Life Cycle Assessment (LCA) of Apple Orchard Management: an insight into sustainable agriculture and new opportunities

Meghann Smith, PhD Candidate, Montclair State University
Smithm85@montclair.edu
480-544-7288
1 Normal Ave, CELS 306
Montclair, NJ 07043
Pankaj Lal, Professor, Montclair State University

1. Introduction

1.1. Sustainable Food Production for Climate Change Mitigation

Food systems rely heavily on resource and energy inputs, and are associated with environmental impacts such as emissions to air, land, and water that can affect ecosystem health and productivity. In 2018, agriculture was responsible for an estimated 661 million metric tons of CO2 equivalent, representing 9.9% of total United States (US) greenhouse gas emissions (US Environmental Protection Agency, 2018). In the face of growing populations and need for food, agricultural systems have looked towards sustainable solutions for food production so they are able to meet the needs of the consumer while decreasing environmental consequences where possible. Agricultural sustainability is a fundamental requirement for environmental conservation, food production, and food security. In order to achieve agricultural sustainability, it is essential that policies are put in place that support sustainable practices and that agricultural institutions are provided access to the necessary knowledge and technology in order to avoid eroding biodiversity and environmental quality while preparing for the inevitable challenges of climate change. In an increasingly globalized food system, sustainable agricultural systems face even more challenges in being financially competitive in even its local market. Policies that support the development of localized food systems can support consumer valuation on the relationship between themselves, the producer, and the product (Selfa & Qazi, 2005; Heron & Roche, 2018; Papaoikonomou & Ginieis, 2017). For most agricultural producers, it would be more realistic from an economic standpoint to not be fully localized, but rather distribute in local networks and distribute through larger supply-chains beyond regional networks (Heron & Roche, 2018). Even when distributing outside of the local network, agricultural sustainability can be achieved when internal and external policies align to support the needs of the industry as well as the demands of the consumer.

1.2. A Case for Hard Apple Cider

Apple production is the complete system which includes agricultural cultivation and production as well as post-harvest management, such as food processing and distribution. Apples, like many tree crops, are highly dependent on pesticides and fertilizers, making orchard agricultural systems subject to multiple challenges when it comes to sustainable production practices. Orchard management often also requires a great deal of energy and water resources in order to ensure the orchard's health and productivity, as well as to prepare fruits for sale. While previous studies have attempted to measure the environmental impact of apples (Zhu et al., 2018; Goosens et al., 2017; Keyes et al., 2015), the evaluation of apple production has not yet been extended to hard apple cider. While still mostly relying on dessert apple varieties, orchardists are beginning to turn back to hard apple cider as a means of increased profitability. Hard (alcoholic) apple cider is the smallest, but fastest growing subset in the alcoholic beverage industry. One major benefit of producing cider is that it can capitalize on using dropped, blemished, or otherwise imperfect fruits. Nonalcoholic sweet cider profit values roughly $9/bushel versus hard cider profit valuing about $135/bushel (U.S. Apple Association, 2019). The increasing popularity of high-value artisan products can be seen in the more popular craft brewing industry, which in a way has revealed a path for hard apple cideries to enter the craft beverage market. Similarly, supporting new agricultural ventures is the food system localization movement, which can help to support specialization of high-value grown and crafted goods. Localization of a food system also can help to frame sustainable agriculture and food by encouraging producers to incorporate practices that avoid environmental degradation, support agri-biodiversity, empower employees and local community networks, and support economic growth throughout the local region (Hinrichs, 2003).

While this trend opens an exciting opportunity to reinvigorate small orchards and improve rural, agricultural economies, this growth could also lead to the industry growing beyond its means, creating a strain on the environment. Understanding these environmental challenges on a comprehensive level can be done through a Life Cycle Assessment (LCA), which allows a cradle-to-grave analysis of a product or system for environmental hotspots. LCA allows one to identify which practices within a production system should be targeted to address sustainability concerns.

1.3. Study Scope and Rationale

LCA is a cradle-to-grave assessment approach that is used to estimate the cumulative environmental impact of a system or process. This comprehensive approach considers inputs such as raw materials, energy and water requirements, and land use change as well as outputs such as emissions and waste to better assess the ecological impact of a system throughout the life of a system operation. LCA can be used as a decision-making tool that can be used to identify the environmental hotspots of a system and the key drivers of said hotspots to inform where changes might be made to dampen environmental impact. While many studies have shown success in calculating the environmental impact of apple production (Zhu et al., 2018; Goosens et al., 2017; Keyes et al., 2015), none have been representative of organic orchards in the Northeastern US. Further, while environmental impact assessments of processes like vinification (Meneses et al., 2016; Iannone et al., 2016), brewing (Cimini & Moresi, 2016; Koroneos et al., 2005), and beverage packaging (Cimini & Moresi, 2016; Cimini & Moresi, 2018; Iannone et al., 2016) have been performed, none to our knowledge have explored these aspects in the scope of hard apple cider production.

