Life Cycle Assessment of Ripple Non-Dairy Milk

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1. Introduction

Ripple Foods, Inc. produces a non-dairy milk product that contains protein and nutrients from yellow peas. There are many reasons to expect that milk made from yellow peas should be highly sustainable. For one, peas are legumes, and like all legumes are nitrogen fixing. This means that they replenish the nitrogen content of the soils where they are planted and require very little nitrogen fertilizer, which is energy intensive to produce commercially.

Yellow field peas are notable for being the least expensive and highest protein content non-animal source of protein available. They have a protein content of about 21-25%, and can be split or ground into flour for human consumption (Mckay, 2003). They are also nitrogen fixing, like all legumes, which means they can extract nitrogen from the air and need very little nitrogen fertilizer. They can be used as a transition crop by commodity farmers of things like wheat to avoid the need to till and reduce fertilizer requirements. Yellow peas are also water efficient, capable of achieving 30-bushel per acre yields on only 10 inches of rainfall (Parker, 2014). In addition, Ripple bottles are made from 100% recyclable PET plastic, which is itself 100% recyclable.

In order to scientifically assess the relative environmental impacts of Ripple milk and other substitute products, Ripple embarked on a life cycle assessment study to quantify the greenhouse gas emissions and water requirements of production and use of Ripple milk as compared to dairy milk, almond milk, and soy milk.

2. Goal and Scope

The goals of this study are to examine the greatest contributing factors to Ripple milk's greenhouse gas (GHG) emissions throughout its life cycle, compare Ripple milk to the most popular dairy and non-dairy milks available in the US market, and examine the water consumption of yellow peas as compared to other dairy and non-dairy milk alternatives. The scope of the GHG study covers from the farming to retail steps of dairy and non-dairy milk production, with the added step of packaging production and disposal. The water footprint covers farming of crops for non-dairy milk, and the farming of crops for cow feed and cow farming activities for dairy milk.

System Boundary

The system boundary defines the scope of activities and emissions associated with a life cycle analysis. General classes of inputs and outputs are identified for key processing steps. The system boundary for the substitute products is the same to ensure that the analysis is performed on a consistent basis. Transport emissions of finished products are excluded from this study because they are the same in all cases, and therefore cancel out. The system boundary diagram in Figure 1 shows the life cycle steps that are included in the Ripple, almond, and soy milk life cycle assessment. The life cycle steps for dairy milk are slightly different, as shown in Figure 2.

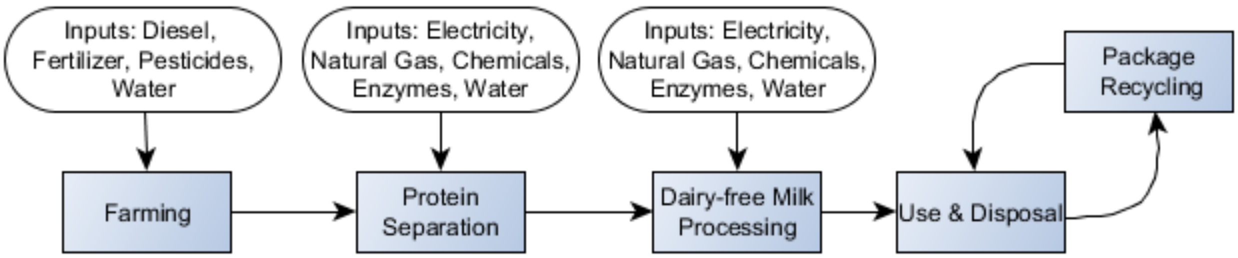

Figure 1. Non-Dairy Milk System Boundary Diagram

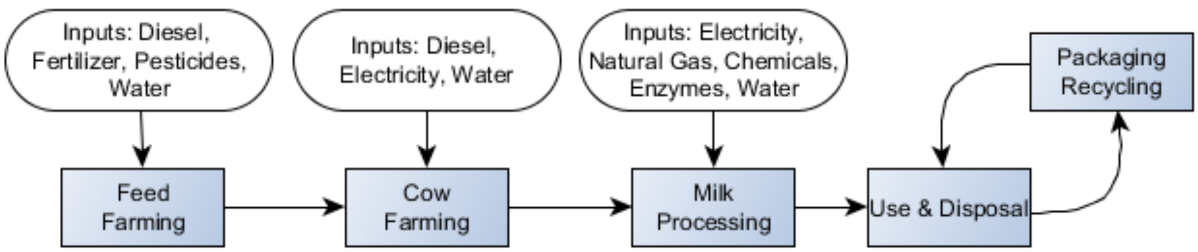

Figure 2. Dairy Milk System Boundary Diagram

Each of the pathways examined here generates a number of co-products. For example pea meal is used for animal feed, almond husks can generate electric power, and dairy milk production results in beef and tallow. The primary product is the protein laden legume or milk and the other products have lesser value. A co-product credit for the feed products is applied based on economic allocation.

Functional Unit

The functional unit for the life cycle assessment study is the mass of protein in a liter of milk. Each type of milk contains a different amount of protein. Therefore, with the protein functional unit, the life cycle emissions for a liter of milk are divided by the protein content in the milk. This means the GHG emissions and water use are compared between the milks based on the amount of protein that is contained in a liter of milk. Reporting results based on the protein in a liter of milk takes into account the packaging required to deliver the protein in the functional unit. The results would be different for different sizes of milk containers since the amount of packaging required to contain different volumes does not scale linearly.

3. LCA Modeling Approach

Life cycle assessment (LCA) is a methodology for studying the potential environmental impacts incurred throughout the entire life of a product system. This LCA examines potential emissions from the production, use, and disposal of these four products in terms of GHG emissions and fresh water consumption.

Every product has its own life cycle, composed of many different steps. The life cycle of Ripple milk includes the farming of yellow peas, the production of Riptein (a protein isolate of yellow peas), Ripple milk production, retail, and production and disposal of its PET beverage container. It also includes the production of all upstream inputs, such as fertilizer, electricity, and natural gas, and transport of intermediate and finished products. This analysis includes all pathway process steps, including processing peas into protein isolate, milk processing, packaging, and disposal of packaging. Upstream emissions are also included. This refers to the embedded GHG burden associated with process inputs such as electricity and natural gas. Emission factors for the modeling of process GHG impacts were taken from the GREET_1 2016 model.[1] Retail and transport to retail are excluded from this analysis since they are assumed to be identical for all products.

