Life Cycle Assessment (LCA) of the Hard Apple Cider Production System

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ABSTRACT: Improved accessibility to and availability of fresh produce has allowed the general population to rely heavily on corporate agribusiness, which has forced small farms begin to seek other means of profitability. This trend is reflected within orchard management, where farmers are beginning to produce hard apple cider as a means to increase profit through product sales and agritourism. The increasing popularity of high-value artisan products as demonstrated by the craft brewing industry has allowed a path for cider to enter the craft beverage market. This business venture represents a potential method to improve inter-generational transition of land ownership and management by engaging new markets. While entering the cider market may be a step towards revitalizing private orchards, as with any industry growth, there is potential for increased pressure on the environment and natural resources. In order to evaluate agricultural and cider production methods that may have environmental impacts, life cycle assessment (LCA) can be used to identify opportunities for improvement in production systems. In this study, LCA is applied to multiple management scenarios (such as organic and conventional growing techniques), fermentation and product storage techniques, and packaging type to assess areas of high and low impact in this cradle to grave assessment. In the agricultural phase, nutrient exchange, irrigation, fertilizers, pesticides, herbicides, supplies and fuel are considered. In the cider production phase, cold storage, water and detergent/sanitization needs, pressing equipment and energy requirements, filtration, yeast, and preservative agents are considered. In the packaging phase, cleaning and sanitization needs, primary and secondary packaging, labels and marketing material, transport equipment and fuel requirements are considered. The application of LCA helps to identify improvement opportunities within the cider production system to reduce environmental impacts, which can be useful for the development of regional legislation to could support orchard's attempts to seek other means of profit in a manner that ensures environmentally conscious practices.

I. Introduction

Improved accessibility and availability of fresh produce has allowed the general population to rely heavily on corporate agribusiness, making the small American farm less of a necessity and more of a novelty (Gunders, 2012; Sidal et al., 2013). Between globalization and improvements in shipping and storage methods, orchardists have begun to seek other means of profitability (Farm to Plate Strategic Plan, 2013; U.S. Department of Agriculture, 2012). While still mostly relying on dessert apple varieties, orchardists are beginning to turn towards hard apple cider in order to keep their farms profitable (LeHault, 2011; U.S. Apple Association, 2019). The increasing popularity of high-value artisan products as seen in the craft brewing industry has allowed a path for cideries to enter the craft beverage market (Sidali et al., 2013). Now recognizable American-made cider brands such as Angry Orchard and

Woodchuck have further re-introduced cider to the American palate, building a customer base for cider once again. In addition, the craft beverage industry has created a huge tourist following, and many farms have begun to expand their operations to include some form of agritourism (Adams & Adams, 2011; Elliot & Papadopoulos, 2016). Producing cider allows for another agritourism opportunity, unique from beer or wine, allowing orchardists to increase profitability for all edible products. The production of heritage high-value products like cider provides economic benefits and cultural sustainability to the local, rural communities in which the producers reside (Rogerson, 2016; Cloutier et al, 2016; Richards, 2018). Cider is now the smallest, but fastest growing portion of the alcoholic beverage industry (LeHault, 2011). While this trend opens an exciting opportunity to reinvigorate small American orchards and improve rural, agricultural economies, this growth could also lead to the industry growing beyond its means, creating a strain on the environment.

Apples, and other tree crops, are highly dependent on pesticides and fertilizers, making orchard agricultural systems subject to multiple challenges when it comes to sustainable production practices. Because it takes most apple tree species three years to produce fruit, crop rotation as a pest population limiter and nutrient recycler is not a viable option (Penvern et.al, 2012). Additionally, the demands from commercial and private customers inhibit growers from focusing on creating a natural ecosystem that might better encourage pest control and crop growth. Prior to modern agricultural practices and consumer demands, farmers created these symbiotic ecosystems though maintaining natural meadows for grazing lands and seasonal livestock grazing. However, this practice may create challenges in modern agricultural systems due to Food and Drug Administration (FDA) standards for raw manure exposure. Alternatively, cider producers could use apple waste, pomace, as feedstock for animals as well as a method of soil adaptation. Within small practices, addition of pomace to orchard soils can assist as a weed killer and brush reducer, as well as assist in soil erosion prevention.