In this investigation, we utilize LCA to explore the environmental impacts of organic apple production in the Northeastern US, and investigate hard apple cider production and distribution as a means for low-impact added value for organic orchards. In our LCA, we constrain our input parameters to underscore the growing conditions in the northeast, and modify data from previous studies to be representative of the specific conditions in a locally made and distributed hard apple cider production system. In doing so, we can interpret our LCA findings to help guide future policy development for strategies related to support organic farming and agribusiness. In this study, we investigate the following research questions: 1) what is the environmental impact of organic orchard management, 2) how does organic management compare to conventional management, 3) what is the environmental impact of hard apple cider production and distribution?

2. Materials and methods

2.1. Life Cycle Analysis (LCA)

We performed the LCA in SimaPro Version 9.1 software because it contains several impact assessment methods and an extensive inventory of databases that we modified to best conform to the parameters of our analysis for our system boundary area. We use the ReCiPe 2016 method for the analysis, using the hierarchist perspective, which is considered the consensus model most commonly used in scientific research with calculated emissions based on a global perspective of a 100-year time horizon (National Institute for Public Health and the Environment, 2016; Goedkoop et al., 2009). The ReCipE midpoint impact categories are suitable for detecting environmental impacts early in the cause-effect chain, which represents a large number of impact categories, including climate change, ozone depletion, human toxicity, ecotoxicity, land and water stress, and resource depletion, among others (Table 1). The endpoint impact categories are better suited to evaluate a more holistic view of the end of the cause-effect chain and is based on damage, where impacts on human health, ecosystem health, and resource availability are directly derived from the midpoint characterization factors (Goedkoop et al., 2009).

Table 1. ReCiPe Midpoint and Endpoint Impact Categories

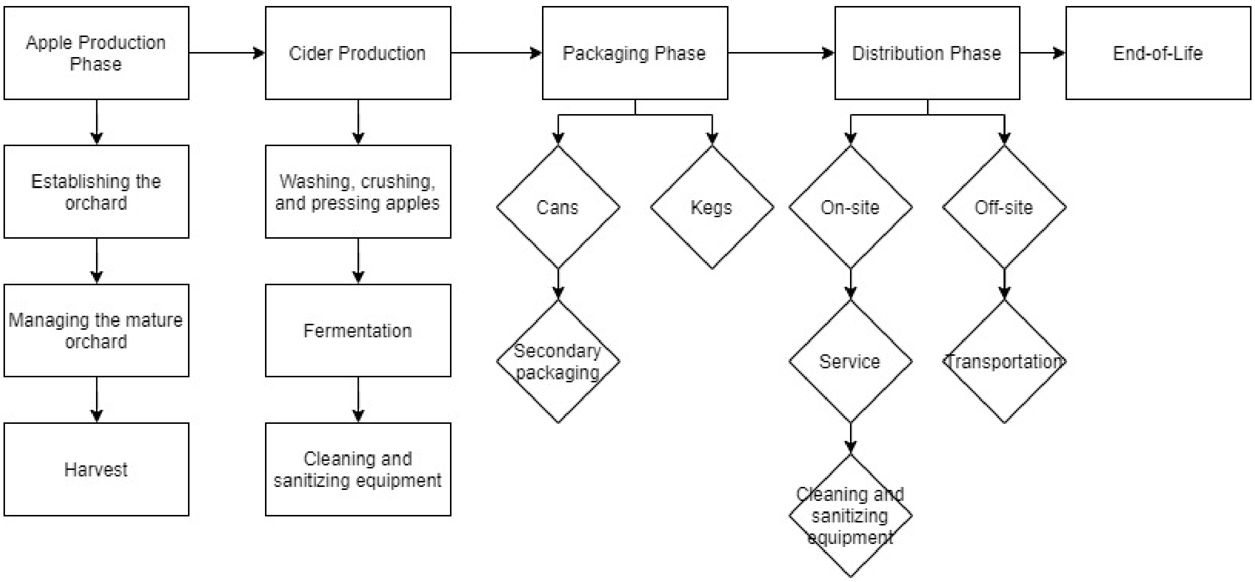
Midpoint Impact Category	**Abbreviation**
Global warming	GW
Stratospheric ozone depletion	OD
Ionizing radiation	IR
Ozone formation, Human health	OFH
Fine particulate matter formation	PM
Ozone formation, terrestrial ecosystems	OFT
Terrestrial acidification	TA
Freshwater eutrophication	FT
Marine eutrophication	ME
Terrestrial ecotoxicity	TE
Freshwater ecotoxicity	FE
Marine ecotoxicity	ME
Human carcinogenic toxicity	HC
Human non-carcinogenic toxicity	HN
Land use	LU
Mineral resource scarcity	MS
Fossil resource scarcity	FS
Water consumption	WC
Endpoint Impact Category	
Human health	HH
Ecosystem health	EH
Resource scarcity	RS

