Almond Milk vs. Cow Milk Life Cycle Assessment

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Executive Summary

Green consumerism has influenced shoppers to purchase more environmentally friendly products to reduce their ecological footprint. Almond milk has become a popular alternative from cow milk because it is thought to have reduced environmental impacts, such as lower emissions and fewer land requirements. However, almond production requires intensive water usage and pesticide use.

This study analyzed previous LCAs and reports as well as use a hybrid LCA to determine which product has less of an environmental impact. However, various assumptions were made in order to increase the accuracy of the data we found. The scope of this analysis does not include packaging and transportation to stores or disposal. For almond milk, the unit processes are: almond farming, water, transportation, energy and almond processing For cow milk, the unit process are: milk production, water, transportation, energy and milk processing.

Comparing one liter of each, almond milk production does indeed emit fewer greenhouse gases than does cow milk; nevertheless, cow milk production uses less water than almond milk production. More specifically, one liter of almond milk uses 1,611.62 *gallons* of water and emits 0.36 *kg* CO_2e. One liter of cow milk uses 77 gallons of water and emits 1.67 *kg* CO_2e. Almond milk uses 1,534.62 more gallons of water per liter than cow milk, but it emits 1.31 kg CO_2e per liter less than cow milk. When conducting our sensitivity analysis, we found that the most sensitive process is co-product emission credit for both almond and cow milk. This study concludes that these two products present a trade-off where consumers must decide which environmental impact is more important: water usage or climate change.

Goal and Scope

The goal of this analysis is to compare the environmental impacts from the production of almond milk and cow milk. We aimed to inquire if the increase in consumption of almond milk would make the drought in California worse and if the overall greenhouse gas emissions are drastically lower. This study focuses on the impacts of these two products in California because both are important to the state's agricultural markets and because California is crucial to the nation's agricultural market. We analyzed the production and processing of both milks, weighing their effects on water usage and greenhouse gases through a hybrid LCA to combine both process and EIOLCA techniques for the cradle-to-gate life cycles of both products. From the standard process-based LCA, we used the 2002 sector for the EIOLCA, published LCA's, and data from companies to zoom in on specific processes to get a better analysis of some of the "hotspots" within each product. to provide consumers with a recommendation as to which is more environmentally friendly and sustainable. We also aim to conclude if green consumerism is achieving its intended purpose: having a positive effect on the environment.

Overview of Literature

In our research and data compiling stage, we found that there were more sources on cow milk than almond milk. Nevertheless, we used the information that was readily available to the maximum extent in order to get more accurate and precise data. For each LCA used, co-products were accounted for, so the data taken from each study was already a net value of carbon emissions.We used two main LCA's to supplement our cow milk data. The first LCA was *Regional analysis of greenhouse gas emissions from USA dairy farms*, which focused on the American dairy industry [Thomas, Popp, et al. 2008]. This LCA took data from over 500 farms and computed greenhouse gas emissions per kilogram of milk. They also calculated averages of various feeding and manure management techniques. Their methodology included using data on crop production (annual yield of crop/acre) and annual fertilizer and pesticide totals. The second LCA used for our cow milk data was *Greenhouse Gas Emissions from the Dairy Sector* [Food and Agriculture Organization 2010] . This study focused on global emissions for cow milk separating cradle-to-gate and gate-to-retail. Their methodology included source of emissions and assigning allocation techniques for dairy products. For example, for milk they chose all system related emissions such as production, processing and transport and for allocation techniques they chose protein content. We took the world averages from the cradle-to-gate portion of the study.

For almond milk, we also used two LCA's. The first LCA, *A comparative assessment of greenhouse gas emissions in California almond, pistachio, and walnut production,* looked specifically into tree-nut farming in the Central Valley of California [Brodt, Kendall et al. 2014]. Their methodology consisted of using a process-based LCA with multiple years of the orchard life cycle accounting for changes in irrigation energy requirements, soil nitrous oxide emissions and fuel combustion emissions. Their model was originally developed for almond production, but they adapted it for walnut and pistachio production. The second LCA for almond milk, *Life Cycle–based Assessment of Energy Use and Greenhouse Gas Emissions in Almond Production,* used the same methodologies as the previously stated LCA, only with the modification that it focused solely on almonds [Brodt, Kendall et al. 2015]. Their methodology included using LCA-based methods to calculate GHG emissions, energy use, direct water use and other air pollutants from field to factory gate. Moreover, they analyzed their results with and without co-products. In addition, we used the A*lmond Eco-Efficiency Analysis* conducted by the BASF Corporation that measured life cycle impacts and costs such as emissions, toxicity, resource consumption, and energy [Braden, Burkey et al. 2011]. This report gathered data on Braden Farms, an almond farm and Hilltop Ranch, an almond processing facility both based in California. The data used from this report helped calculate the water usage from almond farming.

Life Cycle Assessment

Functional Unit

The function of the products, cow milk and almond milk, is to provide nutrition. The functional unit to compare two different types of milk will be 1 liter of cow milk and 1 liter of almond milk. This allows us to make our results and recommendations readily available to the consumer. Other LCA's used the energy corrected milk at the farm gate as a functional unit, but this is not relatable to the consumer because they understand milk through their purchasing practices. We chose to not use gallons as our functional unit because liters provide larger quantities of data and we will use gallons as a unit for one of our impact analysis.

System Boundary, Method, Flow Diagram

In our analysis we used a hybrid LCA that constituted both process and EIOLCA techniques for the cradle-to-gate life cycles. From the standard process-based LCA, we used the 2002 sector for the EIOLCA, published LCA's, and data from companies to calculate our impact analysis. For the process LCA on cow milk we took the life-cycle stages from the Fluid milk and butter manufacturing and milk production sectors from the EIOLCA. For the almond milk process LCA, most data was collected from the Hilltop Ranch and Braden Farms 2010 almond production and processing study. The rest of the data was supplemented from the Tree nut farming sector from the EIOLCA. Due to the lack of information on almond milk, we assumed that the process would be similar to that of soy milk allowing us to use the soy sectors available in EIOLCA. Our methodology will be depicted by the calculations in Figure 5. We define our system boundary to be cradle-to-gate, which means we did not consider packaging, transportation to stores, or disposal. For cow milk, this will begin with the feed, water, and land for raw milk production, up through cow milk production. For almond milk, this begins with the land and water in almond (orchard) production, up through almond milk production. Transportation from field to factory is included within.

