Title
Advancing Environmental and Social Life Cycle Assessment in California and Costa Rica to Inform Sustainable Agriculture

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Advancing Environmental and Social Life Cycle Assessment in California and Costa Rica to Inform Sustainable Agriculture

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[1] This Masters Thesis is written in the format of a PhD Dissertation Proposal for Qualifying Exam.

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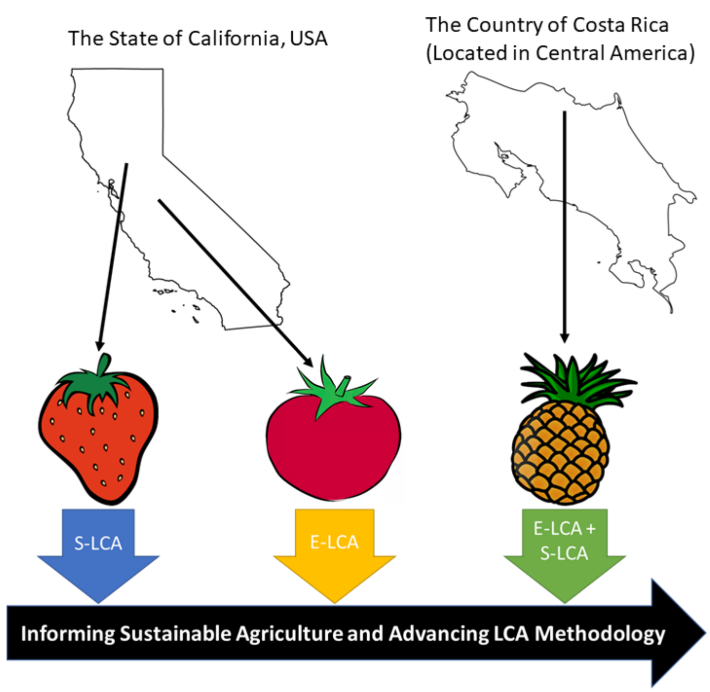
Abstract

Agricultural practices have developed immensely to feed a globally growing population. As our agricultural systems have grown for more globalized food systems, many practices have been implemented without considering the sustainability of these actions. Annually, approximately one-third of food globally produced for human consumption is lost or wasted, contributing to 19%-29% of our global anthropogenic greenhouse gas emissions. Therefore, finding a balance between the environment, society, and economics is of utmost importance for our growing agricultural needs. Environmental, social, and economic advantages and disadvantages can be assessed through Life Cycle Assessment (LCA) to better understand and improve our current food systems. This dissertation proposal conducts a combination of four different environmental and social LCAs and advances LCA methodology. The environmental impacts of fresh tomatoes produced in California are assessed in the first chapter and the second chapter proposes a methodology to assess social implications of the strawberry system in California. Lastly, the third chapter includes a combination of addressing environmental and social implications of large-scale pineapple farming in the northern area of Costa Rica. The E-LCA methodology is advanced through the inclusion of quantified farm level food loss as Life Cycle Inventory (LCI). Similarly, S-LCA framework is improved upon through the refining of the 2020 United Nations Environment Program's methodology and demonstrating concrete examples of abstract social performance. California and Costa Rica were chosen as case study areas because of the role agriculture plays in their economy and their increasing importance on environmental conservation. The goal of this dissertation proposal is to address environmental and social implications of agricultural products and improve LCA methodology and inform participating growers and consumers of the sustainability of our food systems.

Graphical Abstract



Introduction

Globally, food security conversations focus on increasing agricultural productivity and tend to overlook current unsustainable practices that can contribute to vulnerabilities in our global food systems (Gil et al., 2019; Mechlem, 2004). Approximately, 19%-29% of our global anthropogenic greenhouse gas emissions are from our food systems (Vermeulen et al., 2012). The United Nations Sustainable Development Goal 2 Target 2.3 seeks to double agricultural productivity by 2030, and while target 2.4 considers the sustainability of food production systems, it continues to focus on increasing production (UNDESA, 2021). Globally, approximately one-third of food produced for human consumption is lost or wasted annually (UNEP, 2021). In the U.S., food waste statistics are similar to global statistics where food waste accounts for 30-40% of the U.S. food supply (USDA, 2021). Between the years 2010-2016, the Intergovernmental Panel on Climate Change (IPCC) found that eight and ten percent of emissions contributing to the climate crisis were from food loss and food waste respectively (UNFCC, 2020). While feeding a growing planet is of great concern, it is similarly important to reflect on our current agricultural practices and assess their sustainability. Historically, our agricultural practices have evolved to feed a growing population; from crop rotation revolutionizing agriculture in the 18th century, John Deere's invention of the steel plow in 1837 to the creation of the tomato harvesting machine in the 1950s by UC Davis' Jack Hanna and Coby Lorenzen, our agricultural system has changed greatly from the original domestication of plants and animals more than 10,000 years ago. Ensuring long term environmentally, socially, and economically sound practices is in the best interest of those who inhabit this planet.

A Life Cycle Sustainability Assessment (LCSA) is a rigorous evaluation of environmental, social, and economic benefits and disadvantages of a product or system. To assess the sustainability of a product or system, LCSA incorporates three different analyses (1) Environmental Life Cycle assessment (E-LCA), (2) Social Life Cycle Assessment (S-LCA), and (3) Life Cycle Costing. These assessments strive to evaluate potential, and actual (when applicable[2]), environmental, social, and economic advantages and disadvantages of products or systems throughout their entire life cycle. E-LCA has become a popular tool, and its application in agricultural systems has increased during recent years (Dieterle et al., 2018; Finkbeiner et al., 2010; Scheepens et al., 2016). The USDA Ag Data Commons provides resources and datasets with E-LCA as a tool (USDA ADC, 2021). E-LCA, in agricultural systems, can be used to analyze the environmental impacts within our food systems and find current processes that can be adapted towards more environmentally sound practices.

