A COMPARISON OF LAND, WATER AND ENERGY USE BETWEEN CONVENTIONAL AND YEAST-DERIVED DAIRY PRODUCTS: AN INITIAL ANALYSIS

Mark Steer
University of the West of England

Report prepared for Perfect Day
16th June 2015

ABSTRACT

Yeast-derived milk (YDM) is being developed as a potentially healthier and more efficient alternative to conventional milk. Life cycle assessment (LCA) was used to assess the environmental impacts of large-scale YDM production based on the systems being developed by the company Perfect Day. The results indicate that production of 1 L YDM requires 0.98 MJ energy, 19.7 m^3 water, 0.28 m^2 land, and emits 0.43 kg CO_2-eq GHG emissions. In comparison to conventionally produced milk, YDM involves approximately 24-84% lower energy use, 98% lower water use, 77-91% lower land use, and 35-65% lower GHG emissions. These results must be considered as preliminary data and may be subject to considerable alteration with the acquisition of better data sets. However, despite high uncertainty, it is concluded that the overall environmental impacts of YDM are substantially lower than those of conventionally produced milk.

INTRODUCTION

Livestock farming is a major contributor to environmental degradation and anthropogenic carbon emissions. Total emissions from global livestock equal 7.1 gigatonnes of CO_2-equivalent per year, representing 14.5 percent of all anthropogenic GHG emissions (Gerber *et al*. 2013). Approximately 65% of these emissions and produced by cattle and, while the emission intensities (i.e. emissions per unit of product) from dairy cattle are significantly lower than beef cattle (~85 CO_2-eq per kilogram of protein produced vs ~300 CO_2-eq kg^{-1}), they still account for around twenty percent of the sector's overall GHG outputs (Gerber *et al*. 2013). Furthermore dairy farming has significant detrimental impacts on the availability of freshwater, land availability, nutrient loading of waterways and biodiversity (e.g. see Steinfeld *et al*. 2006; Baskaran *et al*. 2009). Such concerns may be particularly pertinent in California, the largest dairy producer in the USA, given the likelihood of continuing water scarcity in the state (e.g. see Schaible and Aillery 2012).

In the face of rising human populations, increasing rates of consumption and climate change, there is a pressing need to create food production systems which deliver step changes in efficiency of land, water and energy use. Biotechnological measures may provide a suite of opportunities for realising the need for sustainable intensification by moving food production from field to factory (e.g. Tuomisto and Teixeira de Mattos 2012).

This report compares the environmental impacts of conventional dairy systems with the forecast environmental impacts of production of dairy products via a non-bovine pathway (YDM) which involves the production of milk proteins by yeast combined with vegetable oil, as being developed by Perfect Day.

METHOD

1.1 Goal and Scope Definition

The aim of this Life Cycle Analysis study is to analyse the input-output (I/O) streams of Perfect Day milk production, and compare the relative impact contributions of each step with those of comparable stages of conventional cow milk production. We attempt to establish baseline information, given predicted manufacturing practices, to be further refined when processes are finalised. Given the preliminary, scoping nature of the study, results are neither accurate or specific and rely on assumptions and data augmentation. We assume that the production of Perfect Day milk at the Perfect Day lab will be comparable to production elsewhere in the US, and used generic, second-hand data that we assume represents common industrial practices, rather than seeking cooperation with specific vendors. Similarly, the study analyses generic data from the US dairy industry, and beyond where necessary.

The scope of the study was a cradle-to-factory door assessment, echoing the stages involved in the production of *raw whole* milk from dairy cows, namely, substrate or feed acquisition and milk production. Analysis was limited to all stages prior to the transport of the final raw milk product to a processing plant, as it was assumed that subsequent stages were identical for both Perfect Day and conventional milk, and that the milk products are identical, used at same rate and in same manner.

1.2 Functional Unit

The study analysed milk produced at the Perfect Day brewery. One kg of milk leaving the factory gate is taken as the functional unit.