Within the ReCiPe framework, we are able to generate a number of environmental impact assessment models. Contribution analysis allows us to determine which processes within a system play a significant role in environmental contribution, which we will use to assess organic orchard management as well as the hard apple cider production system. Comparison analysis allows us to relate the substance emissions of multiple processes, which we will use to compare organic and conventional apple orchard management methods. Each of these analyses provides environmental inventory details, which is a list of substance emission to the midpoint and endpoint impact categories, and calculates the emissions associated with each of the impact categories. Through these multiple analyses, we can gain a more accurate depiction of the environmental impact of a system or systems, providing results which may inform management, strategy, and policy decisions.

2.2. System boundary & assumptions

The purpose of this study is to estimate the environmental impacts and identify improvement opportunities in the life cycle of hard apple cider produced in the Northeastern region of the United States. To do this, we will explore different agricultural approaches to orchard management (conventional and organic), hard apple cider production, and explore various levels of distribution within the region. The selected functional unit (FU), to which all values are related, was a 12-fluid ounce serving of hard apple cider. The system boundaries of the analysis, as depicted in Figure 1, takes into account a cradle-to-grave analysis including all aspects of the products' life cycle.

Figure 1. LCA System Boundary



Some key assumptions of our model include consistent production volume of apples between the two different agricultural systems, conventional and organic. Certain pieces of equipment were not included in the production and packaging stages, such as fermentation chambers, refrigeration equipment, and filling equipment. While the production and disposal of these equipment does have known high environmental impacts such as energy costs associated with raw material extraction and refining, similar studies have excluded ancillary equipment in their inventories and rather included only their impact while in use (Meneses et al., 2016; Iannone et al., 2016; Rodriguez-Gonzalez et al., 2015). To address this, we only considered the water and electricity consumption associated with completing these processes (crushing, pressing, filling, etc.) for our analysis. Transportation estimations were also made when considering the distribution of the final product. Relationships between producers and distributors vary greatly depending on state alcohol sale and distribution laws, as well as consumer supply and demand. Thus, distance and volume estimations were made based on a 100-mile radius (approximately 160-km) from where the cider produced, a distance which in much literature is considered 'local' for consumable goods (Smith & MacKinnon, 2007). Activities, such as refrigeration before customer sales or consumption, were also not taken into account; while cider is most commonly consumed cold, it is challenging to estimate electricity use without extensive consumer behavior studies.

2.3. Life Cycle Inventory

The life cycle inventory consists of the collection, interpretation, and preparation of data necessary for the environmental assessment within the project's system boundaries. The Ecoinvent (version 3) database was utilized as the principal source of background data; however, the majority of the processes and material information were adapted so that they were representative of the observed system. Agricultural phase data was adapted from primary data obtained from Rodale Institute, an organic agricultural research facility in Pennsylvania, which shared information on their apple orchard management practices. Where specific primary data could not be obtained, data from previous literature were used to complete the inventory (Cimini & Moresi, 2016; Meneses et al., 2016; Iannone et al., 2016; Rodriguez-Gonzalez et al., 2015). For each phase within the system boundary, input data (i.e. materials, natural resources, energy requirements) and output data (i.e. emissions) were included. All data was adapted to be representative of our functional unit, 12 fluid ounces, or a single serving, of hard apple cider.

The agricultural phase begins with establishment of the orchard, which includes the tree nursery producing fruit seedlings, soil cultivation, planting trees, installation of a trellis system, and sowing grass seed. We assumed normal precipitation levels (254 m3/ha) in the Northeast (National Climate Report, 2019), which is considered adequate rainfall for most apple trees, and therefore did not include a drip irrigation system in our model. While irrigation is often considered common practice for many agricultural systems, this is not necessarily the case for plots of all sizes nor for organic farming systems. When considering conservation agricultural practices, irrigation systems should match the scope of the farm, and manual irrigation methods are not unheard of in small farms like Rodale Institute which informed our data inventory. After three years with continued soil cultivation, the apple trees are assumed mature and fruiting, which is when the orchard moves to a more productive phase. The productive phase includes soil cultivation, compost application, pesticide and fungicide application, mowing, harvesting, transporting the harvest to the cider production facility, and all associated machine use. Carbon dioxide uptake by biomass was estimated at 49 tons/hectare (World Food LCA Database, 2016). Annual compost application was estimated at 12 tons/hectare (Rodale Institute, 2019). One of the largest challenges with managing orchards using organic practices is dealing with pests. Pest management (insecticide and fungicide applications) was estimated as the following: dormant oil at 18.7 liters/hectare annually, Procidic at 0.44 liters/hectare, Sulfur at 6.7 kg/hectare 10 times annually, Surround at 56 kg/hectare 5 times annually, Entrust at 0.73 liters/hectare DiPel at 2.2 kg/hectare and Madex at 0.15 liters/hectare each 5 times annually (Rodale Institute, 2019). We assumed 100% emissions to soil for all pesticide materials. Water needs for applying insecticide and fungicide were estimated using the suggested dilution method for each product above, and the associated emissions were calculated using the World Food LCA Database guidelines. Diesel needs were estimated based on tractor and trailer transport requirements for applying pesticides, bimonthly mowing in the summer months (June-September), bimonthly manual fruit thinning in June, annual manual pruning done during the winter months (December-February), and harvesting. The average annual production was assumed to be 40.8 tons/hectare based on the Ecoinvent (v3) US apple production dataset.