In 2020, the UNEP/SETAC updated the guidelines to conduct the S-LCA of products and address how stakeholders are directly and indirectly affected by products and processes (UNEP et al., 2020). However, S-LCA is still a relatively new (first guidelines published in 2009 (Andrews, 2009)) and complementary analysis. The S-LCA guidelines are to serve as a map to "offer a foundation to… assess the social and socio-economic impacts of [a] products' life cycles" as there are still areas for development (Ciroth et al., 2011). The S-LCA framework is

[2] UNEP S-LCA guidelines state that "S-LCA mainly focuses on assessing potential social impacts". Actual social impacts need to demonstrate causal relationships. In this case, the actual impacts refer to the environmental impacts and potential impacts refer to the social impacts (UNEP et al., 2020).

focused around five main stakeholder categories: (1) workers, (2) consumers, (3) local community, (4) society and (5) value chain actors (Ciroth et al., 2011; UNEP et al., 2020, 2021). The newest guidelines included a sixth stakeholder category of children (UNEP et al., 2020). While a basic framework for the methodology for S-LCA has been established by UNEP/SETAC, researchers conducting S-LCA can play a large role in developing and refining the framework. As social impacts can tend to be seen as more abstract, scholars can assist organizations in creating more sustainable practices/products while additionally informing consumers.

The study sites of California, U.S. and Costa Rica were selected because of the increasing importance of balancing environmental conservation, social wellbeing, and economic development. Being the top agriculture producing state in the U.S. in 2021 and supporting 1.2 million jobs in 2020, California is a great location to assess current agricultural practices and their sustainability (CDFA, 2022; USDA ERS, 2022a). The USDA Economic Research Service (ERS) stated that, in 2017 (when the last Census of Agriculture was conducted), the top five counties in U.S. agricultural sales were all in California (USDA ERS, 2022c). In 2021, California fresh fruit (third largest agricultural export by sales, after tree nuts and other plant products) made more than U.S. $2.5 billion (USDA ERS, 2022b). Costa Rica similarly acts as a good location to address sustainable agriculture practices through a life cycle approach as agriculture and eco-tourism play a large role in the Costa Rican economy while additionally experiencing much success in the countries environmental policies (Banco Mundial, 2022; Instituto Costarricense de Turismo, 2021). From 2017-2019 64.8% of tourists visiting Costa Rica noted that ecotourism was their main motivation to visit Costa Rica (Instituto Costarricense de Turismo, 2019). As a continually developing nation, it is essential that Costa Rica focuses on balancing the economic opportunities both sectors bring to the country while also considering the utmost wellbeing of those inhabiting Costa Rica and any visitors.

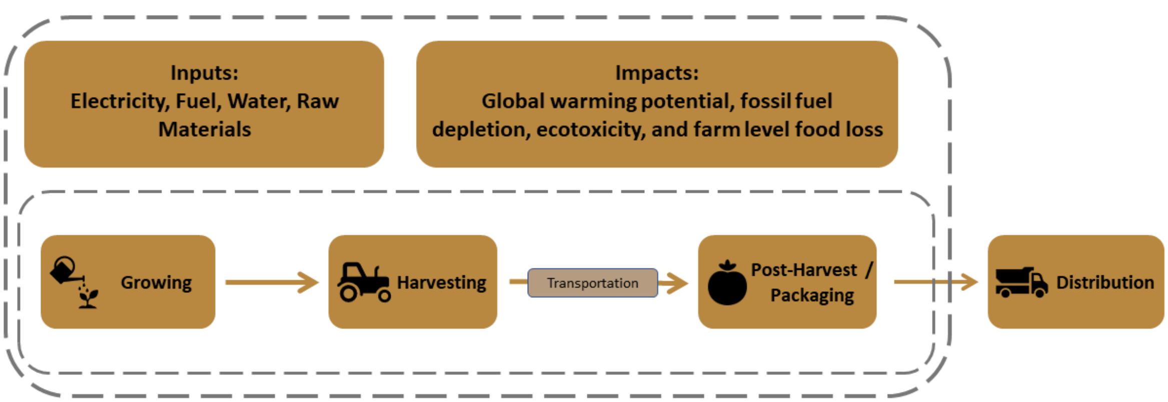
For this dissertation, three agricultural products will be assessed through LCA. The first chapter will quantify the environmental impacts of one kg of fresh tomatoes grown in the state of California. A farm-to-gate E-LCA will be used to assess the stages of growing up until the products are packaged to be sent to market with a special focus on tomato loss throughout the boundaries selected. Additionally, these results are put into perspective of the environmental impact of processed tomatoes. The second chapter will address the social impacts of strawberry production in California. As the main producer of strawberries to the U.S., the social performance of the Californian strawberry production will be assessed through the lens of the workers and local community. The third chapter will include a combination of E-LCA and S-LCA to better understand the sustainability of large-scale pineapple production in the northern region of Costa Rica, the nation's highest pineapple producing region (Cámara Nacional de Productores y Exportadores de Piña, 2020). The E-LCA will assess the cradle-to-gate Global Warming Potential (GWP) of one serving of fruit (165 grams including moisture) where the assessment will include impacts of distribution but will stop at the importing port. The S-LCA will explore the social performance of large-scale pineapple production in the northern region of Costa Rica for workers and the local community. The combination of these chapters will be used to advance the E-LCA and S-LCA frameworks and assist in improving sustainable agriculture in California and Costa Rica.

Chapter 1 (revise and resubmission to the International Journal of LCA): Environmental Life Cycle Assessment on Fresh Tomatoes in California.

Abstract

Globally, one third of food produced for human consumption is lost or wasted annually. As the most consumed canned vegetable and the second most consumed fresh vegetable in the U.S., tomatoes can act as a marker for national food loss and agricultural sustainability. The purpose of this study was to better understand the environmental life cycle impacts of fresh tomatoes to assist in creating a more sustainable tomato and overall food system within the U.S. This study quantified the environmental impacts of one kg of fresh tomatoes grown in California from farm to gate through Life Cycle Assessment and compared to another study on processed tomatoes (diced tomatoes and tomato paste). The stages of growing, harvest, post-harvest, and packaging were considered. Through a partnership with a Californian tomato grower, farm level food loss data was collected for fresh tomatoes by weighing tomatoes left after harvesting as part of the Life Cycle Inventory. Produce intended for human consumption was categorized into four categories (missed, second passing, damaged and, ripe/mature) in consultation with the grower. Overall, the average percent farm level food loss was 53%. The environmental impacts of fresh tomatoes were: (1) Global Warming Potential (GWP) (0.22 kg $CO_{2\ eq}$/kg), (2) Fossil Fuel Depletion (FFD) (0.12 MJ surplus/kg), and (3) Ecotoxicity (1.7 CTUe/kg). The GWP of processed diced tomatoes was 27% lower than fresh tomatoes and tomato paste was 280% greater than fresh tomatoes. The higher GWP of tomato paste could be due to the thermal processes required for tomato paste that are not necessary for fresh tomatoes. To put in perspective, for one kg of fresh tomatoes sent to market, an estimated four to six fresh tomatoes are lost while one third of a processed tomato is lost for one kg of processed tomato sent to processing plant (including the same system boundaries). Results demonstrated the importance of addressing and decreasing farm level food loss in fresh tomato production. A second pass of tomato harvest and/or greater automation could reduce farm level food loss and associated environmental impacts. After food loss, the next greatest impact for GWP of fresh tomato production was energy. Using energy efficient technologies and shifting to more renewable energy sources is recommended. A better understanding of the environmental life cycle impacts of fresh tomatoes and food loss associated with their production can assist in creating a more sustainable tomato and overall food system within the U.S.

