Solving Coffee's Dirty Not-So-Little Secret

Opportunities for Upcycling and Recycling Coffee Fruit

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EXECUTIVE SUMMARY

In the 2018/2019 growing season, global coffee production hit 170 million bags (approximately 24 billion pounds) of coffee beans, with an estimated value of over $48US billion (International Coffee Organization, 2019).

Depending on the type of coffee consumed, a pound of coffee beans roasted for black coffee emits about 5 pounds of CO_2e (Killian, Rivera, Soto, & Nacichoc, 2013). Although large portion of these emissions are attributed to distribution channels and consumption, emissions from fertilizer use, decomposing organic matter, and organic matter in wastewater account for most of the emissions in the country of origin, ranging from 1.9-4 kg/co2e per kg of coffee beans (Killian, Rivera, Soto, & Nacichoc, 2013; Rikxoort, Schroth, Läderach, & Rodríguez-Sánchez, 2014; Brew Organic, n.d.). Progress has been made towards Fair Trade practices with lower environmental footprints, however less than half of coffee farms have adopted voluntary sustainable standards (International Institute for Sustainable Development, 2019).

In addition to the emission form the coffee production, there is a not so little dirty secret in the coffee industry: unused coffee by-product. There was almost 100 billion pounds of by-product created from the 170 million bags of coffee in 2018/2019 that could be used for food products, composting, or biogas (Janissen & Huynh, Chemical composion and value-added application of coffee industry products: A review, 2018) (Franca & Soares-Oliveira, 2009) (Chala, Oechsner, Latif, & Müller, 2018). Of that 100 billion pounds, approximately 58% of it was the nutrient rich coffee fruit. Left unmanaged, that 58 billion pounds of wasted coffee fruit could generate up to 14.2 million metrics tons of CO2e. That is equivalent to 15.6 billion pounds of coal burned or the emissions from 3 million passenger cars from an entire year.

In addition to composting on the coffee farm, current value-added products from the coffee fruit include consumer food products, biofuels, and feedstock for animals (Klingel, T. et. al. , 2020). By encouraging greater levels of upcycling and recycling of the coffee fruit by-product, health and environmental concerns can be converted into industry leading best-practices that maximize the 3 Ps of sustainable business: people, profits, and the planet.

By reducing the emissions with upcycled by-products in the coffee lifecycle and sustainable farming practices, farmers may have the opportunity to generate additional revenue streams, decrease costs, and improve crop yields. If best practices are widely adopted, there is an opportunity for the coffee industry to become a leader in carbon-neutral, zero-waste practices.

INTRODUCTION

170 million bags of coffee were produced in 2018/2019, up from 158 bags in 2017/2018 (International Coffee Organization, 2019), equal to approximately 24 billion pounds of coffee. In the past decade, coffee production has increased over 20% and the market is expected to continue to grow at an annual rate of 2.2% of the next decade (International Coffee Council, 2019).

As world-wide coffee production continues to increase to meet a growing demand, so do the environmentally harmful by-products of the coffee supply chain. While most coffee drinkers think of coffee grounds as the primary by-product of their morning cup of coffee, 120 billion pounds of coffee cherries were harvested to produce the 24.2 billion pounds of coffee in the 2018/2019 season. This left nearly 100 billion pounds of by-product throughout the production process, including 58 billion pounds of the nutrient rich coffee fruit (Chala, Oechsner, Latif, & Müller, 2018) (Didanna, 2014).

Although a portion of the coffee fruit by-product is composted, not all farmers practice efficient composting, leaving much of the coffee fruit by-product to rot in poorly managed composting pits or be discarded into waterways, harming water quality and decreasing biodiversity. There is great potential to decrease the carbon footprint while providing value-added products to consumers and increasing profits throughout the supply chain.

This white paper will address the opportunities and challenges of increasing coffee production by focusing on two themes:

- **Sustainable Growth:** Meeting the increasing global coffee demand is challenged by a warming planet and low-profit margins for coffee farmers. Finding ways to supplement farmer income, decrease financial and environmental costs, and increase coffee yield will be required to ensure sustainable income and production.

- **Environment:** Coffee's by-products have potential environmental and human harm if not responsibly managed. Although a large portion of coffee by-product is recycled into compost, what remains is waste that, left untouched, contributes to global warming, polluted waters, and causes potential health concerns.

