Energy 395 – Bass Connections in Energy: Innovation and Design

Land Footprint Calculator

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Table of Contents

Executive Summary
Introduction
Approach / Methodology
Technical Design
Calculator Prototype
Land Area Data9
Harvest Coffee Land Area Data10
Burlap Sack Data
Export and Domestic Consumption Coffee Data11
Kilograms of Coffee Produced by Country11
Geospatial Mapping of Coffee Land Area12
Methodology12
Tree Cover Density
Geospatial Analysis16
Tableau Map and Dashboard
Setting up a User Interface16
Environmental Benefit Analysis
Land Use Impacts due to Agriculture
Coffee Land Use/Intensity
Social Benefit Analysis
Target Market Analysis
Basic Business Plan
Current Implementation
Cost of Development
Future Business Opportunities
Recommendations for Future Work
Appendix A: Decision Matrix
Works Cited

Executive Summary

The amount of land used throughout the production process of a single product currently remains an invisible externality. The following paper details the development of a Land Footprint Calculator, which accounts for the total land footprint of a particular product, in order to shed light on the role consumptive and productive habits have on local ecology. A land footprint is the aggregate amount of land area in hectares used throughout a product's supply chain. The land use calculator developed out of a particular case study on the coffee industry. The coffee industry was chosen for its land use impact, abundance in everyday life, supply chain generalizability, and data availability. Data was taken from global import and export data to calculate the average land use per kilogram of coffee produced as well as the price per kilogram in each coffee-producing country. The amount of eligible land in for coffee growth is based on ArcGIS data considering average air temperatures, precipitation, and elevation. The resulting Land Footprint Calculator take dollars spent and country of origin as inputs and outputs the total land used in hectares and an overall 'score.' The score is a number out of 100 reflecting the relative ecological friendliness of the purchase based on land use practices related to the purchase. The score and total land use are accompanied by a country map and a breakdown of the land use by supply chain contributors. The resulting dashboard informs the consumer or producer of the impacts on global land use on a regional scale. A fully developed calculator will consider all levels of a products supply chain in order to produce an accurate reflection of a products impact. Additionally, applications of the calculator could enable offset implementation to counteract land use.

Introduction

Changing the characteristics of land has a long list of negative externalities. These negative externalities are invisible, resulting in uneducated consumption and production habits. When a forest is changed into cropland, the resulting changes in hydrology result in increased runoff which exacerbates erosion. Additionally, cultivating crops inherently decreases the amount of biodiversity on the land. This also decreases the degree in which soil is held together via roots leading to increased erosion as well as the destruction of habitats for local fauna. Deforestation also decreases the amount of carbon dioxide stored in the land as well as results in denitrification. Overall, the use of land has a myriad of negative, long-lasting impacts, all of which contribute to global climate change. Additionally, land characteristics vary, and specific uses of land require specific characteristics; in this way land of a particular use is a limited resource. The importance of land conservation cannot be overstated. Yet, the current free market economy does not account for land exhaustion. One company, Carbon Analytics, is attempting to account for these environmental externalities through the development of a series of calculators serving to help tie the exact monetary cost equivalent to the environmental impact of a good or service. The conversion to the currency standard allows a metric with which economies can reconcile the true cost of the product with the market price.

In the field of market analysis, a critical portion of the Triple-Bottom line is drastically underrepresented. Economics accounts for a large portion. Social benefits are slowly being integrated into businesses; however, the economic consequences of environmental impacts largely remain missing from the picture. Though some companies utilize greener practices, it is only possible to market these more sustainable products if the company can obtain very specific standards and inspections, such as "organic" or "fair trade." Additionally, if a sustainable practice result in reduced profit, many companies will discontinue it. There is no direct economic conversion from environmental impact to the true cost of the good or service, meaning companies are not incentivized to maximize environmental friendliness.

Holding culpable parties responsible for their own land exhaustion, a land use calculator confronts both consumers and producers with a visible metric of the impacts of decisions. Through explicit visualization, consumers are given an additional metric with which to weigh into their consumer habits. Currently, destruction of natural environments and ecosystems due to economic activities is largely invisible to the consumer, leading to ill-informed purchases. These purchases provide a basis by which producers continue to exhaust resources without repercussions. Providing both consumers and producers with a visible link between their personal actions and their direct impacts promotes a sense of culpability. This culpability provides an avenue for change.

In order to develop strategies for future expansion, the coffee industry served as an ideal starting point for several reasons. First, coffee has a relatively high land footprint. Coffee is number six in the world in terms of land use per kilogram at $21.62 \text{ m}^2/\text{kg}$ making it an industry with a high land use impact (Ritchie & Roser, 2020). Additionally, coffee is a highly visible product. All around the world, millions drink coffee every day. This abundance suggests a large group of individuals who would be interested in the calculator's results. In terms of development, the coffee industry also presents a couple key advantages. The coffee industry already has a general sense of environmentalism, demonstrated through accountability mechanisms such as 'fair trade' and other certifications. These encourage visibility and transparency within the industry, which in term provides data. This data aided the development of a land use calculator which took into account coffee growth practices. Finally, coffee has a relatively simply first layer supply chain which allowed for considerations from multiple feeder industries without the need for multitudes of data. Due to its many benefits, the coffee industry served as a good starting point for the basis of this developmental land use calculator, that can in turn be translated into other industries.