The life cycles of other non-dairy milks are similar. The analysis of dairy milk GHG emissions relies on prior studies, but includes comparable steps.

Non-Dairy Milks

Data was collected from a range of publicly available sources to reflect the farming inputs of fertilizer, pesticides, and energy for yellow peas, almonds, and soy beans. Fertilizer and pesticide data was not available for yellow peas; so, average farming inputs for lentil farming were adjusted based on grower reports from the pea farmers that supply Ripple Foods (Muehlbauer, 2016). Almond farming inputs were taken from a 2015 life cycle assessment of almond farming in California that took into account the 26 year life cycle of almond trees (Kendall, 2015). Fertilizer needs vary over the life cycle of the tree, so the 26 year average number was used in this analysis. Pesticide, herbicide, and farming energy inputs were taken from the GREET 1 2016 model defaults for soybean production. The environmental impacts of all farming inputs were modeled in GREET 2016 (ANL, 2014), which incorporates the upstream emissions for all of the agricultural inputs. The contribution of agricultural emissions for yellow peas is shown in Figure 4.

For almonds, field emissions were estimated based on 1.5% of the applied nitrogen as almonds to not result in nitrogen fixation emissions as shown in Figure 4.

[1] Argonne National Laboratory, ANL. (2016). "The greenhouse gases, regulated emissions, and energy use in transportation (GREET) model, Version 1_2016."

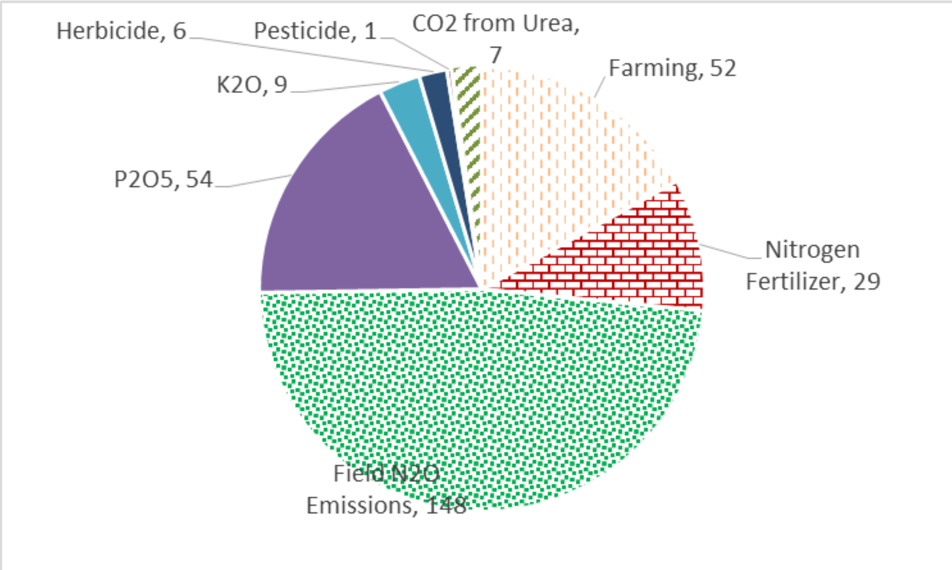

Figure 3. Agricultural GHG emissions for Ripple Peas (g/kg crop).

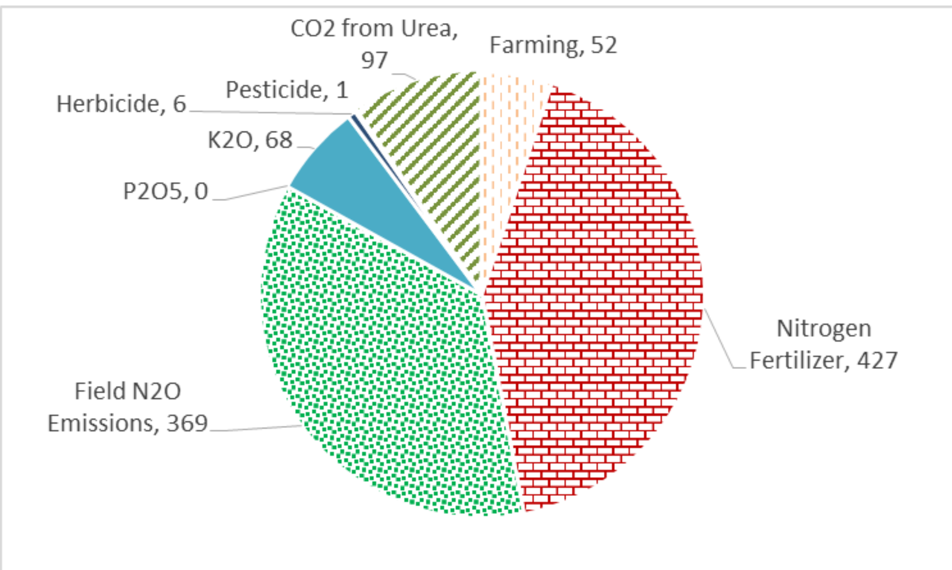

Figure 4. Agricultural GHG emissions for Almonds (g/kg of crop).

For most agricultural crops, one of the largest sources of GHG emissions is N_2O from applied nitrogen fertilizer. In the case of nitrogen fixing legumes, N2O emissions are also produced from the nitrogen associated with fixation. Thus several sources of nitrogen contribute to the formation of N_2O, unconverted fertilizer, nitrogen from fixation in nodules as well as above ground crop residue. While legume result in fixation emissions the N per unit of crop is comparable to other crops like corn and almonds. These N_2O sources were estimated using the European Commission's Global Nitrous Oxide Calculator, the GNOC model (European Commission JRC, 2014). Fertilizer inputs and yields used for soybeans and yellow peas in this study were inputted to the GNOC model along with the growing region, and the model determined the N_2O emissions from every potential emission source, as shown for soybeans in Figure 5 and for yellow peas in Figure 6.

