On-farm Energy Use in the Dairy Industry

Guangnan Chen[1*], Tek Maraseni[2], Thomas Banhazi[1], Jochen Bundschuh[2]
[1] National Centre for Engineering in Agriculture, University of Southern Queensland, Toowoomba, 4350
[*]Email: chengn@usq.edu.au
[2] Institute for Agriculture and Environment, University of Southern Queensland, Toowoomba, 4350

ABSTRACT

Dairying is one of largest agricultural industries in Australia. This paper reviews the on-farm energy use in various dairy operations. It is found that the total direct on-farm energy needed to produce one kilogram of milk varies between 0.41-0.83 MJ/kg milk in Australia. This is in comparison with 0.19-2.47 MJ/kg milk overseas. The differences in energy uses are mainly due to different farming systems and technologies adopted and also different analysis methods employed. The large variation of energy uses indicates the significant opportunities for reducing energy use.

Keywords: Energy, Benchmark, Dairy, Farms

1. INTRODUCTION

Dairying is one of Australia's largest agricultural sectors, with around 1.6 million dairy cows on 7,500 dairy farms producing over 9 billion litres of milk per year [1, 2]. The Australian dairy industry has a farm gate value of AU$4 billion, while the factory gate value will be more than twice this number. Australia also exports some 50% of dairy production. About 40,000 people are directly employed on dairy farms and related manufacturing plants.

Energy is used both on-farm and off-farm in the dairy industry. It can be further divided into direct energy used, ie. the fuel and electricity consumed, and the indirect energy (embodied energy) involved in the manufacturing of all other inputs such as equipment and agro-chemicals [3]. Direct energy may be consumed in three major forms on most farms: 1) general electricity usage for lighting, appliances, irrigation; 2) fuel use for machinery, tractors and vehicles; and 3) heating/cooling.

Life Cycle Assessment (LCA) is an internationally recognised approach for evaluating the environmental impacts of products and services [3]. It analyses and quantifies the environmental impacts of the whole process of making, using and disposing a product. LCA is often used to compare the environmental damages assignable to products and services, and further to choose the least burdensome one. The quality of a LCA project is strongly dependent on the quality of inventory data, including the on-farm energy use data [4].

The aim of this paper is to review the energy use data for the dairy industry in Australia and around the world. This is the first step in reducing energy use and the associated greenhouse gas emissions.

2. DAIRY FARMING PROCESSES AND ENERGY SOURCES

Overall, most dairy farms in Australia adopt the pasture-based management system with approximately 70% of feed requirements coming from grazed pastures, although there is currently a trend of increases in farm intensification largely achieved through greater reliance on supplementary feeding and increase usage of nitrogen fertiliser [5]. In comparison, most of the milk produced in Europe is produced from farms using feedlot systems.

The farming processes of dairy farms may include the following broad types of activities:

- Field operations, including feed (grazing and forage) production, feed harvesting, feeding and manure management. Some energy consumption is also required for the transport of purchased feed and agro-chemical materials. In Australia, the grain/concentrate is generally purchased from outside the farm.
- Shed operations. The main uses of energy may include water heating, milk harvesting and milk cooling.

Dairy farms rely on a variety of energy sources, including both renewable and non-renewable resources. At present, fossil fuels, including electricity, petrol, diesel and to a lesser extent LPG (propane), and natural gas (for water heating) supply most of the energy required by the dairy industry. Fuels are needed for the operation of tractors and various machinery and also required for the transportation of fertilizer, grass seeds and other goods to the farm. Electricity is mainly used for two purposes including:

- Water pumping. This may be needed for cleaning, animals drinking and crop irrigation.
- Stationary operations. These may include electricity uses for various machines and appliances including heating, cooling and ventilation.

A recent survey by Dairy Australia [6] has found that 40% of dairy farms in Australia have installed some sorts of renewable energy technology, mostly in the form of heat pumps, solar water heating and/or photovoltaic panels for electricity generation.

3. ON-FARM ENERGY USE BENCHMARKS

There were a number of studies in Australia and overseas on the energy use in the dairy industry, including the reviews by Ahokas et al. [7] and Sims [8]. A range of different indicators have also been used. These included MJ/kg milk, MJ/litre milk, MJ/ha, MJ/cow, MJ per tonne of milk solid etc.