The cider production phase begins with washing the apples, where water needs were estimated at 200 gallons/ton (Water and Wastewater Use in the Food Processing Industry). Next, the apples are crushed then pressed, where we estimated electricity needs based on a vinification LCA study by Iannone et al., (2016). This process produces apple pomace, which is the pulpy residue from crushed fruit which contains skins, seeds, stems, and other fibrous material. Pomace is returned to the system and can be used as a component to create compost, which in turn fertilizes the orchard. The remaining cider then goes through a UV pasteurization process, from which we estimated electricity requirements at 0.22Joules/gram of juice (Rodriguez-Gonzalez et al., 2015). The pasteurized cider then moves to a collection container, where yeast is added for temperature controlled fermentation (Meneses et al., 2016; Iannone et al., 2016). Cleaning and sanitizing is a crucial component of safe consumable goods production; conventional food-safe cleaning and sanitizing agents and the water required for washing equipment was approximated

(Meneses et al., 2016). After two to four weeks, the cider has fermented, and can move to the packaging phase.

The cider is packaged in aluminum cans with a volume of 12 fluid ounces (0.35 liters) for distribution, and steel kegs with a volume of 30 liters for on-site consumption (which contains approximately 84 12 fluid ounce servings). Data for this phase was primarily informed from a study by Cimini and Moresi (2016), though calculations were made to be representative of our FU and system requirements. Canned packaging considered the primary packaging requirements, including secondary aluminum for the can, shape casted aluminum for the tab, label paper, ink, ink dilutant, and acrylic binder. Packaging needs for distribution were also considered, which included a cardboard 6-pack holder and cardboard case (holds four 6-packs) and the associated ink and adhesive needs for labelling both pieces. Kegged packaging consisted only of primary packaging, as they were not distributed outside of the facility, which included stainless steel, ink, ink dilutant, and the plastic ball for the keg coupler. Electricity requirements for filling both primary packaging types was estimated at 0.00108 kWh per FU. Recycling is included in both datasets for the aluminum can and the steel keg. While the aluminum cans are single-use, they are fully recyclable. Similarly, the steel keg can be reused indefinitely when cleaned and handled with care, has a life expectancy of over 30 years, and is also 100% recyclable.

The distribution phase consists of both on and off-site cider sales. For this, we assumed an equal split of product distribution, where 50% was sold on-site and 50% was sold off-site. On-site sales consists of pouring the cider from the keg into a glass, and considers the water and detergents required to clean the serving glass. On-site distribution also considers the water and detergents required to clean the keg for reuse, which were estimated based on the data obtained which informed the production phase (Meneses et al., 2016). We assume cellar keg storage remains at a palpable serving temperature, and therefore have not included refrigeration or electricity in this model. Not included in this scenario are the other amenities that would typically be associated with a tasting room, and focuses solely on the requirements of the product. Off-site distribution consists of transporting the packaged cans using a lightweight commercial vehicle (Ecoinvent, v3) driving a distance of 100-miles (160-km) (Smith & MacKinnon, 2007). Based on the cargo load capability, we estimated the maximum carrying capacity of 200 cases of cider per delivery. Not included in this scenario, are the refrigeration requirements, etc. associated with the distribution center sometimes used at the point of sale.

3. Results and Discussion

3.1. Inventory Analysis

The resulting inventory for the inputs of the hard apple cider production system is shown in Table 2, with values related to the FU of one 12 fluid ounce serving.

Table 2. Life Cycle Inventory, key inputs for the hard apple cider production system

Phase	Input	Amount	Unit
Agricultural	Carbon dioxide	0.4804	kg
	Energy, in biomass	5.4531	MJ
	Occupation, permanent crop, fruit	0.4943	m2a
	Transformation, from permanent crop	0.0246	m2
	Transformation, to permanent crop	0.0246	m2
	Water	2.2E-09	l
	Establishing Orchard	3.42E-03	p
	Fruit tree seedling, for planting	3.42E-03	p
	Mulching	2.46E-04	ha
	Planting tree	3.42E-03	p