Result: Total N_2O Emissions

Location ID	948 - 510
Country name	UNITED STATES
Total soil N_2O emmissions [kg N_2O-N ha^{-1}]	1.5745
Total soil N_2O emmissions [g CO_2eq $MJ^{-1}{}_{crop}$]	11.5364

Result details - values are given in [kg N_2O-N ha^{-1}] unless specified differently

Direct N_2O emissions from fertilizer application $N_2O_{(dir,F)}$	0.1397
Direct N_2O emissions from drained/managed organic soils N_2O_{OS}	0.0000
Indirect N_2O emissions produced from leaching and runoff from fertilizer application $N_2O_{(L,F)}$	0.0000
Indirect N_2O emissions produced from atmospheric deposition of N volatilised $N_2O_{(ATD)}$	0.0179
Above-ground residue dry matter AG_{DM} [kg d.m. ha^{-1}]	3934.2654
Annual amount of N in crop residues F_{CR} [kg N ha^{-1}]	141.6854
N input from sugarcane vignasse and filtercake F_{VF} [kg N ha^{-1}]	0.0000
Direct N_2O emissions from N in crop residues $N_2O_{(dir,CR)}$	1.4169
Indirect N_2O emissions produced from leaching and runoff from N in crop residues $N_2O_{(L,CR)}$	0.0000

Figure 5. Nitrous Oxide Emissions from Soybean Farming

Result: Total N_2O Emissions

Location ID	948 - 510
Country name	UNITED STATES
Total soil N_2O emmissions [kg N_2O-N ha^{-1}]	0.8947
Total soil N_2O emmissions [g CO_2eq $MJ^{-1}{}_{crop}$]	13.7750

Result details - values are given in [kg N_2O-N ha^{-1}] unless specified differently

Direct N_2O emissions from fertilizer application $N_2O_{(dir,F)}$	0.0426
Direct N_2O emissions from drained/managed organic soils N_2O_{OS}	0.0000
Indirect N_2O emissions produced from leaching and runoff from fertilizer application $N_2O_{(L,F)}$	0.0000
Indirect N_2O emissions produced from atmospheric deposition of N volatilised $N_2O_{(ATD)}$	0.0056
Above-ground residue dry matter AG_{DM} [kg d.m. ha^{-1}]	2579.8320
Annual amount of N in crop residues F_{CR} [kg N ha^{-1}]	84.6472
N input from sugarcane vignasse and filtercake F_{VF} [kg N ha^{-1}]	0.0000
Direct N_2O emissions from N in crop residues $N_2O_{(dir,CR)}$	0.8465
Indirect N_2O emissions produced from leaching and runoff from N in crop residues $N_2O_{(L,CR)}$	0.0000

Figure 6. Nitrous Oxide Emissions from Yellow Pea Farming

Farming emissions are multiplied by the amount of plant matter in the finished milk to give the carbon intensity of farming on a volumetric basis. The kg of plant matter per liter of milk are determined based on the protein content of the feedstock and the protein content of the finished milk product. A loss rate of 27% is assumed for all non-dairy milks based on Ripple's proprietary processing data, meaning that 1.38 kg of farmed plant matter feedstock will become 1 kg of plant matter in the finished milk product.

Processing data such as electricity and natural gas use for protein isolation and milk production for Ripple milk was taken directly from facility operating data. Two scenarios were considered for almond milk processing. In Scenario 1, almond milk processing data copies the milk processing data for soy milk, taken from a publicly available study which used inventory data from the Ecoinvent database. In scenario 2, the processing data from Ripple's production process was used for almond milk processing and soy milk processing, making the three products equivalent for this life cycle stage. In all cases, processing emissions result from the use of electricity and natural gas in the facility that processes the feedstock into non-dairy milk. The resulting greenhouse gas emissions from electricity and natural gas usage were modeled based on GREET 2016 data.

Ripple milk is packaged in a polyethylene terephthalate (PET) bottle, while most almond and soy milks are contained in a Tetra Pak box, which is made of several layers of material including aluminum, paper board, and polyethylene. The PET used in Ripple milk bottles is 100% recycled PET. Tetra paks are more challenging to recycle, but it is technically possible. This study assumes a recycling rate of 12.66% for Tetra Paks. The greenhouse gas emissions associated with PET collection and recycling were taken from a 2011 LCA of PET beverage bottles consumed in California (Kuczenski, 2011). The greenhouse gas emissions associated with tetra pack production, collection, and recycling were taken from a 2012 life cycle assessment of Italian Tetra Pak production, and assume a 1000 mL container with a polyethylene cap (Scipioni, 2012).

In addition, water movement and pumping contribute to the energy cost of the transportation of water in the state of California, where much of the population lives in cities that are distant from fresh water sources, especially in the Southern half of the state. Many agricultural regions are in areas that have limited natural water resources, where agriculture is made possible by the vast network of canals that transport water from the Colorado River, San Joaquin River, and Sierra mountains. California produces 83% of the world almonds, and the majority of these are grown in the San Joaquin Valley region (Geisseler, 2014). The energy required to delivery water to agriculture has been studied and was reported on in a California Energy Commission report on California's Water-Energy Relationship (Klein, 2005). On average, the delivery of water to a farm, excluding irrigation pumping energy, which is already included in GREET's estimates for farming GHG emissions, amounts to 0.0003 kWh/gallon. This number was multiplied by the amount of surface and rain water (i.e. green and blue water, as defined in section 7 on water footprinting) required for almond growing in California to determine the added energy for water transport in California.

Dairy Milk

The life cycle of dairy milk involves the production of corn and other feed for cows, manure management and enteric emissions, and the allocation of emissions between milk and meat production. An in-depth analysis of dairy farming was outside the scope of this study. Instead, the carbon intensity of dairy milk was taken from two 2013 studies that examined the cradle to farm gate and the farm gate to end of life emissions of American produced dairy milk (Thoma, 2013a, 2013b). These studies used a biophysical approach to allocation as described in their 2012 publication (Thoma, 2012). Emissions from transport to retail and refrigeration were subtracted for the Ripple analysis in order to be consistent with the assumptions and scope for the LCA of non-dairy milk life cycles.

