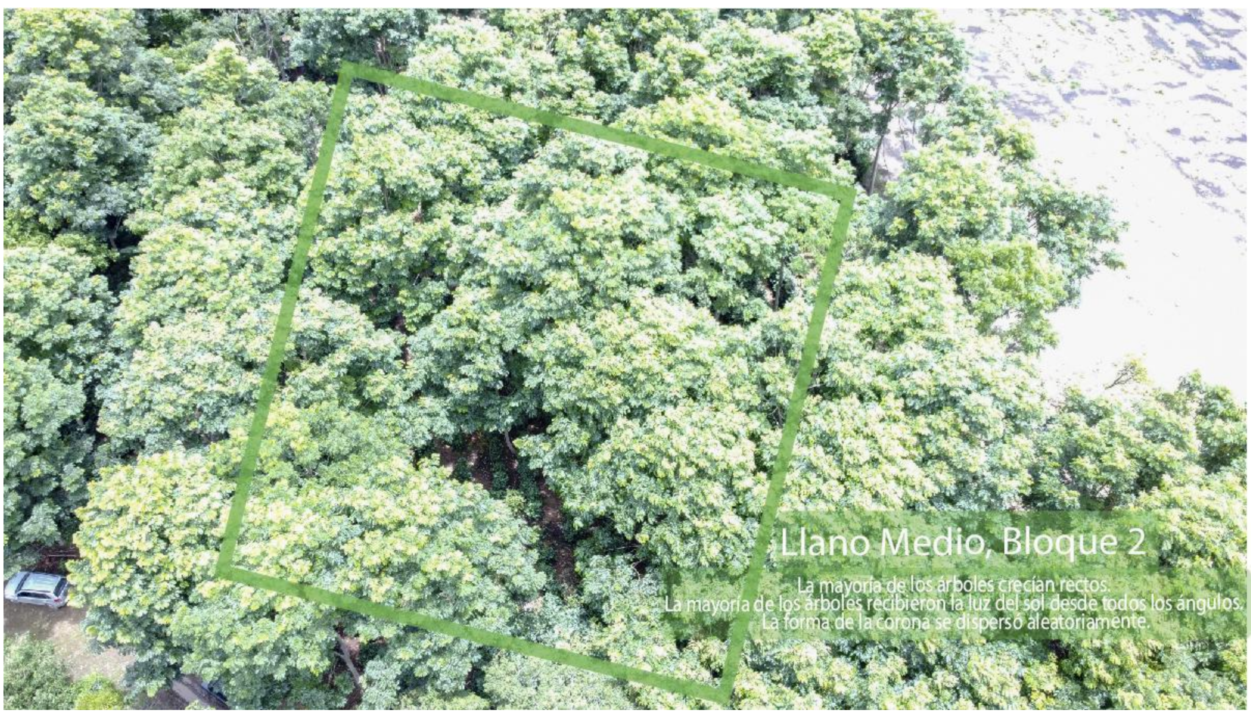
Chili Picante
Melaza
Cebolla
Ajo
Rosemary
Mint
Oregano
Natural Water Drains
Mega Boro
Imberex
Mixes Into Wáter
Keep Floor Clean
Alternate application usage based on seasons
Cut shade and grass
Use natural microrganisms in plants and soil