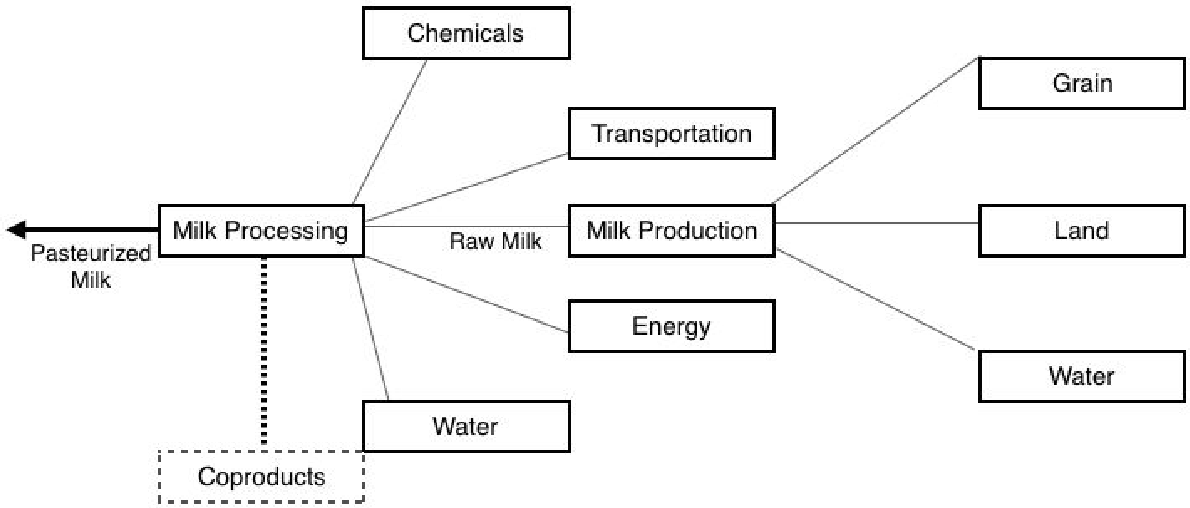


Figure 1. Whole Milk Flow-Diagram

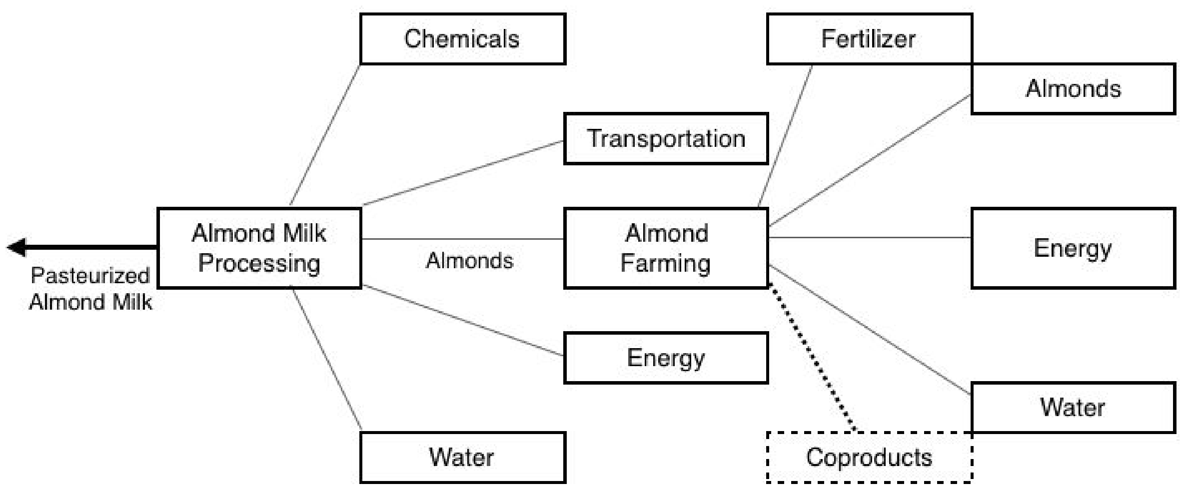


Figure 2. Almond Milk Flow-Diagram

Life Cycle Inventory

		Emissions					
	Unit process	CO2 (kg)	CH4 (kg)	N2O (kg)	HFC/PFC (kg)	Water Use (gal)	Data Source
Cow Milk	Cattle Ranching and Farming *	0.006	0.054	0.034	-	-	EIOLCA
	Milk Production	0.046	0.453	0.081	-	1.99969	
	Grain Farming	0.021	0.012	0.111	-	52.36	
	Power Generation and Supply	0.57	0.0012	0.004	0.004	11.00022	
	Sugarcane and sugar beet farming ^	-	-	-	-	1.99969	
	Other	0.192	0.034	0.046	0.002	9.6404	
Almond Milk	Tree Nut Farming	0.051	-	0.07	-	691.0645751	
	Fertilizer *	0.008	-	0.014	-	-	
	Almond Processing *	0.037	-	-	-	-	
	Power Generation and Supply	0.082	0.0002	0.0005	0.0005	101.4340204	
	Cotton farming ^	-	-	-	-	272.1400566	
	Grain farming ^	-	-	-	-	442.0214255	
	Other	0.038	0.02	0.013	0.001	104.7389224	

* refers to processes that were prominent in CO_{2e} emissions, but not in water usage
^ refers to processes that were prominent in water usage, but not in CO_{2e} emissions

Impact Analysis

Results for Greenhouse Gas Emissions

Almond milk greenhouse gas emissions were found by taking the average of two LCA sources that looked deeper into the production of almond farming. The first LCA found the total net emissions per kilogram of almonds to be 1.88 kg CO_2e kg^{-1} almond (Marvinney, Kendall, Brodt, 2014) while the second found emissions to be 0.92 kg CO_2-eq kg^{-1} almond (Marvinney, Kendall, Brodt, Zhu, 2015). Along with the sample LCA's, we looked at the EIOLCA for the Tree Nut Farming sector and found emissions to be 1.40 kg CO_2e kg^{-1} almond. Taking the average of these three reports yields:

$$\frac{1.40\ kg\ CO2ekg^{-1} + 1.88\ kg\ CO2ekg^{-1} + 0.92\ kg\ CO2ekg^{-1}}{3} = 1.40\ kg\ CO2ekg^{-1}\ almond$$

As we are basing our study off of a homemade recipe of almond milk, we have found that there are approximately 194 almonds per batch and the average weight of an almond is 1.2 g. Converting this yields:

1.40 kg CO2e kg^{-1} almond * .2333 kg almond L^{-1} almond milk = .3266 kg CO2e L^{-1} almond milk

Because each of these studies only looks into almond farming, we have decided to equate soybean processing with raw almonds to almond processing. The following calculations were obtained to find the greenhouse gas emissions that arise from almond processing when we looked at Soybean and other Oilseed Processing sector on the EIOLCA:

$$\frac{Oilseed\ farming\ GWP}{Soybean\ and\ other\ Oilseed\ Processing} = \frac{1370\ tonne\ CO2}{154\ tonne\ CO2} = 8.896$$

Setting this equal to the information we already have yields:

Almond Farming GWP/ (Estimated) Almond Processing GWP = .3266 kg CO2e/(Estimated) Almond Processing GWP = 8.896
(Estimated) Almond Processing GWP = .0367 kg CO2 e

Adding the values for almond farming and almond processing together yields the following total emissions for 1 kg of almond milk:

.0367 kg CO_2e L^{-1} + .3267 kg CO_2e L^{-1} =0**.3634 kg CO_2e L^{-1} almond milk**

Using multiple world-wide studies on the farming techniques of cow milk, we were able to calculate the CO_2 emissions per kilogram of milk. The first study yielded 2.4 kg CO_2 kg^{-1} of milk (FAO 2010). The next study found the production-weighted national average greenhouse gas emissions to be 1.23 kg CO_2 kg^{-1} fat and protein corrected milk (Thoma et al. 2013). Lastly, according to the EIOLCA for Fluid Milk and Butter Manufacturing, the greenhouse gas emissions are 1.25 kg CO_2 kg^{-1} milk. Thus, taking the average of the three sources yields:

$$\frac{(2.4 + 1.23 + 1.25) kg\ CO2\ kg^{-1}}{3} = 1.62\ kg\ CO_2\ kg^{-1}\ \text{cow milk}$$

Converting this into our functional unit we have the greenhouse gas emissions for 1 L of cow milk as:

1.62 kg CO_2e kg^{-1} cow milk $\times$ 1.03 kg milk L^{-1} cow milk = **1.67 kg CO_2e L^{-1} cow milk**

Each functional unit's greenhouse gas emissions were analyzed further to see which industries and practices contribute most to each product's global warming potential. Using EIOLCA at $1 million for each sector's GWP in kg CO_2, we took the percentage breakdowns of the top 5 influencing sectors and applied these percentages to the total emissions calculated above. A sample calculation for the Milk production makeup of the cow milk emissions is below:

- Total GWP in tonne CO_2 for Fluid milk and butter manufacturing: 2280 tonne CO_2
- GWP in tonne CO_2 for sector with the most influence (Milk production): 1190 tonne CO_2
  - ➔ $\frac{1190\ tonne\ CO2}{2280\ tonne\ CO2} = .5219$
- Thus, 52.19% of Fluid milk and butter manufacturing greenhouse gas emissions come from the Milk production sector
  - ➔ 1.67 kg CO_2 L^{-1} cow milk × .5219 = **.871 kg CO_2 L^{-1} cow milk**

This equation was used for each of the breakdowns below:

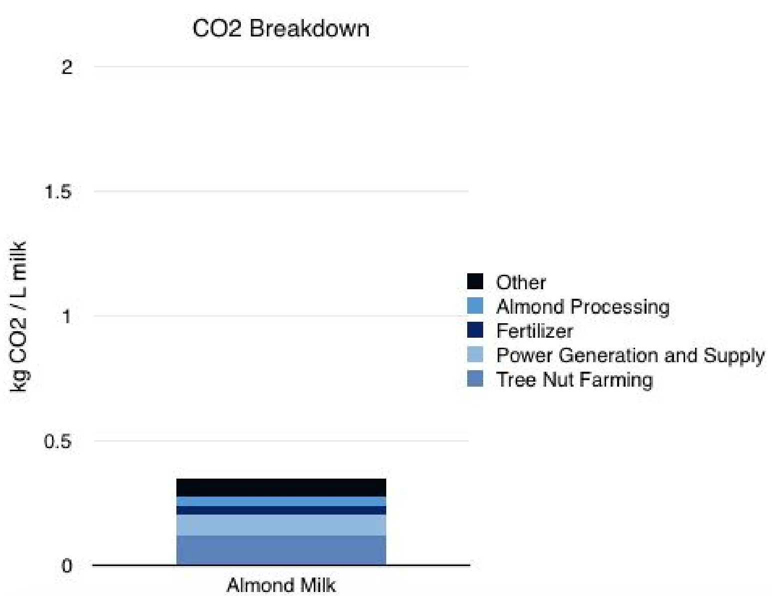


Figure 3 Almond Milk CO_2 Breakdown

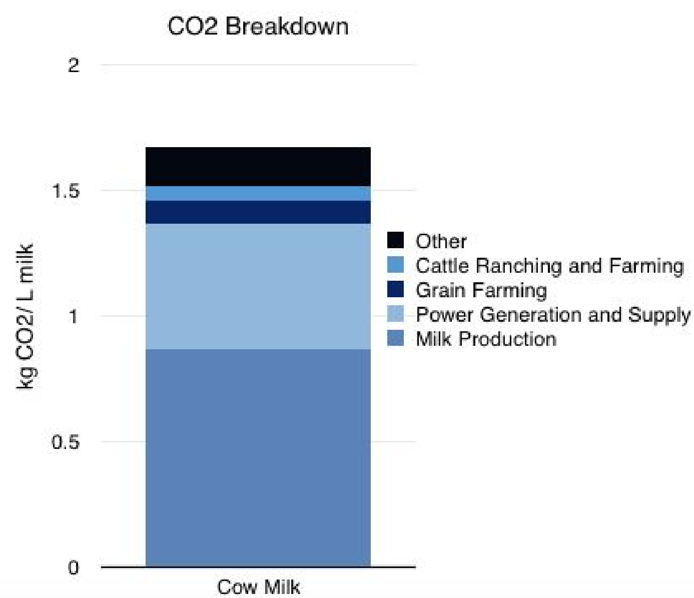


Figure 4 Cow Milk CO_2 Breakdown

Furthermore, we decided to break down the Milk Production sector in the cow milk bar graph to obtain more specificity in the graph. Doing so resulted in making the Milk Production input smaller and adding to the other inputs because top contributors to the Milk Production sector were Power generation and supply, Grain farming, and Cattle ranching and farming. The results were:

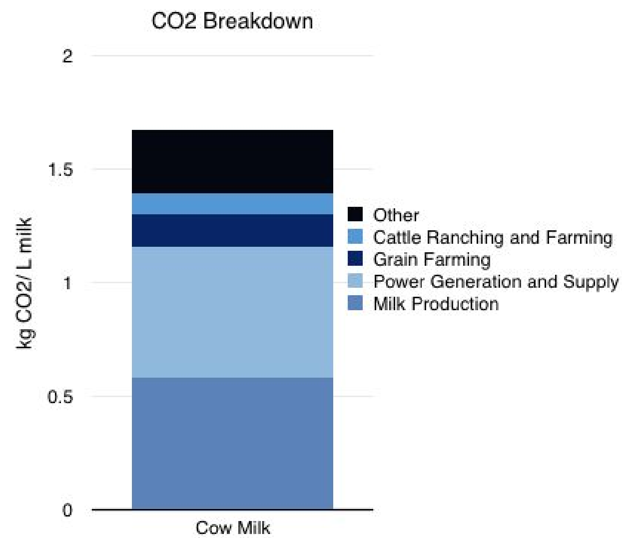
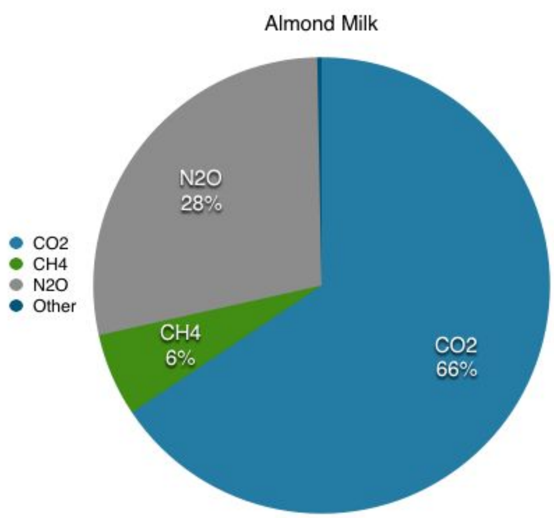
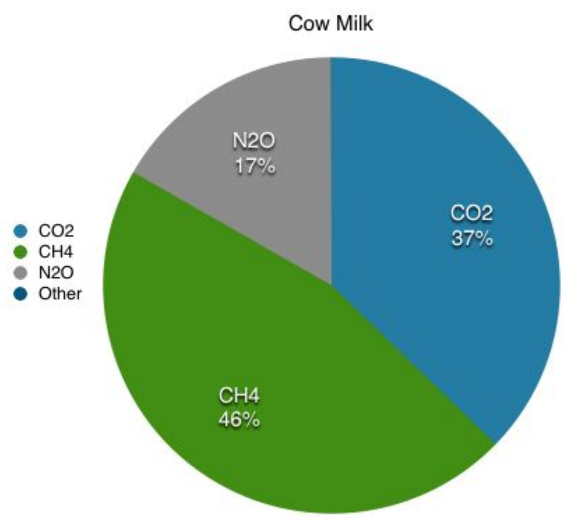


Figure 5 Cow Milk-Milk Production CO_2 Breakdown

Looking at the bar graph, we can see that the main inputs for both forms of milk come from the farming and production processes and Power generation and supply. However, it is difficult to look further into the farming/production processes due to the lack of data on greenhouse gas hotspots in both industries' production. Due to this lack of data, we used EIOLCA which pointed us to the influencing sectors rather than specific influencing processes. Because of this, we also looked at the breakdown of top contributing greenhouse gases in each industry to see if we could combine this with our current data to get a better idea of where the bulk of the impacts were coming from.





From analyzing these two graphs, combined with the graphs earlier produced, we are able to look more closely and infer where each sector's main greenhouse gas emissions come from.