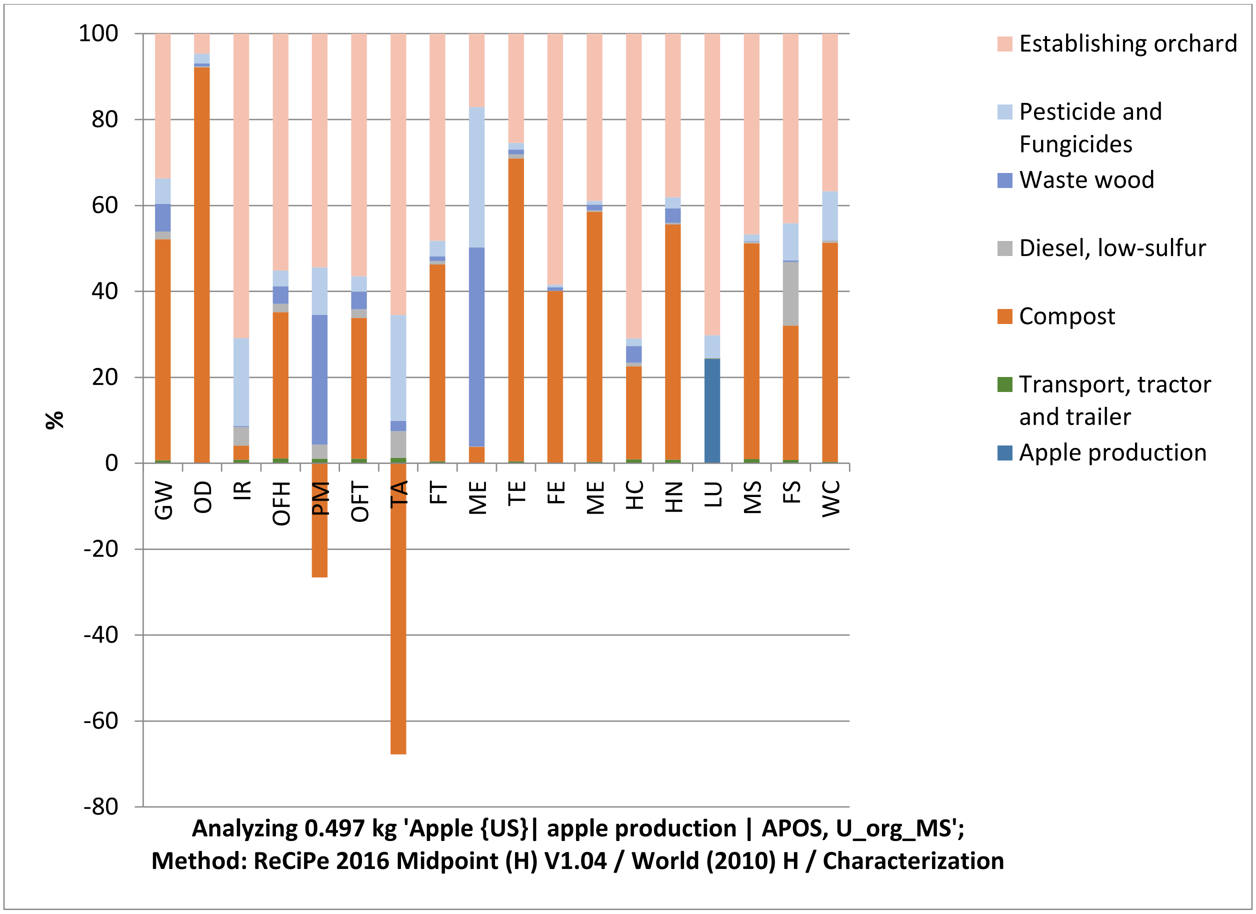
	Trellis system	4.93E-05	ha
	Compost	0.5529	kg
	Pesticides and Fungicides	0.0148	kg
	Packaging for insecticides	9.06E-06	kg
	Diesel, low-sulfur	8.94E-03	lbs.
	Transport, tractor and trailer	2.44E-03	tkm
Production	Water	0.6720	gal
	Electricity	5.04E-03	MJ
	Yeast	1.28E-04	kg
	Cleaning and Sanitizing agents	1.5222	kg
Packaging	Aluminum	13.227	g
	Steel	105.6	g
	Adhesive	3.279	g
	Ink	2.44E-04	g
	Ink dilutant	1.43E-03	g
	Label	0.69	g
	Can closure	3.8	g
	Plastic lock keg coupler	0.055	g
	Electricity	2.08E-03	g
	Corrugated board	18.711	g
	Adhesive for board	3.279	g
Distribution	Glass	0.1889	kg
	Water	0.33	gal
	Cleaning and sanitizing agents	0.5385	kg
	Transportation, light commercial vehicle	1.88	tkm
End of Life			