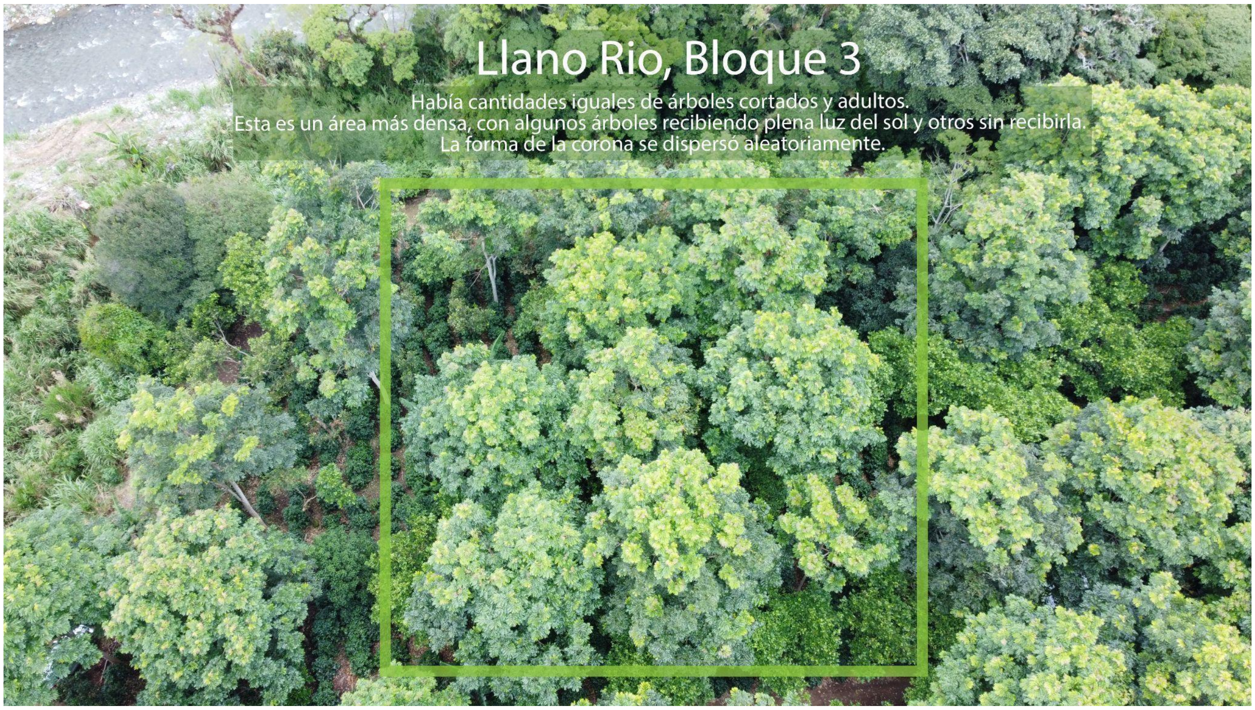
Appendix C - Calculations behind Number of Plots Required

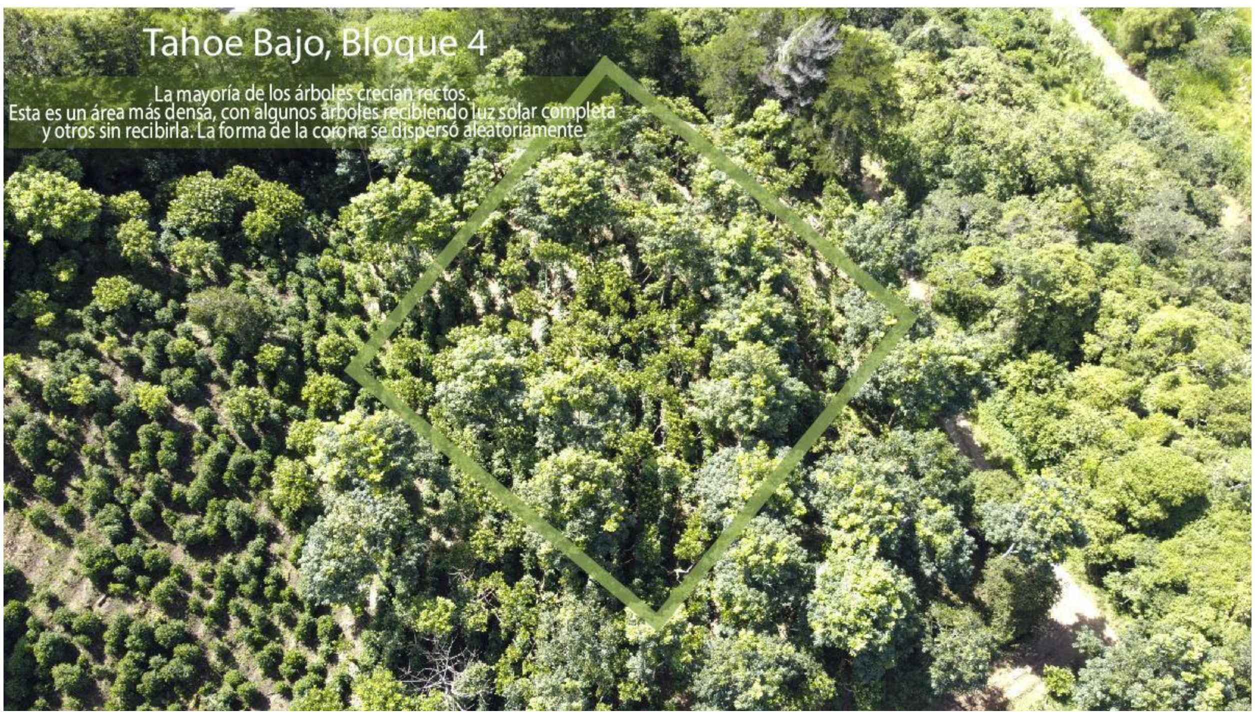
Total production area of RA farmers	503.6757
(in square meters)	5036757
1% of total production area	50367.57
plot size in square meters 35x35=	1225
1% PA / plot size	41.11638367
Plots required to meet 1% =	42
Coopedota land plots:	8
Necessary farmer plots	34