If a full cradle-to-grave analysis is later required, product loss in the supply chain, including wasted or spoiled milk by consumers and out-of-date milk at retail, will need to be taken into account. This is equivalent to 29.6% loss of all milk produced prior to it being consumed (USDA, 2010a). This loss is reported as 12% at retail and 20% at consumption and is not differentiated by milk-fat content. These losses in the supply chain affect the reference flows of upstream processes; specifically, the required flow into the consumption phase is approximately 1.25 kg per kg consumed, and the flow into the retail channel is approximately 1.14 kg per kg delivered to retail. This results in a reference flow of 1.42 kg milk leaving the processing unit (Thoma 2013).

1.3 System Boundaries

The system boundaries include:

- the agricultural processes of *beet/cane* sugar cultivation;
- the agricultural processes of sunflower oil cultivation;
- raw material production and processed, acquisition and transport to the Perfect Day lab;
- yeast culture operations;
- the production of Perfect Day milk;
- and the management of wastes and production of heat and electricity.

In choosing which specific inputs to include, we adopt a 1 % cutoff threshold for mass and energy. We exclude by-products including roots, sugar pulp and yeast excess, instead considering them as an avoided production of cattle feed. The production of yeasts were not included in the system boundaries since their influence on the analysis results can safely be assumed as negligible (e.g. see Cordella *et al*. 2008). We did not include in the inventory processes components such as human resources, and the manufacturing, maintenance or disposal of infrastructure. At this stage we also do not include the impacts of land use change which may be caused by a shift from conventional dairy towards lab-based production, but this will be an important element for future research.

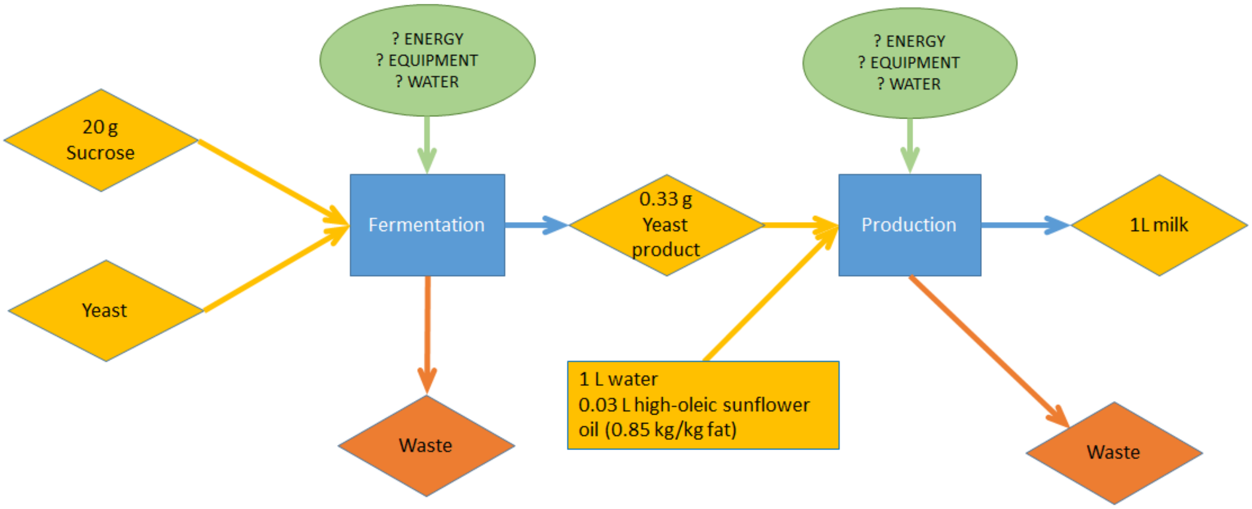

Figure 1: summary of Perfect Day production system

The environmental impacts considered were the extent of agricultural land use, water consumption, energy consumption and greenhouse gas emissions.

1.4 Audience

The primary audience are consumers who may use the results to compare environmental impacts of choosing conventional cow versus Perfect Day milk, and for internal use in order to use the results to identify opportunities to reduce GHG emissions, land use and/or water use.