One visible difference between the two sectors is the much larger percentage of methane emissions that comes from cow milk. This is unsurprising considering that methane emissions are primarily derived from livestock and the decomposition of waste or manure. This shows that a large bulk of greenhouse gas emissions on cow milk is due to simply farming cows, which is unavoidable if cow milk is the desired end product. Another difference that arises is the large contribution that nitrous oxide has when it comes to almond farming; this is primarily due to fertilizers. Again, fertilizers, much like cows, are needed for the almond milk production process. Both have high percentages of carbon dioxide emission which, most likely, is primarily derived from the Power generation and supply sector. Almond processing and cow milk processing are both heavy on carbon dioxide emissions. We can see how much higher the percentage of carbon dioxide is in almond milk, however, for both industries much of these emissions are derived from the processing plants and it brings into question what differing methods are used for each process.

Results for Water Usage

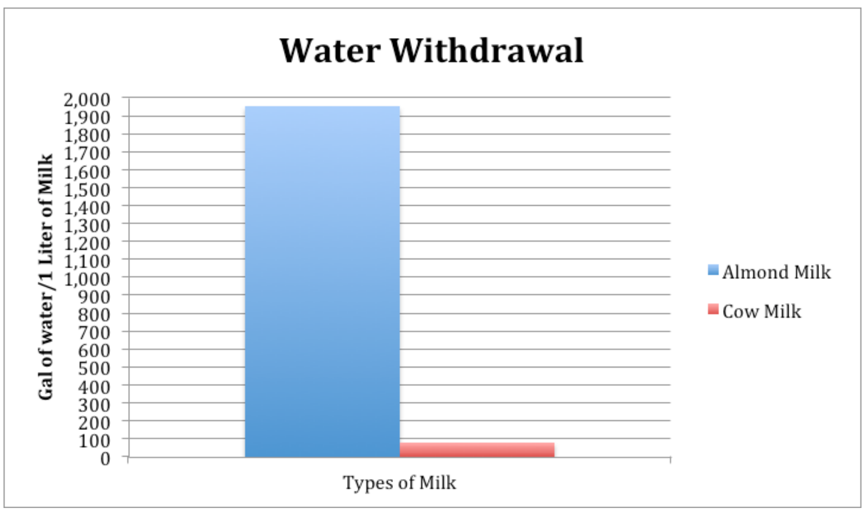


Figure 6 Water Withdrawal (EIOLCA)

Almond Milk

Almond milk water usage was calculated using data from *Almond Eco-Efficiency Analysis* (BASF Corporation, 2011) and EIOLCA. The *Almond Eco-Efficiency Analysis* reports life cycle inputs between Braden Farms and Hilltop Ranch, an almond farm and processing plant, respectively, situated in California. The report states that in 2010, Braden Farms used 977,553 gallons of water per acre to produce 2500 lbs of almonds. Assuming that one almond weighs 1.2 grams, 944,983.3 almonds are produced from one acre [Calorie Counter n.d.]. Since there was no accessible data from almond milk manufacturers on the amount of almonds in a liter of milk, we used a homemade almond milk recipe [The Kitchn 2015]. We found that in one cup of almond milk, 46 almonds are needed, which converts to 194.43 almonds per liter of almond milk. To calculate how much water is used in one liter of almond milk, we gathered information on how many almonds are produced in one acre and how many almonds are needed to produce one liter of almond milk. We calculated that for 1 liter of almond milk, 201.13 gallons of water were needed.

We calculated that:

$$\frac{977{,}553\ gal\ water}{1\ acre} \times \frac{1\ acre}{944{,}983.3\ almonds} \times \frac{194.43\ almonds}{1\ L\ almond\ milk} = 201.13\ \frac{gal\ water}{1\ L\ almond\ milk}$$

For EIOLCA, we used the 2002 US Producer Model for $1 million of economic activity under Tree nut farming. For all sectors, water withdrawal amounted to 495,000 kGal. Tree nut farming accounts for the whole industry engaged in growing tree nuts while data from the *Almond Eco-Efficiency Analysis* comprises of two almond companies in California. Therefore, averaging these two calculations will not result in accurate data. When taking into consideration our unit of production, 1 liter of almond milk, and narrowing our environmental impact to only the state of California, Braden Farm data will produce more accurate data. However, the *Almond Eco-Efficiency Analysis* does not report the amount of water used in processing almonds into almond milk. We must use EIOLCA to take into account both almond farming and almond processing. As mentioned in the greenhouse gas emissions section, we equated Soybean and other oilseed processing to the almond processing into almond milk. In order to take into account our functional unit, we took an average of costs between two different brands of almond milk that use Californian almonds. We are assuming that the cost of packaging is negligible thereby allowing us to use the retail price as the economic activity for EIOLCA.

Retail prices of almond milk:
Silk Original Almondmilk: $3.22/0.5 *gal*
Blue Diamond Almond Breeze Original Almondmilk: $3.54/0.5 *gal*
Average $= \frac{\$3.38}{0.5\ gal} \Rightarrow \frac{\$3.38}{1.892705\ L} \Rightarrow \frac{\$1.7858}{1\ L\ almond\ milk}$

For 1 liter of fluid almond milk, we ran EIOLCA under the 2002 US Producers Model for $0.0000017858 million.

The following is the calculation of using Soybean and other oilseed processing in lieu of almond processing:

$$\frac{Oilseed\ farming}{Soybean\ and\ other\ oilseed\ processing} = \frac{0.135\ kgal\ water}{0.163\ kgal\ water} = 0.82822086$$

$$0.82822086 = \frac{Tree\ nut\ farming}{Almond\ processing}$$

Let x = almond processing

$$0.82822086 = \frac{Tree\ nut\ farming}{x}$$

$$0.82822086 = \frac{0.885\ kgal}{x}$$

$$x = 1.068555\ kgal\ water\ used\ in\ processing\ almonds\ into\ almond\ milk$$

Total amount of water used using almond production data from the Almond Eco-Efficiency Analysis and almond processing from EIOLCA:

$$Almond\ production\ +\ almond\ processing\ =$$

$$0.20113\ kgal\ + 1.068555\ kgal\ = 1.269685\ \frac{kgal\ water}{1\ L\ almond\ milk}$$

$$=> 1,269.69\ \frac{gal\ water}{1\ L\ almond\ milk}$$

Total amount of water used using data only from EIOLCA:

$$Almond\ production\ +\ almond\ processing\ =$$

$$0.885\ kgal\ + 1.068555\ kgal\ = 1.953555\ kgal\ water$$

$$=> 1,953.555\ \frac{gal\ water}{1\ L\ almond\ milk}$$

An average of the two values of gallons of water used is:

$$Avg\ gal\ water = \frac{(1,269.69+1,953.555)\ gal\ water}{2} = 1,611.62\ \frac{gal\ water}{1\ L\ almond\ milk}$$

Treenut farming
0.838/0.885 = 94.63%= tree nut farming
0.018/0.885= 2.11%= grain farming
0.018/0.885= 2.11%= power generation and supply
0.003/0.885= 0.19%= pesticide and other agricultural chemical manufacturing
0.002/0.885= 0.19% = cotton farming
0.001/0.885==fruit farming

Soybean and other Oilseed processing
0.079/0.163 = 48.47% * 1.069= 0.518/1.069 = grain farming
0.050/0.163 = 30.67% * 1.069= 0.328/1.069= cotton farming
0.016/0.163 = 9.82% * 1.069= 0.105/1.069= power generation and supply
0.010/0.163 = 6.13% * 1.069= 0.066/1.069= oilseed farming
0.001/0.163= 0.006%*1.069= 0.007/1.069= pesticide and other agricultural chemical manufacturing
0.001/0.163=0.006%*1.069= 0.007/1.069= all other crop farming