Note. This chart explains the process behind calculating how many plots were necessary to reach 1% representation of Rainforest Alliance production areas.

Appendix E - Coopedota Plots in Drone Photos



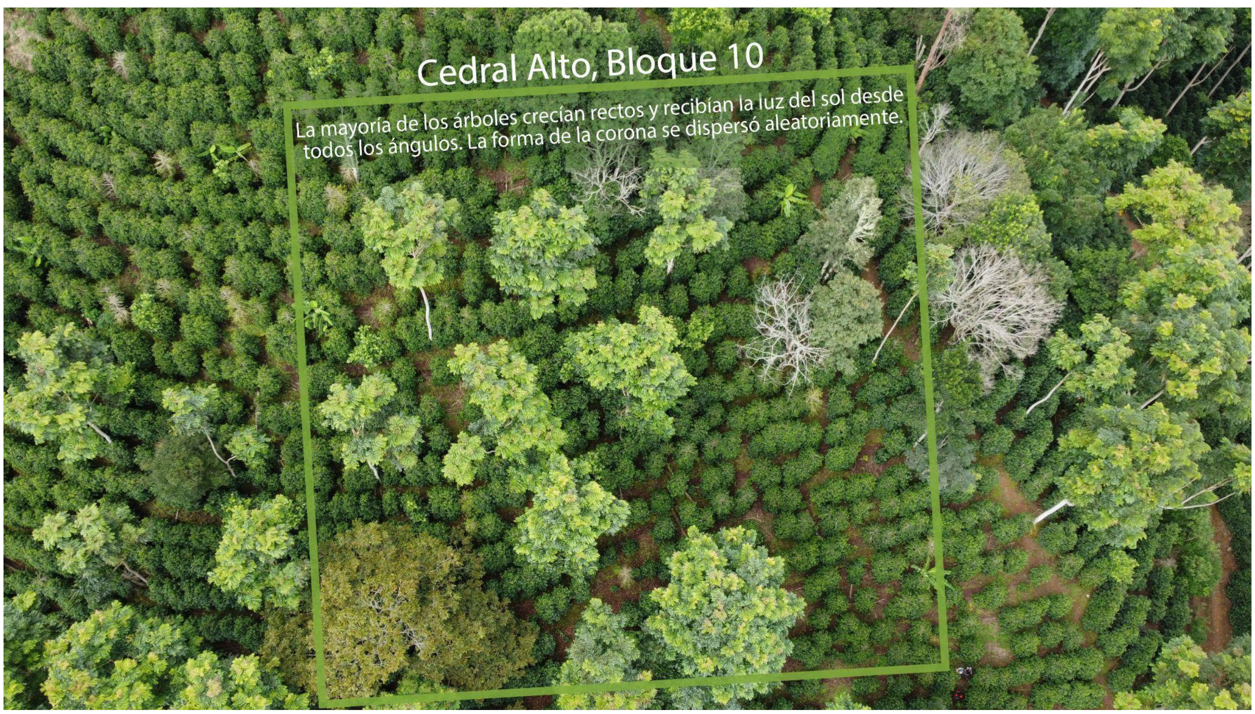

Llano Rio, Bloque 3
Había cantidades iguales de árboles cortados y adultos.
Esta es un área más densa, con algunos árboles recibiendo plena luz del sol y otros sin recibirla.
La forma de la corona se dispersó aleatoriamente.


Tahoe Bajo, Bloque 4
La mayoría de los árboles crecían rectos.
Esta es un área más densa, con algunos árboles recibiendo luz solar completa
y otros sin recibirla. La forma de la corona se dispersó aleatoriamente.


Tahoe Alto, Bloque 5
Había cantidades iguales de árboles cortados y adultos.
La mayoría de los árboles recibieron la luz del sol desde todos los ángulos.
La forma de la corona se dispersó aleatoriamente.


