Life Cycle Associates

Ripple Milk Life Cycle Assessment

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TERMS AND ABBREVIATIONS

Btu	British Thermal Unit
CA	California
CARB	California Air Resources Board
CI	Carbon Intensity
CO_2e	Carbon Dioxide-Equivalent
GHG	Greenhouse Gas
GREET	Greenhouse Gases Regulated Emissions and Energy Use in Transportation
HHV	Higher Heating Value
kWh	kilo-Watt Hour
LCA	Life cycle analysis
LCI	Life Cycle Inventory
LHV	Lower Heating Value
MJ	Megajoule (= 947.83 Btu)
mmBtu	Million British Thermal Units
MW	Mega-Watt
MWh	Megawatt-Hour

1. Introduction

Ripple Foods, Inc. produces a plant-based dairy-alternative milk made from yellow peas that is highly nutritious and sustainably produced. As Ripple milk provides the highest protein-content of available plant-based milks, which is comparable to the protein content of dairy milk, the nutritious value of Ripple Milk is easy to understand. Less obvious may be the reasons that Ripple Milk is a highly sustainable product.

First, yellow peas are legumes, and like all legumes, they are nitrogen-fixing. This means that they extract nitrogen from the air and replenish the nitrogen content of the soils where they are planted. Therefore, they require minimal nitrogen fertilizer, which is energy-intensive to produce commercially. Yellow peas can also be planted as a cover crop in grain and oilseed planting rotations to reduce fertilizer requirements for those crops. Planting yellow peas as a cover crop provides the additional advantage of avoiding the need to till the soil, which otherwise would result in release of greenhouse gases to the atmosphere.

Second, yellow peas are a water-efficient crop, requiring minimal, if any irrigation beyond natural rainfall in order to grow. They are capable of achieving 30-bushel per acre yields on only 10 inches of rainfall. (Parker, 2014).

Third, Ripple bottles are made from 100% post-consumer recycled PET (polyethylene terephthalate) plastic which results in lower greenhouse gas emissions than using virgin plastic material. PET is the most recyclable and recycled plastic material, and therefore, a highly sustainable choice for packaging material. Other packaging alternatives, including the popular multi-layer cartons (e.g., TetraPaks[1]). While technically recyclable, such cartons are associated with low recycling rates due to a shortage of facilities capable of handling the processing required to disassociate the polyaluminum layers from the cardboard (Path Water, 2019).

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 of Ripple milk as compared to that for dairy milk, and several plant-based milks including those produced from almonds, soybeans, coconut, and oats.

[1] Tetra Pak is one of several brands that market beverages in asceptic cartons created by annealing cardboard, aluminum and polyethylene layers. Commonly asceptic multilayer cartons are referred to by this brand name.

2. LCA Approach

2.1 Goal and Scope

The goals of this Study are to examine the greatest contributing factors to Ripple milk's greenhouse gas (GHG) emissions (carbon footprint) and water use (water footprint) throughout its life cycle, and compare them to those for dairy and several popular plant-based milks available in the US market (oat, almond and coconut). The scope of this Study covers from the farming to retail steps of dairy and plant-based milk production. The carbon footprint also includes the packaging production and disposal step of the life cycle.

2.2 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 and other plant-based milk life cycle assessments. The life cycle steps for dairy milk are slightly different, as shown in Figure 2.

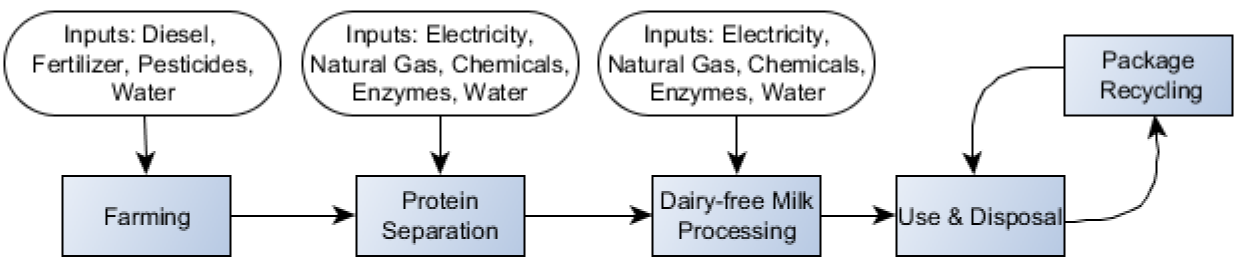

Figure 1. Plant-based Milk System Boundary Diagram

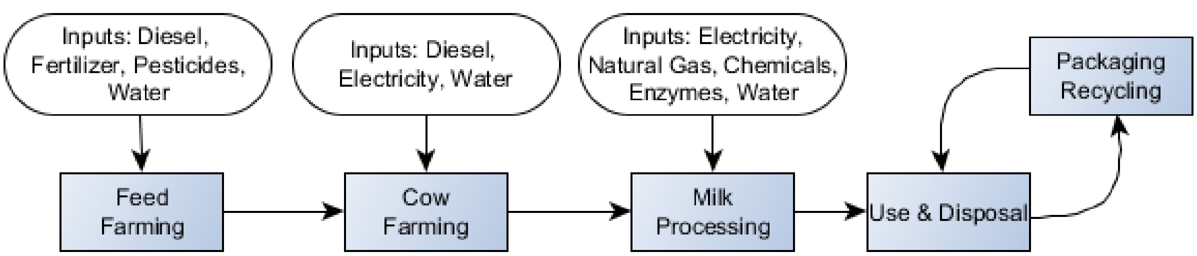

Figure 2. Dairy Milk System Boundary Diagram

Each of the pathways examined here generates a number of co-products. For example, pea meal, oat fiber, and almond husks are used for animal feed, almond orchard prunings and coconut husks can fuel electricity generation, and dairy milk production results in beef and tallow. The primary product is the protein-laden legume or milk, and the co-products have less value. A co-product credit for the feed products is applied based on economic allocation.

2.3 ISO Standards

This study followed life cycle analysis standards (14040) (Figure 3) established by the International Organization for Standardization (ISO). All steps were followed with the exception of engaging third party review and stakeholder input.