Graphical Abstract



Background/significance

A current sustainability issue, and one that has received growing attention, is addressing food loss and food waste in our food systems. Globally, approximately one-third of food produced for human consumption is lost or wasted annually (UNEP, 2021). In the U.S., food waste statistics are similar to global statistics where food waste accounts for 30-40% of the U.S. food supply (USDA, 2021). Thus, it is crucial that our food systems be analyzed to address any sustainable changes that can be made to reduce the amount of food loss and associated emissions. When food is not consumed, it is not only the food that is lost but also the resources (water, fertilizer, energy, etc.) used to produce that food (Kummu et al., 2012; Searchinger et al., 2013; Wunderlich & Martinez, 2018).

In 2019, the USDA Economic Research Service (ERS) found that tomatoes are the second most commonly consumed vegetable in the U.S. (both fresh and canned), after potatoes, and the most commonly consumed canned vegetable (USDA ERS, 2020). In recent years, California has become one of the leading producers of fresh tomatoes and the leading producers of processed tomatoes in the U.S. (Wu et al., 2018; Zhengfei Guan et al., 2018). Fresh tomatoes are a good indicator to estimate farm level food loss in the U.S. and can be used to better understand the environmental impacts within the supply chain in the U.S. agricultural system.

This study measures farm level food loss of fresh tomatoes and uses E-LCA to quantify the environmental impacts of the fresh tomato supply chain in California. The results from this fresh tomatoes E-LCA are compared to E-LCA results of processed tomatoes from UC Davis (Winans et al., 2020). This California fresh tomato E-LCA can provide information to better understand the environmental impacts of the fresh tomato systems and how they compare to those of the processed tomato systems. E-LCA results include the impacts of each process and can be used to identify the largest environmental contributors. Using fresh tomatoes as an indicator for farm level food loss, the interpretation of the results of this E-LCA can inform the public and policymakers about marketing and consumption habits of food to aid in creating more sustainable food systems within California, and the U.S.

Research Questions

1. What are the environmental impacts of one kg of fresh tomatoes grown in California from the stages of growing to packaging?
2. How does one kg of fresh tomatoes compare to one kg of processed tomatoes for the same system boundary?

Objectives

1. Quantify farm level food loss for fresh tomatoes in California
2. Quantify the environmental impacts of the fresh tomato supply chain using Life Cycle Assessment for (1) GWP, (2) FFD, and (3) ecotoxicity impact categories.
3. Compare the environmental impacts of fresh tomato production in this study to that of Winans et al. (2020) processed tomato study.

Methods

The ISO 14040 framework include four major steps: (1) the definition of goal and scope, (2) inventory analysis, (3) impact assessment, and (4) interpretation (ISO, 2006). The functional unit selected to assess the environmental impacts of fresh tomatoes was one kg of fresh tomatoes sent to market. This functional unit was selected to provide consistency for the comparative analysis to the UC Davis E-LCA on processed tomatoes (Winans et al., 2020). The processes included in the system boundary of this fresh tomato E-LCA were growing, harvesting, post-harvest, and packaging (see graphical abstract). The inventory analysis stage included Life Cycle Inventories (LCIs) available in SimaPro 9.2.0.1 with values from literature, in field data collection for on farm level food loss (following Johnson et al., 2018 and Baker et al., 2019 methodology), and data obtained from a fresh tomato producer. The definition of food loss from the Food and Agriculture Organization (FAO) was utilized to address farm level food loss (FAO, 2019 as cited in FAO, 2021)[3].

Farm level food loss was quantified through collaboration with a California tomato grower with approval of the University of California, Merced's Institutional Review Board (IRB) (UCM2020-172). Farm level food loss data was collected three times during the harvesting season of fresh tomatoes in California in July, August, and September of 2021. For each field visit, a plot that consisted of three rows (15 ft) by 10 ft (one case) or three rows (15 ft) by 20 ft (2 cases) as a representative area of the field (Baker et al., 2019; Hanson et al., 2016; Johnson et al., 2018). Product that was left after harvesting was weighted depending on their respective categories (see Fig.1). Food loss values were used in addition to the LCIs found in the software SimaPro 9.2.0.1 through the libraries "Ecoinvent 3 – allocation at point of substitution – system" and "Agri-footprint 5 – mass allocation" (PRé Sustainability, 2021).

[3] The United Nations Food and Agriculture Organization (FAO) describe food loss as "the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers (FAO, 2019 as cited in FAO, 2021).

Fig. 1: Categories for farm level food loss characterization along with their description and picture. Categories were selected through conversations with a grower: (a) Missed: product that could have been harvested but was left behind, (b) Second Passing: product that could be harvested if the field were to be harvested again in the future, (c) Damaged: product that would not meet retail standards, (d) Ripe/mature: product that was too mature to be harvested as a marketable fresh tomato.

The E-LCA was conducted using SimaPro version 9.2.0.1 produced by PRé Sustainability (PRé Sustainability, 2021). In SimaPro, the TRACI 2.1 method was used for the impact assessment. The impact categories selected to assess the environmental implications of fresh tomatoes in California were (1) GWP, (2) FFD, (3) ecotoxicity. These three categories were selected because: (1) GWP allows for a comparison of the impacts of fresh tomatoes to other agricultural products and their effects on the climate crisis, (2) energy plays a large role in the post-harvest/packing facility (FFD), and (3) agricultural goods can require a substantial amount of chemical or biological applications that can affect the environment (ecotoxicity).

Results

The GWP of one kilogram (kg) of fresh tomatoes was 0.22 kg $CO_{2\ eq}$ per kg fresh tomato. FFD was 0.17 MJ surplus per kg and ecotoxicity was 1.7 CTUe per kg fresh tomato. For GWP and FFD, the top contributors were related to electricity or the manufacturing of chemicals applied to crops (e.g. steam processes for insecticide production, petroleum and gas for packaging production). The packaging process had the highest impact value for all impact categories, generally related to food loss and electricity or process related to the manufacturing of chemicals.