Pikin, Bloque 6
Se talaron más árboles que los que crecieron.
La mayoría de los árboles recibieron la luz del sol desde todos
los ángulos. La forma de la corona se dispersó aleatoriamente.


Cedral Bajo, Bloque 7
La mayoría de los árboles crecían rectos y recibían la luz del sol desde todos los ángulos. La forma de la corona se dispersó aleatoriamente.


Cedral Alto, Bloque 10
La mayoría de los árboles crecían rectos y recibían la luz del sol desde todos los ángulos. La forma de la corona se dispersó aleatoriamente.

Appendix F - LCA Creation and Boundaries

Step 1: Calculating Coffee Production

Find the coffee produced or processed at each stage

Determine the carbon footprint of specific source of emission to one functional unit

Present as a function of 1 kg green coffee bean

Step 2: Calculating Carbon Emissions

Multiply the input value by its specific emission factor

For fossil fuel emissions and electricity energy use national average emission factors for Costa Rica

Emissions for land transportation, fertilizer, and pesticide should refer to Costa Rican Ministry of Environment and Agricultural

Step 3: Carbon Footprint Calculation

Total and standardized in kg of CO2

Divided by the total amount of coffee produced or processed at each stage, resulting in the carbon footprint of each stage expressed in kg CO2ekg–1 green coffee.

Cradle and Cultivation

GHG of Coffee Production (Growing stage)

- Embodied emissions from fertilizers - 1.32 kg CO2
- Application of fertilizers - .016 kg NO2
- Embodied emissions from limestone fertilizer- 0.72 kg CO_2/kg of product
- Fertilizer application of limestone - 0.44 kg CO_2/kg of product
- Embodied emissions from dolomite - 0.75 kg CO_2/kg of product
- Fertilizer application of dolomite- 0.47 kg CO_2
- Fertilizer transportation to producers - medium truck - 0.2127 kg CO2
- Fertilizer transportation to farmers (gasoline) - .7268 kg CO2
- Fertilizer transportation to farmers (diesel) - .6162 kg CO2

GHG of Coffee Production (Exportation)

- Farm to Coopedota w/ Diesel Average- 2.61 kg CO2 / liters of diesel
- Farm to Coopedota w/ Gasoline Average- 2. 23 kg de CO2 / liters of gasoline

Coffee Processing

GHG of Coffee Production

- Electricity consumption .0365 kg CO_2e / kWh
    - Coffee bean processing carried out in one facility and electricity usage for the following purposes

- Reception: for pumping water used to transport the coffee from the receiving tank to an elevated tank;
- Pulping: to feed the pulping machine and pumping water to the conveyor once the grains are pulped;
- Fermentation: to pump water and move the coffee from the fermentation pools to the pre-dryer
- Washing: to pump water
- Pre-drying: to feed the fans that carry heat to the coffee f. Drying: biomass is used to generate heat, but electricity is used to power machinery
- Storage: to transport the coffee to wooden silos and to feed the fans that control humidity in the metal silo
- Morteado: to drive the dehulling machine
- Classification: to feed the sorting machine
- Bagging: to transport the coffee beans to the roasting facilities k. Lighting used in the roasting facility
- Grinding: to grind coffee beans for sale

- Use of Combustibles
  - Back loader- 2.613 kg CO2 / liter
  - Dump truck- 2.613 kg CO_2e / liter
  - Liquid Petroleum gas - 1.611 kg CO2/ liter - petroleum liquid gas usage used to activate the roaster to provide a light, medium or dark roast

Appendix G - Calculations of Syngas and Electrical Energy

Coffee Cherry Pulp to Syngas

7,600 tons of coffee cherry residue (1 ton = 1,000 kg) wet
7,600 x .60 dry = 4,560 tons dry
4,560 tons dry= 4,560,000 kg

Syngas to KWh

kwh of electricity from syngas = calorific value of syngas * efficiency of generator * 0.278 kWh/MJ

5.1 MJ/kg x 17.5 x 0.278 kWh/MJ = 24.8115 kwh

Reed, T B, and Das, A. *Handbook of biomass downdraft gasifier engine systems.* United States:
N.p,. 1988. Web. doi:10.2172/5206099

Table comparison of composting vs. gasification of CO2 equivalence
Net zero carbon dioxide