Almond processing
48.47% * 1.069= 0.518/1.069= grain farming
30.67% * 1.069= 0.328/1.069= cotton farming
9.82% * 1.069= 0.105/1.069= power generation and supply
6.13% * 1.069= 0.066/1.069= oilseed farming

Almond Milk (Treenut farming + Almond processing)
0.838/1.954= tree nut farming
0.536/1.954= grain farming
0.330/1.954= cotton farming
0.123/1.954= power generation and supply
0.127/1.954= other

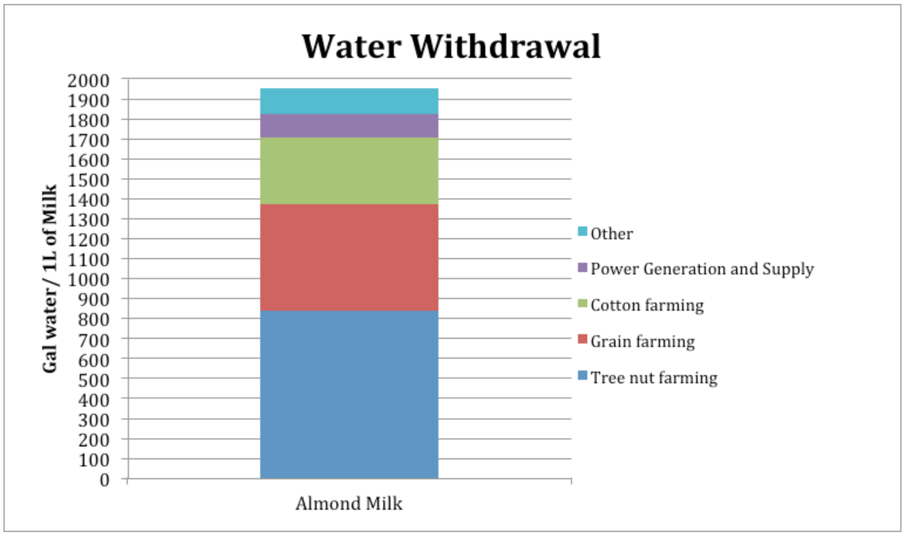


Figure 6 Almond Milk Water Withdrawal (EIOLCA)

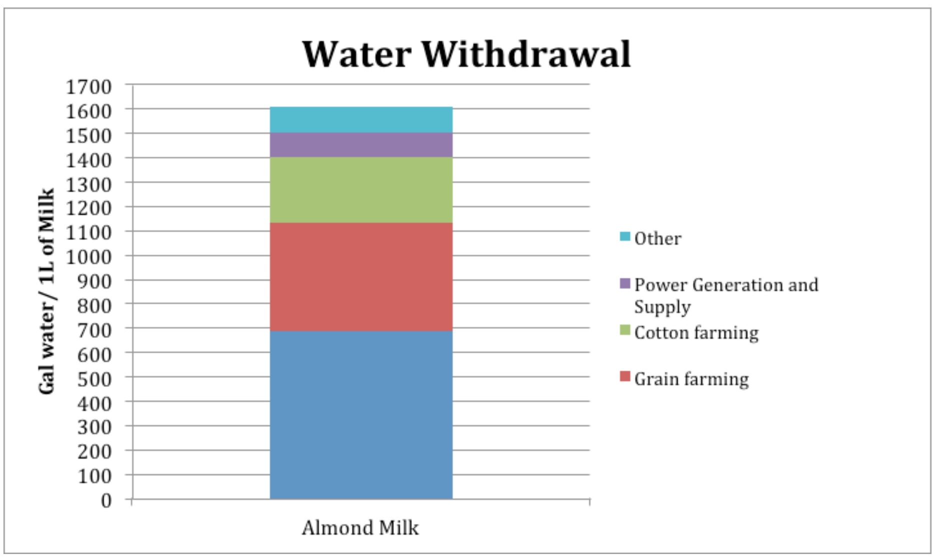


Figure 7 Almond Milk Water Withdrawal (EIOLCA and LCA)

Cow Milk

To calculate the water usage per liter of cow milk, we used data from a study focusing on the geospatial analysis of water use from U.S. dairy production and EIOLCA. The study evaluated the water impact of U.S. on-farm dairy production. We combined the data for on-farm water use and irrigation water use because the study distinguishes that for dairy producers, irrigation for growing feed is the primary water-utilization challenge than on-farm use. Moreover, the study concluded that when reducing on-farm water use, the impact on overall water stress was small. On-farm water use includes manure application to fields. We calculated total water use separately because the study does not define what “total water” encompasses, but we estimate that this includes on-farm water use and cleaning (tools, equipment, stations and cattle). We averaged out the data from hydrological accounting regions specific to CA and found water usage per day per cow knowing that a cow makes 7 gallons of milk per day. For dairy on-farm use and irrigation use per cow per day, we calculated 511.8 gallons. For total water use per cow per day, we calculated 274.3 gallons. However, this study did not focus on processing. We reverted to using EIOLCA to find out the total water usage for cow milk production and processing.

To calculate the water usage for cow milk through EIOLCA, we used the same model as almond milk, but instead used the Fluid milk and butter manufacturing industry. For the economic activity, we averaged two whole milk products based in California.

Market Pantry Whole Milk: $1.79/0.5 *gal*

Alta Dena Whole Milk: $2.49/0.5 *gal*

$\text{Average} = \frac{\$2.14}{0.5gal} => \frac{\$2.14}{1.892705\ L} => \frac{\$1.1306}{1\ L\ cow\ milk}$

For 1 liter of fluid milk, we ran EIOLCA under the 2002 US Producers Model for $0.0000011306 million. EIOCLA determined the water withdrawal for all sectors in the Fluid milk and butter manufacturing at 0.077 kGal. We calculated the percentages of the top 5 sectors within each cow milk industry to determine the total water usage. The formula is as follows:

- Total water withdrawal for Fluid Milk and Butter Manufacturing: 0.077 kGal
- Water withdrawal for sector (grain farming): 0.053 kGal

=0.053 kGal/ 0.077 kGal

=68.831% of Fluid Milk and Butter Manufacturing water withdrawal comes from Grain Farming sector

.011/.077=14.286% = power generation and supply

0.002/.077 =2.597%= milk production

0.002/.077=2.597%= sugarcane and sugar beet farming

0.002/.077=2.597%= all other cop farming

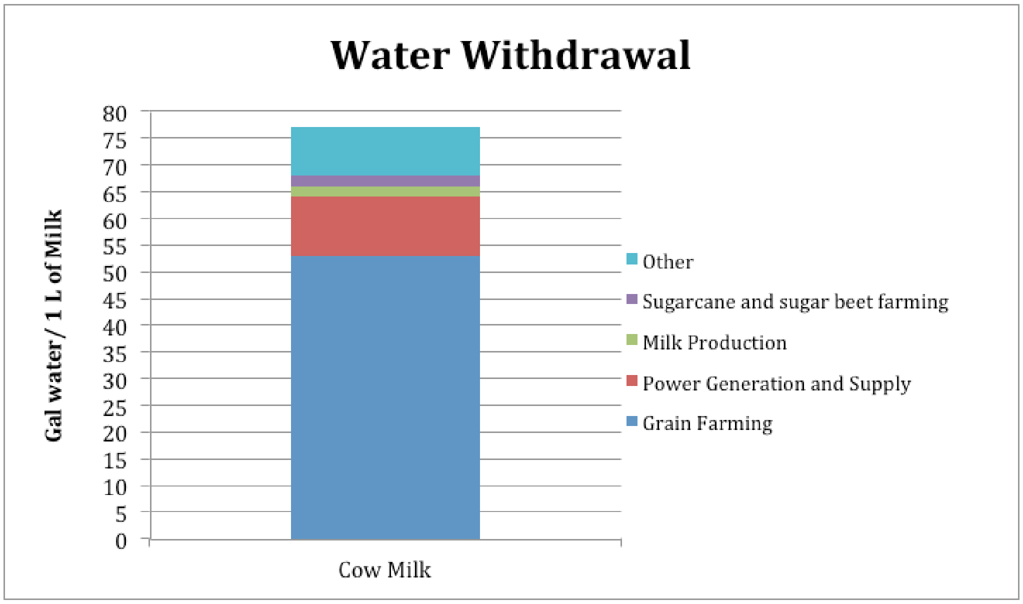


Figure 8 Cow Milk Water Withdrawal

Nutrition and Impacts Analysis

We assumed that consumers value cow and almond milk for their calcium and vitamin D content. Nutrition labels for each beverage is attached in the appendix, but this table summarizes the content of calcium and vitamin D in a single eight ounce serving:

Recommended daily value percentages for one serving (8 ounces)		
	Almond Milk (Silk and Blue Diamond)	*Conventional Cow Milk*
Calcium (%)	45	30
Vitamin D (%)	25	25

Table 1

This table summarizes how much water and greenhouse gases are consumed and emitted for one percent of the daily recommended value of each nutrient:

	For 1% of daily recommended calcium		***For 1% of daily recommended vitamin D***	
	Water (gal)	*CO_{2e} (kg)*	*Water (gal)*	*CO_{2e} (kg)*

Almond Milk *(Silk and Blue Diamond)*	*8.471956616*	0.002639925148	*15.24952191*	0.004751865267
Conventional cow milk	0.6072431404	0.006873463968	0.7286917684	0.008248156762
	(A) uses **13.95x** more water	(C) emits **11.86x** more CO_{2e}	(A) uses **20.93x** more water	(C) emits **7.90x** more CO_{2e}

Table 2

Overall, we found that almond milk is more water-intensive, while cow milk is a heavier emitter of CO_{2e}. The results of our findings were unsurprising given almond's reputation of requiring enormous quantities of water and livestock production being a large contributor to greenhouse gas emissions. There were substantial differences between the amount of water used and CO_{2e} emissions between both milks.

Sensitivity Analysis

In a sensitivity analysis, we hold all but one variable constant and adjust it to determine how it affects an end result. We perform this multiple times to test different variables, and compare them to get an overarching grasp on which variables are the most impactful and can be altered or made more efficient and sustainable. We conducted a sensitivity analysis for both cow milk and almond milk to determine which inputs or processes produce the greatest amount of greenhouse gas emissions. The processes and emission numbers were taken from the EIOLCA 2002 Producer sector data collected by Carnegie Mellon.

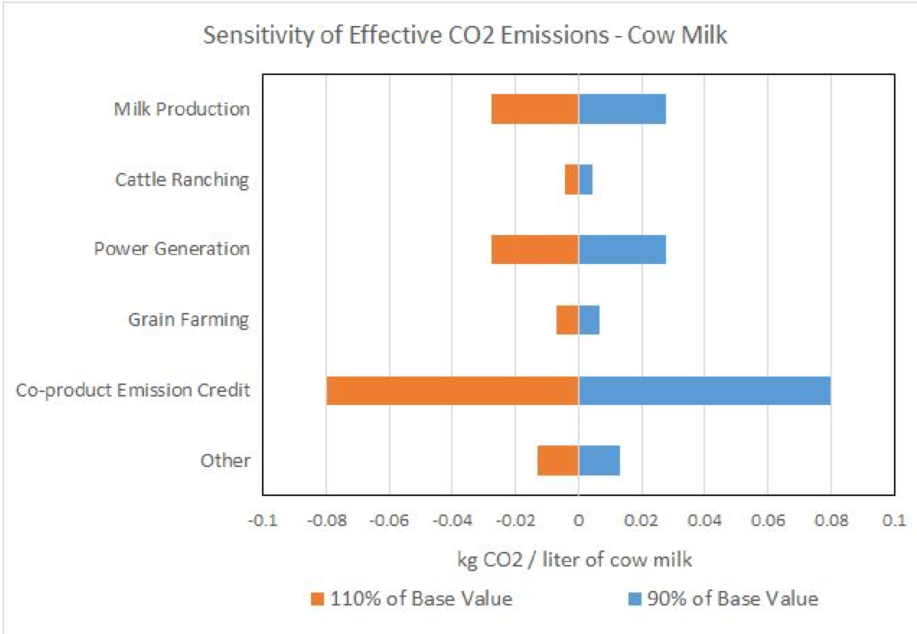


Figure 9 Cow Milk Sensitivity of Effective CO_2 Emissions

For cow milk, the processes compared included Milk production, Cattle ranching, Power generation and supply, Grain farming, and co-product emission credit. The remainder was conglomerated into a general "Other" section. The top three emitting processes were co-product emission credit, Milk production, and Power generation. Co-products were 47.81% of cow milk by mass, consisting of distilled grains (feed), butter, cream, etc., and so was a heavy emitter. Given that a liter of cow milk generates 1.67 kgCO2, using 90% of minimum and 110% maximum of the base value, altering co-product amounts whether by lessening them or increasing them, would change overall kgCO2 by +/- 0.0798.

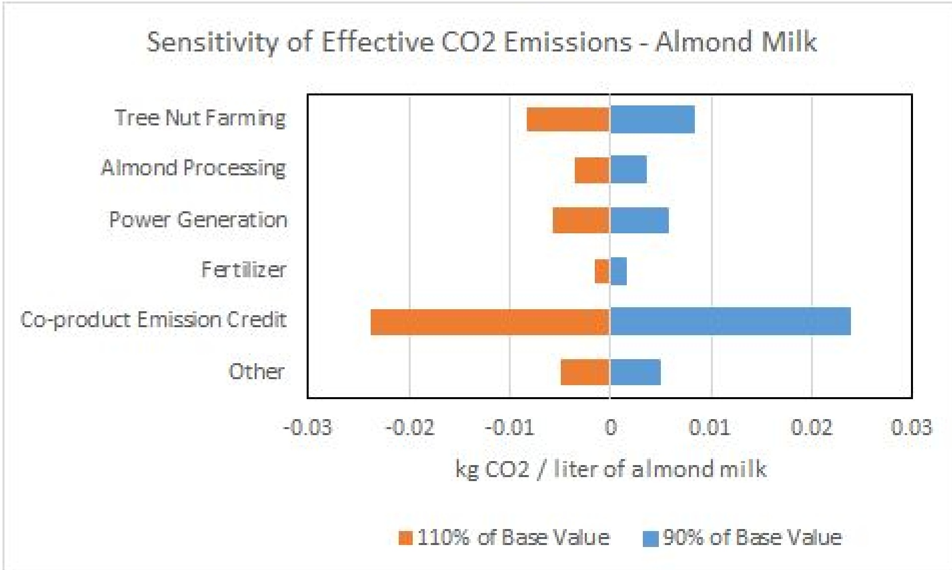


Figure 10 Almond Milk Sensitivity of Effective CO_2 Emissions

For almond milk, the processes compared included Tree nut farming, Almond processing, Power generation and supply, Fertilizer, and co-product emission credit. Again, the remainder was conglomerated into a general "Other" section. The top three emitting processes for almond milk were co-product emission credit, Tree nut farming, and Power generation. Co-products were 68.40% of almond milk by mass, consisting of almond husks and shells. Given that a liter of almond milk generates 0.3492 kgCO2, using 90% of minimum and 110% maximum of the base value, altering co-product amounts, whether by lessening them or increasing them, would change overall kgCO2 by +/- 0.0239.