1.5 Life Cycle Inventories

Data for the LCA was obtained from scientific and industry literature and the EcoInvent database 3.1. Unit processes were constructed within OpenLCA® and linked to EcoInvent upstream processes. The outputs of these processes were compared to published data on the resource requirements of conventional dairy systems in the US, where possible, and other locations where required.

2. Inventory Analysis

Inventory data were gathered to cover four major production stages: the agricultural production and refining of sunflower oil and sucrose; the transport of these products to the Perfect Day factory (production assumed to take place in South Dakota (sunflower oil) and Florida (sucrose); and the subsequent production of YDM at the Perfect Day factory in California.

Where a range of values were given for individual elements of the inventory, the most parsimonious has been chosen for the analysis, therefore providing a conservative estimate of the production requirements and impacts.

Table 1: Inventory Analysis of YDM production process

Materials and Production of Perfect Day milk		**Source**
Sunflower oil		
Land use	7.70 m^2 kg^{-1}	USDA
Water use	12.30 kg kg^{-1}	Spinelli *et al*. 2013
Energy use	9.26 MJ kg^{-1}	Spinelli *et al*. 2013
GWP	0.68 kg CO_2e kg^{-1}	Spinelli *et al*. 2013
Sucrose		
Land use	2.42 m^2 kg^{-1}	USDA
Water use	1111.11 kg kg^{-1}	Carr and Knox, 2011; Cock 2003
Energy use	0.71 MJ kg^{-1}	Seabra *et al*. 2011
GWP	0.23 kg CO_2e kg^{-1}	Seabra *et al*. 2011
Transportation		
Energy use	2.7 MJ tn-km^{-1}	ecoinvent
GWP	180 kg CO_2e tn-km^{-1}	ecoinvent

YDM synthesis		
Water use	1.295 L kg^{-1}	Cordella *et al*. 2008
Energy use	0.421 MJ kg^{-1}	Lalonde *et al*. 2013
GWP	0.41 kg CO_2e tn-km^{-1}	Lalonde *et al*. 2013

The results of the modelling process are compared to published data concerning the production requirements of US dairy systems (Appendix 1).

3. Results

The forecast impacts of YDM production suggest considerable savings in all impact categories studied when compared with conventional dairy systems. YDM production can reduce land use by 77 to 91%, water use by 98%, energy use by 24-84% and GWP by 35-65%.

Table 2: Modelled land, water and energy requirements, plus GWP, of producing 1 L YDM compared to data for conventional dairy production.

	Land (ha)	Water (L)	Energy (MJ)	GWP (kg CO_2e)
Sunflower oil	0.23	0.40	0.28	0.02
Sucrose	0.05	18.00	0.01	0.00
Transport	-	-	0.27	0.00
YDM synthesis	-	1.30	0.42	0.41
Total YDM	**0.28**	**19.69**	**0.99**	**0.44**
Conv. Dairy	1.2 – 2.97	1093	1.3 – 6.2	0.67 – 1.23
Efficiency saving	**77 – 91 %**	**98%**	**24 – 84%**	**35 – 65%**

4. Conclusion

While these results must be treated as preliminary estimates, and potentially subject to change, they provide a strong indication that the Perfect Day production systems can provide dramatic efficiencies in terms of land, water and energy use.

There are some limitations of the study which need to be addressed in the future, such as the impacts of land use change (which aren't addressed in this analysis, but require consideration), as well as sensitivity analyses which would assess the robustness of these results given different input parameters.

References

Baskaran, R., Cullen, R., & Colombo, S. (2009). Estimating values of environmental impacts of dairy farming in New Zealand. *New Zealand Journal of Agricultural Research*, *52*(4), 377-389.

Carr, M. K. V., & Knox, J. W. (2011). The water relations and irrigation requirements of sugar cane (*Saccharum officinarum*): a review. *Experimental Agriculture*, *47*(01), 1-25.

Cock, J. H. (2003). Sugarcane growth and development. *International Sugar Journal*, *105*(1259), 540-552.

Cordella, M., Tugnoli, A., Spadoni, G., Santarelli, F., & Zangrando, T. (2008). LCA of an Italian lager beer. *The International Journal of Life Cycle Assessment*, *13*(2), 133-139.