Dairy milk is assumed to be packaged in a high-density polyethylene (HDPE) container with 29% recycled content. The greenhouse gas emissions for dairy packaging are taken from the Thoma et. al life cycle assessment of dairy production (Thoma, 2013a).

Inventory Data Sources

The sources of data for the life cycle inputs for each product were selected to be as recent and geographically relevant as possible. A range of published literature and national data sources were used in this LCA. Table 1 shows the source of data for each aspect of the life cycle assessment model described above.

Table 1. Life Cycle Inventory Data Sourcing

Life Cycle Stage	Ripple Milk	Almond Milk	Soy Milk	Dairy Milk
Feedstock production	(Muehlbauer, 2016); (USDA, 2016)	(Kendall, 2015)	(USDA, 2016)	*farm-to-farm gate (Thoma, 2013b)
Protein isolation	Ripple Data	Ecoinvent	Ecoinvent	N/A
Milk production	Ripple Data	Ecoinvent	Ecoinvent	(Thoma, 2013a)
Packaging & EOL	(Kuczenski, 2011)	(Scipioni, 2012)	(Scipioni, 2012)	(Thoma, 2013a)
Water Consumption	(Mekonnen, 2010b)	(Mekonnen, 2010b)	(Mekonnen, 2010b)	(Mekonnen, 2010a)

4. Greenhouse Gas LCA Model

Life cycle inventory (LCI) data reflects the emissions associated with farming inputs, process fuels, transport segments, and any process or input relevant to production. Emissions can occur directly, as in the case of fertilizer off-gassing or natural gas combustion, or indirectly, as in the case of inputs to farming such as fertilizer or pesticides, which reflect the emissions required for production.

In this LCA, emissions that were calculated from process inventory data use the emission factors in the GREET 2016 model. LCI data in GREET 2016 are organized as a column (or array) of energy use and emissions values. An LCI array can represent a single process fuel or feedstock, such as natural gas used for fuel production, or it can represent aggregated fuel cycle results, such as ethanol transport and distribution.

For example, the LCI array result for U.S. average natural gas combusted in a stationary reciprocating engine is presented in Table 2. The life cycle data are organized in two arrays in this case, using the methodology of the GREET model, but the results can be presented at any level of disaggregation. The first column accounts for the WTT energy use and emissions associated with natural gas recovery (extraction) and transport, processing to pipeline gas, and pipeline delivery to the point of use. The second column shows natural gas engine emission factors and the third column indicates the total natural gas LCI array. The table indicates that most of fuel cycle emissions for natural gas (and all fossil fuels) arise from the fuel combustion (the carbon in fuel) rather than from fuel production.

Table 2. Example LCI Data for Natural Gas Combusted as a Stationary Fuel (GREET_1 2015)

Natural Gas Life Cycle Emission Factors (g/mmBtu)	Recovery, Processing, & Pipeline transport	Stationary Fuel Combustion	Total Emissions
VOC	10.36	2.54	12.90
CO	32.19	24.97	57.16
NO_x	40.56	41.05	81.61
PM10	0.56	3.51	4.07
PM2.5	0.49	3.51	3.99
SO_x	12.02	0.27	12.29
BC	0.15	0.58	0.73
OC	0.16	1.50	1.66
CH_4	207.42	1.06	208.48
N_2O	1.42	0.35	1.77
CO_2	6,747	59,363	66,110
CO_2c	6,830	59,413	66,243

The LCI data are combined (multiplied) with life cycle input parameters to model life cycle energy use and emissions associated with each pathway input. Life cycle input parameters characterize all pathway steps, including feedstock production, chemicals and natural gas or waste heat for processing, fuel for distribution, and fuel combustion. Table 4 shows the model inputs for the Ripple LCA model.

Allocation Method

Allocation refers to the partitioning of inputs and outputs to more than one product output. ISO 14044 provides guidelines on how to handle allocation. First, whenever possible, it should be avoided by dividing the unit processes so that there is no co-production, or by expanding the system to take into account the functions of the co-products. When allocation cannot be avoided, inputs and outputs should be partitioned based on the underlying physical relationships between the products and their uses, such as by energy content or mass. If physical relationships cannot be used as a basis for allocation, then inputs and outputs should be allocated in a way that reflects the relationship of the co-products to one another, such as their relative economic market value.

The production of pea isolate for Ripple milk results in the co-production of starch and fiber that are used as animal feed. Likewise, almond and soy milk also have co-products. Almond shells are burned for electricity and almond husks are used for animal feed. Soy milk production also results in an animal feed co-product.

The Ripple process converts pea feed to pea isolate. Pea starch is a co-product that is sold as animal feed. A simplified flow diagram is shown in Figure 7. For the purposes of the LCA, energy inputs and emissions were allocated to the processed material and the pea starch.

Several options for allocation are possible with the results shown in Table 3. The starch has a lower value than the processed protein. Therefore an economic allocation was selected as the most representative approach. This method is consistent with the LCA of almonds performed by UC Davis.

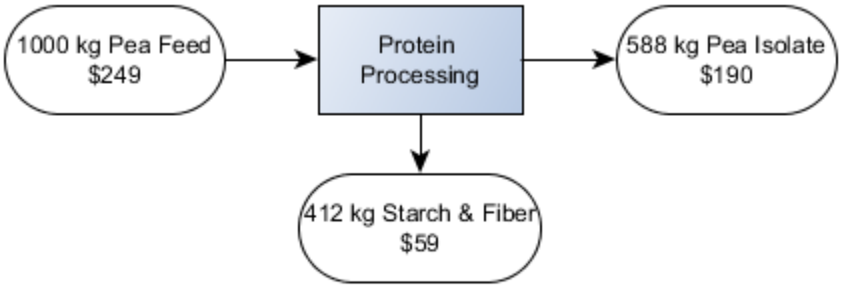

Figure 7. Economic Allocation Process Flow Diagram for Ripple Peas

The value of the processed pea protein is calculated from the difference in the price of the pea feed and the starch. Starch is valued at the price of corn. Therefore the value of the pea feed is determined by difference, which provides the basis for the economic allocation.