Another challenge in sustainable practices is energy use. Apples are a perishable product and have a limited shelf-life without refrigeration. Even more susceptible to temperature control is the unpasteurized juice extracted from apple cider. In most states, orchards are not allowed to sell unpasteurized juice directly; however, traditional hard apple cider production requires unpasteurized juice for ideal naturally occurring yeast fermentation. Without some extent of temperature control, the two-week fermentation period standard for brewing practices could potentially result in a spoiled (bacterial contamination resulting in an unsafe, inedible vinegar) product. While it is becoming increasingly popular to open an on-site tasting room, it is realistically not the most profitable means of product distribution or brand recognition. Similarly challenging is water use; water is used throughout the life cycle of apple orchards to hard apple cider. Clean water is one of the most important aspects of food safety and dealing with contaminated or grey water in a legal, sustainable, and sanitary way can be a large investment for small operations. The selection of cleaning and sanitation products is equally important to protect employees and customers, as well as meet food safety standards.

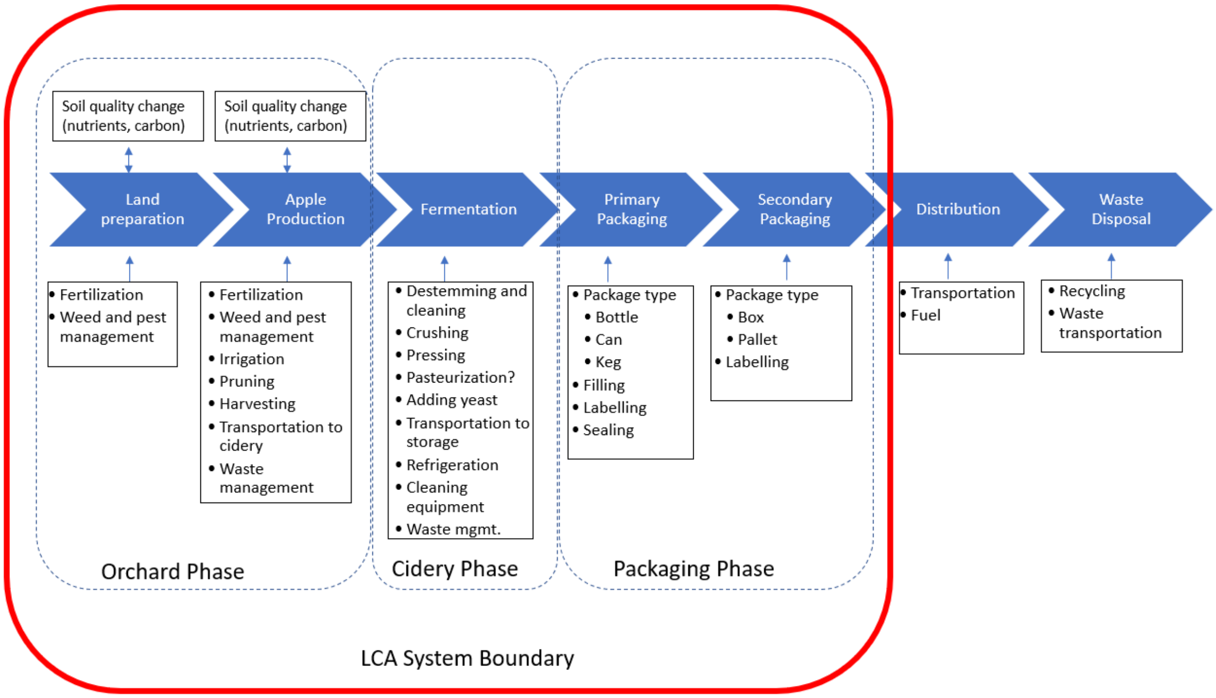
Printing and packaging choices can also present challenges, especially because these choices are the most obvious reflections of the businesses' commitment to sustainable practices to the customer (Cimini & Moresi, 2016). In general, reuse is a more sustainable practice than recycling. Breweries and craft beer bars have popularized the use of growlers – where customers can take away 325-750mL of a product dispensed from the tap in their own container. While environmentally-friendly, this practice does not necessarily assist in product marketing or business growth. When it comes to printing, sourcing paper, inks, and adhesives all have an effect on the product's overall environmental footprint. While debatable, it is currently believed that single-use aluminum cans have a lower carbon footprint than single-use glass bottles based on weights effect on fuel and transportation, and current U.S. recycling practices and standards (Cimini & Moresi, 2016). Conveniently, that is the currently trend of the alcoholic beverage industry due to customer demand.