- **Opportunity:** According to the International Coffee Council, over 100 million households depend on coffee for their livelihood and almost 80% of global production is on smallholder farms in less developed countries (International Coffee Council, 2019). The coffee industry has a unique opportunity to become both carbon-neutral and zero-waste with proper investment and upcycling. Biofuels, feedstock, nutrient rich foods and beverages, and fertilizer maximize usage of the coffee fruit remnants, and can provide additional income opportunities for coffee farmers.

COFFEE FRUT BY THE NUMBERS

There is amble opportunity to maximize the revenue to farmers in upcycling the coffee fruit, while decreasing harmful greenhouse gases caused by wasted by-products. To produce the 24 billion pounds of coffee beans exported in 2018/2019, an estimated 58 billion pounds of coffee fruit is left as a by-product.

If not upcycled or recycled correctly, that 58 billion pounds could emit 14.2 million metric tons of CO_2e, which is equivalent to 35 billion miles driven by a car – enough to circle the global almost 1.4 million times (EPA, Greenhouse Gas Equivalencies Calculator, 2017). Just 5% of the food-grade coffee fruit is estimated to be sold (Thorton, 2020), leaving 54 billion pounds of coffee fruit to manage through additional consumer product supply chains, composting opportunities, and biofuel use. If the consumer market is maximized, an additional $261 million in revenue could be generated by coffee producing counties.

SUSTAINABLE GROWTH

As coffee consumption increases, there are two primary ways to meet demand: convert more forested land to agricultural land or increase yields of the coffee fruit. Coffee producing countries are already facing the risk of losing productive farmlands due to climate change and converting forested lands into coffee farms adds greater stress on the environment by limiting CO_2 sequestration. Therefore, increasing yields for coffee through smarter and more sustainable farming practices is the only feasible path to meet the growing demand. There is also the potential to increase coffee farmer revenue streams by upcycling coffee by-products that would otherwise go to waste.

Climate Change and Coffee

Wealthier, more developed countries tend to have the highest consumption rates of coffee, while less-developed nations tend to be the highest producers of coffee beans. While many consumers feel their coffee is essential to start the day, coffee's economic impact is vital to small farms around the world. However, the livelihoods of small farmers are being threatened more each year.

Coffee growing regions are bound by a limited temperature zone, with Arabica coffee beans thriving best in the heat sensitive subtropical highlands near the equator. As the climate grows warmer, these farmlands are at great risk of becoming unproductive, with an estimated 43% of the land becoming unfarmable by 2050 even with emissions cuts to limit warming temperatures. Lower quality Robusta coffee is more tolerant of warmer conditions, but with ideal conditions at 10° North and South of the equator, extreme weather events are a concern (International Institute for Sustainable Development, 2019) (International Coffee Council, 2019).

Low wages and a warming climate are beginning to decrease the number of coffee plantations. In just 18 months, from 2018-2019, over 100,000 acres of coffee plantations were lost in Colombia, about 4% of the nation's farmland (Schiffman, 2019). As some farmers cannot earn a profit and seek better paying jobs, climate change is also impacting farms. In the Colombian farming region, the temperature is increasing 0.3 degrees Celsius (0.5 degrees Fahrenheit) every decade. Extended draughts and heavy rains have caused topsoil erosion, a large threat to the coffee growers. With approximately 80% of coffee being grown on small farms (under 5 hectares), farmers have limited resources to invest in new technology or machinery to update their practices.

A solution to this challenge is to identify ways to minimize the impact of the coffee by-products on the environment, while increasing revenue and coffee yields for farmers.

ENVIRONMENT

Greenhouse Gas emissions, polluted waterways, and loss of biodiversity are just a few of the environmental concerns that come from multiple sources in the coffee production process.

The coffee bean only makes up 20% of the weight of the coffee fruit when it is picked from the tree (Mutua, 2000). The 'waste' is fruit rich in nutrients that could be used for compost, biofuel, food products, fertilizer, and feedstock. However, this excess fruit provides an environmental challenge, as its high levels of caffeine, tannins, and chlorogenic acid must be reduced before it is suitable for use as an upcycled or recycled product.

The coffee lifecycle impact is heavily determined by the processing method. Coffee production has six major steps. Growing the cherry, harvesting cherries from trees, processing the cherries to extract the coffee bean (seed), transporting the seed to roasters, and then roasting and consuming/brewing the coffee. While transportation from coffee producing regions to coffee consuming countries employs diesel- and gas-powered engines, processing the coffee fruit and managing the remaining by-products contribute to several environmental concerns.