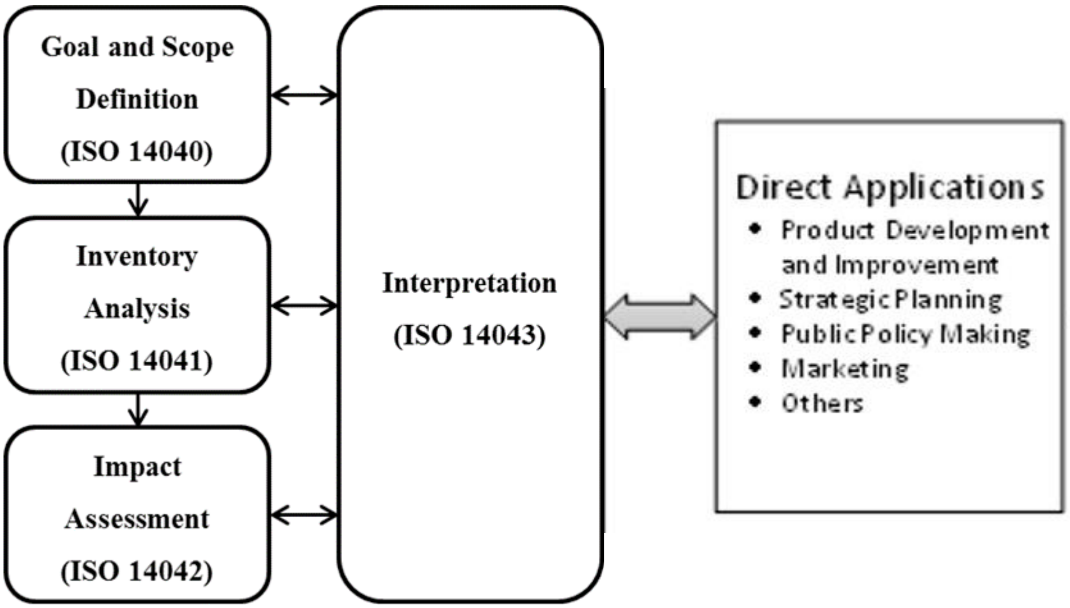

Figure 3. International Organization for Standardization 14040 Standard for Life cycle analysis. Source: ISO, 2006.

2.4 Functional Units

Two functional units were included in this analysis: GHG emission results are shown on a per liter of milk basis, and per the amount of protein in one liter of milk. Each type of milk contains a different amount of protein. Therefore, for the protein functional unit, the life cycle emissions for a liter of milk are divided by the protein content in the milk. This means for the protein-basis FU, 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 contained 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.

2.5 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 milk products, in terms of GHG emissions and fresh water consumption.

Every product has its own life cycle, comprised of multiple different steps. The life cycle of Ripple milk includes the farming of yellow peas, yellow pea protein isolate production, Ripple milk production, retail, and production and disposal of its 100% recyclable 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. Emission factors for modeling process GHG impacts were taken from the GREET_1 2020 model.[2] 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 plant-based milks are similar to Ripple's. Several varieties of Ripple milk are produced. Ripple Original milk is assessed in this Study. The analysis of dairy milk GHG emissions relies on prior studies, but includes comparable steps.

3. Life Cycle Inventory

3.1 Plant-based Milks

Data were collected from a range of publicly available sources to reflect the farming inputs of fertilizer, pesticides, and energy for yellow peas, almonds, coconuts, and oats. Fertilizer and pesticide data were not available for yellow peas; so, average farming inputs for lentil farming (USDA, 2016) were adjusted based on grower reports from the pea farmers that supply Ripple Foods (McKay et al., 2003). Almond farming inputs were taken from a life cycle assessment of almond farming in California that accounted for the 26-year life cycle of almond trees (Kendall, 2015). Fertilizer needs vary over the life cycle of an almond tree, so the 26-year average fertilizer application was used in this analysis. Oat fertilizer data was taken from USDA[3] (2015). Coconut fertilizer inputs were calculated based on Dumelin (2009). Pesticide, herbicide, and farming energy inputs were taken from the GREET1_2016 model defaults for canola production[4] (ANL, 2016).

The environmental impacts of all farming inputs were modeled in GREET_1 2016 (ANL, 2016), 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 oats and almonds, field emissions were estimated based on 1.3% of the applied nitrogen as unlike peas, these crops do not result in nitrogen fixation emissions (Figure 5, Figure 6, respectively).

[2] Argonne National Laboratory, ANL. (2020). "The greenhouse gases, regulated emissions, and energy use in transportation (GREET) model, Version 1_2020."
[3] An average fertilizer use was calculated for the top five oat-producing states (SD, MN, ND, IA, WI).
[4] Canola farming energy consumption is approximately three times greater than that of soybean production, and is implemented in this study as a conservative value.

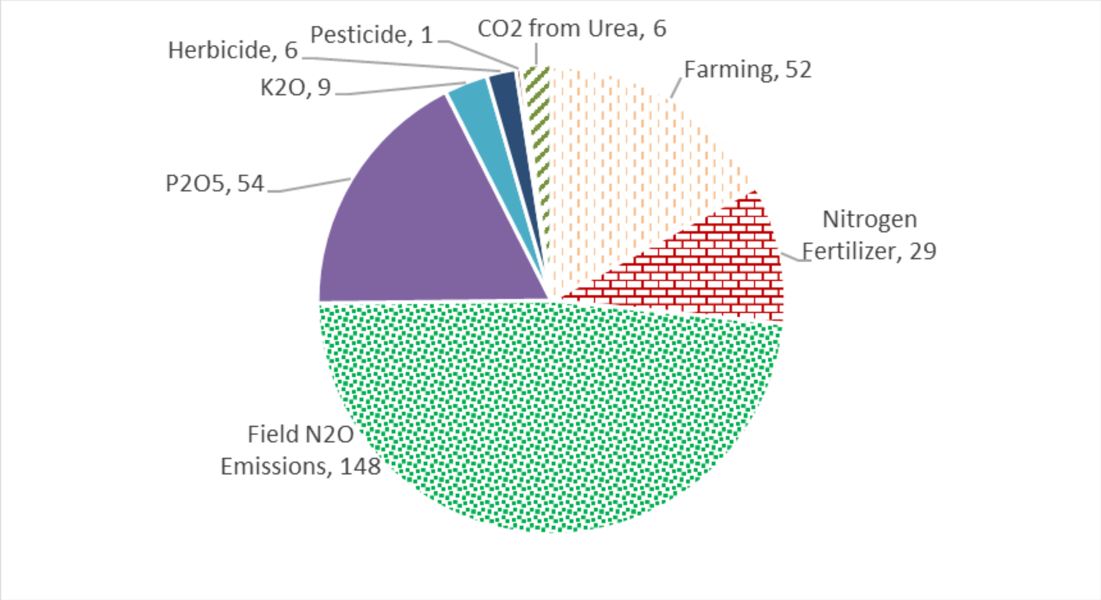

Figure 4. Agricultural GHG emissions for Ripple Peas (g/kg crop).