The incorporation of land use into the free market as a market externality will shed light on the previously invisible consequence of consumption and production. This increased visibility will naturally lead to increased awareness and education of consumers, producers, and sellers of their own culpability in the global land destruction. Hopefully, this culpability will lead to accountability through pressure from consumers as well as pressure through industry standards. That accountability brings about change in practice and slowly leads to conservation and prevention of further losses.

Approach / Methodology

The first step of the Land Footprint calculator was to define the project scope. The scope of the analysis was limited to a single industry, which still proves to be extensive in its complete supply chain composition. Thus, the focus of the calculator was on depth rather than breadth. The industries that were considered for further development included coffee, chocolate, poultry, beef, dairy, airlines, and tech manufacturing. These were considered as a set of possibilities that would demonstrate various supply chain depths and a variety of production processes in order to give a more complete thought process to further deliberations.

The most important criteria in determining which industry would be studied at depth was information availability. The availability and accessibility of data on each industry's supply chain was critical to the success of the project. An industry with little available data would be impossible to construct a calculator from and would fail the goals of the project. The second most important factor was generalizability. Secondary only to being able to make the calculator, the calculator also had to be useful and reproducible. A calculator for a niche product, hidden far from the common consumer's eyes, would effect little change. The impact of an environmental land footprint calculator relies on core principles that are intuitive and popular, and thus the generalizability of the industry and the resulting ability of the consumer to envision the land impact of their purchase, was critical. Generalizability also included the ability of the calculator to be adapted for other industries in the future, and thus increase the impact of the project.

Next in importance was quantifiable land impact, or the ease at which the available data could be transformed into a reasonable land use footprint. Industries with established criteria for assessing environmental impacts, such as coffee and beef, ranked highly. Despite having little standard metric for total land use, these industries have procedures for environmental analysis that would form the first steps of the calculator and would lend legitimacy to further analysis. The fourth criterion was the approximate time it would take to create a calculator for that supply chain. This was based roughly on data availability and theoretical ease of transforming that data into a land footprint, and higher scores meant a timeline fitting more comfortably within the academic year.

Since business cooperation was necessary as well, potential for clients and public perception was also included as criteria. The client criteria were strongly based on Carbon

Analytics existing client base and future clients who wanted to see a land footprint version. Public perception was based on what consumer awareness would be if a land footprint measure were published with the product. Products that were commonly purchased, or had environmental standards already associated with them and that were proven to influence purchase were more highly ranked. Lastly, a parameter was included as 'fun' that marked the team's interest in addressing each industry.

Coffee	8.15
Chocolate	7.15
Poultry	6.32
Beef	5.67
Dairy	7.42
Airline	5.72
Tech Manufacture	5.82

Table 1. Weighted sum for each considered industry (10.0 maximum).

An abbreviated version of the weighted decision matrix, showing just the final scores each considered industry, is shown above in Table 1. Based on the results of the decision matrix, the coffee industry was selected for further study, performing exceptionally well in data availability and quantifiable land impact.

Technical Design

Calculator Prototype

In order to make a comprehensive land footprint calculator of the coffee industry, data which would be most important in generating an accurate measure of the land use of a coffee product had to be identified. Some of these data included total land area per country, harvested land area for coffee beans, land requirement for jute burlap sacks and number of these sacks used, import and export data for coffee beans in each country, mass of coffee bean grown in each country, and a measure of sustainable practice to adjust for factors like shade-grown eco-friendly land uses versus sun-grown or organic versus large-scale agriculture. From this information, the calculator would be developed that would take the purchase price and country of origin for any size coffee purchase and convert that to a total land use.



Figure 1. Flow chart of data transformations from initial collection to final metrics.

In step 4, to yield the final metrics, the calculator scales the input purchase by its fraction of total net exported coffee, and proportionately calculate mass of coffee bean purchased. This mass would then be scaled to a land use by its representative fraction of the total harvested coffee bean, and further translated into a fraction of the total land use of the country. This fraction is then transformed into the absolute land use for a given amount of coffee bean. A detailed breakdown of this calculation is shown in Figure 2 below. The land use metric can then be weighted by any additional certifications, such as organic or fair trade, to yield an "eco-friendliness" score.



Figure 2. A conceptual representation behind calculating total land use footprint.

There are two potential end users for the product – large coffee companies, such as Starbucks, who may want to measure their land use impact to gain a competitive advantage with eco-conscious consumers, and individual consumers. It should be noted that the interface for individual consumers would also be extremely useful in pitching an idea to companies, as this version is quite intuitive and easier to understand. It requires just an input of the purchase cost and the country of origin for the beans. The company use, however, would be a connected database to an excel spreadsheet of all of their coffee purchases. In this case, for a large company making hundreds of purchases daily, this would be a large Excel or QuickBooks database with purchase cost and country of origin for the coffee beans. This is a record that the company would produce. They then connect this data to the calculator interface, and it generates a single land use impact score for the entire list of recent coffee purchases.

Land Area Data

Data was collected on the total land area in km² of every country currently defined by the Central Intelligence Agency World Factbook (Central Intelligence Agency, 2020). This information was used to estimate the percentage of land coffee production assumed by country.

Harvest Coffee Land Area Data

In order to obtain a reliable estimate for the land area that is occupied by country, data was obtained from the Food and Agriculture Organization of the United Nations on total land area harvested. Data was obtained on all available countries on total land area harvested in hectares for green coffee in 2018.