Table 1 shows the by-products are each stage of processing.

Table 1: By-products are each stage of coffee bean processing.

	Dry Processing		Wet Processing		
Step	De-hulling		Pulping	Fermentation & Washing	Drying
By-product	Cherry fruit (husks)		Coffee fruit (skins and pulp)	Mucilage and wastewater combined with organic matter	Parchment
Possible environmental impact	CH4 (methane) from improper waste management		Damage to waterways caused from high chemical and biological oxygen demand without proper treatment. CH_4 (methane) from improper waste management. Acidic water damaging to plants and animals.		

Impact to Water Sources and Biodiversity

Wet processing leaves over 3 tons of wet pulp by-product for every 1 ton of harvest coffee beans. This is in addition to the large amount wastewater containing organic waste that, in these large quantities, is harmful to wildlife. The effluent left from the fermentation and washing processes is acidic (pH below 4) and contains a high concentration of organic matter and suspended solids from the pulp, mucilage, and parchment (Beyene A, Kassahun Y, Addis T, et al., 2012).

Oxygen is depleted in water due to excess organic matter being introduced.

The pollution and biodiversity loss are due to a high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the organic material (the coffee fruit) left in coffee wastewater. BOD represents the amount of oxygen consumed by bacteria and other microorganisms as they decompose organic matter. Since the bacteria use the oxygen in the water there is less oxygen available for aquatic life (Beyene A, Kassahun Y, Addis T, et al., 2012) (Chala, Oechsner, Latif, & Müller, 2018) (Enden & Calvert, 2010).

BOD measures the quantity of oxygen required to oxidize all organic material into carbon dioxide and water. The higher the BOD, the less oxygen available for aquatic plants and animals. BOD from wastewater from coffee processing has been measured between 1,000 mg/l and 20,000 mg/l; WHO's guidelines are 100 mg/L for discharged water. The COD measures all chemicals (organic and inorganic) in the water and has been measured between 22,000 mg/l and 50,000 mg/l (Enden & Calvert, 2010). The World Health Organization (WHO) outlines a permissible limit of 300 mg/L for discharged water (World Health Organization, 2011).

Figure 3: Biological Oxygen Demand Impact on Aquatic Animals

The exponentially larger BOD and COD levels in coffee wastewater inhibit biodiversity and can cause nearly 100% deoxygenation of rivers. While the off-season provides time for the water to recover, the same study found that “pollution sensitive” aquatic life fails to survive (Beyene A, Kassahun Y, Addis T, et al., 2012).

Coffee waste, when not responsibly managed, can leach into nearby soil and water sources.

Acid Conditions causes nutritional deficits in Soil and Water

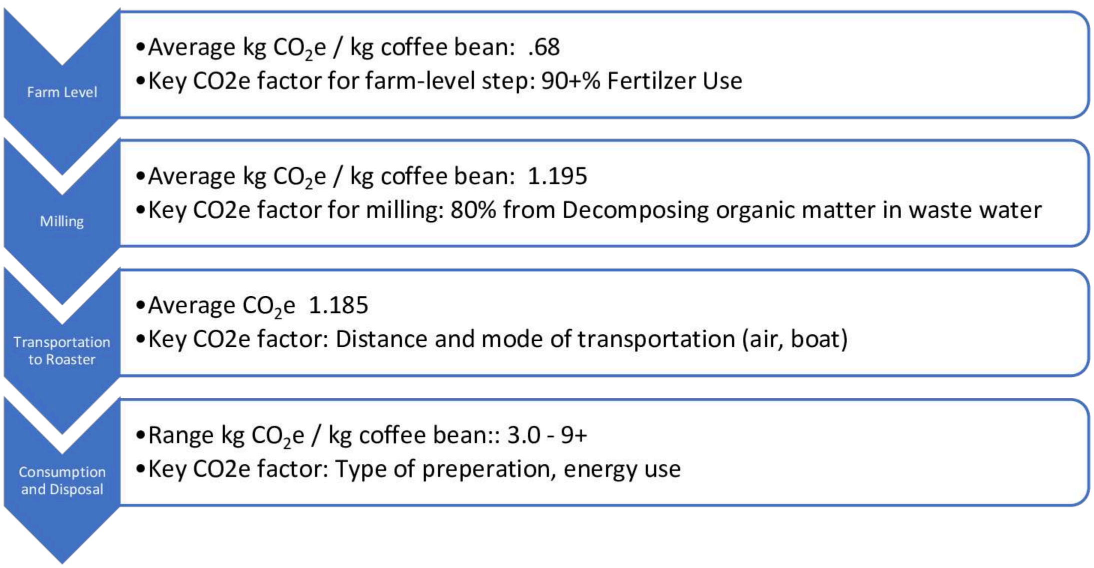
The nature of the coffee fruit is highly acidic, and the acidity of wastewater is often measured below 4.0 pH, while the WHO recommended wastewater discharge is between 6.8 − 8.5 (lower pH levels indicate more acidic water). The pH levels combined with the COD and BOD levels have been found to cause skin irritation, stomach problems, nausea, and breathing difficulties for citizens living near the polluted waterways (Haddis A, Devi R., 2008). During the producing season, the pH was low enough to reduce the water source pollution from 7.0 to 6.2 (Beyene A, Kassahun Y, Addis T, et al., 2012) Additionally, under acidic soil conditions, phosphorus, calcium, and magnesium can become unavailable due to an overabundance of aluminum and manganese. If wastewater leeches into the soil, the abundance of aluminum in low pH levels may limit the ability of a coffee tree to extract water and other nutrients.