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. *Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities.* Food and Agriculture Organization of the United Nations (FAO), Rome.

Hess, T., Aldaya, M., Fawell, J., Franceschini, H., Ober, E., Schaub, R., & Schulze- Aurich, J. (2014). Understanding the impact of crop and food production on the water environment—using sugar as a model. *Journal of the Science of Food and Agriculture*, *94*(1), 2-8.

Schaible, G., & Aillery, M. (2012). Water conservation in irrigated agriculture: Trends and challenges in the face of emerging demands. *USDA-ERS Economic Information Bulletin*, (99).

Seabra, J. E., Macedo, I. C., Chum, H. L., Faroni, C. E., & Sarto, C. A. (2011). Life cycle assessment of Brazilian sugarcane products: GHG emissions and energy use. *Biofuels, Bioproducts and Biorefining*, *5*(5), 519-532.

Spinelli, D., Jez, S., & Basosi, R. (2012). Integrated Environmental Assessment of sunflower oil production. *Process Biochemistry*, *47*(11), 1595-1602.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & De Haan, C. (2006). *Livestock's long shadow* (p. 392). Rome: FAO.

Sultana, M. N., Uddin, M. M., Ridoutt, B., Hemme, T., & Peters, K. (2015). Benchmarking consumptive water use of bovine milk production systems for 60 geographical regions: An implication for Global Food Security. *Global Food Security*, *4*, 56-68.

Thoma, G., Popp, J., Nutter, D., Shonnard, D., Ulrich, R., Matlock, M., ... & Adom, F. (2013). Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. *International Dairy Journal*, *31*, S3-S14.

Tuomisto, H. L., & Teixeira de Mattos, M. J. (2011). Environmental impacts of cultured meat production. *Environmental science & technology*, *45*(14), 6117-6123.

Appendix 1: Summary of dairy review

Author	**Year**	**Area**	**Scope**	**Functional unit**	**Land use**	**unit**	**Water use**	**unit**	**Energy use**	**unit**	**GWP**	**unit**
Hospido et al	2003	Spain	Cradle to dairy gate	kg milk	-	-	-	-	6.2	MJ	1.1	kg CO2 equiv
Arsenault et al	2009	Canada	Cradle to farm gate	kg FPCM	2.59	m2	-	-	-	-	0.97	kg CO2 equiv
Arsenault et al	2009	Canada	Cradle to farm gate	kg FPCM	2.83	m2	-	-	-	-	0.99	kg CO2 equiv
Baek et al	2014	Korea	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	1.13	kg CO2 equiv
Casey and Holden	2005	Ireland	Cradle to farm gate	kg FPCM			-	-	-	-	1.3 - 1.5	kg CO2 equiv
Cederberg and Flysjo	2004	Sweden	Cradle to farm gate	tn milk	1500 - 2900	m2	-	-	2.1 - 2.7	GJ	900 - 1040	kg CO2 equiv
Cederberg and Mattson	2000	Sweden	Cradle to farm gate	tn ECM	1900 - 3500	m2	-	-	2.5 - 3.6	GJ	950 - 1080	kg CO2 equiv
Christie et al	2011	Australia	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	1.04	kg CO2 equiv
Christie et al	2012	Australia	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	1.04	kg CO2 equiv
Dyer et al	2010	Canada	Cradle to farm gate	kg milk protein	-	-	-	-	-	-	28.9 - 32.6	kg CO2 equiv
Eshel et al	2014	USA	Cradle to farm gate	kg protein consumed	150	m2 /yr	2.45	m3	-	-	30	kg CO2 equiv
Gollnow et al	2014	Australia	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	0.90 - 1.39	kg CO2 equiv
Guerci et al	2013	Denmark	Cradle to farm gate	kg FPCM	1.07 - 1.87	m2	-	-	-	-	1.10 - 1.66	kg CO2 equiv
Guerci et al	2013	Germany	Cradle to farm gate	kg FPCM	1.07 - 1.63	m2	-	-	-	-	0.55 - 1.32	kg CO2 equiv
Guerci et al	2013	Italy	Cradle to farm gate	kg FPCM	0.68 - 1.63	m2	-	-	-	-	1.11 - 1.91	kg CO2 equiv
Haas et al	2001	Germany	Cradle to farm gate	tn milk	-	-	-	-	1.3 - 2.7	GJ	1000 - 1300	kg CO2 equiv
Hagemann et al	2011	Canada	Cradle to farm gate	kg FPCM	2.67	m2	-	-	-	-	1.2	kg CO2 equiv
Hortenhuber et al	2010	Austria	Cradle to farm gate	kg milk	1.17 - 2.44	m2	-	-	-	-	0.81 - 1.18	kg CO2 equiv
Jayasundara & Wagner-Riddle	2014	Canada	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	1.03	kg CO2 equiv
Lundie et al	2002	Australia	Cradle to farm gate	kg milk	-	-	-	-	-	-	1.045	kg CO2 equiv
McGeough et al	2012	Canada	Cradle to farm gate	kg FPCM	1.34	m2	-	-	-	-	0.67	kg CO2 equiv
Meul et al	2014	Belgium	Cradle to farm gate	tn FPCM	768 - 1050	m2	-	-	-	-	887 - 1154	kg CO2 equiv
Mollenhorst et al	2014	Netherlands	Cradle to farm gate	kg milk protein	26.1 - 31.6	m2 /yr	-	-	-	-	-	-
O'Brien et al	2012	Ireland	Cradle to farm gate	tn FPCM	727.9 - 933.3	m2 /yr	-	-	-	-	874.3 - 1027.4	kg CO2 equiv