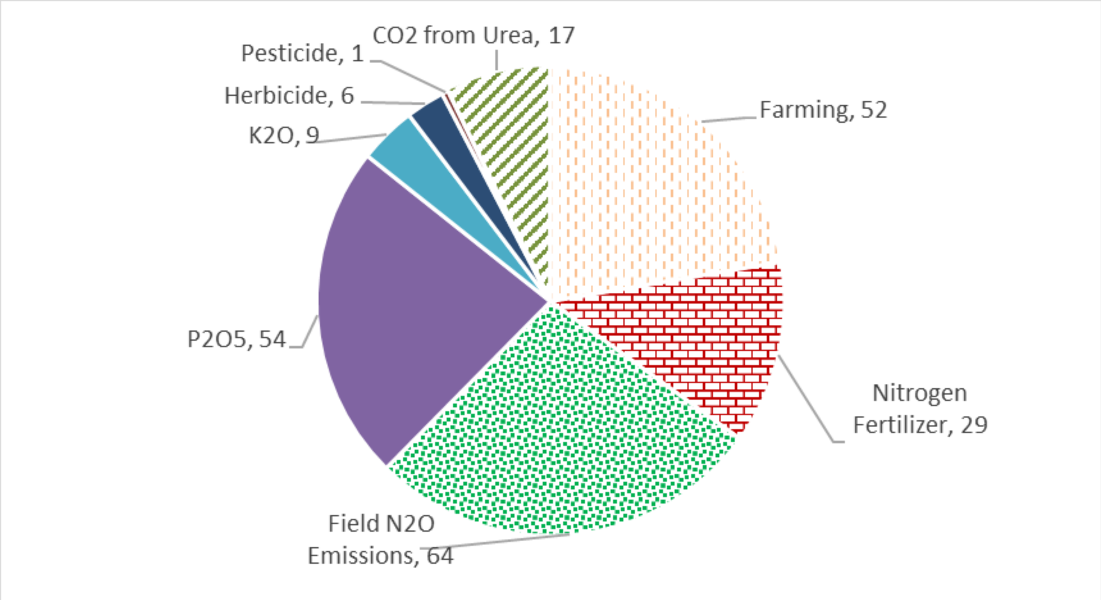

Figure 5. Agricultural GHG emissions for Oats (g/kg of crop).

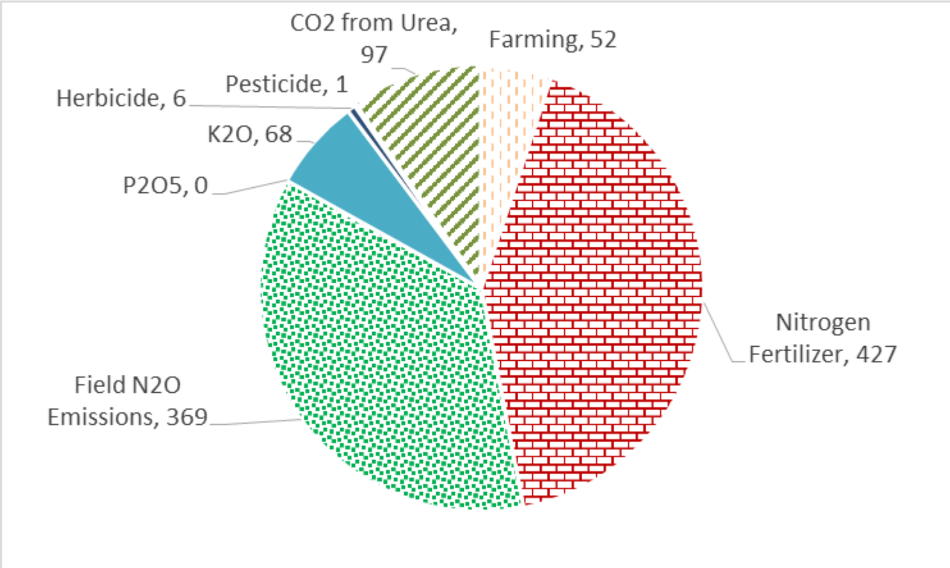

Figure 6. Agricultural GHG emissions for Almonds (g/kg of crop).

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, N_2O 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 legumes result in nitrogen fixation emissions, the amount of 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, referred to as the GNOC model (European Commission JRC, 2014). Fertilizer inputs and yields used for yellow peas in this study were entered into the GNOC model along with the growing region, and the model determined the N_2O emissions from every potential emission source, as shown in Figure 7.

Farming emissions are multiplied by the amount of feedstock in the finished milk to calculate the carbon intensity of farming on a volumetric basis. The kg of feedstock 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 plant-based 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 each of the finished milk products.

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 7. Nitrous Oxide Emissions from Yellow Pea Farming

For all plant-based milk products, processing emissions result from the use of electricity and natural gas in the processing facilities. Power consumption for pea protein isolate production, as well as power and gas consumption for Ripple milk production, was taken directly from facility operating data. Processing data for almonds was based on Winans et al. (2020), and for coconut, was assumed to be the same as for almonds since source data were unavailable. For oats, energy and water use rates were based on (Swedish Institute for Food and Biotechnology, 2013). To compare GHG emissions associated with US-based oat milk production, the energy consumption from the Swedish Institute for Food and Biotechnology (2013) was modeled for a generic production plant. The resulting greenhouse gas emissions from electricity and natural gas usage for oats and almond milks were modeled based on the US average grid mix reported in GREET1_2020 (ANL, 2020). The coconut milk LCA (Franklin, 2012) reported total emissions associated with processing and not the source data, therefore, these emissions were divided equally and assigned to inputs for electricity and natural gas. Since 80% of Ripple milk is produced in Toronto, Canada, this proportion of energy consumption was modeled based on the grid mix for the Province of Ontario, and the remaining 20% of electricity consumption was modeled based on the same US Average Mix, as used for oats and almond milks.