USA

From a survey of 14 dairies in Texas and California, Capareda et al. [9] found that total on-farm energy usage (electricity and fuels) ranged from 464 kWh (1.67 GJ) to 1,637 kWh (5.89 GJ) per year per cow for a pasture dairy in Northeast Texas. Assuming a daily milk production of 29.5 kg and a 300 days per year milk production, this leads to an on-farm direct energy index of 0.19~0.66 MJ/kg milk (Table1).

In another study [10], 32 energy audits were conducted on intensive dairy farms across central and northern New York. It was found that generally, dairy on-farm direct electricity use varied between 800 and 1200 kWh/cow-year, or between 2.88~4.32 GJ/cow-year. The average milk yield was high at 10,908 kg/cow-year. After taking account of the energy use due to propane and fuel oil, the average on-farm energy intensity was calculated as 0.69 MJ/kg milk.

Belgium

Annual average total energy input on large (over 100 cows) specialised dairy farms in 2000–2001 was found by Meul et al. [11] to be 36.3 GJ/ha, consisting 12.1 GJ/ha (33.4%) of direct on-farm and 24.2 GJ/ha (66.6%) of indirect energy inputs. The average direct on-farm energy use was 1.23 MJ/kg milk.

Germany

Energy consumption of three types of dairy farms in the Allgäu region, Germany, has been estimated by Haas et al. [12] ranging between 0.74 to 1.72 MJ/kg milk.

Sweden

Diesel use on 46 Swedish dairy farms was found to range between 62 and 191 litre per ha, with an average of 113 litre per ha [13, 14]. The electricity use at farm level was between 0.3-0.6 MJ per kg milk, where the largest inputs were the milking, cooling and lighting [14].

New Zealand

Wells [15] found that the direct on-farm energy intensity for NZ was 9.6 GJ per tonne of milk solid, which translates to around 0.71 MJ/kg milk.

United Kingdom

The total energy input was found to be 57.5 GJ/ha per tonne of milk solid, consisting of 17.2 GJ (30.0%) of direct on-farm energy inputs or 2.47 MJ/kg milk. UK dairy farmers used significantly more fuels but less electricity than their counterparts in NZ [16]. Furthermore, the use of concentrates and forage in the UK is significantly higher than that used in NZ, reflecting the different production systems.

Australia

In Australia, some on-farm energy use and production data is available from LCA studies. Christie et al. [5] analysed the energy uses of a sample of 41 dairy farms. It was found that the average amount of on-farm direct diesel consumed was 0.0044 litres per kg milk (0.17 MJ/kg milk) and the average amount of electricity was 0.067 kWh (0.24 MJ/kg milk). It was further found [17] that energy use represented approximately 9% of Victorian dairy farm businesses emissions profile, in comparison with methane (73%), and nitrous oxide (18%).

Direct on-farm energy input	Country	References
0.19~0.66 MJ/kg milk	USA	[9]
0.69 MJ/kg milk	USA	[10]
1.23 MJ/kg milk	Belgium	[11]
0.74~1.72 MJ/kg milk	Germany	[12]
0.71 MJ/kg milk	NZ	[15]
2.47 MJ/kg milk	UK	[16]
0.41 MJ/kg milk	Australia	[5]

Table 1: Direct on-farm energy input from different countries

Overall, it can be found from Table 1 that the total direct on-farm energy needed to produce one kilogram of milk varies between 0.19-2.47 MJ/kg milk. The lowest energy usage (0.19 MJ/kg milk) was achieved at a pasture dairy in Northeast Texas. For this particular farm, there was neither irrigation nor housing structures for the cattle. The dairy also only milked twice daily, decreasing its electricity usage. The highest energy usage (2.47 MJ/kg milk) took place in the UK, because of high use of fuels as well as concentrates and forage.

It is further noted that higher energy use in Table 1 does not always necessarily lead to a higher energy cost. This is because fossil fuels (diesel and petrol) and electricity have a different cost structure. Fossil fuels are generally cheaper than electricity. ADIC [18] shows that electricity accounts for 2.4% of total dairy farm operating costs, compared with 0.8% in other livestock and cropping enterprises. This is because dairy farming’s main energy source is electricity, while cropping, sheep and beef grazing mainly rely on transport fuels.

The differences in energy uses in Table 1 may be due to the following factors:

- Different farming systems and technologies adopted (in particular the electricity used for irrigation pumping and animal housing in northern hemisphere farms, the amount of supplementary feeding, and the milk yield per cow).
- Different analysis methods. For instance, some analyses include fodder feed production, while others may only include the direct energy consumed on-farm.