3.2. Organic Apple Orchard Management

3.2.1. Contribution Analysis

The results of the organically managed apple orchard impact assessment can be found in Table 3, and are illustrated in Figure 2. The most important operations in terms of environmental load are factors included in establishing the orchard, namely the wooden trellis system, and fertilization through spreading compost. Orchard establishment can be relatively intensive, thus having an expected greater environmental impact than a mature orchard, which requires less active management. Compost for fertilization has environmental impacts, both negative and positive. Compost is made of organic waste, which generates methane, ammonia, and nitrous oxides amongst other greenhouse gases. Compost can also effect water quality, due to leaching of nitrates, ammonium, organic compounds, and phosphate. We also see depicted the environmental benefits of compost in both the fine particulate matter formation and terrestrial acidification impact categories. Compost use is also associated with improved soil nutrition, moisture, and structure, which encourages soil retention and decreases the need for synthetic fertilizers and chemical pesticides. Carbon dioxide emissions, or carbon footprint, associated with organic apple orchard management totaled 0.0346 per FU. When normalizing the data, which puts each impact category into a greater perspective, freshwater and marine ecotoxicity are seen are the most heavily effected categories. This finding is expected, as agricultural run-off, or agriculture point-source pollution, is known to heavily effect groundwater and nearby river systems (US Environmental Protection Agency, 2019).

Figure 2. Impact assessment results of the organic apple orchard agricultural phase



3.2.2. Comparison Analysis

The conventionally managed apple orchard data used for this analysis was obtained through the Ecoinvent (version 3) database, which used data which was representative of a commercial orchard of equal productivity. The results of the organically managed and conventionally managed apple orchards are shown in Table 3, where we can see that the organic orchard out-performs conventional management across 17 of the 18 impact categories. These findings were supported through the findings of previous studies done by Zhu et al. (2018) and Goosens et al. (2017), which found organic orchard systems to be significantly less impactful than conventionally managed ones. The only impact category where organic has a larger environmental impact is terrestrial ecotoxicity, which can be attributed to the use of compost, which can more heavily effect water and may impact soil quality as. Once again, we see that freshwater and marine ecotoxicity are the most heavily effected impact categories. The primary difference between the two agricultural systems was the fertilizer and pesticide types and amounts, and the use of an irrigation system. As anticipated, this irrigation system had a large environmental impact and was found to be one of the largest contributing inputs for the system. The endpoint impact categories show that the organic system outperforms conventional in both the human and ecosystem health impact categories. Damage to human health is measured in DALY, or Disability-Adjusted Life Years, which takes into account the years lost to premature death and expressing the reduced quality of life due to illness in years. Damage to ecosystem health is measured in the number of species lost per year due to reduced quality of terrestrial and water ecosystems. Resource scarcity is measured in US dollars, which represents the extra costs involved for future mineral and fossil resource extraction.

Table 3. Impact assessment results, organic and conventional apple orchard management

Impact category	Unit	Organic	Conventional
GW	Kg CO2 eq	0.0392	0.046
OD	Kg CFC11 eq	2.48E-7	2.82E-7
IR	kBq Co-60 eq	0.000744	0.0026
OFH	Kg NOx eq	0.000126	0.000168
PM	Kg PM2.5 eq	3.52E-5	4.99E-5
OFT	Kg NOx eq	0.000133	0.000177
TA	Kg SO2 eq	2.58E-5	0.000226
FT	Kg P eq	1.17E-5	1.99E-5
ME	Kg N eq	7.62E-6	0.000111
TE	Kg 1,4-DCB	0.089	0.0773
FE	Kg 1,4-DCB	0.00689	0.00842
ME	Kg 1,4-DCB	0.00139	0.00159
HC	Kg 1,4-DCB	8.25E-5	8.55E-5
HN	Kg 1,4-DCB	0.00169	0.00266
LU	M2a crop eq	0.351	1.77
MS	Kg Cu eq	0.000372	0.000428
FS	Kg oil eq	0.0084	0.00855
WC	M3	0.000328	0.0442
HH	DALY	8.29E-8	1.67E-7
EH	Species/yr	1.61E-8	3.26E-9
RS	USD2013	0.00254	0.0028

3.3. Hard Apple Cider Production System

The results of the impact assessment can be found in Table 4, while the contribution analysis is visually depicted in Figure 3. We see that the packaging phase accounts for the greatest level of environmental contribution across most impact categories. As anticipated, packaging shows the greatest impact in three areas of concern: water consumption, marine ecotoxicity and freshwater ecotoxicity. Impact on water consumption is primarily due to the water required to process steel, the primary material for the keg packaging scenario. However, due to the reuse value and relatively long life of kegs, they are still considered one of the most eco-friendly packaging methods. Impact of water ecotoxicity is largely due to the can packaging scenario where the aluminum accounts for approximately 40% of the overall impact in each category. While these impacts are not to be ignored, aluminum cans have been identified as one of the least detrimental single-use packaging forms for beverages. Glass bottles, while also a recyclable option, have shown a much higher environmental impact than secondary aluminum cans in previous studies (Cimini & Moresi, 2018). We can also see that off-site distribution plays a large role across many impact categories which affect both ecosystem and human health, which can be attributed primarily to the diesel fuel use and associated emissions in transporting the goods. Our model presents a case of equal volume on- and off-site distribution, assuming the consumed cider has an equal likelihood of being obtained either directly from the producer or at a nearby retailer. The production phase had the largest impact on stratospheric ozone depletion and land us, which can primarily be attributed to the water and electricity requirements.