Burlap Sack Data

In order to include the first layer of the supply chain, the land use of burlap sacks was incorporated into the analysis. Burlap sacks are the primary method of coffee bean transportation during the shipping process from their country of origin to distributors and manufacturers. Burlap sacks are made from the skin of the jute plant, which is woven together to create a sack that typically holds up to 70kg (150lbs) of coffee beans and is often branded with the name of the exporting country or distribution company.



Figure 3. Branded Burlap Sack used for coffee bean transport

In order to estimate the land use impact of each burlap sack that is used for transport, first the surface area of material that is used for the average burlap sack was calculated. Then, working backwards, data from India's jute manufacturing sector was used to find the ratio of how much raw jute is used to create a finished jute product. In this case, it is safe to assume that all jute products have approximately the same ratio of raw jute to finished jute product, because of the homogenous nature of jute products that are typically manufactured, namely, jute cloths, yarns, and sacks.

Finally, the global jute yields were used in order to find how much land the raw jute takes up. Multiplying the number of burlap sacks used in global shipments, assuming all coffee is transported in these bags, by the land use of raw jute required to make each burlap sack, and taking into account the average number of times each burlap sack is reused in transporting coffee beans, the incremental land use that burlap sacks can be approximated and added to overall coffee land use. In order to keep this data updated going forward, it will be important to be aware of rising global jute yields. As jute continues to be harvested at a more efficient rate, less land will subsequently be used to produce the material that makes each burlap sack.

Export and Domestic Consumption Coffee Data

In order to understand the total purchases of a company from a specific country, export and domestic consumption data were collected. This data is significant because it enables the use of price as a means of calculating total amount of coffee purchased. Coffee export data was obtained from World's Top Exports, outputting the cost of coffee exports in USD as of 2018 (Workman, 2020). Data on world domestic consumption, which effects the total kg of coffee produced in relation to total domestic export, was obtained from the International Coffee Organization (ICO, 2020).

Kilograms of Coffee Produced by Country

In order to link coffee export prices and coffee production, data was collected on total kilograms of coffee produced by country. This data was also obtained from the International Coffee Organization for the year 2018, to maintain consistency (ICO, 2020).

Geospatial Mapping of Coffee Land Area

Methodology

The two main types of coffee, Arabica and Robusta, are grown under different environmental conditions. Overall, about 75% of world production is Arabica; Robusta accounts for most for the rest of coffee production (Larson, 2003). Arabica grows at a higher altitude and lower temperature than Robusta. As a result, two separate geospatial analyses were conducted on each type of coffee, depending on each coffee type's specific elevation, temperature, and precipitation range. In order to evaluate the geographic extent of Arabica and Robusta coffee separately, type-specific ranges of environmental factors were examined.

Environmental Factor	Arabica	Robusta
Elevation	914-2800 m	0-1200 m
Average Air Temperature	20 °C	24-26 °C
Rainfall	1200-1800 mm / year	1600mm+, withstands
		2000mm+ which arabica does
		not
Mean Annual Temp	18-21 °C, quality degradation	22-26 °C, or 24-30°C depending
_	after 23 °C, dead around 30 °C;	on source
	degradation below 17 °C	

Table 2. Environmental growing conditions of Arabica and Robusta coffee.

Information on average temperature (°C) and precipitation (mm) were acquired from the WorldClim database, at a 30-second spatial resolution (WorldClim.org, 2020). The data is averaged from the years 1970-2000 by month. Because this data is more than two decades old, it is likely that geographical shifts in coffee production have occurred since. In order to understand the annual average temperature and precipitation in one location, an average temperature was calculated across the 12 months at a given location in ArcGIS Pro version 2.4.3 so that only one value was output for temperature or precipitation for each pixel.

In order to incorporate elevation into the calculations, 30-Arc second digital elevation model shapefiles from North America and South America were utilized from the ArcGIS portal. The elevation shapefiles were derived from the U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS), using the Global 30 Arc-Second Elevation (GTOP30). Two different shapefiles were used for the analysis, one clipped to the extent of North and Central America, and one clipped to the extent of South America.

Robusta

For the geospatial analyses for Robusta, the following ranges for each environmental factor were selected:

Elevation: 0-1200 m *Temperature*: 23-30 °C *Precipitation*: 1600-2200 mm

Arabica

For the geospatial analyses for Arabica, the following ranges for each environmental factor were selected:

Elevation: 800-2800 m *Temperature*: 18-22 °C *Precipitation*: 1200-1800 mm

Ranges were chosen that were supported by the literature, using information incorporated from several sources to choose an appropriate range. Because these analyses were done in an ArcGIS model, the range values can be updated if new or more credible data suggests more accurate values.

Tree Cover Density

A dataset that contains a proxy for tree cover density in order to highlight coffee production areas that correspond with greater tree canopy cover was also included in the analysis. A Tree Cover Density layer (Hansen/UMD/ Google/NASA) was used in order to elaborate on where tree cover is most prevalent in relation to where the two types of coffee can be produced. Coffee production areas that overlap with areas of high forest density are likely to be the most destructive, especially if a sun-tolerant method is chosen, which will be discussed in the Environmental Benefit Analysis section.