For the GWP, the process that resulted in the highest contribution to the environmental impacts of fresh tomatoes was the number of tomatoes lost (46%) followed by electricity (11%) (see Fig. 2a). The main contributor to FFD was electricity (17%) and the process steam from natural gas (17%) followed by process steam from light fuel oil (12%) (see Fig. 2b). The largest contributor to ecotoxicity was tomato loss (57% process contribution) (see Fig. 2c). A reduction of farm level food loss through manual labor and/or automation could result in 26% lower GWP per kilogram of fresh tomatoes. Alongside a decrease in farm level food loss for a more sustainable fresh tomato system, a change in electricity use, packaging and increasing efficiency of current technologies is recommended. Fig. 5 (located in the appendix) demonstrates the process contribution results without accounting for food loss, demonstrating the importance of changing electricity used.

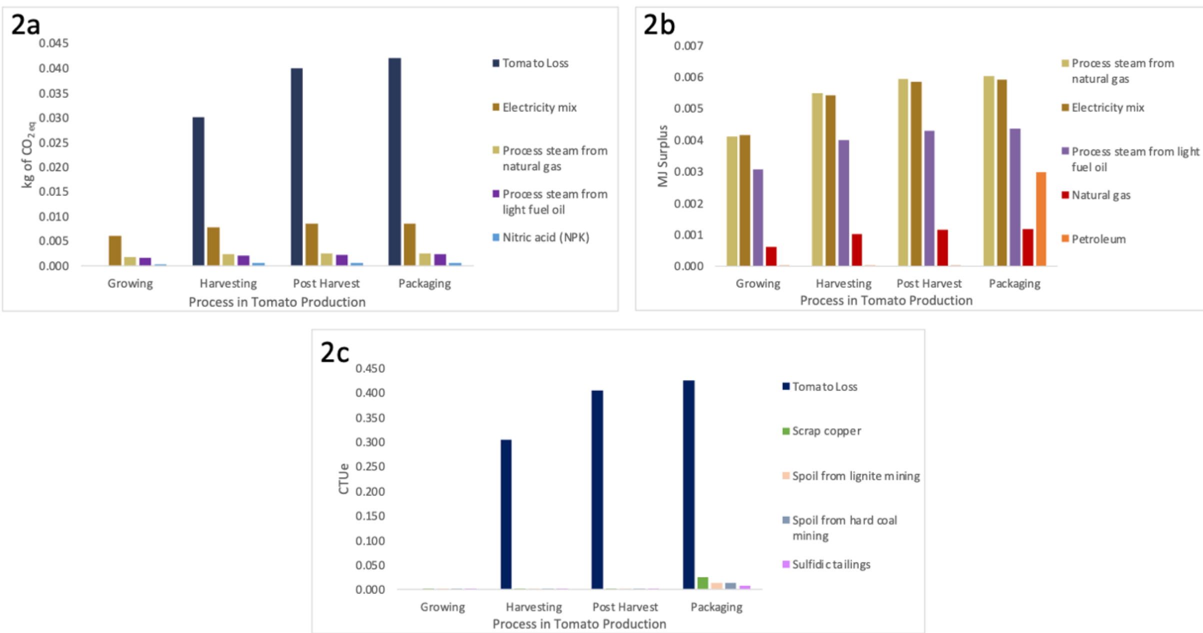
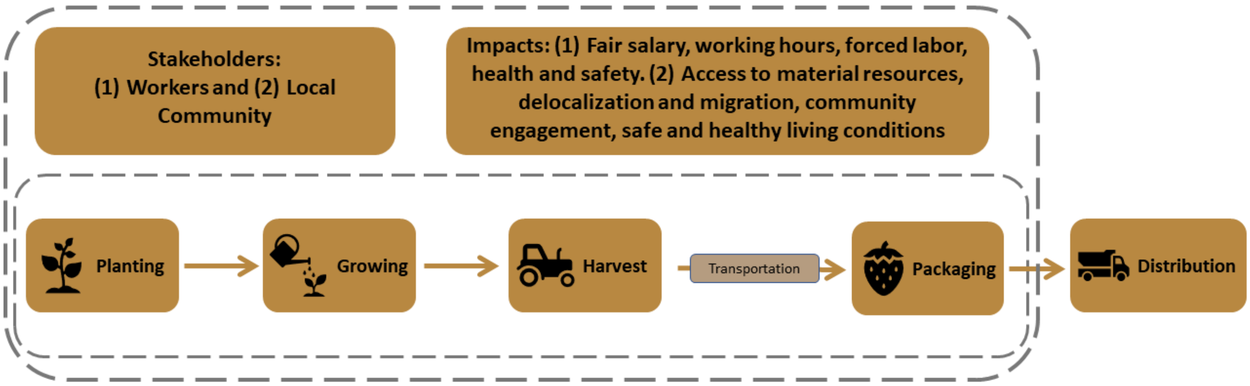


Fig. 2: Process contribution by stage for impact categories of (a) GWP, (b) FFD and (c) ecotoxicity.

Assuming a fresh tomato weighs approximately 100g (a small tomato weighs approximately three oz while a medium tomato weighs approximately 5 oz (Teague, 2020)), approximately six tomatoes are lost for every one kilogram of fresh tomatoes sent to retail while one-third of a processed tomato is lost for every kilogram of tomato produced (Winans et al., 2020). Additionally, the average percent loss experienced in the field was 53%. Of the experienced farm level food loss, 42% was categorized as second passing, 26% was mature or too ripe for harvesting, 22% could have been harvested but was missed, and 10% were damaged. The grower had mentioned that 20 years ago a second passing/harvesting of the field was a common practice, however this practice was ceased for economic reasons (costs exceeded profitability). Under current conditions and prices, a further economic assessment would provide valuable information to better evaluate if a second passing would be an advantageous practice for growers and/or how this could be incentivized to reduce farm level food loss (Johnson et al., 2019)

Chapter 2 (expected fall 2023): Social Life Cycle Assessment of Strawberries in California.[4]

Graphical Abstract



Background/significance

Consumers have the opportunity to choose between similar products. Previously we could weigh the cost and quality of said product and more easily select the product that fits our needs. Today, these decisions have become more complicated as we are faced with many options and various degrees of ethical and/or sustainable products. Consumers have become more conscious of the environmental impacts of their purchased products as well as social and local economical disadvantages and advantages.