This study attempts to assess the environmental impact of the hard apple cider industry to determine solutions for best management practices. To do this, the impact of conventional and organic apple production systems will be assessed to better understand how different farming practices may influence environmental and human health as well as resource availability. The agricultural stage is likely the highest impact stage within hard apple cider production, due to the many necessary energy and water inputs required to ensure orchard health and apple yield. Apples are known to be particularly challenging to grow under organic growing practices in the northeastern region of the United States due to their susceptibility to pest infestation and blight. Because of this, apples are frequently seen on environmental group's 'dirty dozen' lists as having high levels of pesticide residues. For the safety of those consuming apples as well as the growing interest in organically produced produce, it is important to understand the environmental impact of organic versus conventional farming practices to see if switching towards organic farming is a sustainable solution that would make meaningful contributions to environmental and human health. Further, this project will explore different packaging methods (canning, bottling, and kegging) to determine which method is preferable in order to market a product as environmental conscious. The production and distribution of products often holds a direct connection to the consumer which could dictate how the product consumer views the company. By identifying the lowest impact method of cider production and distribution before a system is set in place, companies can be better prepared on how they are going to promote their products as being more environmentally friendly. By assessing production, packaging and distribution of a product, a company can show the consumer that they have not thought of their product from a cradle-to-gate perspective but rather have an investment in the end of the products' life as well, taking more responsibility of their products' environmental impact.

II. *Methodology*

This objective will be addressed by completing a Life Cycle Assessment (LCA). LCA is often used in determining the environmental impact of consumable products (Hospido et al., 2005; Point et al., 2012). The system boundaries will be identified by looking at existing hard apple cider business models that utilize apples from an orchard on the same land as the cider production takes place.

<u>Figure 1. LCA System Boundary</u>



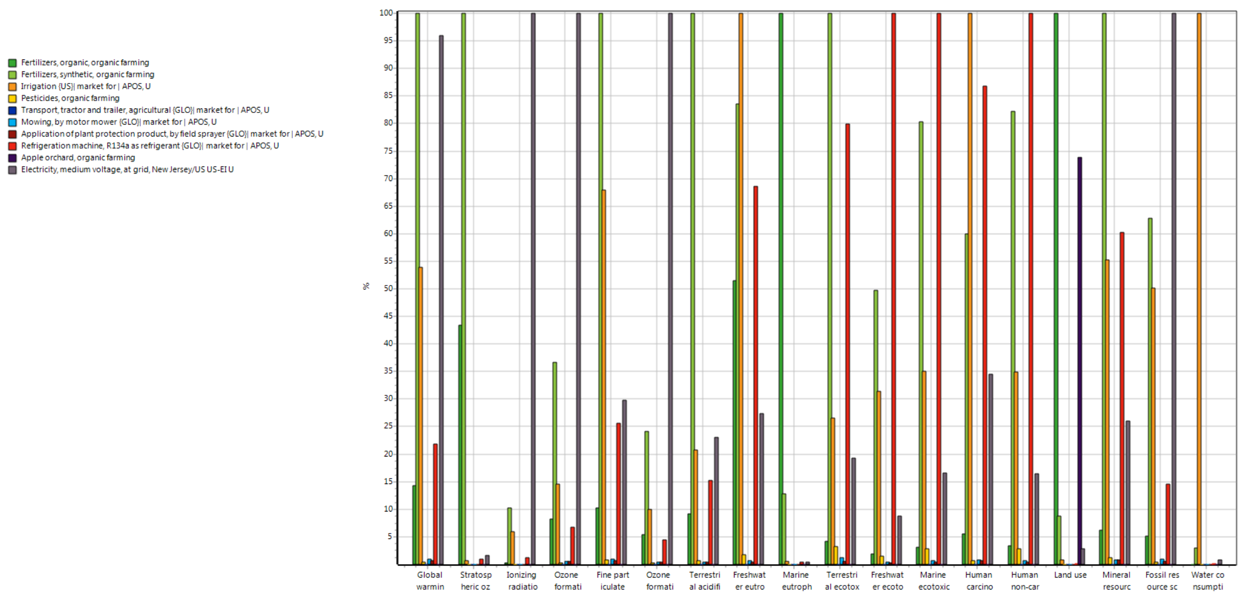
The assessment will be completed using SimaPro software, in conjunction with environmental input data attained from the Agri-footprint and EcoInvent databases available through SimaPro. Where inventory is unavailable, data will be obtained through previous literature to complete inventory data. Additional data for the agricultural phase was attained from Keyes et al. (2015) and Zhu et al. (2018) where they evaluated the impacts on conventional and organic apple production in Canada and China respectively. Additional data for the cider production phase was attained from Iannone et al. (2016) where they explored performance of wine production through a life cycle assessment, and modified to represent current practices for cider production. Additional data for the packaging phase was attained from Cimini & Moresi (2016) where they explored the carbon footprint of beer packs in different formats. All data was adjusted to represent a final yield of 30L of hard apple cider, roughly the volume of a standard keg (29.33L).