Caffeine and Polyphenols can Negatively Impact Aquatic Life

The health benefits derived from roasted coffee by the end consumer can be an environmental concern when unmanaged or in high levels for wildlife. Green coffee beans contain a high level of polyphenols, like tannins, which have been found to contain antioxidants, reduce cardiovascular disease, provide anti-inflammatory properties, and help with weight management. However, they also degrade much slower than other soil organic matter (SOM). Because of the slow biodegradability of polyphenols, they tend to remain in the environment for lengthier periods of time, and cause concerns with the speed organic matter can decompose, potentially limiting the opportunity for composting coffee fruit pulp. Along the same lines, while caffeine has been shown to improve cognitive function in aquatic life and mammals, caffeine can result in reduced fertility and juvenile growth (Janissen & Huynh, Chemical composition and value-adding applications of coffee industry by-products: A review., 2017).

Known Methane Emissions During the Production Cycle

Depending on the type of coffee consumed, the average CO_2e for a serving of coffee is between 21 grams of CO_2e and 150 g CO_2e (PCF Pilot Project, 2009; Hassard, Couch, Techa-erawan, & Mclellan, 2014). While recommendations on standardized approaches to calculate GHG emissions in the coffee lifecycle exist (Sevenster & Verhagen, 2010), the large range of CO_2e emitted is based on farming technique, distance traveled, and how the coffee bean is prepared for the consumer (black coffee, espresso, instant). The ranges are also driven by the diverse practices and standards between countries. There is consensus on the largest drivers of CO2e at various stages of production and consumption (figure 2 based on (Killian, Rivera, Soto, & Nacichoc, 2013).



Most emissions at the farm level come from fertilizer use; one study in Costa Rica found that .96 kg co2e per kg of the total release of 1.02 kg CO_2e per kg of beans produced at the farm level came from fertilizer use. Multiple research projects have found similar impact of agrochemicals (Pramulya, Bantacut, Noor, & Yani, 2019) (Killian, Rivera, Soto, & Nacichoc, 2013). At the milling stage, the overwhelming cause of emissions are from organic biomass decomposing in wastewater. While many studies include wastewater and decomposition from organic matter in the overall CO_2e models for coffee, there is large variation in management techniques of waste, leading to potentially under-counting CO_2e on non-treatment farms.

Depending on the farming type, the farm level and milling process in Latin America range from .62-1.08 kg CO2e / kg of coffee beans (Rikxoort, Schroth, Läderach, & Rodríguez-Sánchez, 2014).

The carbon footprint continues to build once the coffee fruit is a 'bean' and ready to ship to the roaster's destination. Distance of travel and mode of transportation from the country of origin to the roaster averages about the same as the milling process, while the roasting, consumption, and disposal of used coffee beans adds the largest carbon footprint. The emissions from the coffee lifecycle do not account for soil erosion, biodiversity loss, and a decreasing carbon sink caused by deforestation to create farms, nor the carbon sink of well-managed, multi-crop soil on coffee farms. (Sevenster & Verhagen, 2010)

The environmental impact of coffee processing waste and coffee quickly adds up. By decreasing fertilizer use, reducing organic matter left to decompose, and rethinking preparation of coffee, the footprint of coffee would fall dramatically.