Figure 3. Contribution analysis, hard apple cider production system

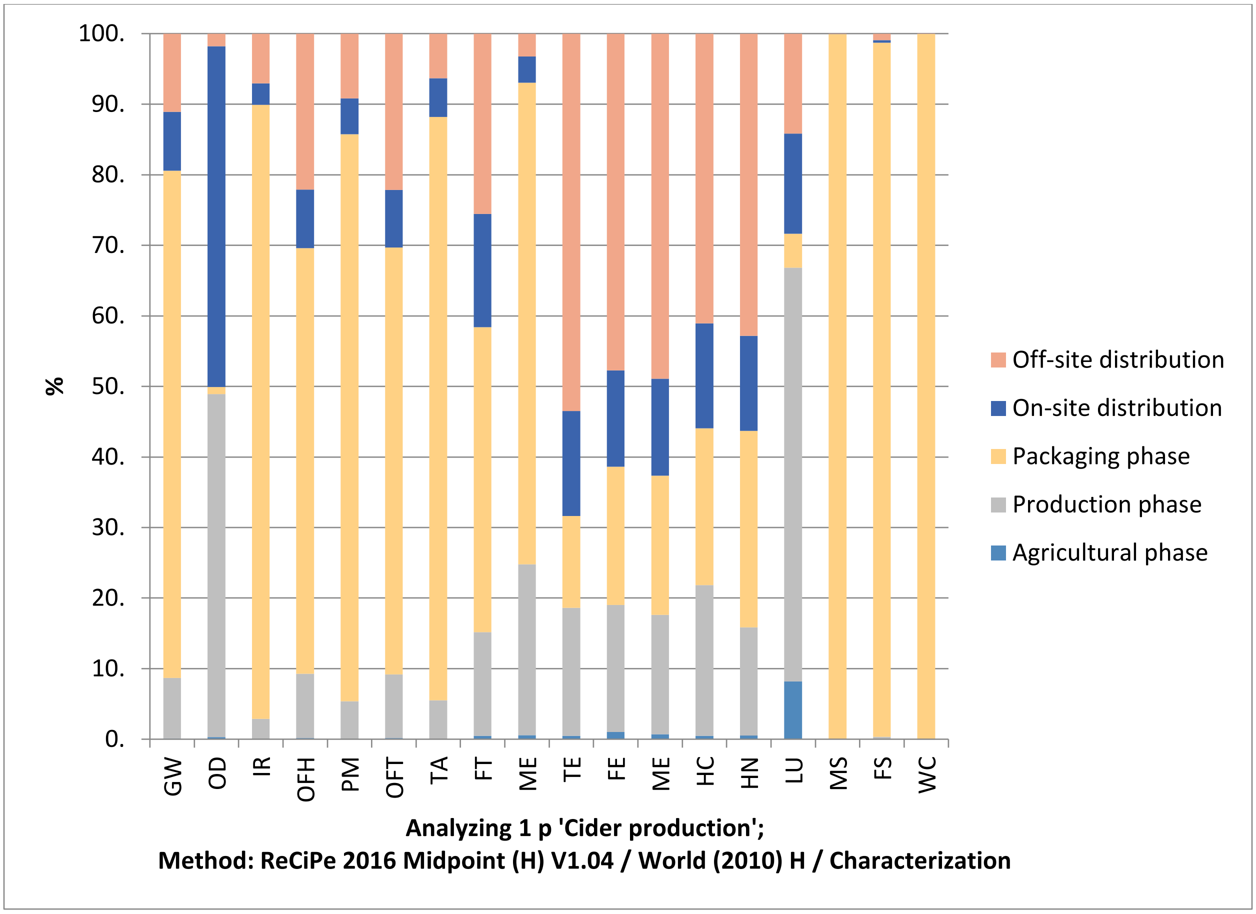


Table 4. Impact assessment results, hard apple cider production system

Impact category	**Unit**	**Agricultural phase**	**Production phase**	**Packaging phase**	**On-site distribution**	**Off-site distribution**	**Total**
GW	Kg CO2 eq	0.0346	2.831	23.719	2.75	3.65	33
OD	Kg CFC11 eq	3.87E-7	6.02E-5	1.25E-6	5.99E-5	2.21E-6	.000124
IR	kBq Co-60 eq	0.000811	0.0473	1.454	0.0505	0.118	1.67
OFH	Kg NOx eq	0.000126	0.00672	0.0444	0.00611	0.0163	0.0737
PM	Kg PM2.5 eq	3.78E-5	0.00377	0.051	0.00325	0.00582	0.0635
OFT	Kg NOx eq	0.000133	0.00684	0.0459	0.0062	0.0168	0.0759
TA	Kg SO2 eq	2.58E-5	0.01091	0.1646	0.0109	0.0126	0.199
FT	Kg P eq	1.17E-5	3.75E-4	0.0011	0.000409	0.000652	0.00255
ME	Kg N eq	7.62E-6	3.36E-4	0.0009	5.15E-5	4.53E-5	0.00139
TE	Kg 1,4-DCB	0.206	8.06	5.7749	6.61	23.7	44.4
FE	Kg 1,4-DCB	0.00733	0.1301	0.1413	0.0988	0.345	0.722
ME	Kg 1,4-DCB	0.00636	0.1583	0.1842	0.128	0.457	0.934
HC	Kg 1,4-DCB	0.00192	0.0847	0.0882	0.059	0.163	0.397

HN	Kg 1,4-DCB	0.0859	2.527	4.6007	2.23	7.08	16.5
LU	M2a crop eq	0.351	2.512	0.205	0.609	0.606	4.28
MS	Kg Cu eq	0.000365	0.01594	48.153	0.0127	0.0171	48.2
FS	Kg oil eq	0.0084	0.421	122.974	0.409	1.18	125
WC	M3	0.000328	0.485	744.960	0.0294	0.00975	745
HH	DALY						0.00173
EH	Species.yr						1.02E-5
RS	USD2013						39

The endpoint impact categories estimate damage to human health at 0.00173 DALY, damage to ecosystems at 1.02E-5 species per year, and resource scarcity estimates an added cost of $39 associated with future mineral and fossil resource extraction.

4. Conclusions

In this study we perform an LCA to evaluate the benefits of organic apple orchard management compared to conventional orchard management, and assess the environmental impact of the hard apple cider production system. The system boundaries of our analysis include the agricultural phase (orchard establishment, management, and harvest), the production phase (crushing and pressing apples, fermentation, cleaning, and sanitation), the packaging phase (canning and kegging), the distribution phase (for on- and off-site product sales), and end-of-life (recycling and waste disposal). We gathered our data and presented our results using the functional unit of 12 fluid ounces, the standard serving size for hard apple cider.

A contribution analysis of organic apple orchard management showed that applying compost as fertilizer and establishing the orchard played the largest role in contributing to environmental impact. We identified freshwater and marine eutrophication as the major impact categories where improvements should be focused on, primarily having to do with the emissions associated with agricultural runoff related to compost use. A comparative analysis of organic and conventional management practices showed organic to have a significantly lower environmental impact across most categories. In addition to exclusively using organic fertilizers, pesticides, and fungicides (which generally are associated with lesser emissions), the organic model did not