Figure 4. Arabica and Robusta predicted land area and tree cover in South America. Darker purple colors represent tree cover densities ranging from 85-100%, while lighter yellow and empty areas represent areas of lower tree canopy cover, ranging from about 0-20% tree cover. The Robusta and Arabica growing areas do not represent the actual extent of growth, but rather where environmental conditions might allow for growth of each coffee type.



Figure 5. Arabica and Robusta predicted land area and tree cover in Central America. Darker purple colors represent tree cover densities ranging from 85-100%, while lighter yellow and empty areas represent areas of lower tree canopy cover, ranging from about 0-20% tree cover. The Robusta and Arabica growing areas do not represent the actual extent of growth, but rather where environmental conditions might allow for growth of each coffee type.

Geospatial Analysis

Robusta coffee generally tolerates lower elevations and warmer temperatures than does Arabica. Arabica coffee generally has more specific growing conditions, thus limiting the available land on which its production occurs. In general, the total possible land area that support the growing conditions of Robusta coffee is much greater than the possible growing area for Arabica. According to the data analysis, in South America, the potential land area that supports production of Robusta is about 13.4 times that of the area that supports Arabica production. Possible growing area of Robusta is about 3.3 times that of Arabica in Central America. Further, the geospatial analysis demonstrates that predicted Robusta growth areas overlap significantly with areas of high tree density, particularly in South America (Figure 4). Thus, production of Robusta may be more destructive to the environment, depending on where it is grown.

Tableau Map and Dashboard

Setting up a User Interface

Tableau is a software notable for exceptional graphics and visualization of data, and a platform for further data analysis. In the scope of the Land Calculator footprint, it seemed like a reasonably more advanced data analytics program to employ over linked spreadsheets in Excel or Google Sheets, which over little flexibility in visualizations, filtering, and coordination of graphics. The end goal was a usable interface, which Excel and Sheets could not easily produce, while Tableau had the analytics power and much simplified user interface.

The Tableau workbook was synced to a live version of the data stored in the Excel spreadsheet, meaning that the addition of any data to the Excel spreadsheet that had been previously utilized would be reflected in the Tableau program immediately without reuploading and networking all existing file pathways.

Several sheets were then created that would be potentially useful in a final user interface. The first sheet was a country map, where each geographic location on the map was crossreferenced with data on total coffee production and color coded according to the "Score" that was the calculated metric based on eco-friendly practice. The second sheet was the land impact from each piece of the coffee supply chain, for a specific country. For example, if Brazil was selected, then Sheet Two would display the land cost of burlap and coffee farming for all Brazilian coffee. Sheet Three was set up as the actual calculator itself. Two parameters were created, which asked the user for a country and a cost (how much the consumer spent on coffee from that country). Based on those inputs, an algorithm calculated the approximate land area that that coffee purchase had and yielded the output, as well as its environmental Score.

A Dashboard was then set up which dynamically linked each of the sheets and displayed them live. Through parameter values, conversions, and dynamic filters, each of the sheets was coordinated to display data for the country that the user selected, and the final land use was displayed in hectares based on the consumer's purchase price and country. Below is an example of the interface given a purchase of \$100 of Peruvian coffee beans. Peru is a median country in terms of land area under eco-friendly certifications and in terms of land use per kg of coffee, which is why this transaction scored a 48.69.



Figure 6. Land impact of an example consumer purchase.

Environmental Benefit Analysis

In an increasingly globalized world, decisions or policies made in one location can have consequences in an entirely different region. Consumers often have little knowledge of what goes into the production of products or what resources are expended in the process due to the complexity of the global supply chain. Consumption patterns and demand in one part of the globe are often linked to indirect changes in land use and production in another part of the globe as markets. Due to the complexity of supply systems, consumers are increasingly urging for transparency in business management and products. Lee and Shin (2010) demonstrated a positive relationship between consumer awareness of socially responsible company activities and consumer purchase intentions, meaning that consumers are actively interested in supporting more responsible businesses. Recently, "eco-labels" have become more prevalent, providing consumers with information on the sustainability of products. Antonetti and Maklan (2003) demonstrated that consumers who perceived their decisions positively effect environmental issues were more likely to act more sustainably and make responsible buying choices. These labels and accounting tactics also create accountability in the supply chain and pressure companies in the same industry to comply with stricter guidelines.

Previous accountability methods have been used to reduce the footprint of companies and raise awareness of environmental impacts. Having accountability methods in place help isolate the specific sectors that are most impactful and thus require the most transformation (Lombardi et al., 2017). For example, urban carbon footprints, if standardized and made comparable across cities, can help demonstrate statistically significant ways to reduce urban energy consumption and limit environmental impacts both within city boundaries and in processes directly impacted by city consumption, such as electricity (Lombardi et al., 2017). Although often strenuous, there already exist mechanisms to calculate the environmental impacts of specific industries, products or companies, depending on what stressor is being measured. For example, several companies and platforms have developed carbon footprint tracking, such as Carbon Analytics and the EPA, each targeting different sectors or constituents. However, in order to give weight to these tracking systems, it is important to assign attributable values or "scores" to the progress of specific companies or entities. Ultimately, it is important to standardize the reporting and accountability process of creating a calculatable footprint model. Without standardization, it is complex for

businesses, consumers, and governments to compare their impacts on the planet and determine viable, efficient solutions to combating climate change. Having a reporting mechanism to underscore how specific products and companies are impacting distant lands can allow for the creation of appropriate national and international policy if consumer interest lies in sustainability and transparency.