Composting	After Gasification
0.058 - CH_4/ kg	0 - CH_4/ kg
1.5 CO_2/ kg	0 - CO_2/ kg

Appendix H - Biochar Production

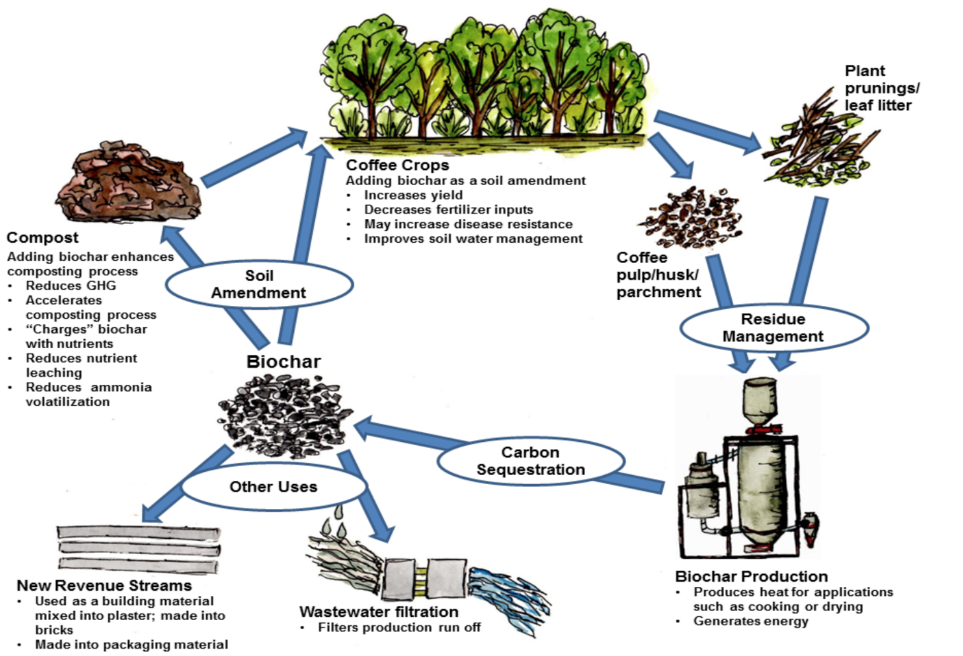


Figure 2: Biochar integration into a coffee production system, and potential impacts; source: Thayer Tomlinson, 2015

(Draper & Tomlinson, 2015)

References

2020 Certification Program. (n.d.). Rainforest Alliance. Retrieved April 5, 2022, from https://www.rainforest-alliance.org/for-business/2020-certification-program/

Arboreal - Tree height. (n.d.). App Store. Retrieved April 5, 2022, from https://apps.apple.com/us/app/arboreal-tree-height/id1444138299

Aristizábal-Marulanda, Valentina, et al. (2020) *Study of Biorefineries Based on Experimental Data: Production of Bioethanol, Biogas, Syngas, and Electricity Using Coffee-Cut Stems as Raw Material.* Environmental Science and Pollution Research, vol. 28, no. 19, pp. 24590–24604., doi:10.1007/s11356-020-09804-y.

Barbosa, V. (2011, June 30). *Ever wondered how much carbon is stored in a tree?* CABI Blogs. https://cabiblog.typepad.com/hand_picked/2011/06/ever-wondered-how-much-carbon-is-stored-in-a-tree.html

Castillo-Benavides, José Alberto, et al. (2014) "Revisión De Los Sistemas De Gasificación De Biomasa Para LA Generación De Energía EN Costa Rica DE 1982, ." *Revista Tecnología En Marcha*, 2018, doi:10.18845/tm.v31i4.3955.

Dal-Bó, Vanessa, et al. (2019) "Process Synthesis for Coffee Husks to Energy Using Hierarchical Approaches." *Renewable Energy*, vol. 142, pp. 195–206., doi:10.1016/j.renene.2019.04.089.