Data will be studied using the ReCiPe model, which utilizes both a midpoint and endpoint impact assessment framework. Midpoint impact categories (18) include climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, mineral resource depletion, and fossil fuel depletion. The endpoint impact categories include damage to human health, ecosystem diversity, and resource availability. The multiple scenarios of hard apple cider in the bottling/packaging/distribution phase will be evaluated separated to identify the hotspots within each system and evaluate the lowest-impact system.

III. *Results*

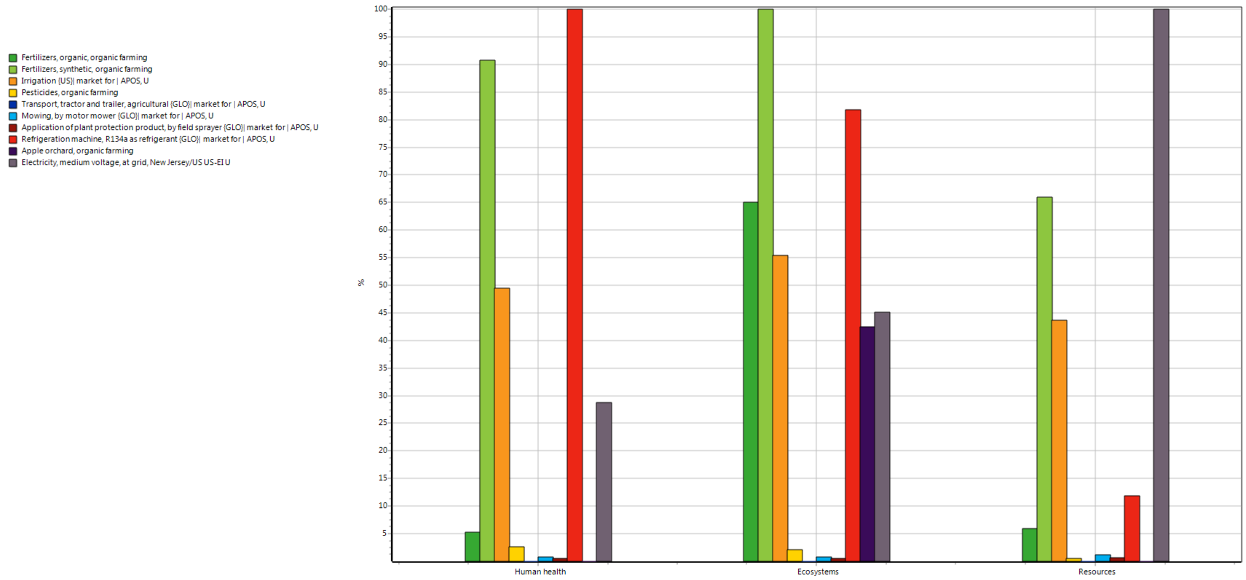
The organic orchard management scenario included input factors such as organic and synthetic fertilizers, application of plant protectants, irrigation, tractor and trailer use, mowing, land use, electricity use, and refrigeration for storage. Using the ReCiPe midpoint analysis, we found that the most highly impacted categories were human carcinogen, freshwater ecotoxicity, marine ecotoxicity, and human noncarcinogens. Refrigeration, irrigation, and synthetic fertilizers were most responsible for those environmental impacts.