Water movement and pumping contribute to the energy cost of water transport in 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 in the state have limited natural water resources, where agriculture is made possible by a vast network of canals that transport water from the Colorado River, San Joaquin River, and the 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 deliver water to agricultural production areas was reported 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.

3.2 Milk Packaging

Ripple milk is exclusively packaged in a polyethylene terephthalate (PET) bottle made from 100% post-consumer recycled material (rPET). The other plant-based milks included for purpose of comparison in this Study are packaged in a variety of materials, including PET, gable cartons, and multi-layered cartons[5], the latter being comprised of several layers of material including paper board, aluminum and polyethylene. Dairy milk is commonly packaged in high density polyethylene (HDPE) (Thoma et al., 2013), which is used to represent dairy milk packaging in this Study. For the sake of consistent comparison, all other plant-based milks were assumed to be packaged using PET. The GHG emissions associated with other packaging materials are also reported in this Study for reference.

PET is the most recycled plastic material in the U.S. and globally (29%: EPA, 2021). Multi-layer cartons are more challenging to recycle, due to the combined polyaluminum materials that are difficult to separate and extract. Although technically feasible to recycle multilayer cartons, few facilities have the capability to do so. For example, Eunomia (2020) reported recycling rates for multilayer cartons from 21.4% to 47.8% for 4 European countries where recycling facilities were available. While several obstacles to circularity exist for recycling of multilayer cartons (Eunomia, 2020), recycling of PET, largely derived from plastic water bottles, supports greater circularity. The emissions associated with both of these packaging types are comparable, however, the availability of facilities capable of recycling PET, and relatively strong recycling rates provide added benefits to use of PET. Additionally, it is feasible to construct bottles from 100% rPET, as done for Ripple's packaging, whereas, the combined aluminum-polyethylene layer in maximum multi-layer cartons presents a recycling challenge. Ripple's use of rPET as milk packaging material, therefore provides the combined advantage of low GHG emissions, high recyclability, and high realized recycling rates.

3.3 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 referenced from two 2013 studies that examined the

[5] While several brands exist, Tetra Paks are the most prevalent brand, and multi-layer boxes are therefore commonly referred to as "Tetra Paks".

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 et al., 2012). Emissions from transport to retail and refrigeration were not represented in the Ripple analysis and other plant-based milk LCA comparisons in order to be consistent with the assumptions and scope for these LCAs.

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

3.4 Inventory Data Sources

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

Table 1. Life Cycle Inventory Data Sourcing for Plant-Based and Dairy Milks

Life Cycle Stage	Ripple, Pea	Almond	Oat	Coconut	Dairy
Feedstock production	USDA, 2016; GREET	Kendall, 2015; Winans et al., 2020	USDA, 2015; GREET	Dumelin, 2009	Thoma, 2013b[1]
Protein isolate Production	Lie-Piang, 2021	N/A	N/A	N/A	N/A
Milk production	Ripple Data; Biograce I v 4d	Winans et al., 2020; Biograce I v 4d	Swedish Institute Food, 2013	Franklin Associates, 2012	Thoma, 2013a
Packaging & EOL	Winans et al., 2020	Kuczenski & Geyer, 2011	Kuczenski & Geyer, 2011	Kuczenski & Geyer, 2011	Thoma, 2013a
Water Consumption	Mekonnen, 2010b	Mekonnen, 2010b	Mekonnen, 2010b	Mekonnen, 2010b	Mekonnen, 2010a

[1]Farm-to-farm gate

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_1 2020 model (ANL, 2020). LCI data in GREET 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. Table 2 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 3 lists the power sources (ANL, 2020; CARB 2018) used in this Study.

Table 2. Example LCI Data for Natural Gas Combusted as a Stationary Fuel (ANL, 2020)

Natural Gas Life Cycle Emission Factors (g/mmBtu)	Recovery, Processing, & Pipeline Transport	Stationary Fuel Combustion	Total Emissions
VOC	10.320	2.540	12.86
CO	31.994	22.210	54.204
NO_x	40.003	36.400	76.403
PM10	0.473	3.507	3.98
PM2.5	0.421	3.507	3.928
SO_x	11.551	0.269	11.82
BC	0.132	0.579	0.711
OC	0.151	1.501	1.652
CH_4	219.231	1.060	220.291
N_2O	1.416	0.750	2.166
CO_2	6,066	59,367	65,433
CO_2c	6,149	59,410	65,559

Table 3. Grid Mix Regions and Sources

Milk	Ripple	Almond	Dairy	Oat	Coconut
Water Transport		CA Mix			
Farming	US Avg	US Avg	Embedded[1]	US Avg	Embedded
Protein Isolate	Embedded	NA[2]	NA	NA	NA
Milk Processing	80% Ontario Mix; 20% US Avg	US Avg	US Avg	US Avg	Embedded

[1] Indicates that power emissions were published as a total in the respective LCA source, per Table 1.

[2] NA = not applicable because these milks do not include a protein isolate as an ingredient

The LCI data are 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 4Table 3 lists the inputs for this Study.

Table 4. LCA Milk Modeling Inputs

Milk	Ripple	Almond	Oat	Coconut[a]	Dairy[b]
Farming Inputs					
Nitrogen (lb/lb)	0.0071	0.1070	0.0196		
P_2O_5 (lb/lb)	0.0347	0	0.0161		
K_2O (lb/lb)	0.0141	0.1090	0.0182		
Diesel (Btu/tonne)	519,149	519,149	519,149		
Pesticides (g/tonne)	42.90	42.90	42.90		
Herbicide (g/tonne)	300	300	300		
CA Water Transport (kWh/tonne)		531.8			
Processing					
Electricity (kWh/kg milk)	0.049	0.059	0.14	0.218	
Natural Gas (MJ/kg milk)	0.729	0.065	1.17	2.043	
Additives					
Sunflower oil (% by mass)	1.49%	1.49%	0.8%	0%	
Cane Sugar (% by mass)	2.37%	2.88%	2.9%	2.92%	
Packaging kg CO_2e/ 1 L bottle	0.051[c]	0.190[d]	0.190[d]	0.190[d]	0.125
Additional Parameters					
Protein content, finished milk	3.33%	0.55%	1.25%	0.25%	3.38%
Plant content, finished milk (kg/kg)	0.198	0.036	0.377	0.104	0.338

[a]Assumed to be the same as for soy milk; Greenhouse gas emissions for coconut oil production (Dumelin, 2009) represent aggregate value for coconut farming emissions, therefore farming emissions not listed here.
[b] Dairy milk inputs are not shown since dairy milk life cycle emissions are based on literature sources only.
[c] Ripple sources 100% post-consumer recycled PET for all of their product, therefore, this value differs from the packaging values applied to other plant-based milks in this comparison.
[d] A variety of packaging types are used for plant-based milks. Here, a value for PET bottle packaging is employed for the sake of comparison. See Table 5 for alternative packaging LCI data that could be applied.