Thus for both types of milk, the most sensitive process is co-product emission credit. In both production processes, these other non-milk and non-almond products are created at the same time, meaning some of the greenhouse gases emitted can be credited, or are produced by, the co-products rather than the beverages themselves. If in future milk processes co-products could be decreased, whether by increased production efficiency or otherwise, far fewer emissions would be released. Secondly would be to make the core processes, namely Milk production and Tree nut farming, more efficient. Because core processes are often more difficult to change, it may be simpler for production to make the third most impactful process, Power generation and supply, more efficient.

Uncertainty and Variability

Based on the sensitivity analysis, uncertainty or variability in the three largest factors--co-product emission credit, the core process, and power generation and supply--would have the largest impacts and changes to greenhouse gas emissions. The percentage of co-product emission credit used for both beverages was determined by mass; using a different measure, for example economic proportions, could have resulted in vastly different total greenhouse gas emissions. Either main food, be it milk or almonds, can generate a different amount of co-products simply due to different cows, fields, feed, etc., being sources of uncertainty that lead to great variability. Different farms and production methods can lead to varying amounts of emissions by affecting all the processes; for example, different farms may use different amounts of power generation in their production. Therefore our results may vary depending on individual companies compared to the sector average. Factors such as the type of feed given to cattle, the amount of almonds used in a liter, e.g. 2% versus pure almond, water used for trees, etc. can all affect the resulting emissions. We called Crystal Creamery, a milk company based in California, and their cattle required 54 pounds of dry matter as feed and produced about 8 gallons of milk per day; other farms may or may not use as much feed or produce as much milk. Though other processes, such as fertilizer use, also contribute to greenhouse gas emissions, their impact is dwarfed by the main contributors and have a relatively negligible range of sensitivity so we did not focus on them.

Summary

Based on our research, cow milk generates nearly 10 times more greenhouse gases per liter than almond milk does. However, almond milk production uses approximately 17 times more water than cow milk production does per liter. When comparing by daily nutritional values, almond milk still uses more water than does cow's milk, and cow's milk emits more greenhouse gases than almond milk, so it is difficult to make a clear-cut decision as to which is more sustainable to consume. The decision in this study comes at a trade-off, whether the more dire need for environmentalism is a drought-friendly option, or if it is a low-emission option. Consumers must personally evaluate their decisions to see which impact they deem more important. Moreover, we concluded that green consumerism does not necessarily equate to environmentally-friendly products. The rise in green consumerism has led to an interest in sustainability in order to compete and succeed in this new market. Unfortunately, this does not produce the most sustainable products in the market. In order to have a positive impact on the environment, almond milk and cow milk must change its production process and management.

For future studies, we recommend further analyzing impacts such as land usage, separated categories for water usage, and calculating the processes from cradle-to-grave. Almond orchards require many acres to be planted on, while dairy cattle farms also take up much land.

Determining specific differences in water use, such as for feed or irrigation, to process milk or almonds, or to finally produce the product can also be a good section to research. Lastly, incorporating transportation to stores or the end of the life cycle, disposal, could give a more complete view and comparison of the two products.

Limitations of Current Work

In order to simplify our LCA, some assumptions had to be made. We assumed that these are conventional, not organic-fed, dairy cows. This will affect the water use and greenhouse gas emissions by the cattle. In addition, we assumed that no milk is lost in the dairy milk pasteurization process. As mentioned above, there was lack of data on almond milk processing and production. In order to obtain our data, we assumed that the processing and production of almond milk was similar to that of soymilk. This assumption allowed us to work with the data from EIOLCA on soybean processing and oilseed farming. Moreover, we assumed that the almonds are grown and spread uniformly on an orchard or field so that water use can be averaged. The numbers from Hilltop Ranch and Braden Farms,may not represent the whole almond milk industry because they are based in California and there are almond farms in other states. Limitations of our research include the fact that we did not focus on non-hotspot impacts such as chemicals or other inputs included in milk pasteurization. We used an average company's numbers for almonds (Braden Farms and Hilltop Ranch), and for cow milk, we used average sector numbers. Our process flow diagram may omit many intermediate steps in order to present the main processes more clearly.

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Contribution

Jacqueline Ho
Research, data collection, sensitivity analysis and graphs, uncertainty and variability, summary, proofreading and formatting

Ingrid Maradiaga
Research, data collection, water usage calculations and graphs, contacting companies, overview of literature, citations, proofreading and formatting

Jamika Martin
Research, data collection, greenhouse gas emissions calculations and graphs, flowcharts, overview of literature, LCI spreadsheet, proofreading and formatting

Huyen Nguyen
Research, data collection, calculation inputs, citations, proofreading and formatting

Linh Trinh
Research, data collection, LCI spreadsheet, nutrition and impact analysis, proofreading and formatting

Appendix

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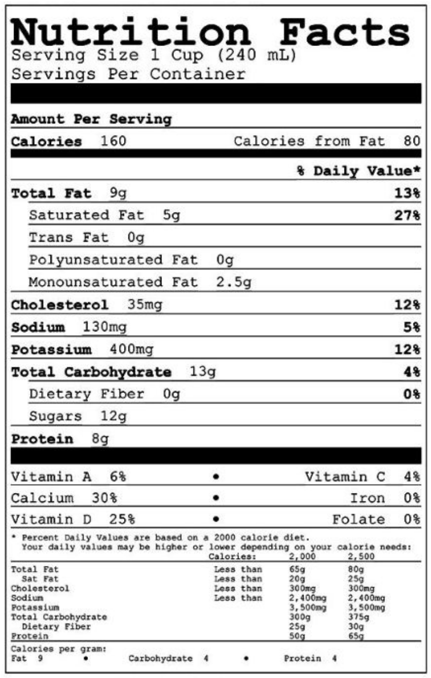
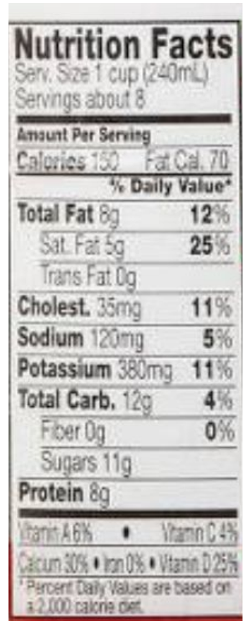
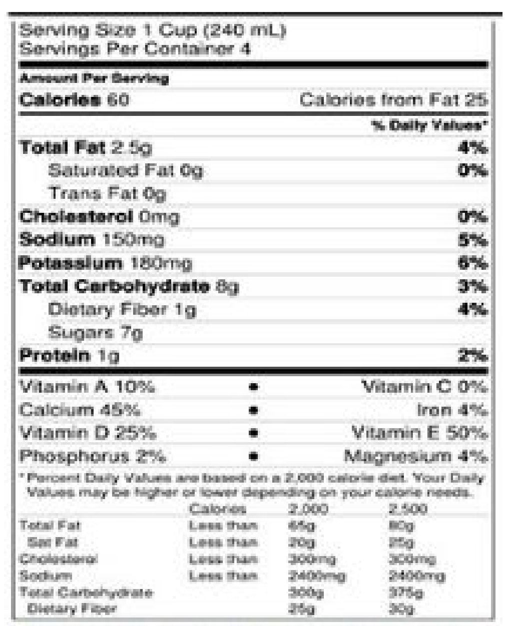
<td>Cow Whole Milk</td>
<td>Alta Dena Whole Milk