Table 3. Ripple Co-product Allocation Method

Component	Price ($/kg)	Mass (kg)	Economic Value ($)	Protein (kg)
Pea	$0.25	1000	$249.12	220
Starch	$0.14	411.6	$59.14	82.5
Processed Pea	$0.32	588.4	$189.98	137.5
Pea Allocation Factor		58.84%	**76.26%**	62.50%

Table 4. LCA Modeling Inputs

Parameter	Ripple Milk	Almond Milk	Soy Milk	Dairy Milk[1]
Farming Inputs				
Nitrogen (lb/lb)	0.0052	0.1070	0.006	
P_2O_5 (lb/lb)	0.0074	0	0.017	
K_2O (lb/lb)	0.0148	0.1070	0.028	
Diesel (Btu/tonne)	519,149	519,149	519,149	
Pesticides (g/tonne)	42.9	42.9	42.9	
Herbicide (g/tonne)	300	300	300	
CA Water Transport Energy (kWh/tonne)		531.8		
Processing				
Electricity (kWh/kg milk)	0.213	0.218[2]	0.218	
Natural Gas (MJ/kg milk)	3.191	2.043[2]	2.043	
Additives				
Sunflower oil (% by mass)	1.40%			
Cane Sugar (% by mass)	2.37%	2.88%	2.84%	
Additional Parameters				
Protein content of finished milk	3.31%	0.41%	3.29%	3.38%
Plant content of finished milk (kg/kg)	0.208	0.026	0.123	

1. Dairy milk inputs are not shown since dairy milk life cycle emissions are based on literature sources only.
2. Almond milk processing inputs are assumed to be the same as soy milk.

Life Cycle Impact Assessment

The GREET model is configured to determine energy inputs, GHG emissions, and criteria pollutant impacts. This analysis focuses on GHG emissions. GHG emissions are expressed as grams of carbon dioxide equivalent per liter of milk (g CO_2e/L), and are referred to as the carbon intensity (CI). The GHG emissions constituents considered in this analysis are CO_2, N_2O, CH_4, CO, and volatile organic compounds (VOCs).

Global warming potentials (GWP) (g CO_2e/g constituent) for CH_4 and N_2O are taken from the Intergovernmental Panel on Climate Change (IPCC) global warming potential (GWP) values (IPCC 2007) for a 100 year time horizon. CO and VOC are oxidized to CO_2 in the atmosphere, and thus have a GWP of 1 when expressed as CO_2 (fully oxidized form). The analysis excludes the climate impact of secondary and higher order atmospheric species that arise from direct emissions, including ozone, oxides of nitrogen (NO_x), and secondary aerosols.

5. Greenhouse Gas LCA Results

Two scenarios were considered in this analysis due to the lack of primary data on the processing of almond milk. In the first scenario, electricity and natural gas facility inputs for almond milk production are taken from Ecoinvent (Weidema, 2013). In the second scenario, the processing energy reported by Ripple facilities was used for almond processing as well.

Two functional units were also considered in both scenarios. In the first case, GHG emission results are shown on a per liter of milk basis. In the second case, GHG emission results are shown in terms of the amount of protein in a L of milk. The co-product credit for Ripple and Almond milk is calculated based on the following formula:

Credit = (1-Allocation Factor)*(Farming + Processing Emissions)

The feed co-product results from the farming and processing steps, so the allocation factor is only applied to these two steps.

Table 5. Scenario 1: GHG Life Cycle Emissions

Scenario 1: Baseline				
1a. Volume Basis				
Results (g CO_2e/L milk)	**Ripple**	**Almond**	**Soy**	**Dairy**
Farming	64.8	33.5	31.2	1,273
Processing	343	259	262	112
Packaging & EOL	76.1	104.4	104.4	82.3
Co-Product Credit	(96.9)	(16.5)		
Total (g CO_2e/L milk)	387	396	397	1,467
1b. Protein Basis				
Results (g CO_2e/kg protein)	**Ripple**	**Almond**	**Soy**	**Dairy**
Farming	1,959	1,013	942	38,461
Processing	10,373	62,917	7,956	3,305
Packaging & EOL	2,300	25,412	3,174	2,434
Co-Product Credit	(2,928)	(4,016)		
Total (g CO_2e/kg protein in a L of milk)	24,467	149,831	19,627	44,199