Table 5. LCI Data for Milk Packaging

Packaging Type	Low	Source	High	Source
PET	0.190	Kuczinski & Geyer, 2012	0.216	Winans et al., 2020
rPET	0.051	Winans et al., 2020	0.152	Stefanini et al., 2020
HDPE	0.079	Winans et al., 2020	0.165	Bertolini, 2016
Gable Top Carton	0.062[a]	WRAP, 2010	0.085[b]	WRAP, 2010
Multi-layer Carton	0.050	Scipioni et al., 2012; IFEU, 2020[c]	0.113	Pasqualino et al., 2011

[a] To landfill
[b] Energy from waste

[c] Median of range with 50% recycling

4.1 Greenhouse Gas Emission 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 (ISO 2006a, b). 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, which is commonly referred to as system expansion via substitution. 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. In this Study, an economic allocation method was employed to account for emissions associated with co-products[6].

The refinement of peas to produce pea isolate for Ripple milk results in the co-production of starch and fiber that are used as animal feed. Likewise, almond, oat and coconut milk production generate co-products (Table 6).

Table 6. Co-Products Associated with Types of Plant-Based Milks

Plant-Based Milk	**Co-products**
Pea	Starch (animal feed)
Almond	Shells and Orchard Prunings (energy production), husks (animal feed)
Coconut	Water, Oil, Desiccated White Meat (human consumption), Desiccated Brown Meat (animal feed), Husks (energy production)
Oat	Starch/Fiber (animal feed)

The co-product credits for Ripple, Almond 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

4.2 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

[6] The displacement value of substitute products is variable and uncertain as ingredients are not produced with the intent of making co-products. Econ allocation is relatively simple to apply despite variations in price data. The resulting credit is proportional to the value of the coproduct and does not overstate it, which could result if, for example, mass balance or substitution methods were applied.

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) AR5 GWP values (IPCC, 2014) 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 functional units were considered in this analysis. 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 one liter of milk (Table 7).

Table 7. GHG Life Cycle Emissions of Finished Milks

Volume Basis					
Results (g CO2e/L milk)	**Ripple**	**Almond**	**Dairy**	**Oats**	**Coconut**
Crop Production	60.5	36.3	1,273	87.7	114.48
Isolate and Milk Processing Tot:	191.3	37.4	111.7	103.3	108.5
Isolate Electricity + NG	111.9	-		-	-
Milk Processing Electricity	17.8	26.5	EIT	71.6	51.00
Milk Processing NG	50.3	4.5	EIT	21.9	51.00
Milk Additives	11.2	6.4	EIT	9.8	6.50
Chemicals and Additives	-	-	-	-	-
Packaging & EOL	50.6	190.3	124.5	190.3	190.3
Packaging Type	rPET	PET	HDPE	PET	PET
Co-Product Credit	(2.5)	(4.2)		(3.8)	(114.5)
Total (g CO2e/L milk)	299.8	259.8	1,509.3	377.5	298.8
Ripple % Difference		15%	-80%	-21%	0.3%
Protein Basis					
Results (g CO2e/kg protein)	**Ripple**	**Almond**	**Dairy**	**Oats**	**Coconut**
Crop Production	1,814	1,090	38,192	7,018	45,251
Isolate and Milk Processing Tot:	5,739	6,793	3,305	8,262	42,885
Electricity	534.8	4,813.9	EIT	5,727	20,158
NG	1,510.4	813.2	EIT	1,750	20,158
Milk Additives	337.0	1,165.4	EIT	785	2,569
Packaging & EOL	1,517	34,604	3,685	15,226	75,226
Co-Product Credit	(75)	(757)		(302)	(45,251)
Total (g CO2e/kg protein per L r	8,995	41,729	45,180	30,204	118,112
Ripple % Difference		-78%	-80%	-70%	-92%

EIT = embedded in total GHG emissions reported by published LCA study.