The goal of the Land Footprint Calculator is to link final consumption of a product to resource use and eventually land use/intensity of a given product. The intention is to give consumers and companies a more holistic view of a product's environmental impact, with the hope that more informed consumers and producers will result in more responsible product sourcing and purchasing. Further, reducing domestic consumption of products that are especially detrimental to the environment or land intensive can and will influence how and where land is being used for growing primary crops. This in turn can affect rates of deforestation in countries where local policy is not influential in preventing land-consumptive practices (Bruckner et al., 2015). Furthermore, understanding the land intensities of primary commodities is crucial to evaluating and tracking along the global supply chain and connecting environmental and economic statistics (Bruckner et al., 2015). However, very limited and incomplete data exists on primary land use due to lack of documentation and constantly changing patterns of use. Thus, the analysis elaborates on one method to account for the land used in the process of creating a final product.

There exist two main types of land-use accounting methods: physical and economic accounting (Bruckner et al., 2015). Physical accounting uses physical units of biomass to account for global production chains. It utilizes information on production, imports, exports, and domestic use in order to create a holistic understanding of the land-use for a particular end use product (Bruckner et al., 2015). By allocating responsibility for land use based on final volumes and consumptions of a product, the total land use can be estimated based on the yield and productivity of the crop utilized to make the product (Schaffarzik et al., 2015). This method is better at accounting for less processed products, such as food and primary crops. On the other hand, economic accounting examines land flows through the economy and is better at predicting the land intensity of more highly processed products. Using input-output tables of monetary flows per year, this accounting method uses expenditure data to determine land use intensities. However, in an economic land use accounting model, land use is often distributed somewhat ambiguously due to lack of specific economic data (Schaffarzik et al., 2015). In this Land Footprint Calculator, both

physical and economic accounting methods are incorporated by taking into account a given company's expenditures on a product as well as the total physical quantity of product purchased. Due to lack specific land use information, these numbers were applied on a country-wide scale.

Land Use Impacts due to Agriculture

The global population is projected to reach 9 billion by 2050 (Foresight, 2009). As a result, global demand for food, products, and fuel will increase drastically. Despite the fact that crop yields are increasing 1-2% annually (Gibbs et al., 2010), this alone will not be enough to support the rapidly growing and consumptive global population. A significant part of the UN's sustainable development goals is centered around the transformation of global agricultural system so that it is not only more sustainable and less environmentally intensive, but also so that it can meet the demand of the growing population. Of the world's 13.4 billion hectares land area, about 3 billion hectares are arable, of which about half is already cultivated (Smith et al., 2010). In order to fully account for growing demand, it is likely that the world will see a net expansion in agricultural land, as has been demonstrated over the past several decades. For example, between 1980 and 2000, agricultural lands increased by about 629 million hectares in developing countries. Further, Gibbs et al. (2010) predicts that an additional 10 billion hectares of land will need to be developed for agricultural purposes by 2050 if the current rate of consumption persists, which is far greater than the amount of arable land on the planet.

The type of land that cropland replaces has large implications for the environmental footprint of agricultural development. For example, land that is already damaged or cleared for other uses might be the best option for agricultural development because it would reduce the environmental impact of expansion. Already, about 15% of the 11.5 billion hectares of vegetated land on the planet is degraded due to pollutants and other harmful anthropogenic practices (Smith et al., 2010). This number will only increase as more land is cleared for highly intensive agricultural practices. According to Gibbs et al. (2010), 55% of new agricultural land between 1980 and 2000 across the tropics was developed on intact forest with greater than 40% canopy cover, and another 28% from disturbed forests (Gibbs et al., 2010). Clearing of intact forest also increased by about 6% globally during this time, and the trend is likely continuing into current years (Gibbs et al., 2010). Future projections demonstrate that agricultural lands are only expected to expand; depending on the model used to predict agricultural expansion, croplands are expected

to increase by anywhere from 6-30% (Smith et al., 2010). Furthermore, developing countries, where rich, tropical forests are more prolific, are carrying the burden of agricultural development, seeing an expansion in total cropland area by about 10.1% from 1995 to 2007 (Gibbs et al., 2010). Clearing of tropical forests has huge ecological and climate change consequences that will only exacerbate the rate at which the globe is warming and put increased stress on arable lands and water resources.

Tropical forests are the most carbon-rich, biodiverse biomes on earth (Strassburg et al., 2009). As a result, deforestation is one of the main drivers of climate change and biodiversity loss globally. In fact, land conversion is the second largest driver of anthropogenic climate change, accounting for almost 20% of the total (Strassburg et al., 2010). Forests are both large carbon sinks and areas of high biodiversity, so limiting deforestation due to agriculture will be key to mitigating anthropogenic footprints. Forests also provide many ecosystem services that are essential to life on earth and remove large quantities of greenhouse gases from the atmosphere. About 6-17% of total global atmospheric carbon emissions are a direct result of deforestation (Baccini et al., 2012). Removing above and below ground biomass as a result of deforestation releases all of the carbon once held in the trees through burning and decomposition. Further, soil carbon stocks are significantly reduced by the conversion of almost any land type to cropland. Guo and Gifford (2002) demonstrated that conversion of native forest or pastureland to cropland reduces the soil carbon storage capacity of the land by about 42% and 59% respectively, whereas the conversion from cropland to secondary forests increases the soil carbon stock by 53%. However, even conversion of used cropland back to tree plantations or secondary forests can never fully recover the amount of carbon initially lost during conversion (Guo & Gifford, 2002). Further, because agriculture is a very energy and resource intensive process, constant tilling and soil disruption allows for further loss of mass amounts of gaseous carbon into the atmosphere (Guo & Gifford, 2002).