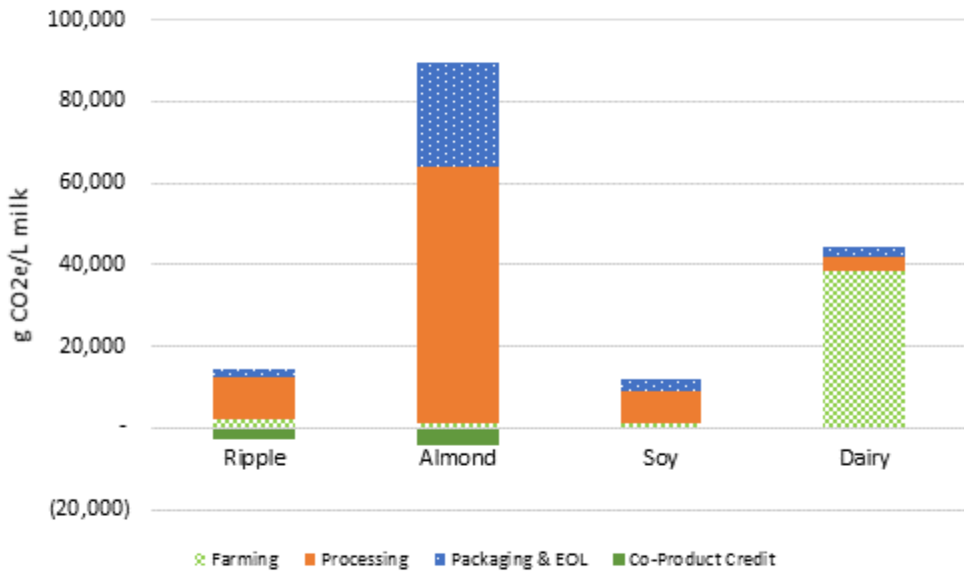

Figure 8. Life Cycle GHGs Emissions on a Protein Basis

Table 6. Scenario 1: GHG Life Cycle Emissions

Scenario 2: Almond Milk Modeled Using Ripple Processing Data				
2a. Volume Basis				
Results (g CO_2e/L milk)	**Ripple**	**Almond**	**Soy**	**Dairy**
Farming	64.8	33.5	31.2	1,273
Processing	343	337	341	112
Packaging & EOL	76.1	104	104	82.3
Co-Product Credit	(96.9)	(20.9)		
Total (g CO_2e/L milk)	484	475	476	1,467
2b. Protein Basis				
Results (g CO_2e/kg protein)	**Ripple**	**Almond**	**Soy**	**Dairy**
Farming	1,959	8,159	948	38,695
Processing	10,373	81,915	10,360	3,305
Packaging & EOL	2,300	25,412	3,174	2,434
Co-Product Credit	(2,928)	(5,089)		
Total (g CO_2e/kg protein in a L of milk)	24,467	194,709	24,376	44,433

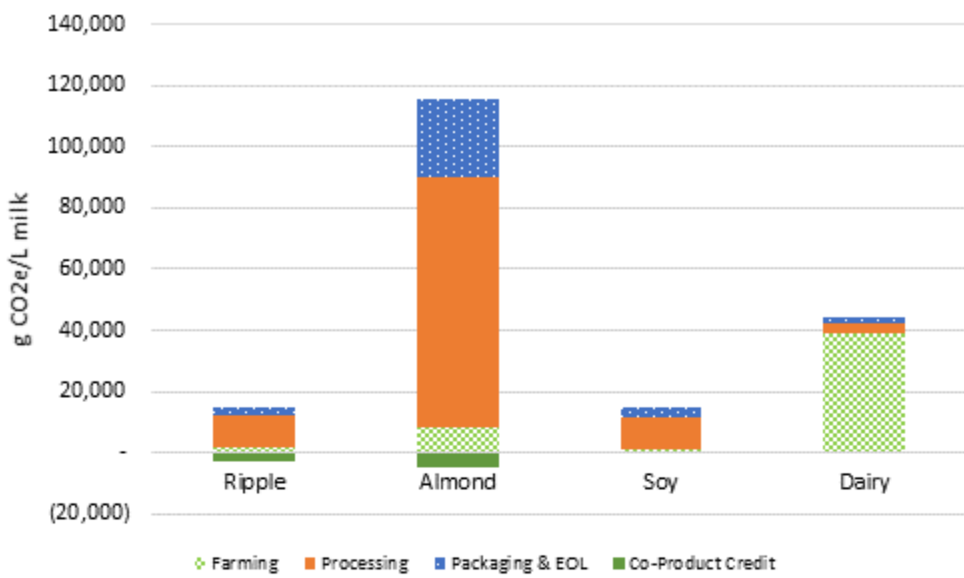

Figure 9. Life Cycle GHG Emissions on a Protein Basis

6. Water Footprint Model

The amount of fresh water used to produce a crop or a food product can be substantial. Water footprinting is a method for estimating the amount of water consumed in the production and use of a product. The water footprint of a product is defined as the total volume of freshwater that is used to produce the product (Hoekstra et al., 2009). The grid- based dynamic water balance model developed by Mekonnen and Hoekstra, 2010, computes a daily soil water balance and calculates crop water requirements, actual crop water use (both green and blue) and actual yields.

A water footprint can include three different categories of water consumption:

- Blue water: Consumptive water use originating from ground/surface water
- Green water: Consumptive water use originating from rain water
- Grey water: Volume of ground/surface water polluted (required for assimilation of fertilizers or pesticides)

In the case of rain fed agriculture, blue water footprint is zero and green water use is calculated by summing up evapotranspiration per day over the growing season of the plant. In the case of irrigated crops, green and blue water consumption is calculated based on soil water balance. The grey water footprint modeled by Mekonnen and Hoekstra refers only to the water required to assimilate nitrogen fertilizer runoff. All three categories of water consumption are included in this water footprint analysis (Mekonnen, 2011).

Water consumption data come from the Mekonnen and Hoekstra Unesco Value of Water Research Report Series numbers 47 and 48. Ripple peas are grown in the Northern US and Canada. U.S. average values are used for the other three products since Ripple products may be competing against a range of milk products from all over the country. Dry peas, almonds, and soybean water consumption are originally reported in cubic meters per ton of crop and are adjusted based on the amount of crop that ends up in the finished milk to show the water footprint per liter of milk on a protein basis. Dairy milk water consumption is already allocated to the finished milk product and is reported in terms of cubic meters per ton of milk. Since non-dairy milks all have some amount of added sugar, the water associated with cane sugar production was also included.

Table 7 shows the water footprint of the each crop and finished milk product. The amount of water it takes to produce a ton of almonds is approximately 6.8 times the amount of water it takes to produce a ton of peas. But compared on a protein basis per liter of milk, almond milk takes 5.7 times as much water as Ripple milk. Dairy milk water consumption is approximately double that of Ripple milk, and soymilk water use is roughly half that of Ripple milk.

Table 7. Water Footprint Results

Product **Region**	**Peas, dry[1]** **Saskatchewan**	**Almonds[2]** **US Avg**	**Soybeans[3]** **US Avg**	**Milk, 1-6% fat[4]** **US Avg**
Water (m3/ton crop)	1,928	13,055	1,662	821[5]
Water (m3/kg crop)	2.1	14.4	1.8	N/A
Water (gal/L milk on a protein basis)	**4,855**	**26,263**	**2,182**	**7,321**

1. Peas dried, shelled, whether or not skinned or split (Product code HS 71310)
2. Almonds, fresh or dried, shelled or peeled (Product code HS 080212)
3. Soya beans (Product code HS 120100)
4. Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat (Produce code HS 040120)
5. Dairy milk water use is reported in m3/ton of finished milk

Sources: Mekonnen, M.M. and Hoekstra, A.Y. (2010). Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands. The green, blue and grey water footprint of crops and derived crop products; Mekonnen, M.M. and Hoekstra, A.Y. (2010). The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands.