Figure 2. Organic Orchard Management Midpoint Impact Factors



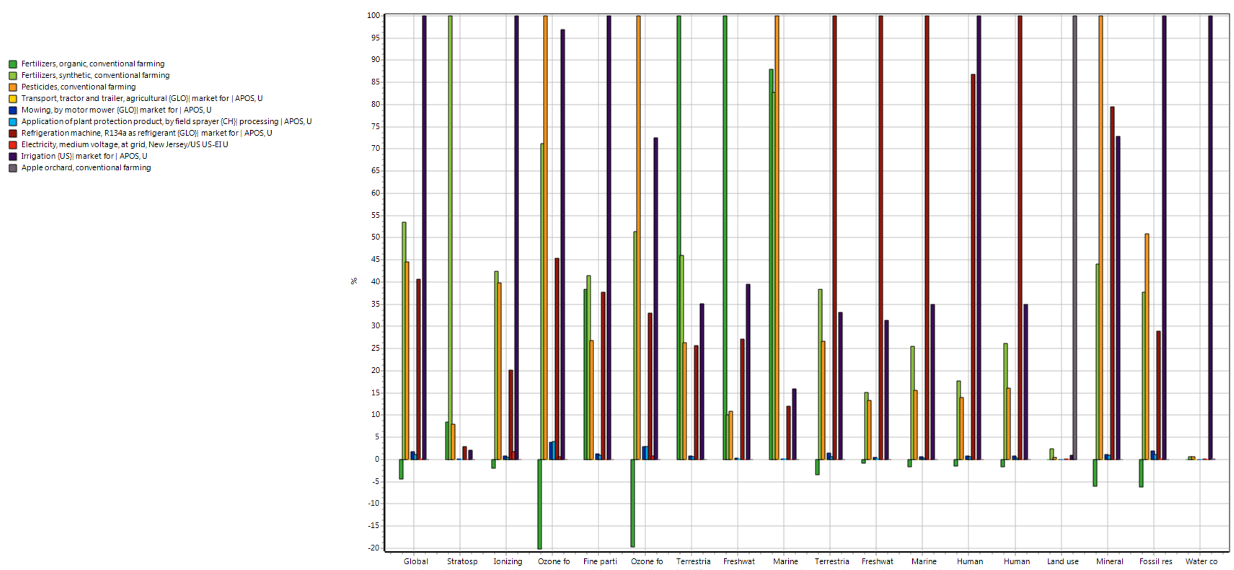
The ReCiPe endpoint analysis showed that human health was the most highly affected category, followed by ecosystems and resources which aligns with the midpoint analysis findings. Again, with refrigeration, synthetic fertilizers, and irrigation being of highest concern.