Furthermore, forests support high levels of biodiversity, which make ecosystems more resilient to the effects of climate change. Biodiversity is crucial to maintaining a healthy, stable natural system. Deforestation is a biophysical driver of habitat loss, causing habitat loss and fragmentation and hastening the rate of extinction. Limiting agricultural practices that require the direct clearing of intact forests will promote increased connectivity between habitats and enable highly specific species to continue to thrive in their current habitat. Lastly, Strassburg et al. (2010)

demonstrate that forest carbon stocks and biodiversity are correlated, meaning that protecting areas that have high species richness will also likely protect areas with high carbon-storing capacity. Thus, determining the best agricultural practices that are the least land-intensive, especially in areas rich in biodiversity and forest cover, will prove crucial to protecting biodiversity and reducing climate change impacts.

Coffee Land Use/Intensity

Growing practices can also limit or exacerbate the ecological footprint of a certain crop or product. In order to understand how impactful a product is to the land associated with its production, it is also imperative to distinguish between different types of agriculture. Because this calculator is specific to coffee production, the land intensities of the different coffee growing practices globally are examined. The two main methods of coffee production are shade-grown and sun-tolerant practices. Historically, coffee bushes were planted under canopies of trees because the species could not tolerate the heat from direct sunlight (Larson, 2003). However, recently, new varieties of "sun-tolerant" coffees have been developed that enable coffee to be grown in direct sunlight. Overall, shade grown methods consist of smaller farms and smaller chemical inputs. Shade grown methods can also provide on-site benefits by maintaining relatively high levels of biodiversity, including trees, plants, small mammals, birds, and reptiles (Messer et al., 2000). Studies have demonstrated that up to 150 bird species can thrive in shade-grown coffee habitats, as well as hundreds of ant and beetle species (Messer et al., 2000). Other ecosystem services provided by shade-grown coffee include pollination, pest control, climate regulation, and nutrient sequestration (Jha et al., 2014). On the other hand, sun-tolerant coffee is more capital intensive and generally takes up more total land area. These more modern coffee-production methods require the removal of tree canopies and often involve increased fertilizer and herbicide applications. While this increases yield per hectare--increasing coffee bush density by up to 500%--it does not support biodiversity and has a lasting impact on the land (Messer et al., 2000). As of 1999, about 30 to 40 percent of coffee from Latin America was grown using this more intensive, sun-tolerant technique.

Coffee undergoes many stages of process, including planting, harvesting, processing, drying, milling, roasting, and grinding of coffee beans (National Coffee Association). Due to limits in the scope of this analysis, only the direct land costs of growing coffee and the burlap sack bags

that are commonly used to transport coffee are examined. However, future studies might elaborate on this analysis by incorporating more of the processes from harvest to final product into the land footprint calculator itself. More specific regional and local data on land use patterns and land types would also prove valuable to creating a more comprehensive calculator.

Ultimately, the Land Footprint Calculator aims to provide credible information and data to consumers and companies so that they can better understand how products directly shape the face of the planet. No negative environmental impacts are anticipated through the creation of the calculator, due to the interface being virtual and strictly data derived. However, the degree to which the product will be effective at providing environmental benefits is dependent on whether businesses can and will be held accountable to the land use/intensity of their products, which will be discussed further in the Target Market Analysis section. Messer et al. (2000) demonstrates that a significant percent of consumers is willing to pay extra for sustainable coffee, showing promise for sustainable consumption of coffee if further labeling and marketing measures were taken to increase transparency. Thus, having consumers aware of the specific land footprint of different brands of coffee might increase responsible purchasing and support accountability in the supply chain, reinforcing more sustainable coffee practices.

Social Benefit Analysis

Implementation of the land footprint calculator will have important social benefits. This Land Footprint Calculator provides numerical data and visuals that are easy to interpret, and intuitive to use with only a few required inputs. By presenting coffee land use data this way, the calculator has the potential to have a real impact on how people make decisions when they purchase a cup of coffee.

A direct benefit of the Land Footprint Calculator is that the consumer will become more informed about land use in the coffee "market," regardless of whether the product ends up with a business, using it to ensure coffee they are selling meets a certain standard for land use, or directly on a website where the consumer can input purchase data themselves. Having land use information on the front end for consumers – for example, through a calculator widget that returns a land use number based on their coffee purchase – may have a butterfly effect on behavior by raising awareness about land use and guiding subsequent consumption, not necessarily just in decisions

with coffee. This butterfly effect may be muted if the calculator is used by a business that sells and markets coffee. In this case, the onus is on that particular business to convey the land use information to the consumer. Conversely, this information could also be presented in a more accessible and effective way than would be discovered by a consumer using a free website, thus improving the social utility of this calculator. Regardless of the magnitude of this impact, the consumer still stands to benefit because they are able to make a more informed choice with data that was previously inaccessible to them.