include an irrigation drip system. Established orchards require an estimated 36.5-52 inches of rain per year to remain in good health; the northeast receives average annual rainfall within this range and thus irrigation is less important when managing an orchard in this region. An impact assessment of the hard apple cider production system showed that the packaging phase played the largest role across most impact categories. However, the endpoint impact categories show that apple cider production can be considered a sustainable business model, with relatively limited impact on human and ecological health and economic strain.

Future research could address some of the assumptions of the study, which exclude the raw materials and disposal of ancillary equipment in the production and packaging phases. By including these data in our system boundary, our model might better represent the impact of the system and address these limitations. Future research could also expand on this model by considering distribution in more detail. Specific details informed by existing hard apple cider producers could help to create a model that is more realistic in representing on- and off-site sales. Continued work in this area could help to identify where solutions might be made in ensuring packaging does not have an exponential impact on the environment, and could instill best practices when identifying a distribution radius which maintains a limited impact for the business's environmental footprint.

Using LCA allows a cradle-to-grave analysis of a system to identify environmental hotspots which can help inform targeted change in order to address sustainability concerns. Agricultural sustainability is a fundamental requirement for environmental conservation, food production, and food security. In order to reach these goals, decision makers from agricultural institutions and policy development must align on the means to achieve agricultural sustainability as well as the support required to reach those goals. Through collaborative support, sustainable agriculture can help to avoid further degradation of environmental quality in a way that is physically and financially achievable. In an increasingly globalized food system, sustainable agriculture faces even more challenges in being financially competitive in even its local market. Even when distributing outside of the local network, agricultural sustainability can be achieved when internal and external policies align to support the needs of the industry as well as the demands of the consumer. Hard apple cider has been identified as a component of sustainable agriculture as a means for low-impact, high-profit added value for an apple orchard. With new insights in this field, we aim to build support for the localization of food systems, which can help to frame sustainable agriculture and food by encouraging producers to incorporate practices that avoid environmental degradation, support agrobiodiversity, empower employees and local community networks, and support regional economic growth.

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