Figure 3. Organic Orchard Management Endpoint Impact Factors



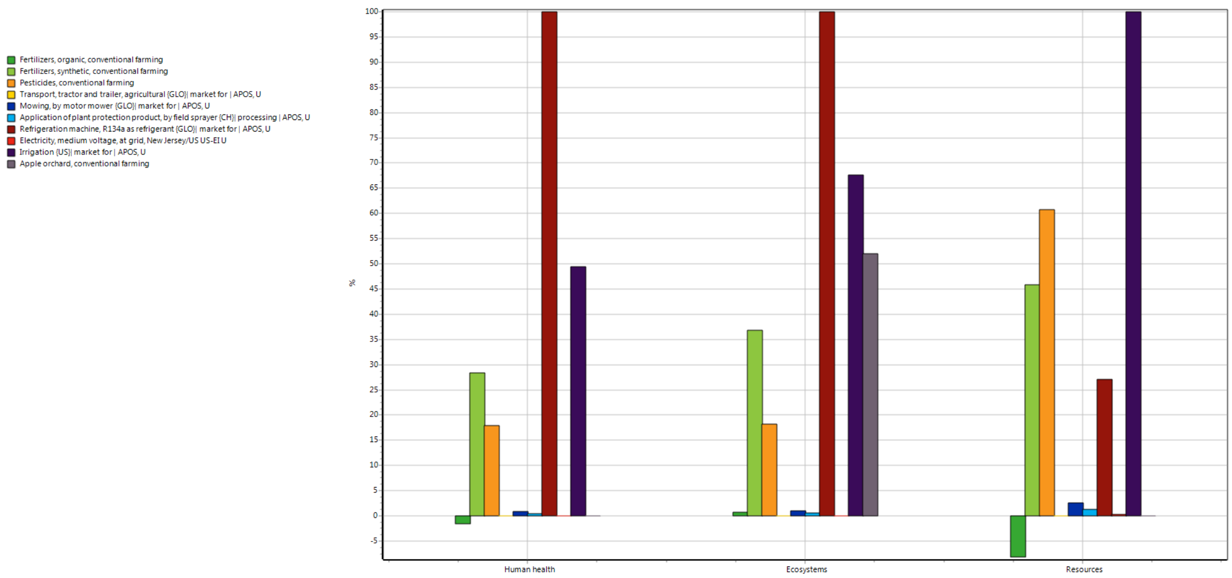
The conventional orchard management scenario showed similar results, where human carcinogens, freshwater ecotoxicity, marine ecotoxicity, and human non-carcinogens were most highly impacted with irrigation, refrigeration, and synthetic fertilizer use being of highest concern. Interestingly, the cow manure use associated with conventional farming was found to have a positive environmental impact on ozone formation, unlike the green manure used in the organic farming scenario.

Figure 4. Conventional Orchard Management Midpoint Impact Factors



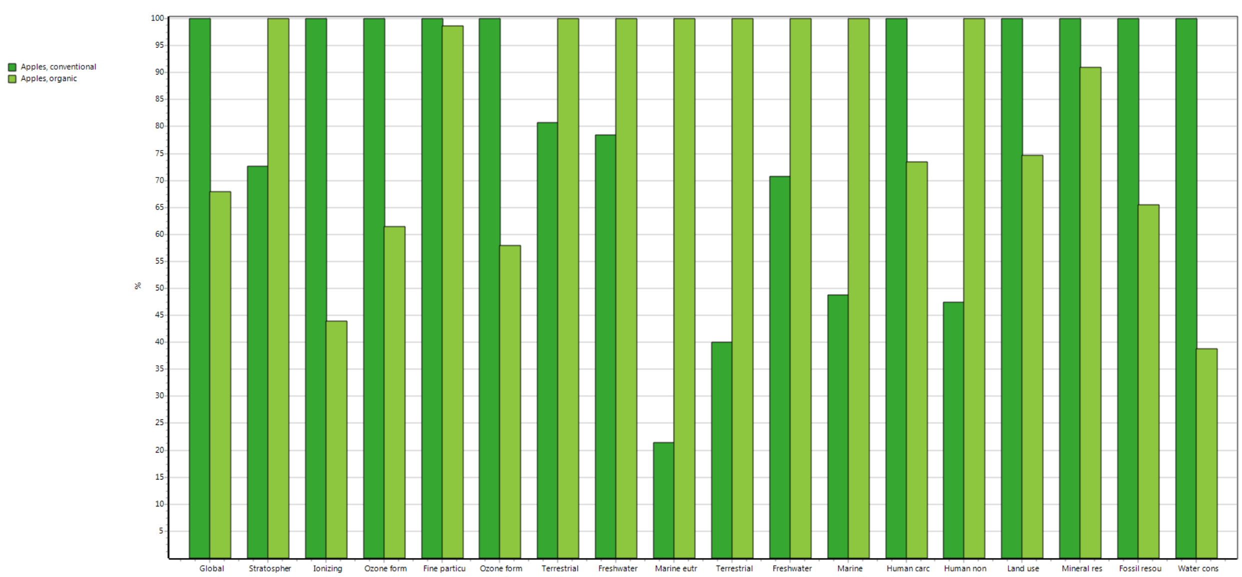
Similarly, the endpoint analysis showed human health to be most highly effected, with refrigeration, irrigation, and synthetic fertilizer use to be of highest concern.