When a trend of more responsible consumption of coffee persists, the areas where coffee is farmed will also see benefits. The winners in this scenario are those living in towns near coffee farmland. Runoff, noise pollution, and deforestation will all go down with more responsible land use. In addition, communities will have more space for substitutes for large farmland – such as urban development, which could include housing, recreation spaces, community centers, and libraries. Many countries that grow coffee also depend on wildlife tourism and related activities for economic growth. Brazil, for instance, was noted for its natural resources being the main driver for tourism in the country, ranking #1 out of all countries considered (Schwab, 2015). An increase in the amount of available land for wildlife and fishing related recreation would mean an influx of economic activity in the country, as well as the economic benefit that comes with related travel, lodging, equipment, and food expenses.

There are also human health benefits that would follow from more sustainable use of farmland in a community. An increase in land available for forests and rainforests is correlated with a healthy environment, increase in wildlife, and cleaner water and air ("Economic Benefits of Land Conservation", n.d.). Sustainable farming practices are also strongly correlated with more ethical farming, which could improve working conditions for farmers, and a decrease in the use of child labor for coffee bean farming.

Target Market Analysis

The Land Footprint Calculator presents a promising business opportunity within the coffeefocused retail industry, especially given the rising standard consumers are demanding from businesses to adopt sustainable and socially responsible practices. With this in mind, there is no real philosophical or geographic barrier that stands in the way of this Land Footprint Calculator being presented as an option to every coffee-focused business possible.

There are 80 prominent coffee chains worldwide ("List of Coffeehouse Chains", n.d.). A cursory search into several of these chains' sustainability initiatives shows that virtually every company publishes information about their efforts to maintain sustainable coffee sourcing, often in an annual report showing progress towards goals set in previous years. For example, Starbucks has published a Global Social Impact report since 2001, much of which focuses on reducing carbon emissions, waste, and water use (Johnson, 2020). Reporting and improving land use from coffee farming would fit in well as a sustainability initiative for a larger coffee chain, if they do not do so already.

The three largest coffee companies worldwide are Starbucks, Dunkin' Donuts, and Tim Hortons, respectively ("Revenue of selected leading coffeehouse chains worldwide", 2015). To maximize the reach of the Land Footprint Calculator, it would be imperative to target the largest companies first, because of the coffee industry's heavy consolidation. According to a 2019 report from Allegra World Coffee Portal, Starbucks, Dunkin' Donuts, and JAB Holding Company-which owns Peet's, Caribou, Pret a Manger, Panera, and others--has ownership over nearly 80% of all coffee shops in the US. These companies also have a large market share internationally, which means that there would be great utility in investing substantial effort into getting these companies to use the Land Footprint Calculator.

Industry leaders also see the rise in specialty coffee shops as a consistent trend in the coming years (Allegra, 2019). While branded coffee shops like Starbucks and Dunkin' saw an aggregate 3.8% growth in 2019, many specialty coffee shops saw revenue grow at much higher rates (Allegra, 2019). In order to compete with larger companies, specialty shops often commit themselves to higher quality coffee, and more sustainable sourcing of coffee. The Land Footprint Calculator would give the opportunity to give these smaller coffee shops the data to back up claims that their coffee is more sustainably sourced than their larger competitors. In addition to coffee chains and specialty coffee shops, any restaurant, convenience store, or retail operation within a department store or bookstore that serves coffee could also be targeted for adoption of the Land Footprint Calculator in a similar manner.

With aggressive marketing and after successful implementation with coffee shops that are early to adopt, the Land Footprint Calculator has the potential to become the standard for land use reporting, incentivizing each coffee company to compete for the lowest and most ethical land use patterns for the coffee they sell.

Basic Business Plan

Current Implementation

One of the most practical way the Land Footprint Calculator can be implemented in its current form is as a widget on a coffee company's website, in a similar fashion to the Carbon Calculator that Carbon Analytics offers to enterprises. Carbon Analytics currently hosts calculators on four company websites – ClimateCare & EcoSphere, which are companies that help other companies and organizations become more sustainable, and Eva Airlines & China Airlines, airlines that operate out of China and Taiwan.



Figure 7. An example of the Carbon Calculator on Eva Airlines' webpage.

The Land Footprint Calculator could be hosted on a coffee company's website in a similar fashion, where customers can input the dollar amount they spent at that particular coffee company to see how much land was used from their level of spending. This will be based on the data gathered, along with financial statements from the coffee company. With more color given by individual companies based on relevant data they may have about sourcing their coffee, a built-in

Land Footprint Calculator can give the customer a comprehensive overview of where their coffee is coming from when they buy from a specific coffee company.



Figure 8. Example of the land footprint widget on Starbucks' website.

The Land Footprint Calculates presents a viable business model for two reasons. The first is that Carbon Analytics has already been in contact with a coffee company that expressed interest in a way to quantify their land use, in addition to the carbon footprint reporting they were already getting from Carbon Analytics. This shows there is an appetite, with coffee companies in particular, for ways to get information about land use and use it in ways to improve.

The second is that Carbon Analytics' existing carbon calculator software has seen success with both sustainability-oriented corporations as well as two international airline companies. This proves that the software itself (the way the data is presented, the efficiency at which it runs, the technical support) is robust and attractive to clients, but also that these companies are willing to give consumers transparency about the amount of carbon they may be using when they use their services. By giving consumers numbers based on company performance, it holds the company accountable to ensure that they are meeting all the sustainable standards that they may put forth in a social impact report, as well as the standards that consumers may expect. In doing so, the company may have to invest in more sustainable sourcing, but they are repaid in building long term trust with the consumer.