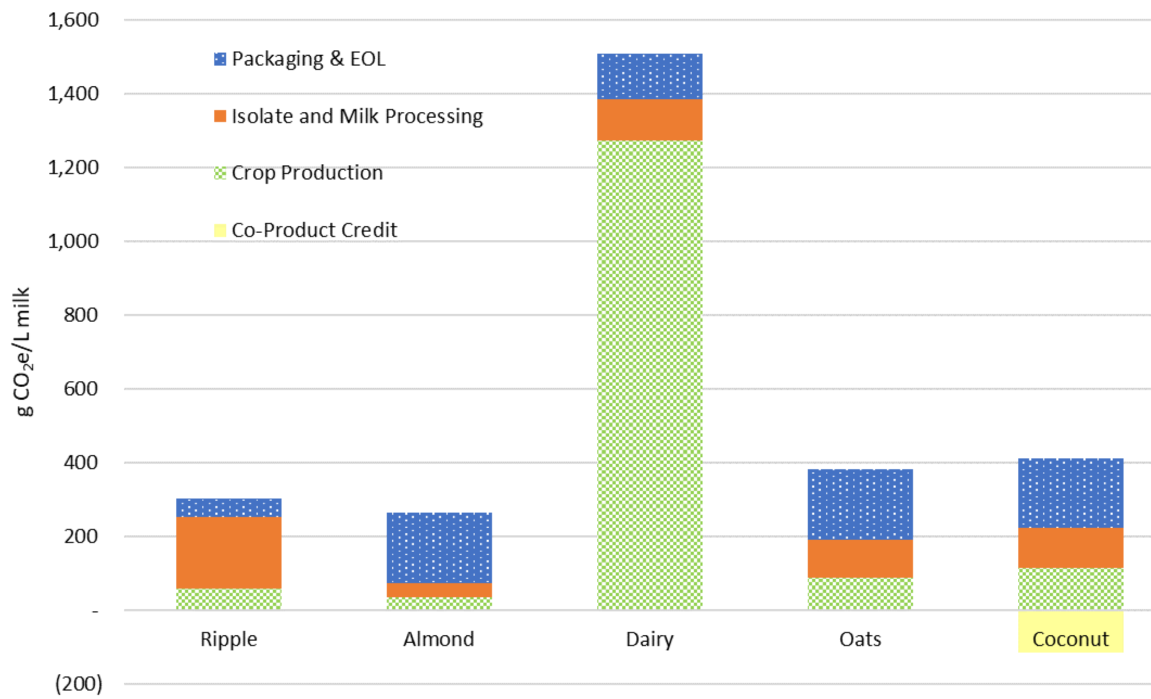

Figure 8. Life Cycle GHG Emissions of Finished Milks on a Volume Basis

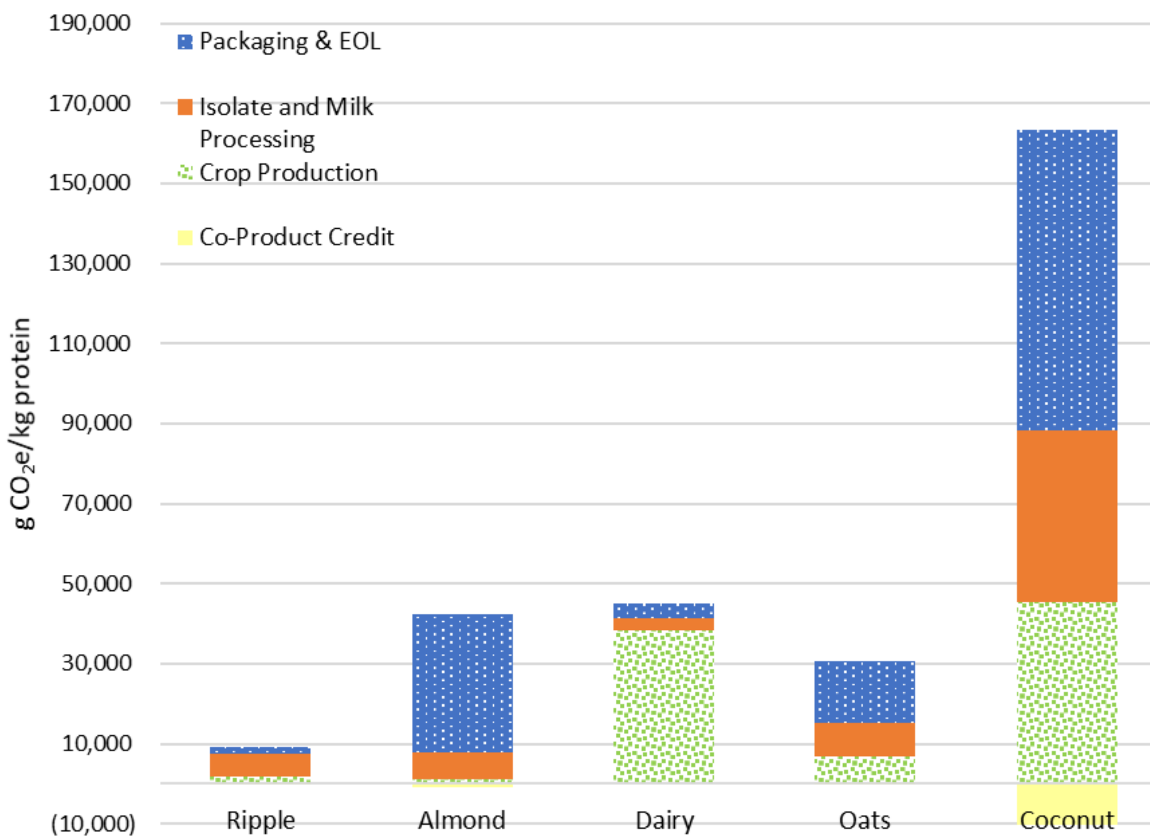

Figure 9. Life Cycle GHGs Emissions of Finished Milks on a Protein Basis

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. As feasible, U.S. average values are used for the other milk products since Ripple products may be competing against a range of milk products from all over the country. Dry peas, almonds, oats and coconut 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 volume basis and 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 the sweetened version of plant-based milks all have some amount of added sugar, the water associated with cane sugar production was also included. Water used in milk processing and included as a product ingredient, were also included in the water footprint.

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.

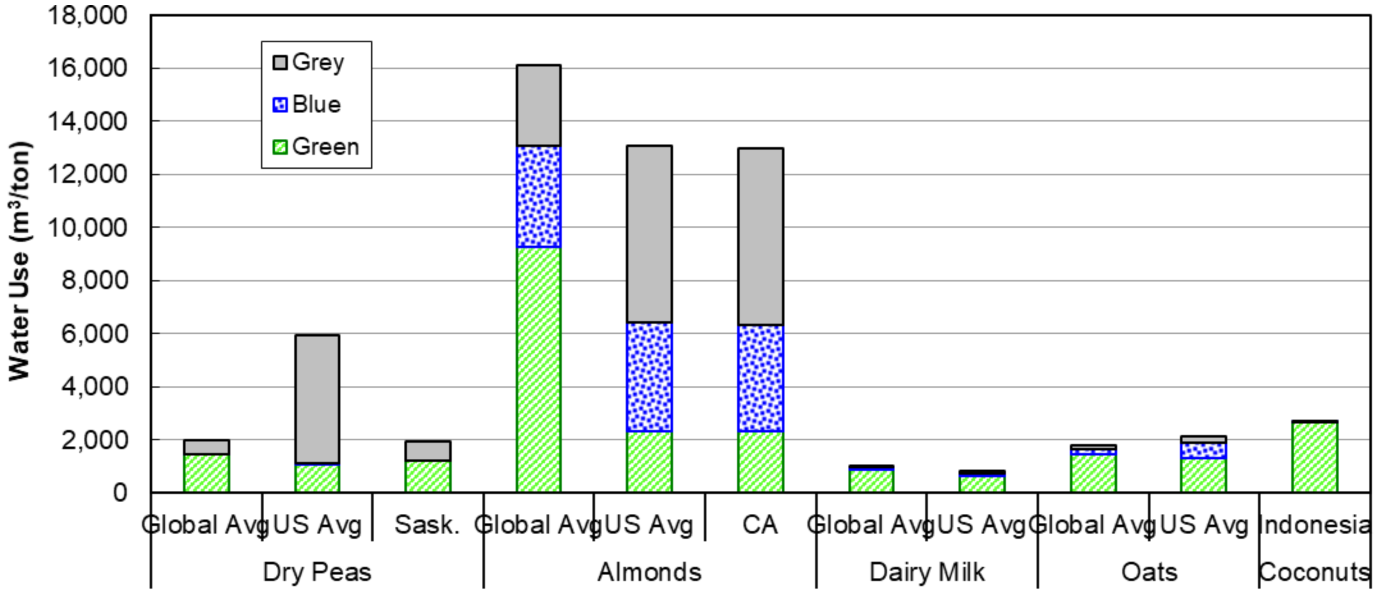

Figure 10. Crop production water use by geographic region.