S-LCAs on fruits have been conducted in recent years. Iofrida et al. (2019) addressed risks of citrus workers in southern Italy where they found the highest concern for citrus workers was musculoskeletal disorders, followed by osteoarthritis (Iofrida et al., 2019). Additionally, industrial clementine workers were exposed to longer risk hours resulting in a better social performance for industrial oranges "mainly due to the shorter duration of a single operation" (Iofrida et al., 2019). S-LCA methodology has also been coupled with E-LCA to better assess the sustainability of a product or system and this approach has been taken by Tecco et al. (2016) for a fruit grower association. The results of Tecco et al. (2016) E-LCA and S-LCA showed that the implementation of mulching and covering raspberry farms resulted in generally positive social impacts, while experiencing neutral or negative environmental repercussions (Tecco et al., 2016).

In 2016, the environmental impacts of one kg of strawberries were assessed for the states of California, Florida, North Carolina, and Oregon (99% of U.S. strawberry production). California demonstrated the lowest GWP (1.75 kg $CO_{2\,eq}$ per one kg of strawberry) compared to the other states analyzed, predominantly due to the large yield of California's strawberries (Tabatabaie & Murthy, 2016). However, to address the full sustainability of strawberry

[4] Further work in the research plan and proposal is intended for a later student in the field continuing the research as part of a dissertation and/or publishable products.

production, it is important to better understand the social implications of the strawberry system. Social implications have begun to be addressed based off of the harvesting stage for farmworkers, but the social implications of various stakeholder groups and stages in a strawberries' lifecycle is required (Delbridge, 2021; Soper, 2020).

Research Question

What is the social performance of California strawberry production for one kg of strawberries sent to market currently and how may that change with increased automation?

Objective

1. Assess the potential social implications of strawberry production in California for workers and local community from the stages of planting to packaging for one kg of strawberries sent to market.
2. Estimate how potential social impacts can be increased or decreased through the introduction of sustainable automation in strawberry production.

Methods

Table 1 includes the stakeholder categories and subcategories that will be assessed for the proposed strawberry S-LCA. The stages of planting, growing, and harvesting will be considered for one kg of strawberries sent to market (see graphical abstract), this scope was selected to use alongside the E-LCA on strawberries conducted by Tabatabaie & Murthy (2016).

Table 1: Stakeholder categories and subcategories for the proposed S-LCA on strawberries in California (UNEP et al., 2020).

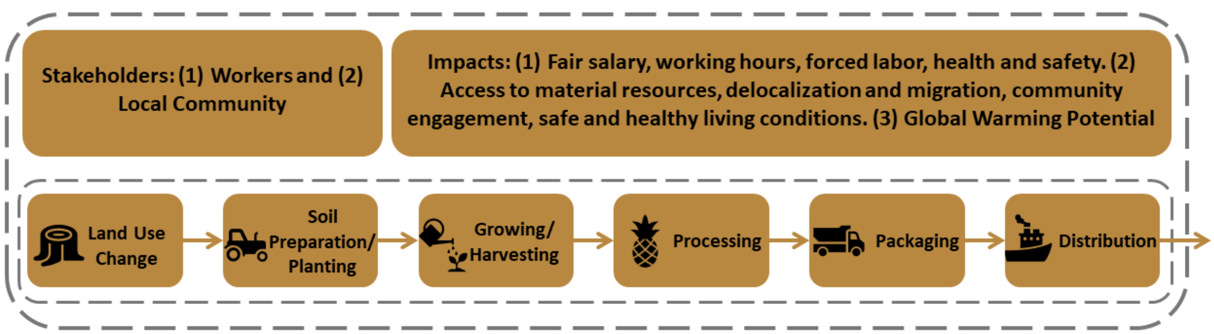
Stakeholder Category	**Subcategory**
Worker	(1) Fair salary, (2) working hours, (3) forced labor, (4) health and safety.
Local Community	(1) Access to material resources, (2) delocalization and migration, (3) safe and healthy living conditions, (4) community engagement, (5) local employment.

The inventory analysis will include the use of secondary data collected through reporting governmental bodies, literature, and qualitative inventory analysis through surveys collected by UC Davis collaborators. Primary data collection will happen in the form of interviews or surveys. Prior to the collection of any primary data, any material used will first be approved by the University of California, Merced's Institutional Review Board (IRB) for human subject research. Collected data will be translated into potential social impact through reference scales for each indicator used, where impact indicators will be quantified to demonstrate social performance (UNEP et al., 2020). Scales will be catered to each indicator, but their general framework will have 5 levels, +2, +1, 0, -1, -2. +2 will describe ideal performance, +1 goes above compliance, 0 complies with laws and basic societal expectations, -1 slightly below compliance, -2 constantly and severely below compliance (UNEP et al., 2020). These reference scales can also look at social risk where four categories are evaluated including very high risk, high risk, medium risk, and low risk (UNEP et al., 2020). Similarly, SimaPro 9.2.0.1 will be used to connect any energy or economic flows, to better understand the social risks (example 2 worker hours in poor working conditions[5]) (UNEP et al., 2021).

Through the interpretation of these social hotspots, the strawberry industry can gain insight into what processes are socially positive and any recommendations for the California strawberry industry for areas of improvement. Furthermore, the implications of the introduction of sustainable strawberry automation will be preliminary explored; these implications will only be explored and commented as the technology is still being developed, and a full-scale assessment is needed after implementation (outside the scope and timescale of this dissertation proposal).

Chapter 3 (expected Spring 2025): Environmental and Social Life Cycle Assessment of Pineapples in Costa Rica.

Graphical Abstract



Background/significance

In 2020, even after experiencing decreases in production due to the COVID-19 pandemic, pineapples were the topmost significantly traded tropical fruits in terms of tonnage and one of the lowest in terms of monetary value (FAO, 2021b). In 2018, Costa Rica accounted for 71% of total volume shares of globally supplied pineapple (Altendorf, 2018). After various medical

[5] "Worker-hours" is an example of an activity variable that is collected during the life cycle inventory process of an S-LCA. UNEP describes the collection of "data for the social flows and indicators, which link with the socio-economic system through the activity variable, just like pollutants and resources from nature are elementary flows for an environmental LCA" (UNEP et al., 2021).

devices, pineapples were the 2nd largest export of Costa Rica in 2019 (Instituto Nacional de Estadística y Censos de Costa Rica, 2020). Pineapple continues to play a large role in the Costa Rican economy as pineapple makes up 7% of their exporting values resulting in a total of approximately U.S. $967 million for Costa Rica (Instituto Nacional de Estadística y Censos de Costa Rica, 2021; Secretaría Ejecutiva de Planificación Sectorial Agropecuaria et al., 2021). Accounting for 24.5% of their agricultural exports, pineapple farms account for approximately 10% of the agricultural land in Costa Rica (O'neal Coto, 2018; Secretaría Ejecutiva de Planificación Sectorial Agropecuaria et al., 2021). As the continued largest grower and exporter of pineapples, Costa Rica continues to transform more land into pineapple farms (Altendorf, 2018; O'neal Coto, 2018). Currently, there are three major pineapple producing regions in Costa Rica and the northern region produces 49% of Costa Rican pineapple production. Growing both organic and inorganic pineapple for fresh pineapple and processed pineapple products, large-scale farms in the northern region will be used as a representation of large-scale pineapple production in Costa Rica (Cámara Nacional de Productores y Exportadores de Piña, 2020).