Draper K, Tomlinson T (2015) *How Biochar Can Improve Sustainability for Coffee Cultivation and Processing*, the Biochar Journal, Arbaz, Switzerland.ISSN 2297-1114 www.biochar-journal.org/en/ct/54. Version of 25 th February 2015. Accessed: 05.04.2022

Giraldi-Díaz, M.R.; De Medina-Salas, L.; Castillo-González, E.; León-Lira, R. (2018) Environmental Impact Associated with the Supply Chain and Production of Grounding and Roasting Coffee through Life Cycle Analysis. *Sustainability*, *10*, 4598. https://doi.org/10.3390/su10124598

How carbon is stored in trees and wood products.pdf. (n.d.). Retrieved April 5, 2022, from https://forestlearning.edu.au/images/resources/How%20carbon%20is%20stored%20in%20trees%20and%20wood%20products.pdf

Komilis, Dimitris P., and Robert K. Ham. (2004) "Life-Cycle Inventory of Municipal Solid Waste and Yard Waste Windrow Composting in the United States." *Journal of Environmental Engineering*, vol. 130, no. 11, pp. 1390–1400., doi:10.1061/(asce)0733-9372(2004)130:11(1390).

Limousy, Lionel, et al. (2019) "Chapter 11 Energy Applications of Coffee Processing by-Products." *Handbook of Coffee Processing by Products: Sustainable Applications*, by Charis M. Galanakis, Academic Press an Imprint of Elsevier, pp. 323–367.

Paniagua-Ramirez, A., Krupinska, O., Jagdeo, V., & Cooper, W. J. (2021). Carbon storage estimation in a secondary tropical forest at CIEE Sustainability Center, Monteverde, Costa Rica. *Scientific Reports*, *11*(1), 23464. https://doi.org/10.1038/s41598-021-03004-5

Parajuli, Prem B., et al. (2014) "Cost Analysis Model for Syngas Production Cost Evaluation Using the Graphical User Interface." *Energy and Power*, vol. 4, no. 2, pp. 35–40., doi:10.5923/j.ep.20140402.02.

Porensky, L. M., & Young, T. P. (2013). Edge-Effect Interactions in Fragmented and Patchy Landscapes. Conservation Biology, 27(3), 509–519. https://doi.org/10.1111/cobi.12042

Ramos-Hernández, Rocío, et al. (2021) "Evaluation of BIOENERGY Potential from Coffee Pulp Trough System Dynamics." *Renewable Energy*, vol. 165, pp. 863–877., doi:10.1016/j.renene.2020.11.040.

Random Number Generator Plus - Dice, Lotto, Coins 2.4.8 Download Android APK. (n.d.). Retrieved April 5, 2022, from https://rng-plus.en.aptoide.com/app

Rittl, Tatiana F., et al. (2021) "High Application Rates of Biochar to Mitigate N2O Emissions From a N-Fertilized Tropical Soil Under Warming Conditions." *Frontiers in Environmental Science*, vol. 8, no. URL https://www.frontiersin.org/article/10.3389/fenvs.2020.611873. Accessed 21 September 2021.

Reed, T B, and Das, A. (1998) *Handbook of biomass downdraft gasifier engine systems.* United States:
N.p,.Web. doi:10.2172/5206099

Ross, D. S., Knowles, M. E., Juillerat, J. I., Görres, J. H., Cogbill, C. V., Wilmot, S., & D'Agati, K. (2021). Interaction of land use history, earthworms, soil chemistry and tree species on soil carbon distribution in managed forests in Vermont, USA. *Forest Ecology and Management*, *489*, 119049. https://doi.org/10.1016/j.foreco.2021.119049

Sánchez-Monge, M. Protocolo de Establecimiento y Medición de Parcelas. Permanentes de Muestreo en Bosque Natural. Red de Parcelas Permanentes de Monitoreo de Ecosistemas

Forestales. INISEFOR (2011) (Translated by J. Moy, 2018; Protocol for the Establishment and Measurement of Permanent Sampling Plots in Natural Forest; For the Network of Permanent Plots for the Monitoring of Forest Ecosystems).

Silva, Valter, et al. (2014) "Analysis of Syngas Quality from Portuguese Biomasses: An Experimental and Numerical Study." *Energy & Fuels*, vol. 28, no. 9, 2014, pp. 5766–5777., doi:10.1021/ef500570t.

Tree species richness increases ecosystem carbon storage in subtropical forests | Proceedings of the Royal Society B: Biological Sciences. (2018, August 22). Retrieved April 5, 2022, from https://royalsocietypublishing.org/doi/full/10.1098/rspb.2018.1240

Wang, L., Weller, C. L., Jones, D. D., & Hanna, M. A. (2008). Contemporary issues in thermal gasification of biomass and its application to electricity and fuel production. Biomass and Bioenergy, 32(7), 573–581. https://doi.org/10.1016/j.biombioe.2007.12.007