Figure 5. Conventional Orchard Management Endpoint Impact Factors



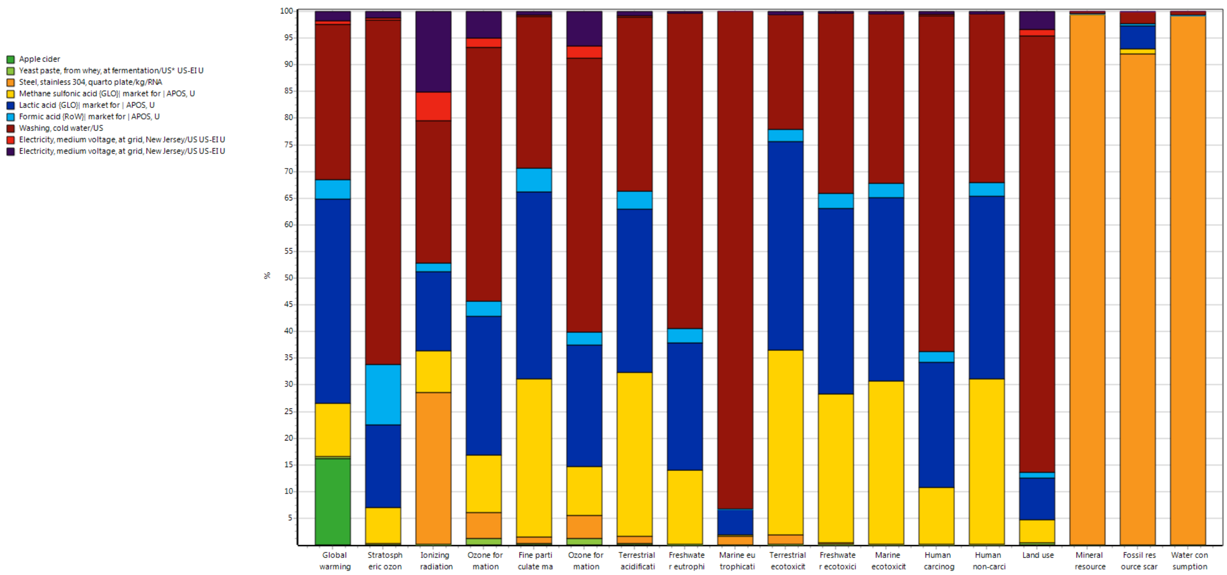
When directly comparing the organic and conventional farming system, one can see that there are benefits for both conventional and organic farming practices. Organic farming has a lesser effect on global warming, ionizing radiation, ozone formation, fine particulate matter, human carcinogens, land use, mineral resource scarcity, fossil resource scarcity, and water consumption.