Cost of Development

With the resources and network that Carbon Analytics have already been building, development of the software would only require assigning the same software engineer that worked on the carbon footprint calculator and adapting it with the per-country land use data. If enough interest in the calculator came at once, it could become necessary to hire additional implementation engineers, as well as technical support to work with specific enterprises, especially if these clients were large coffee chains such as Starbucks and Dunkin' Donuts. However, much of the front-end development, as well as linking with a company's financial statements, has already been done by Carbon Analytics for their existing calculator.

Future Business Opportunities

In the future, the Land Footprint Calculator could also become another layer in one of the many existing certifications for coffee (Table 3).

Certification	Goals
Fair Trade Certified	Advocate for farmer's market access, and
	meet Fair Trade Minimum Price
Rainforest Alliance (RFA)	Ensure farm meets environmental, social, and
	economic factors based on criteria by the
	Sustainable Agriculture Network (SAN)
Smithsonian Bird Friendly	Sets strict standards for canopy and
	vegetation growth on farmland for safety of
	migratory birds
USDA Organic	Ensure coffee is grown in a place that
	supports biodiversity, soil health, and without
	prohibited substances on land for at least 3
	years prior

Table 3. Note. Data are from Bradley (2017)

While not all of the current certifications have immediate relevancy to adding land use, they all promote more responsible coffee farming practices and would stand to gain by also taking into account the aforementioned environmental and social benefits that come with more responsible land use. They are also constantly being updated to incorporate standards as seen fit. For example, the Rainforest Alliance recently merged with the Utz Certification to strengthen the criteria for their certification (Bradley, 2017).

Recommendations for Future Work

A fully functioning land use calculator would ideally provide a seamless transition from input to output, similar to Carbon Footprint Calculators publicly available online today. Through continued development, a land use calculator could serve to mitigate continued destruction while rectifying current and past losses. The following are a few recommendations for future work within the field of a land use calculator.

The current calculator is limited to coffee production and assumes knowledge of origin. It is acknowledged that coffee production is a fine-scale practice and that growing practices can vary widely within individual countries. Further research into production area in specific countries, as well as, specific company links within them will allow for more accurate recounts of economic impact. The current study reveals general practices based on country wide assumptions. Future research would assist in reconciling growing practices with impacts. Thus, finding more smallscale data on local coffee production methods would prove extremely helpful in refining the predictive capacity of land use and intensity of the calculator.

The coffee industry served as a case study for the Land Footprint Calculator. Using the methods of data collection and analysis described, additional industries and subsequent supply chains are essential to the development of an all-encompassing and meaningful calculator. Ideally, the addition of all supply chains would create a comprehensive look at the true impacts of each product used. Furthermore, for the sake of simplicity, the current coffee land footprint calculator considered impact only from the first level supply chain when computing the final land use (in ha). Moving forward, this expansion to other industries will result in a deeper impact analysis of all product, including coffee, and their true global land use footprint.

In order to reach this ideal design, further research into the intricacies of global supply chains will provide a comprehensive look into the true land footprint of a single product. This research implies extensive data analysis as well as access to data not currently in existence. Certain aspects of market supply chains are well documented due to international standards. For example, international trade requires documentation of transportation and exchange, leaving traceable paper trails. However, even these traces prove difficult to follow due to the ornate patterns in modern day trade and transport. On the other hand, within the originating processes of many products, there exists very little trail at all. The exact locations and services are lost to the mass collection and redistribution of goods on a global scale. Further development of a Land Footprint Calculator would delve deeper into the front portions of the supply chain while also constantly updating to new data on the back end.

Land consumption accounts for one aspect of the environmental impact of a product or service. On top of these environmental factors, additional information is needed to address global impacts. Only through the summation of all metrics, whether it be social implications of labor practices, gentrification, working conditions, long term economic impacts or any number of longand short-term consequences, can the true influence of a producer or consumer's decisions be measured. An idealistic impact calculator would include all factors, one of which being land use. Further developments in several fields will hopefully one day definitively draw the connection between action and consequence.

Finally, the motivation behind the Land Footprint Calculator essentially boils down to ecological conservation and climate change mitigation. A land footprint calculator therefore will hopefully encourage positive behaviors. One possible means to attain concrete impacts would be through the implementation of an offset option within the calculator. Though not specifically stopping the land use, an offset would allow a consumer or producer to partially reconcile their actions through an investment in preservation in the future.

Appendix A: Decision Matrix

	Information	Relevance (public	Land Impact		Clients/constitu			
Industry	Availability	perception)	(quantifiable)	Generalizability	ents	Time	Fun	Total
Coffee	10	7	9	4	9	10	10	8.15
Chocolate	9	4	6	4	9	10	10	7.15
Poultry	10	6	3	4	1	6	3	6.32
beef	5	9	10	4	4	6	5	5.67
Dairy	10	9	7	4	8	6	8	7.42
Airlines Travel	5	10	8	7	10	1	10	5.72
Tech Manufactur	3	10	10	10	10	1	9	5.82
Weight	0.4	0.05	0.15	0.2	0.05	0.12	0.03	1

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