OPPORTUNITY: REDUCING EMISSION THROUGH RECYCLING AND UPCYCLING COFFEE FRUIT

If the remnants of the coffee fruit processing were left in an untended landfill, the CO_2e emissions would reach 14.2 million metric tons each year. That is equivalent to 15.6 billion pounds of coal burned or the emissions from 3 million passenger cars from an entire year. Unfortunately, a common practice is to dig a hole for the waste or simply let it flow into waterways.

Compost

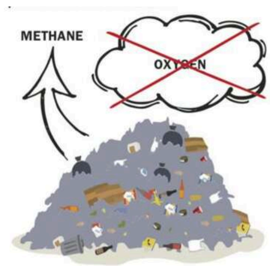
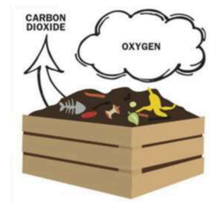
Digging a hole for the coffee fruit to rot will generate .54 kg CO_2e/kg. of fruit, more than two times that of a poorly managed compost pile, and over 25 times that of a well-managed compost pile (EPA, Archived Document: Documentation for Greenhouse Gas Emission and Energy Factors Use in Waste Reduction Model (WARM), 2015) (Brown, 2013). One of the least expensive approaches to minimizing both high BOD/COD organic matter in wastewater and emissions from waste is composting. Composting is a large opportunity since not all farmers use organic compost in their fields and the use of compost would not only reduce synthetic fertilize use (the highest emissions category in coffee farming), but could also help increase carbon sequestration (Nistor, et al., 2018). The cherry waste is essentially a "free" raw material to the farmer and has the potential to replace about 20% of nutrients taken from soil. Husks from dry processed coffee cherries have shown to greatly improve soil fertility (Zoca, S. et. al, 2014). Composting would help decrease soil erosions while limiting synthetic fertilizer use, potentially increasing crop yields.

However, composting is not a silver bullet for coffee waste. Adoption rate, labor, proper management, and relatively slow rate of biodegradability for polyphenols in the coffee fruit all limit how widespread may be the adoption of organic compost. While there is no data on the percentage of composting amongst coffee farmers, in 2016, 34.5% of coffee producers had adopted voluntary sustainable standards (VSS) according to the International Institute for Sustainable Development (International Institute for Sustainable Development, 2019), and an additional 21.4% were potentially VSS compliant. While the sustainability of farms is a positive trend, 44% of farms are still considered conventional farms which follow no sustainable land practices and often use environmentally damaging synthetic fertilizer to increase yield.

Coffee by-products have been used to cultivate mushrooms for over 30 years with promising results and the option to reuse the remaining substance as fertilizer for other crops (Blinova, L, 2017). Labor costs could be prohibitive in correctly managing coffee compost piles as turning the pile is crucial to avoid anaerobic activity as poorly managed piles can emit .21 CO_2e kg. per kg. of waste and managed piles only emit a tenth of that, .02kg. CO_2e/kg. of fruit (Brown, 2013).

Biochar and Composting

Biochar may be an alternative to traditional composting of coffee by-products. Biochar is created using a process called pyrolysis, where organic waste is heated in a biochar oven, producing material that helps to lock carbon into the soil when used as an amendment. Biochar as compost may be able to fix the damage to topsoil from floods and improve the soil's ability to retain nutrients. However, due to over 50% moisture in pulp, converting it to biochar could be a challenge. The husks removed through dry processing and parchment's high lignin and low moisture content make it a more likely candidate for biochar. Dry processing only accounts for 20% of overall coffee production and the parchment represents 12% of the total weight of the coffee fruit; if these two products were converted into biochar, the environmental concerns from wet processed pulp and mucilage would not yet be reduced (Draper & Tomlinson, 2015). Biochar could be a potential revenue stream for coffee farmers and centralized mills, as it has successfully been used in building materials.

	Landfill	**Compost**
		
Total emitted CO2e lb. / lb. of fruit	.54	.007 - .02
Total CO2e for 54 Million lbs. of cherry fruit	13.4 million metric tons	383k – 1095k metric tons

Animal Feed

Using coffee pulp and hulls as animal feed has been successful in some studies, however using coffee by-products have also been shown to be harmful when used as feedstock. Most success stories have shown a maximum of 10-15% coffee by-product to be non-toxic to animals, although some animals have shown negative effects with less than a 10% replacement of tradition feedstock with pulp due to caffeine levels. Farmers may use coffee husks and pulp on their own farms for animal feed or add an additional revenue stream to farmers.