Nutrition Facts
Serving Size 1 Cup (240 mL)
Servings Per Container
Amount Per Serving
Calories 160 Calories from Fat 80
% Daily Value*
Total Fat 9g 13%
Saturated Fat 5g 27%
Trans Fat 0g
Polyunsaturated Fat 0g
Monounsaturated Fat 2.5g
Cholesterol 35mg 12%
Sodium 130mg 5%
Potassium 400mg 12%
Total Carbohydrate 13g 4%
Dietary Fiber 0g 0%
Sugars 12g
Protein 8g
Vitamin A 6% • Vitamin C 4%
Calcium 30% • Iron 0%
Vitamin D 25% • Folate 0%
* Percent Daily Values are based on a 2000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:
Calories: 2,000 2,500
Total Fat Less than 65g 80g
Sat Fat Less than 20g 25g
Cholesterol Less than 300mg 300mg
Sodium Less than 2,400mg 2,400mg
Potassium 3,500mg 3,500mg
Total Carbohydrate 300g 375g
Dietary Fiber 25g 30g
Protein 50g 65g
Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4</td>
<td>Market Pantry Whole Milk

Nutrition Facts
Serv. Size 1 cup (240mL)
Servings about 8
Amount Per Serving
Calories 150 Fat Cal. 70
% Daily Value*
Total Fat 8g 12%
Sat. Fat 5g 25%
Trans Fat 0g
Cholest. 35mg 11%
Sodium 120mg 5%
Potassium 380mg 11%
Total Carb. 12g 4%
Fiber 0g 0%
Sugars 11g
Protein 8g
Vitamin A 6% • Vitamin C 4%
Calcium 30% • Iron 0% • Vitamin D 25%
* Percent Daily Values are based on a 2,000 calorie diet.</td>
</tr>
<tr>
<td>Almond Milk</td>
<td>Silk Original Almondmilk

Nutrition Facts
Serving Size 1 Cup (240mL)
Servings Per Container 8
Amount Per Serving
Calories 60 Calories from Fat 25
% Daily Value*
Total Fat 2.5g 4%
Saturated Fat 0g 0%
Trans Fat 0g
Polyunsaturated Fat 0.5g
Monounsaturated Fat 1.5g
Cholesterol 0mg 0%
Sodium 160mg 7%
Potassium 35mg 1%
Total Carbohydrate 8g 3%
Dietary Fiber <1g 2%
Sugars 7g
Protein 1g
Vitamin A 10% • Vitamin C 0%
Calcium 45% • Iron 2%
Vitamin D 25% • Vitamin E 20%
Riboflavin 4% • Magnesium 4%
*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs:
Calories: 2,000 2,500
Total Fat Less than 65g 80g
Sat Fat Less than 20g 25g
Cholesterol Less than 300mg 300mg
Sodium Less than 2,400mg 2,400mg
Potassium 3,500mg 3,500mg
Total Carbohydrate 300g 375g
Dietary Fiber 25g 30g
Protein 50g 65g
Calories per gram:
Fat 9 • Carbohydrate 4 • Protein 4</td>
<td>Blue Diamond Almond Breeze Original Almondmilk

Serving Size 1 Cup (240 mL)
Servings Per Container 4
Amount Per Serving
Calories 60 Calories from Fat 25
% Daily Values*
Total Fat 2.5g 4%
Saturated Fat 0g 0%
Trans Fat 0g
Cholesterol 0mg 0%
Sodium 150mg 5%
Potassium 180mg 6%
Total Carbohydrate 8g 3%
Dietary Fiber 1g 4%
Sugars 7g
Protein 1g 2%
Vitamin A 10% • Vitamin C 0%
Calcium 45% • Iron 4%
Vitamin D 25% • Vitamin E 50%
Phosphorus 2% • Magnesium 4%
* Percent Daily Values are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs.
Calories 2,000 2,500
Total Fat Less than 65g 80g
Sat Fat Less than 20g 25g
Cholesterol Less than 300mg 300mg
Sodium Less than 2400mg 2400mg
Total Carbohydrate 300g 375g
Dietary Fiber 25g 30g</td>
</tr>
</table>

Sensitivity analysis table

									Effective CO2			Deviation CO2	
Process	**Inputs at each stage**	**Units**	**Base value**	**Min%**	**Max%**	**Minval**	**Base**	**Maxval**	**Minval**	**Maxval**	**Base**	**Minval**	**Maxval**
	milk production	kgCO2/L milk	0.58	90%	110%	0.5229	0.581	0.6391	0.89949879	0.84394357	0.87219928	0.02729951	-0.02825571
	power gen	kgCO2/L milk	0.5792	90%	110%	0.5202	0.578	0.6358	0.90040718	0.84513882	0.87219928	0.0282079	-0.02706046
	grain farming	kgCO2/L milk	0.144	90%	110%	0.1296	0.144	0.1584	0.87908392	0.86531464	0.87219928	0.00688464	-0.00688464
Dairy milk processing	cattle ranching	kgCO2/L milk	0.094	90%	110%	0.0846	0.094	0.1034	0.87669342	0.86770514	0.87219928	0.00449414	-0.00449414
	other	kgCO2/L milk	0.274	90%	110%	0.2457	0.273	0.3003	0.88572951	0.85962525	0.87219928	0.01353023	-0.01257403
XXXXXXXX	Co-product emission credit		47.81%	90%	110%	43%	47.81%	53%	0.952099352	0.792299208	0.87219928	0.079900072	-0.079900072
	Total CO2 emissions	kgCO2/L	1.6712										
	Co-product emission credit	kgCo2/L	0.79900072										
Lifecycle net GHG emissions	Effective CO2 emission	kgCO2/L	0.87219928										

									Effective CO2			Deviation CO2	
Process	**Inputs at each stage**	**Units**	**Base value**	**Min%**	**Max%**	**Minval**	**Base**	**Maxval**	**Minval**	**Maxval**	**Base**	**Minval**	**Maxval**
	other	kgCO2/L milk	0.072	90%	110%	0.0648	0.072	0.0792	0.115272	0.1054224	0.1103472	0.0049248	-0.0049248
	fertilizer	kgCO2/L milk	0.022	90%	110%	0.0198	0.022	0.0242	0.111852	0.1088424	0.1103472	0.0015048	-0.0015048
	power gen	kgCO2/L milk	0.0832	90%	110%	0.07488	0.0832	0.09152	0.11603808	0.10465632	0.1103472	0.00569088	-0.00569088
	tree nut farming	kgCO2/L milk	0.121	90%	110%	0.1089	0.121	0.1331	0.1186236	0.1020708	0.1103472	0.0082764	-0.0082764
Almond milk processing	almond processing	kgCO2/L milk	0.051	90%	110%	0.0459	0.051	0.0561	0.1138356	0.1068588	0.1103472	0.0034884	-0.0034884
XXXXXXXX	Co-product emission credit		68.40%	90%	110%	62%	68.40%	75%	0.13423248	0.08646192	0.1103472	0.02388528	-0.02388528
	Total CO2 emissions	kgCO2/L	0.3492										
	Co-product emission credit	kgCo2/L	0.2388528										
Lifecycle net GHG emissions	Effective CO2 emission	kgCO2/L	0.1103472										

Nutrition analysis table

Dairy milk					**Baseline for 1 % calcium**			**Baseline for 1 % vitamin D**		
Protein (g)	Total carb (g)	Vitamin A (%)	Calcium (%)	Vitamin D (%)	CO2	Water		CO2	Water	
33.8140227	46.49428122	25.36051703	126.8025851	105.6688209	0.006878402	0.60724314		0.0082540	0.7286917684	
Almond milk										
Protein (g)	Total carb (g)	Vitamin A (%)	Calcium (%)	Vitamin D (%)	CO2	Water		CO2	Water	
4.226752838	25.36051703	42.26752838	190.2038777	105.6688209	0.000580152	*8.47195661*		0.0010442	*15.24952191*	