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 entire 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, for example, results in higher levels of water scarcity (Figure 11).

Taking into account the water scarcity factors for the regions in which the respective crops are grown and the milk production plants located, yields the results shown in Table 8. With water scarcity taken into account, growing almonds requires approximately 110 times more water per tonne of crop than growing yellow peas, oats require approximately twice as much water, and coconuts 13 times less.

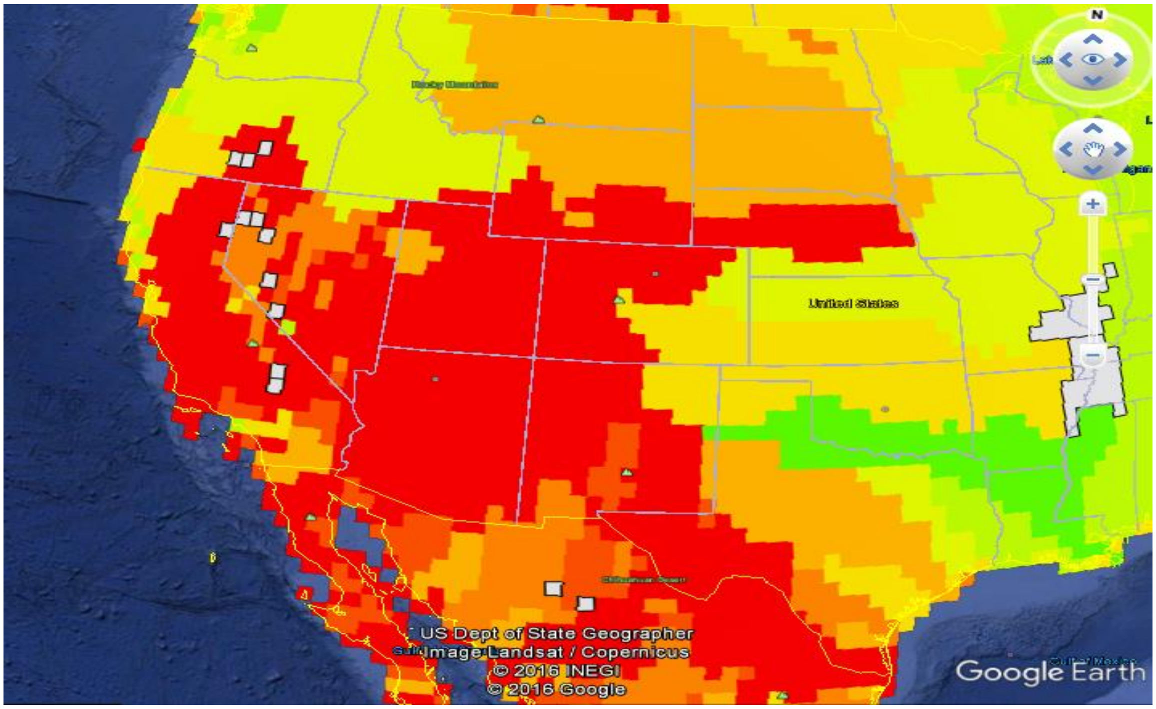

Figure 11. Water Scarcity Map of North America

The water footprint of each milk product is illustrated in Table 8 and Figure 12. The water footprint includes a water-scarcity adjustment factor applied to the water consumed in the farming and processing stages and the amount of water used as a milk ingredient.

Without considering the water scarcity factor (top row), the amount of water consumed in the production of peas, oats, and coconut is relatively comparable, however the amount of water required to produce a ton of almonds is 6.8 times the amount of water it takes to produce a ton of peas. Accounting for regional water scarcity greatly changes the water footprints (Table 8). After accounting for regional water scarcity, finished almond milk production requires nearly 8 times as much water per liter of milk than does Ripple Milk, and dairy and oat milk production consume 7, and 1.4 times as much water, respectively, and coconut milk production consumes 17 times less water.

Evaluating water use on a protein basis per liter of milk further alters the water footprint outcomes. Since Ripple milk is made from yellow peas that are relatively high in protein compared to other non-legume plant-based milks such as almond, oat, and coconut, Ripple milk production requires much less water. For example, on a protein basis, almonds require approximately 112 times as much water to produce as do yellow peas, and oats require 8 times as much. Coconut milk, while containing very little protein, is derived from feedstock that is characterized by low water scarcity, and therefore, on a protein basis, exhibits a water footprint that is approximately three-fourths that of yellow peas while dairy milk's water footprint is approximately 17 times that of Ripple's.

Table 8. Water Footprint Results

Milk Type	Ripple	Almond	Oat	Coconut	Dairy
Milk Input Crop	Peas, dry[1]	Almonds[2]	Oats[3]	Coconut[4]	NA
Crop Growing Region	Saskatchewan	US Avg	US Avg	Global Avg	US Avg
Crop Water Use (m^3/ton crop)	1,928	13,055	2,123	2,687	821 [5,6]
Water Scarcity Factor (SF)[7]	6	88	8.5	0.3	44.6
Crop Water Use, SF-Adjusted					
m3/tonne crop	11,568	1,266,379	19,894	889	40,318
m3/kg crop	11.57	1,266.4	19.9	0.9	40.3
m3/L milk	2.4	45.1	7.6	0.1	
L/L milk	2,434	45,130	7,614	142	41,729
L/L milk, protein basis	73,016	8,205,443	609,103	55,991	1,234,579
Protein Isolate Processing Water Use					
m3/tonne crop	15.2	0	0	0	0
m3/tonne crop, SF-Adjusted	16.7	0	0	0	0
m3/kg crop, SF-Adjusted	16,720.0	0	0	0	0
L/L Milk, SF-Adjusted	3,305.1	0	0	0	0
Milk Processing Water					
L/L milk	4.2	6.4	9.7	5.8	0
L/L Milk, SF-Adjusted	160.9	485.0	342.4	1.2	0
Milk Ingredient Water					
L/L milk	0.9	1.0	0.0	0.3	0
L/L Milk, SF-Adjusted	35.90	37.83	10.58	36.50	0
Total Water Used (L/L milk), SF-Adjusted	5,935.76	45,376.92	7,988.79	366.94	41,728.76