Previously conducted E-LCA on fresh pineapple from Costa Rica demonstrated that the most environmentally intense stage of a pineapples life is the farming stage (Ingwersen, 2012). However, processes like Land Use Change (LUC) and exporting to other countries were not included. Preliminary conversations with individuals from the northern region of Costa Rica (San Marcos de Cutris, Alajuela), both who participate in the pineapple industry and those that don't participate but do live next to pineapple farms, discussed what they see as key issues that the community faces (for example, access to potable water, unannounced spraying of unknown chemicals down streets, etc.). These preliminary conversations demonstrate the environmental and social concerns of the large-scale pineapple farms that surround the local community; thus, a further environmental and social assessment is necessary to better address sustainable changes in the large-scale pineapple industry in Costa Rica. As Costa Rican land continues to be converted to pineapple farms, it is of utmost importance to better understand the implications of these intense process and quantify the impacts of pineapple production by socioeconomic region (Altendorf, 2018).

Research Questions

1. What is the Global Warming Potential (GWP) of one serving (165 grams of pineapple, not excluding moisture) of fresh pineapple produced in Costa Rica and exported to the U.S.?
2. What is the social performance of Costa Rican pineapple production for one serving of fresh pineapples exported to the U.S.?

Objective

1. Quantify the GWP of one serving (165 grams of pineapple, not excluding moisture) of fresh pineapple produced in Costa Rica and exported to the U.S.
2. Assess the potential social implications of large-scale pineapple production in Costa Rica for workers and local community from the stages of Land Use Change (LUC) to distribution for one serving of pineapple fruit.

Methods

For the quantification of the GWP of large-scale pineapple production, the functional unit of one USDA serving of fruit, or 165 grams of pineapple (including moisture), was selected for comparison to other fruits and to the previously conducted E-LCA (Ingwersen, 2012). For this cradle to gate LCA, the processes included in the system boundaries will be land use change, soil preparation, planting, growing, harvesting, processing, packaging, and distribution to importing country port (see graphical abstract). The inventory analysis stage included LCIs available in SimaPro 9.2.0.1 and data from literature and any data provided by the collaborating large-scale pineapple producers in Costa Rica. The geospatial assessment for evaluating the environmental impact by region was accomplishede by the Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC in Spanish) and the SIMEPAR Institute of technology (Centro del Agua del Trópico Húmedo para América Latina y el Caribe (CATHALAC), 2011). The University of California, Merced's Institutional Review Board (IRB) has approved the E-LCA protocol for pineapple in Costa Rica (UCM2021-46). The S-LCA protocol for the S-LCA study will be updated to the relevant IRBs (Costa Rica and U.S.) for human subject's research prior to conducting the S-LCA portion of this project.

For the S-LCA analysis, Table 2 includes the stakeholder categories and subcategories that will be assessed for the pineapple S-LCA. The stages of land use change, soil preparation, planting, growing, harvesting, processing, packaging, and distribution to the importing country port will be considered for one serving of fruit, or 165 grams of pineapple. The survey questions will include both 4-point Likert scale and open-ended questions with themes of their relationship with the environment and the pineapple industry.

Table 2: Stakeholder categories and subcategories for the proposed S-LCA on large-scale pineapple production in Costa Rica (UNEP et al., 2020).

Stakeholder Category	**Subcategory**
Worker	(1) Freedom of association and collective bargaining, (2) fair salary, (3) working hours, (4) forced labor, (5) health and safety.
Local Community	(1) Access to material resources, (2) delocalization and migration, (3) safe and healthy living conditions, (4) community engagement, (5) local employment.

The same methodology for chapter 2 will be followed. However, alongside the inclusion of secondary data collected through reporting governmental bodies and literature, this S-LCA will additionally include interview data collected with approval of the Institutional Review Board (UCM2021-46, updates pending submission and approval). This collected data will be translated into potential social impact through reference scales for each indicator used, where impact indicators will be quantified to demonstrate social performance (UNEP et al., 2020). Scales will be catered to each indicator, but their general framework will have 5 levels, +2, +1, 0, -1, -2. +2 will describe ideal performance, +1 goes above compliance, 0 complies with laws and basic societal expectations, -1 slightly below compliance, -2 constantly and severely below compliance (UNEP et al., 2020). These reference scales can also be used to look at social risk where four categories are evaluated including very high risk, high risk, medium risk, and low risk (UNEP et al., 2020). Similarly, SimaPro 9.2.0.1 will be used to connect any energy or economic flows, to better understand the social risks (example 2 worker hours in poor working conditions) (UNEP et al., 2021). Through the interpretation of these social hotspots, the large-scale pineapple industry in Costa Rica can gain insight into what processes are socially positive and recommendations for the industry will be made for areas of improvement.

Preliminary Results

Preliminary results for the baseline E-LCA are included in Fig. 3, where the GWP of one serving of fresh pineapple is assessed for the major fresh pineapple producing regions in Costa Rica. The Northern region resulted in having the lowest GWP (2.84 kg $CO_{2\ eq}$/serving of pineapple) followed by the Pacific region (3.10 kg $CO_{2\ eq}$/serving of pineapple) and the Atlantic region having the highest GWP value (3.25 kg $CO_{2\ eq}$/serving of pineapple). Process contribution results (shown in Fig. 4) show the impact land use change has on pineapple production, mainly changing previously forested land to large scale pineapple farming land. After land use change, chemical applications should be addressed to improve the sustainability of the fresh pineapple system in Costa Rica. This includes addressing the types of chemicals that are applied, the amount that is being applied, and how often they are applied.