4. ENERGY USE BY INDIVIDUAL ON-FARM OPERATIONS

A number of studies have also investigated the on-farm energy uses of dairy farms [7, 15, 19]. An itemised account of energy inputs relating to key production processes was also reported in some of these studies.

4.1 Machinery and tractor operations

The fuel energy use of various farming field operations has been estimated and reported by Wells [15] (Table 2).

Activity	Average diesel fuel use (Litre/ha)
Subsoiling	18
Discing	12
Chisel ploughing	7
Power harrowing	8
Light harrowing/rolling	4
Conventional drilling	5
Direct drilling	10
Fertiliser spreading	3
Spraying (by aircraft)	3
Boom spraying (by tractor)	1.5-3
Inter-row cultivation	4-6
Forage mowing/conditioning	6
Forage raking	2

Table 2: Average diesel fuel for various agricultural field operations [15]

CAE [20] estimated that to fuel tractors and machinery, dairy farms may require around 7 L of diesel/cow/year, of which 2–3 L is for forage conservation, 1–2 L for cultivation, 1–2 L for feeding out hay and silage, and the rest for pasture renovation and miscellaneous farming operations. This number may be too low. When hay and silage operations are involved, McChesney et al. [21] suggested that a typical hay making system will consume around 23–26 L/ha of diesel fuel, whereas silage requires around 38 L/ha. The total fuel use for forage operation was reported as 135.5 L/ha [22].

Overall, Christie et al. [5, 23] showed that diesel consumption in Australia may be estimated using the formula: Diesel (L) = 25.5 * (t milk solid) + 5500. For an average Australian farm with 220 cows, each producing 5500 litres of milk with 7.5% milk solids, this would translate to 7814 litres diesel use or 52 L/ha or 0.25 MJ/kg milk. In Victoria, the Victoria DEPI (Department of Environment and Primary Industries [24] reported that the average fuel and oil cost was $0.10/kg milk solid, which is $0.10/13.5 kg milk or about 0.185 MJ/kg milk, if the average fuel cost is assumed as $40/GJ .

4.2 Water pumping operations

The dairy industry is the second largest user of irrigation water in Australia [25]. It uses approximately 25% of the surface irrigation water in Australia. It is also a major user of groundwater in all areas especially in South Australia. Surface flood irrigation is most common in northern Victoria, while other parts of southern Australia and Tasmania tend to use the pressured systems which are more energy intensive. Irrigation in the Queensland dairy industry is also undertaken almost wholly using pressured sprinkler systems [26].

For irrigation water pumping, previous research indicates that energy use may be around 4-8 kWh/ML/meter head for electricity and 1.5L/ML/meter head for diesel pumps. It is typically assumed that surface irrigation operates at 10m head (pumping) while this is 30 m head (pumping) for low pressure sprinkler irrigation. Chen et al. [27] assumed the figure of 400 kWh/ML for a hypothetical dairy farm in Queensland. Brown and Macdonald [28] found it varying between 200 and 500 kWh/ML in Tasmania.

4.3 Stationary motor uses

The use of electricity by various dairying equipment has been estimated by Upton et al. [19] (Table 3) and Ahokas, et al. [7]. This is shown by Upton et al. [19] as reaching a total of 42 Wh or 152 kJ/kg milk. Chen et al. [27] assumed this as 35 Wh/kg milk. It was also reported that the combined energy use of milk harvesting and cooling operation in Central Texas was 427 kWh/cow/year or 171 kJ/ litre milk [9]. Milk cooling may be the largest energy user in shed operations (Table 3).

Task/Activity	Electricity use (Wh/L)	kJ/kg milk	Percentage
Milk cooling	13.02	47	31%
Water heating	9.83	35	23%
Milking	8.44	30	20%
Lighting	1.37	5	3%
Other	7.54	27	18%
Water pumping	2.13	8	5%
Total	**42.13**	**152**	**100%**

Table 3: Estimated electricity use in a dairy shed in Ireland [19]