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. Oats (Product code HS 100400)
4. Coconuts (Product code HS 08011)
5. Milk not concentrated & unsweetened exceeding 1% not exceeding 6% fat (Produce code HS 040120)
6. Dairy milk water use is reported by Mekonnen and Hoekstra for finished milk, therefore processing use appears as 0
7. Water scarcity factor (SF) applied to crop water use. http://www.wulca-waterlca.org/project.html

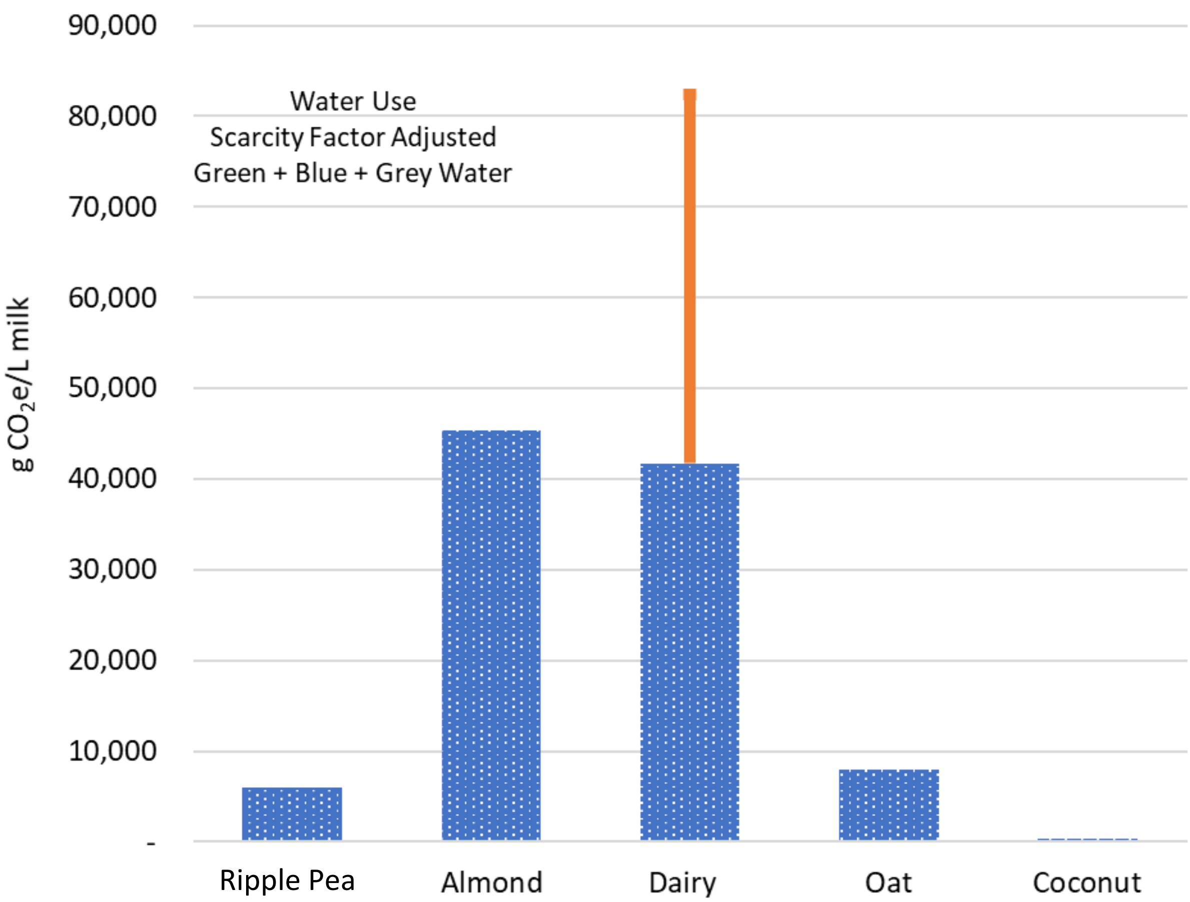

Figure 12. Finished milk water footprints. Dairy error bar reflects variation if water scarcity applied for California (per Henderson and Unnasch, 2017).

7. Discussion

The GHG life cycle impacts of Ripple milk, demonstrate that on a volume basis, Ripple milk emissions are 80% lower than dairy and 21% lower than oat milk. In comparison to coconut milk, Ripple's GHG emissions are equivalent, and compared to almond milk they are 15% higher. The nutritional value of milk, however, is closely linked to its protein content. When comparing Ripple milk to these same milks on a protein-basis, Ripple milk GHG emissions are 70-92% lower than every milk included in this Study (Table 7).

Accounting for regional water scarcity, the Ripple total water footprint is substantially lower than almond (87%) and dairy (86%) milk, 26% lower than oat milk, and 16 times greater than coconut milk. The difference to the dairy water footprint doubles if compared to California-based dairy production, due to the high water scarcity in the state. On a protein basis, the Ripple water footprint improves greatly in comparison to oat, almond and coconut milk, which are relatively low in protein content.

As an economic method of co-product allocation was employed in this Study, a potential source of uncertainty is the fluctuation in co-product prices. A limitation of the study is that most plant-based milks have several added ingredients in order to improve the taste profile, nutritional content, and texture of the finished product. The added sugar in plant-based milk was included in both the GHG analysis and the water footprint in order to be consistent with the sugar content in dairy milk. Ripple milk, some almond milks, including that referenced by Winans et al. (2020), and oat milk based on Oatly (Swedish Institute for Food and Biotechnology, 2013) also contain sunflower oil, and the GHG emissions from this were included in these respective LCAs. Other additives such as emulsifiers, flavor enhancers, and vitamins, however, were excluded from this Study.

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