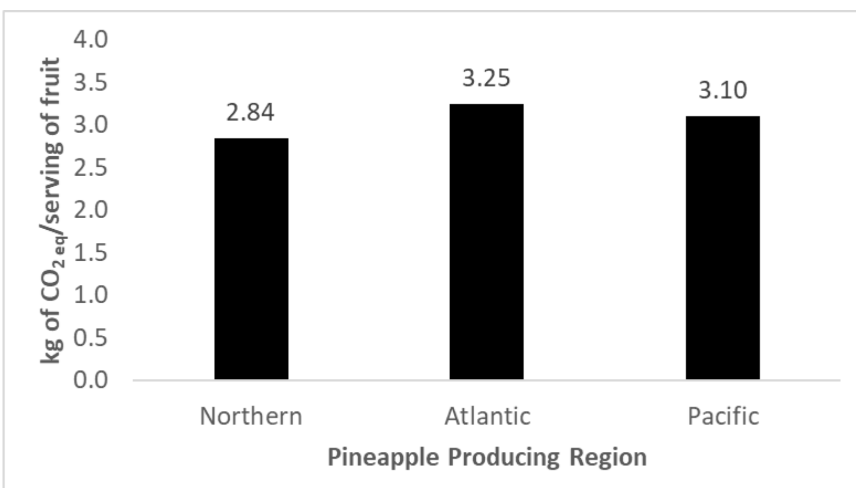


Fig. 3: GWP results for one serving of fresh pineapple for the top three pineapple producing regions in Costa Rica.

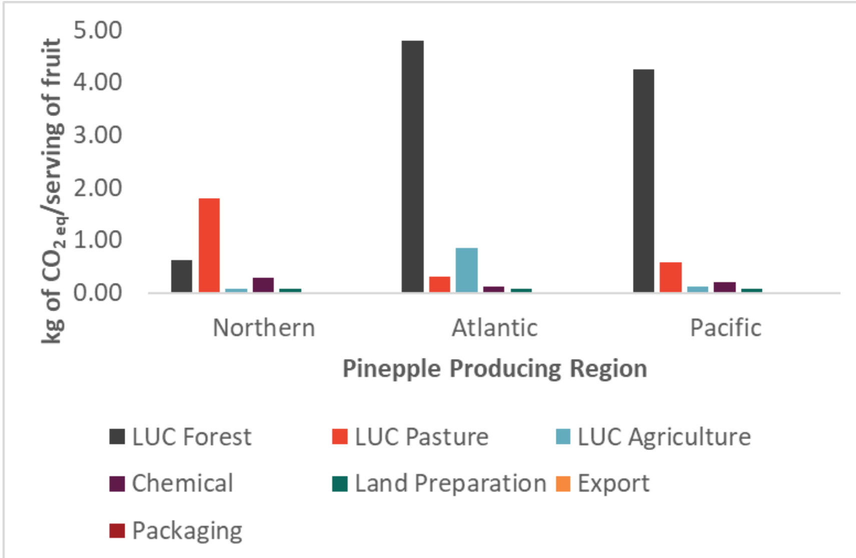


Fig. 4: Process contribution GWP results for one serving of fresh pineapple for the top three pineapple producing regions in Costa Rica.

Preliminary work for the S-LCA portion of this work includes preliminary conversations with interested peoples and the creation of two ArcGIS Story Maps. ArcGIS Story Maps were created in Spanish (https://arcg.is/WSyHb) and English (https://arcg.is/0L4yf4) to be used as a visual tool inform interested people on the proposed work, inform them of their importance and ownership in this study while additionally encouraging their participation and any resulting action that could come from the results of the study. The National Rural Development Institute of Costa Rica (INDER) has local associations for integral development. The researcher has a connection to the local association for integral development in San Marcos de Cutris, Alajuela. Community members will be recruited through this connection since the researcher will be able to attend meetings, as well as through word of mouth. Table 3 (located in the appendix) includes the questions that have been approved by the UC Merced's IRB (UCM2021-46). Questions will be updated for the completion of the S-LCA portion of this chapter.

Conclusion

Through assessing the environmental impacts of fresh tomatoes and the social impacts of strawberries in California as well as the environmental and social impacts of pineapples in Costa Rica, current agriculture practices can become more sustainable. Additionally, both the E-LCA and S-LCA methodologies will be advanced. Chapter one incorporates farm level food loss to better assess the environmental impacts of fresh tomatoes and chapter three broadens the scope of a previously conducted E-LCA of pineapples by including processes such as land use change. As S-LCA methodology is relatively newer, when compared to E-LCA, S-LCA methodology is also improved through chapters two and three by refining goals and bringing abstract social performance into aspects that can be digestible to the organizations and consumers.

These proposed projects aim to support the United Nations Sustainable Development Goals 2 (zero hunger), 3 (good health and well-being), 6 (clean water and sanitation), 8 (decent work and economic growth), and 12 (responsible consumption and production). Goal 2 is addressed by assessing current agricultural practices and suggesting changes for more sustainable practices. Goal 3 is touched upon by addressing potential social implications of current agricultural practices that can damage workers and nearby communities. Addressing reliable access to safe and clean drinking water is for communities near agricultural land is related to Goal 6. Addressing Goal 8 is included with incorporating the importance of the wellbeing of workers in the S-LCAs. Lastly, Goal 12 is encompassed in all chapters for the significance in ensuring sustainable global agricultural systems. The proposed LCA approach will be used as a tool to better understand our agricultural systems in hopes of improving them, advancing E-LCA and S-LCA methodologies and contributing towards the achievement of the UN SDGs.

Timeline[6]

	Chapter 1: Tomato E-LCA	Chapter 2: Strawberry S-LCA	Chapter 3: Pineapple E-LCA + S-LCA
Fall 2021	Field work, LCA analysis		
Spring 2022	Manuscript writing		
Summer 2022	Manuscript submission	Data collection	
Fall 2022	Finalization of dissertation proposal. Qualifying exam.		
Fall 2022/ Spring 2023		Data collection	
Summer 2023		Manuscript writing and submission	
Fall 2023			Conduct interviews for S-LCA
Spring 2024			S-LCA analysis
Summer 2024			S-LCA analysis
Fall 2024	Finalization of dissertation. Final dissertation defense.		

[6] Further work in the research plan and proposal is intended for a later student in the field continuing the research as part of a dissertation and/or publishable products.