5. ENERGY USE OF A HYPOTHETICAL FARM

To further illustrate the energy use in the Australian dairy farms, a simplified hypothetical model of an "average" farm is set up below. This is essentially a pasture-based management system with most of feed requirements coming from grazed pastures. This farm may be used to represent a majority of dairy farms in Australia. Table 4 summarizes the key on-farm direct energy used and outputs produced at this farm on an annual basis. The stocking density is assumed to be 1.5 cows per ha. The milk yield is 5500 L per cow per year. The irrigation water use is 3.5 ML/ha. The irrigation pumping electricity use is 250 kWh/ML. Electricity use due to milking machines and temporary cool storage in the dairy shed is 250 kWh per cow per year or 45 Wh/L milk. The diesel fuel use for pasture and tractor operation is assumed as 7814 litres (52 L/ha). The fertilizer, grass seeds and other goods are also assumed to be transported by trucks from a distance, equivalent to a fuel use of 5 L/ha.

Land use area	150 ha
Total cow numbers	220
Milk production	1210000 litre
Electricity use in the dairy shed	55000 kWh (198000 MJ)
Irrigation water use	525 ML
Electricity use for irrigation pumping	131250 kWh (472500 MJ)
Total electricity use at the site	186250 kWh (670500 MJ)
Diesel fuel use for tractor field operations	7814 litre (301625 MJ)
Truck transport fuel use	750 litre (28950 MJ)
Total direct on-farm energy use for the farm	1001075 MJ
Total direct on-farm energy use per litre of milk	0.83 MJ/kg milk

Table 4: Resources used and outputs produced per year at the hypothetical farm

From the above table, it can be calculated that for this hypothetical farm, the electricity use (670 GJ) makes up 67% of the total direct on-farm energy consumed, including 47% for irrigation water pumping and 20% for shed operations (Fig.1). The diesel fuel use for tractor field operations contributes the other 30%, while the energy for truck transportation is very small at 3%. The direct on-farm energy index is found to be 0.83 MJ/kg milk, which is similar to the range of data reported in Table 1 and also other industry data in Australia [28]. This will translate to around 5~6 cents per kg milk or $275~330 per cow per year.

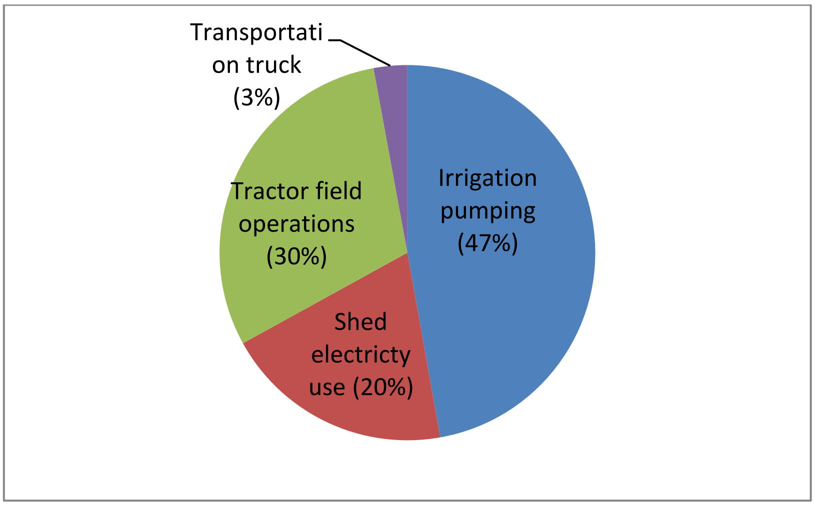

Figure 1: The distribution of on-farm energy uses at the hypothetical farm

6. CONCLUSION

Dairying is one of Australia's largest agricultural sectors, with around 1.6 million dairy cows on 7,500 dairy farms producing over 9 billion litres of milk per year. The majority of dairy farms in Australia use pasture-based management systems with some level of supplementary feeding.

It has been found that the total direct on-farm energy needed to produce one kilogram of milk varies between 0.41-0.83 MJ/kg milk in Australia. This is in comparison with 0.19-2.47 MJ/kg milk overseas. Irrigation may be the biggest energy user in the field in Australia while milk cooling may be the largest energy user in shed operations.

It has been identified that there is currently an insufficient data and study on the comparison of energy use between different dairy farming systems. The success of a LCA project is dependent on good quality data.

A significant amount of energy could be saved by upgrading facilities with newer and more energy efficient equipment, both in the dairy shed and also for irrigation and pumping. Identification and adoption of alternative and renewable energy sources will also have the potential to reduce energy costs and help to protect the environment.

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