The caffeine content, tannins and alkaloids are the limiting factor. While fermentation, drying, and chemical processes have been shown to decrease caffeine and tannin levels, these processes may not be scalable to small farmers (Didanna, 2014).

Biofuels

Biofuels have shown great promise in displacing fossil fuels used in the milling process and provide excellent potential for capturing emissions from wastewater. Biogas is created when the methane that would be released from landfills of coffee waste is captured and reused. Methane production for biogas is most promising in mucilage, followed by pulp and husks. One study determined that if biogas is captured on farms in Ethiopia, it would generate 238,000 MWh of electricity (the equivalent to the emissions from 185,416,537 pounds of coal) and 273,000 MWh of thermal energy (Chala, Oechsner, Latif, & Müller, 2018).

This energy would be enough to complete all coffee processing activities without dependence on fossil fuels. Bioethanol is also a possible recycled product from coffee wastes: Coffee husks have a high carbohydrate content, and have potential to generate higher levels of ethanol than corn stocks; coffee husks have generated 13.6 g/l and corn stalks 5 g/l.

While new technologies and pre-treatment approaches are making biogas a feasible option for small-scale farmers, the upfront costs of machinery and technical knowledge may be a hindering factor in wide acceptance. Since coffee is seasonal, farmers must find ways to maximize machinery and ROI during off-season, which may be done more efficiently on multi-crop farms.

If technology invest and education is available to small and mid-sized farms, coffee production by-products would stay out of waterways and reduce the carbon footprint of processing. Additionally, biofuels could reduce the costs of diesel and fossil fuels, creating a higher profit-margin for farmers.

Consumer food and drink products

Several products are being seen as potential by-products of the coffee fruit, some novel products like energy drinks and flower, and other products like tea that have been consumed for centuries (Klingel, T. et. al. , 2020). The coffee fruit pulp and skin have potential to be used for human consumption as well. In its raw state, the remaining coffee fruit is high in soluble dietary fiber, plant-based proteins, and antioxidants. Studies have found initial indications that the coffee fruit extract could help improve the immune system and improve brain function (Kobayashi T,et. al, 1996).

While more research is needed on the health benefits of coffee fruit, the nutritional values are often higher than the coffee bean itself. 100g of Cascara fruit contains 50% of the recommended daily intake of Biotin and Vitamin E, 35g of fiber, and 6.15g of protein, with less than 1g of fat. For consumers who are caffeine intolerant, caffeine levels are about a 1/3 of coffee. Products currently on the market include drinks and teas, flour containing dried portions of coffee cherries, chocolate, and energy bars. Coffee fruit drinks (Riff) provide alternatives to coffee which will limit the need for continued growth in coffee production on the shrinking available land by making use of the readily available raw materials. (Klingel, T., et. al., 2020)

Selling the coffee fruit to a manufacturer would increase the farmer's revenue. Many farmers make less than $3-4 a day, and 100 pounds of coffee fruit can be sold for $3.00. With more environmentally friendly shade trees producing 450-900 pounds per acre, a small farmer with just 10 hectares (24.7 acres) could potentially earn additional revenue of anywhere from $300 to over $600 each year, in some cases increasing their income by 50%.

Like all consumables, the coffee fruit must be safe for human consumption. The coffee fruit skin must be immediately dried to prevent spoilage. With the inconsistent regulations for coffee production across the globe, the largest challenge for the food industry will be to ensure a consistently food-grade safe material for use. Additional research and certified food safety testing could help create a nutritional product for mass consumption within the coffee producing country and globally.

Coffee Fruit Product Opportunities

Consumables

- Added Revenue for Farmers
- Decreased GHG emissions generated from wasted fruit.
- Need to ensure consumer-safe product.
- Added emissions from transportation and production.

Compost

- Limits or elminates fertilizer needed for fields.
- Increases coffee yields while not increasing costs.
- Decreases GHG emissions by about 96% if managed propoerly.
- Can be labor intensive to manage compost correctly.

Biofuels / Biogas

- Decreases in emissions from fruit piles
- Decreases use of fossil fuels
- Increase expense in machinery
- Must find altenrative organic materials to ensure year-round use

Animal Feed

- Limits cost of feeding livestock or can increase revenue from sale of fruit.
- Must be decaffinated and used sparingly to avoid health concerns in livestock.