O'Brien et al	2012	Ireland	Cradle to farm gate	tn milk solids	9759.3 - 12661.7	m2 /yr	-	-	-	-	11721.8 - 13938.9	kg CO2 equiv
O'Brien et al	2011	Europe	Cradle to farm gate	kg milk	-	-	-	-	-	-	0.81 - 1.02	kg CO2 equiv
O'Brien et al	2011	Europe	Cradle to farm gate	kg milk solids	-	-	-	-	-	-	10.76 - 13.41	kg CO2 equiv
O'Brien et al	2014	Ireland	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	0.92 - 1.80	kg CO2 equiv
Quantis et al	2012	Canada	Cradle to farm gate	kg FPCM	1.7	m2	-	-	-	-	1.01	kg CO2 equiv
Thoma et al (b)	2013	USA	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	1.23	kg CO2 equiv
Thomassen et al	2008	Netherlands	Cradle to farm gate	kg FPCM	1.3 - 1.8	m2	-	-	3.1 - 5.0	MJ	1.4 - 1.5	kg CO2 equiv
Verge et al	2013	Canada	Cradle to farm gate	kg FPCM	-	-	-	-	-	-	1.1	kg CO2 equiv
Verge et al	2007	Canada	Cradle to farm gate	kg FPCM	2.97	m2	-	-	-	-	1.06	kg CO2 equiv
Williams et al	2006	England and Wales	Cradle to farm gate	10,000 l milk	1.14 - 1.98	ha			15,600 - 25,200	MJ	9800 - 12300	kg CO2 equiv
Basset-Mens et al	2009	New Zealand	Cradle to farm gate	kg milk	1.2	m2			1.5	MJ	0.93	kg CO2 equiv
Thomassen et al	2009	Netherlands	Cradle to farm gate	kg FPCM	1.3	m2			5.3	MJ	1.4	kg CO2 equiv
Eide	2001	Norway	Cradle to grave	1000 l milk	-	-	-	-	-	-	515 - 605	kg CO2 equiv
Thoma et al	2013	USA	Cradle to grave	kg milk consumed	-	-	-	-	-	-	2.05	kg CO2 equiv
Ulrich et al	2013	USA	Farm to Processing plant transport	kg milk	-	-	-	-	-	-	0.05	kg CO2 equiv
Nutter et al	2013	USA	Processing	kg milk	-	-	-	-	-	-	0.077	kg CO2 equiv