Figure 10 shows the range of water use values across different geographic regions, broken down by the amount of blue, green, and grey water. As shown in Figure 10, reporting only the total amount of water obscures the relative amount of blue, green, and grey water that contributes to that total. Dry peas use very little blue water in all of the locations cited, and none in Saskatchewan. Grey water is the largest contributor to US average water use for dry peas, much higher than the global average or the Saskatchewan grey water pollution numbers. Almonds are the only crop shown that uses large amount of blue water, in addition to green and grey water. This is likely because almonds in the US are mostly grown in the water scarce California region of the San Joaquin delta, meaning there is very little rainfall and most of the water used is irrigation based or from ground water.

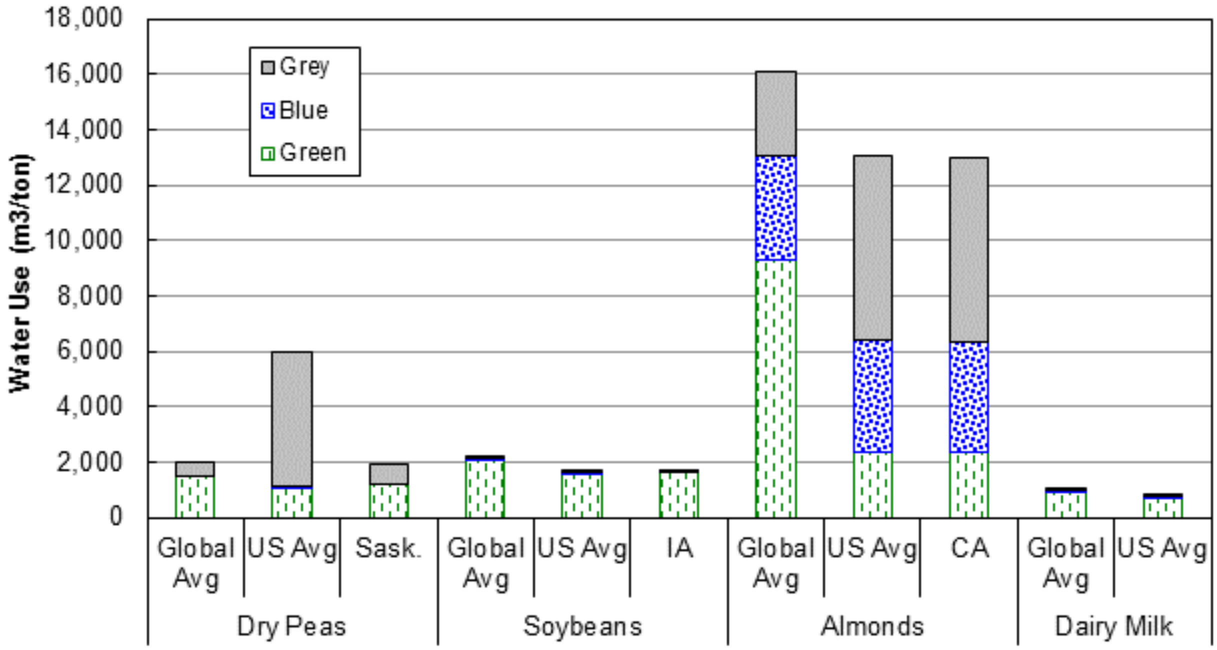

Figure 10. Water Use Comparison by Geographic Region

Water scarcity refers to either the lack of enough water (quantity) or lack of access to safe water (quality). Areas with poor management or low rainfall and groundwater resource are liable to experience more water scarcity. The UNEP/Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative founded the water use LCA (WULCA) in 2007 to focus on water use assessment and water footprinting from a life cycle perspective. They have since developed a methodology for assessing water scarcity is known as the AWARE method (Available Water Remaining), representing the relative Available WAter REmaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met (WULCA, 2016).

$$\text{Water Scarcity Footprint} = \text{Water Consumption} \times \frac{1}{Availability - Demand}$$

The group has made public the google earth files with their calculated water scarcity factors by watershed for the whole planet. Warmer colors indicate higher levels of year round average water scarcity and colder colors indicate lower levels of scarcity. As could be expected, the drier climate of the Southwestern US results in higher levels of water scarcity.