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Appendix

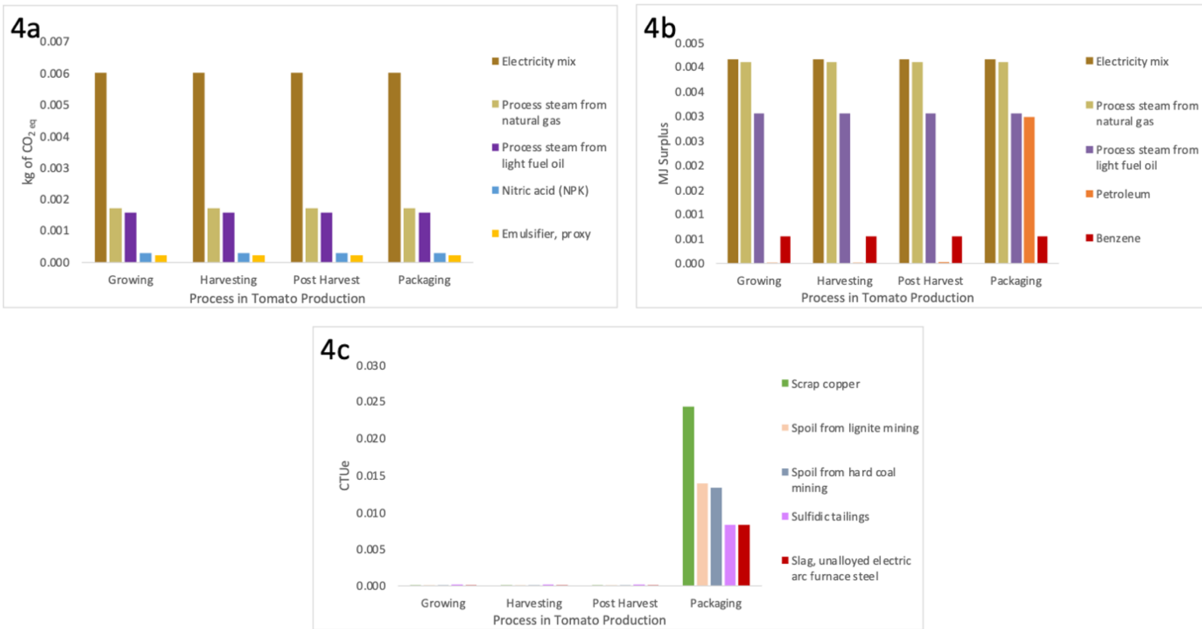

Fig. 5: Process contribution results (without tomato losses) for Life Cycle Assessment of fresh tomatoes by stage for impact categories of (a) Global Warming Potential, (b) Fossil Fuel Depletion and (c) Ecotoxicity.

Table 3: Approved interview questions by the UC Merced's IRB (UCM2021-46) for S-LCA portion of Chapter 3 (E- & S-LCA on fresh pineapple in Costa Rica).

Stakeholder Category	**English**	**Spanish**
Pineapple producers/ industry workers	1. How often is new land purchased to grow more pineapple?	1. ¿Con qué frecuencia se compra nueva tierra para cultivar más piña?
	2. What type of processes must be done after purchasing new land? a. If the processes results in an excess of organic material, where does the excess material go?	2. ¿Qué tipo de procesos se deben realizar después de comprar un nuevo terreno? a. Si los procesos resultan con un exceso de material orgánico, ¿qué se hace con ese material excesiva?
	3. How large is the pineapple farm? a. How much of the pineapple is grown to be organic?	3. ¿Qué tan grande es la piñera? a. ¿Qué cantidad de piña se cultiva para ser orgánica?

	b. How much of the pineapple is not organic?	b. ¿Qué cantidad de piña no es orgánica?
	4. When planting new plants, how many are "sons"? a. How many are new plants? i. Where do these new plants come from?	4. Al sembrar/plantar las nuevas piñas, ¿cuántos son "hijos"? a. ¿Cuántas son plantas/semillas nuevas? i. ¿De dónde proceden estas nuevas plantas?
	5. What chemicals are applied? a. What are the quantities applied? b. How are they applied? c. Who applies these? i. What type of training do they receive? ii. What Personal Protective Equipment do they use?	5. ¿Cuáles productos químicos se aplican? a. ¿Cuáles son las cantidades aplicadas? b. ¿Cómo se aplican? c. ¿Quién las aplica? i. ¿Qué tipo de curso reciben? ii. ¿Qué equipo de protección personal utilizan?
	6. When it is time to harvest, how many pineapples are harvested? a. How many pineapples are given to workers? b. How many pineapples are discarded after picking? i. After cleaning and processing?	6. Cuando llega el momento de cosechar, ¿cuántas piñas se cosechan? a. ¿Cuántas piñas se entregan a los trabajadores? b. ¿Cuántas piñas se descartan después de la recolección? i. ¿Después de limpiar y procesar?
	7. How much does a hectare of pineapple produce? a. What is the amount of pineapples that are discarded? i. Left on farm ii. Damaged by insects iii. Too small iv. Other	7. ¿Cuánto produce una manzana de piña? a. ¿Cuáles son las cantidades de piñas que se desechan? i. Dejado en la piñera ii. Dañado por insectos iii. No el tamaño ideal - demasiado pequeña iv. Otro
	8. How many years will a farm be economically viable?	8. ¿Cuántos años será económicamente viable una finca?
	9. How many pineapples are cleaned to be processed? a. How many pineapples are packaged as whole fruits? b. How many pineapples are processed? i. Juice, concentrate, etc.	9. ¿Cuántas piñas se limpian para procesar? a. ¿Cuántas piñas se envasan como frutas enteras? b. ¿Cuántas piñas se procesan? i. Jugo, concentrado, etc. c. ¿Cuántos se dan a los trabajadores?

	c. How many are given to workers?	
	10. Composting a. What is discarded vs. what is composted?	10. Compostaje a. ¿Qué se desecha? b. ¿Qué se composta?
	11. How is soil quality tested? a. How often is it tested?	11. ¿ Cómo se evalúa la calidad del suelo? a. ¿Con qué frecuencia se evalúa?
Local Community	1. What changes have you noticed since pineapple production was brought to the area? a. Water, flies, economic opportunity, etc.	1. ¿Qué cambios ha notado desde que se llevó la producción de piña a la zona? a. Agua, moscas, oportunidad económica, etc.
	2. How is your water quality? a. Rate 1-10? b. Do you apply any treatment? c. Have you noticed any differences since pineapple production was introduced?	2. ¿Cómo es la calidad del agua? a. ¿Califica 1-10? b. ¿Aplicas algún tratamiento? c. ¿Ha notado alguna diferencia desde que se introdujo la producción de piña?