Figure 6. Conventional vs. Organic Orchard Management Midpoint Impact Factors



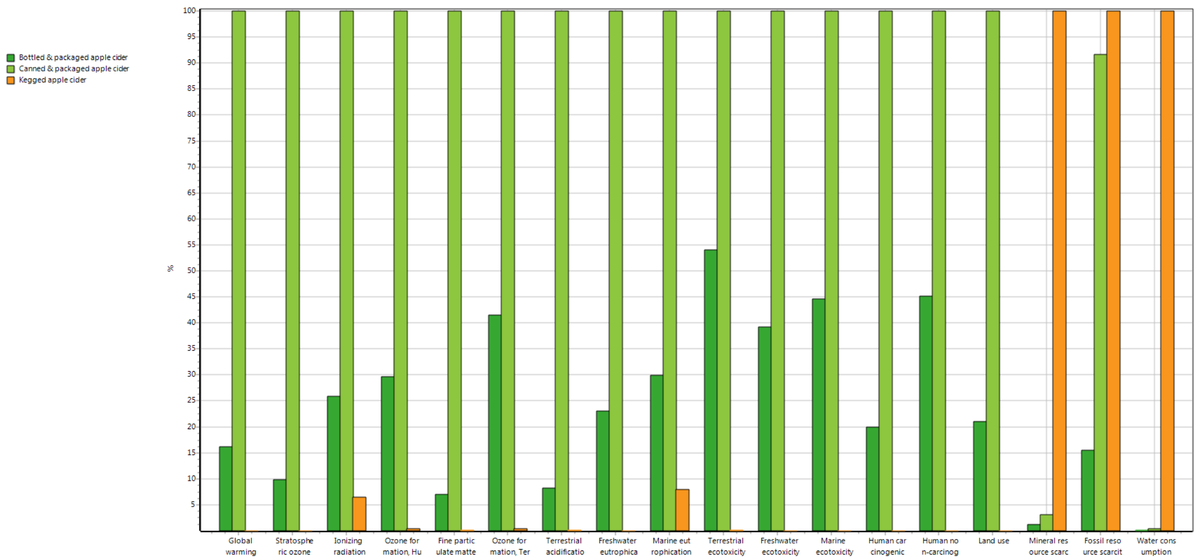
Conventional farming has a lesser effect on stratospheric ozone, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, and human non-carcinogens. Supported by previous figures, human carcinogens were most highly impacted, followed by marine ecotoxicity, freshwater ecotoxicity, and human non-carcinogens. The washing, crushing, pressing, and fermentation of apple cider was evaluated, and found that washing, lactic acid and methane sulfuric acid (cleaning and sanitization agents) had the highest environmental impacts in most categories, and stainless steel (material used for the fertilization tank) most highly impacted mineral and fossil resources and water consumption categories. Human carcinogens, water consumption, and marine ecotoxicity were the most highly impacted categories overall.

Figure 7. Apple Cider Production Midpoint Impact Factors



The packaging scenarios explored the primary and secondary packaging procedure required for bottling, canning, and kegging the final consumable product for external sale. The midpoint analysis showed that canning had the highest environmental impact across all categories, with the exception of mineral and fossil resource scarcity and water consumption, where the production of steel for the keg scenario was most highly effected.

Figure 8. Packaging Scenarios: Bottle, Can, Keg



When the data was normalized, we found that human carcinogens was the most highly impacted category, followed by marine ecotoxicity and human non-carcinogens, again with the canning scenario having the largest environmental impact.

IV. Discussion and Conclusion

Life cycle analysis was used to assess the environmental impact of hard apple cider production, from multiple orchard management, cider production, and packaging perspectives. Overall, it was found that conventional farming had the largest environmental impact in the greatest impacted category – human carcinogens. However, organic farming had the highest environmental impact in human non-carcinogens, marine ecotoxicity, and freshwater ecotoxicity categories. Based on the level impacted, organic farming has the lowest overall environmental impact. Organic practices should be used for apple production if a company wants to market themselves as environmentally conscious. Regardless, product refrigeration, irrigation, and synthetic fertilizer use should be addressed in any farm scenario as they have the largest environmental influence in many environmental categories. Hard apple cider production phase showed that washing and the cleaning/sanitization agents used during washing have the largest environmental influence. However, these processes are essential to produce safe consumable goods. Perhaps utilizing cleaning and sanitization agents with a lesser environmental impact could be used to reduce a products environmental influence, and water conservation practices should be considered. The packaging analysis found that canning had the largest environmental impact, followed by bottling and kegging. While steel production for keg manufacturing has a large environmental impact, they are also the most 'reusable' of the three packaging scenarios making them the best option for packaging. However, if considering shipping outside of the operation, bottling the product is the preferable packaging method for environmentally conscious production and distribution.

This research looked at a cradle-to-gate assessment of hard apple cider production management scenarios. These findings show that legislation should support small businesses to use environmentally conscious practices to improve environmental health and support entrepreneurial efforts in the budding craft beverage and agritourism industries. Future research could expand on this study by looking at distribution and waste management scenarios. Distribution involves transportation, which could show even future incentive for various packaging options in order to support environmentally conscious product production. This research could go further in to exploring how cider consumers waste could influence the environmental impact categories, supporting improved systems for recyclable goods and food waste management practices.

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