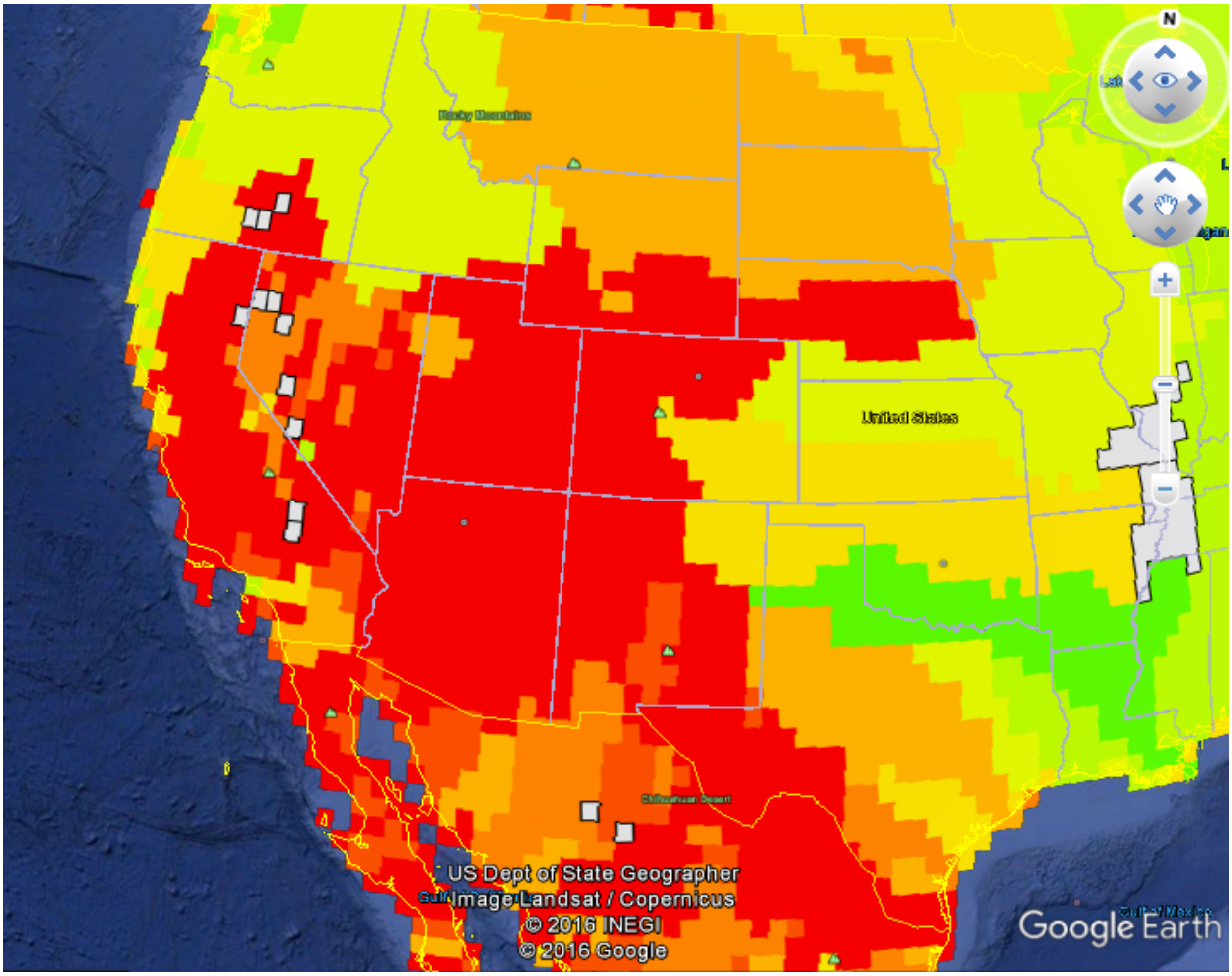

Figure 11. Water Scarcity Map of North America

Taking into account the water scarcity factors for California, Idaho, and Saskatchewan, which are 88, 1.7, and 6, respectively, yield the results shown in Table 8. With water scarcity taken into account, growing almonds requires about 100 times as much water per ton of crop as dry peas. The amount of almond that ends up in almond milk requires 93 times more water on a protein basis. Assuming the water scarcity factor for California results in dairy milk requiring about 28 times more water per liter of milk on both a volumetric and protein basis.

Table 8. Water Footprint Results

Product **Region**	**Peas, dry[1]** **Saskatchewan**	**Almonds[2]** **US Avg**	**Milk, 1-6% fat[4]** **US Avg**
Water Scarcity Factor[6]	**6**	**88**	**88**
Water (m3/ton crop)	11,568	1,148,840	72,248
Water (m3/kg crop)	12.8	1,266.4	
Water (m3/L milk)	2.86	33.153	82.43
Water (gal/L milk)	**755**	**8,758**	**21,775**
Water (gal/L milk on a protein basis)	**22,816**	**2,131,354**	**644,229**

1. Peas dried, shelled, whether or not skinned or split (Product code HS 71310)

2. Almonds, fresh or dried, shelled or peeled (Product code HS 080212)
3. Soya beans (Product code HS 120100)
4. Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat (Produce code HS 040120)
5. Dairy milk water use is reported in m3/ton of finished milk
6. http://www.wulca-waterlca.org/project.html

7. Discussion

The GHG emissions associated with growing yellow peas are much lower than the emissions associated with almond growing. However, due to the relatively small amount of almonds that end up in almond milk, the life cycle impacts of almond milk on a volume basis are very low. However, the actual nutritional value of the milk is closely linked to the protein content. When you compare Ripple milk to almond milk on a protein basis, almond milk has GHG emissions that are eight times as high as Ripple milk. Since dairy milk is high in protein content, while its GHG emissions are three times as high as Ripple milk on a volumetric basis, they are only about twice as high on a protein basis. Soy milk has a very similar GHG profile to that of Ripple milk, which is to be expected given that they are both nitrogen-fixing legumes with a high protein content.

An important source of uncertainty in this study is the energy used in the processing of almond and soybean crops into a protein isolate and finished non-dairy milk. The process energy for Ripple milk comes from Ripple facilities, and has a high level of confidence associated with it. However, the process energy for soy milk was taken from a study that relied on the Ecoinvent database, which typically includes European process data, where practices may differ from those in the United States. Almond milk process data was not available at all, and so two scenarios were run, one using the soy processing data from Ecoinvent and one using the pea processing data from Ripple's primary data. However, the almond life cycle results were compared to the recent UC Davis study of almond farming, and the total life cycle GHGs were found to be comparable, with our study finding a carbon intensity of roughly 1.2 kg CO_2e/kg almonds compared to the UC Davis study's finding of 1.6 kg CO_2e/kg almonds.

A limitation of the study is that most non-dairy milks have several added ingredients in order to improve the taste profile, nutritional content, and texture of the finished product. The added sugar in non-dairy milk was included both the GHG analysis and the water footprint. Ripple milk also contains sunflower oil, and the GHG emissions from this were included in the Ripple LCA. However, other additives such as emulsifiers, flavor enhancers, and vitamins were excluded from this study. In addition, the exact formula for soy milk and almond milk products was not known, and therefore may include additional ingredients similar to sunflower oil that were not included.

Acronyms

Btu	British thermal units
CO_2e	Carbon dioxide-equivalent
GHG	Greenhouse Gas
HHV	Higher heating value
LCA	Life cycle assessment
LCI	Life cycle inventory
LHV	Lower heating Value
MJ	Megajoule (= 947.83 Btu)
mmBtu	Million British thermal units
MWh	megawatt-hour

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