CONCLUSION

In the past decade, coffee production has increased over 20%. However rising temperatures are putting farmable lands and crop yields at risk. This combined with the challenging financial position coffee farmers face every day, creates an urgent need for sustainable solutions that can alleviate both climate concerns and the economic well-being of farmers. Upcycling and recycling the waste generated by the production and consumption of coffee reduces the large amount of the deadly waste that occurs when disposing of the fruit during the traditional coffee lifecycle. Coffee fruit by-products will add value to the nutrient-rich fruit often left to rot away in waterways.

From a sustainability perspective, discarded coffee fruit has deadly consequence. If the waste is irresponsibility managed, the coffee fruit by-products can emit methane in landfills or limit oxygen available for aquatic life in waterway. Caffeine, antioxidants, and tannins are both advantages and risks that must be managed appropriately when upcycling coffee by-products.

By utilizing the coffee fruit, instead of discarding it, improvements to the planet, people, and profits are obvious. Reduced or avoided greenhouse gas emissions from landfills or unmanaged waste means methane emission is limited and the acidity in soil and water is mitigated. By creating a market for the coffee fruit, more jobs could be created at coffee plantations and there is increased revenue with little expense for farmers, as the “waste” pays $.03 per pound. If handled correctly, the nutritional value of the coffee fruit could create a source for plant-based protein and antioxidants which can be used in energy drinks or foods or used to help alleviate hunger in coffee producing countries.

There is more than enough to coffee fruit waste to maximize profits for farmers through selling the crop for consumer goods, decreasing costs through biofuel conversation, and increasing yields through compost.

Many of these solutions require investment and a collaborative industry approach. If this investment can be made for the greater good of the coffee industry, utilizing the coffee fruit for upcycled consumer products, compost, biofuel, or animal fed stops environmental concerns before they start by immediately harnessing the power of the coffee fruit.

WORKS CITED

Beyene A, Kassahun Y, Addis T, et al. (2012, November). The impact of traditional coffee processing on river water quality in Ethiopia and the urgency of adopting sound environmental practices. *Environ Monit Assess*, pp. 7053-7063. doi:10.1007/s10661-011-2479-7

Blinova, L. (2017). Review: Utilization of Waste From Coffee Production. *Research Papers Faculty of Materials Science and Technology Slovak University of Technology*. doi:10.1515/rput-2017-0011

Brew Organic. (n.d.). *The Carbon Footprint Of Tea & Coffee – Farm To Cup*. Retrieved from https://www.breworganic.com/coffee-environmental-impact/#1-the-carbon-footprint-of-the-tea-and-coffee-supply-chain-up-to-consumption%C2%A0

Brown, S. (2013). Connection: Climate Calculations. *BioCycle, 54*(6), 52.

Chala, B., Oechsner, H., Latif, S., & Müller, J. (2018, July). Biogas Potential of Coffee Processing Waste. *Sustainability*. doi:10.13140/RG.2.2.21430.96326

Didanna, H. L. (2014). *A critical review on feed value of coffee waste for livestock feeding.*

Draper, K., & Tomlinson, T. (2015). *The Potential for Biochar to Deliver Greater*. Ithaka Institute and International Biochar Initiative.

Durrel, K. (2019, December 13). Coffee cherry antioxidants: Testing uncovers broader benefits of upcycling the coffee bean fruit. *Nutrition Insight*.

Enden, J., & Calvert, K. (2010). Review of coffee wastewater characteristics and approaches to treatment.

EPA. (2015). *Archived Document: Documentation for Greenhouse Gas Emission and Energy Factors Use in Waste Reduction Model (WARM).* Washtingon, DC: EPA. Retrieved from https://archive.epa.gov/epawaste/conserve/tools/warm/pdfs/WARM_Documentation.pdf

EPA. (2017). *Greenhouse Gas Equivalencies Calculator*. (EPA WebArchive EPA, US Government) Retrieved from https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Franca, A., & Soares-Oliveira, L. (2009). Feasibility of ethanol production from coffee husks. *Biotechnology Letters*.

Haddis A, Devi R. (2008). Effect of effluent generated from coffee processing plant on the water bodies and human health in its vicinity. *Hazard Mater*, pp. 259-262. doi:10.1016/j.jhazmat.2007.06.094

Hassard, H., Couch, M., Techa-erawan, T., & Mclellan, B. (2014). Product carbon footprint and energy analysis of alternative coffee products in Japan. *Journal of Cleaner Production, 73*, 310-321. doi:10.1016/j.jclepro.2014.02.006.

International Coffee Council. (2019). *Coffee Development Report.*

International Coffee Organization. (2019). 2018/19 Marks Second Consecutive Year of Surplus. Retrieved from http://www.ico.org/#:~:text=2018%2F19%20Marks%20Second%20Consecutive,6.7%25%20to%2066.04%20million%20bags.

International Institute for Sustainable Development. (2019). *Global Market Report: Coffee.* https://www.iisd.org/sites/default/files/publications/ssi-global-market-report-coffee.pdf.

Janissen, B., & Huynh, T. (2017, October). Chemical composition and value-adding applications of coffee industry by-products: A review. *Resources Conservation and Recycling*, pp. 110-117. doi:10.1016/j.resconrec.2017.10.001.

Janissen, B., & Huynh, T. (2018). Chemical composion and value-added application of coffee industry products: A review. *Resources, Conservation & Recycling, 128*, 110-117.

Killian, B., Rivera, L., Soto, M., & Nacichoc, D. (2013, November). Carbon Footprint Across the Coffee Supply Chain:The Case of Costa Rican Coffee. *Journal of Agricultural Science and Technology*, 151-170. doi:10.17265/2161-6264/2013.03B.001

Klingel, T. et. al. . (2020). A Review of Coffee By-Products Including Leaf, Flower, Cherry, Husk, Silver Skin, and Spent Grounds as Novel Foods within the European Union. *Foods, 9*(5), 665.

Klingel, T., et. al. (2020). A Review of Coffee By-Products Including Leaf,. *Foods*.

Kobayashi T,et. al. (1996). Effects of coffee cherry on the immune system in SHN mice. . *Anticancer Research, 16*(4A), 1827-1830.

Mutua, J. (2000). *Post Harvest Handling and Processing of Coffee in African Countries.* Rome: FAO, AGSI.

Nistor, E., Dobrei, A. G., Dobrei, A., Carmen, D., Sala, F., & Prundeanu, H. (2018). N2O, CO2, Production, and C Sequestration in Vineyards: a Review. *Water Air and Soil Pollution, 229*. doi:10.1007/s11270-018-3942-7

PCF Pilot Project. (2009). Case Study: TCHIBO Private Kaffee Rarity Machare. Retrieved from http://www.pcf-projekt.de/files/1232962944/pcf_tchibo_coffee.pdf

Pramulya, R., Bantacut, T., Noor, E., & Yani, M. (2019, December). Carbon Footprint Calculation For Gayo Arabica. *INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH, 8*(12). Retrieved from http://www.ijstr.org/final-print/dec2019/Carbon-Footprint-Calculation-For-Gayo-Arabica-Coffee-Primer-Processing.pdf

Rikxoort, H. v., Schroth, G., Läderach, P., & Rodríguez-Sánchez, B. (2014). Carbon footprints and carbon stocks reveal climate-friendly coffee production. *Agronomy for Sustainable Development, 34*(4), 887-897. doi:10.1007/s13593-014-0223-8

Schiffman, R. (2019, July 11). As Climate Changes, Colombia's Small Coffee Farmers Pay the Price. *Yale Environment 360*. Retrieved from https://e360.yale.edu/features/as-climate-changes-colombias-small-coffee-farmers-pay-the-price

Sevenster, M., & Verhagen, V. (2010, November). *GHG emissions of green coffee: Toward a standard methodology.*

Stylianou, N., Guibourg, C., & Briggs, H. (2019). *Climate change food calculator: What's your diet's carbon footprint?* https://www.bbc.co.uk/news/science-environment-46459714: BBC.

Thorton, P. (2020, April 29). Personal Interview.

World Health Organization. (2011). *Guidelines for Drinking Water Quality.* Water Sanitation and Health. World Health Organization. Retrieved from https://www.who.int/water_sanitation_health/publications/2011/9789241548151_ch12.pdf

Zoca, S. et. al. (2014). Coffee processing residues as a soil potassium amendment. *International Journal of Recycling of Organic Waste in Agriculture, 3*, 155-164. Retrieved from https://doi.org/10.1007/s40093-014-0078-7