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Energy demand on dairy farms in Ireland

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ABSTRACT

Reducing electricity consumption in Irish milk production is a topical issue for 2 reasons. First, the introduction of a dynamic electricity pricing system, with peak and off-peak prices, will be a reality for 80% of electricity consumers by 2020. The proposed pricing schedule intends to discourage energy consumption during peak periods (i.e., when electricity demand on the national grid is high) and to incentivize energy consumption during off-peak periods. If farmers, for example, carry out their evening milking during the peak period, energy costs may increase, which would affect farm profitability. Second, electricity consumption is identified in contributing to about 25% of energy use along the life cycle of pasture-based milk. The objectives of this study, therefore, were to document electricity use per kilogram of milk sold and to identify strategies that reduce its overall use while maximizing its use in off-peak periods (currently from 0000 to 0900 h). We assessed, therefore, average daily and seasonal trends in electricity consumption on 22 Irish dairy farms, through detailed auditing of electricity-consuming processes. To determine the potential of identified strategies to save energy, we also assessed total energy use of Irish milk, which is the sum of the direct (i.e., energy use on farm) and indirect energy use (i.e., energy needed to produce farm inputs). On average, a total of 31.73 MJ was required to produce 1 kg of milk solids, of which 20% was direct and 80% was indirect energy use. Electricity accounted for 60% of the direct energy use, and mainly resulted from milk cooling (31%), water heating (23%), and milking (20%). Analysis of trends in electricity consumption revealed that 62% of daily electricity was used at peak periods. Electricity use on Irish dairy farms, therefore, is substantial and centered around milk harvesting. To improve the competitiveness of milk production in a dynamic electricity pricing environment, therefore, management changes and technologies are required that decouple energy use during milking processes from peak periods.
Key words: energy use, milk production, smart metering

INTRODUCTION

The removal of the milk quota system in the European Union in 2015 is likely to increase milk production per farm and to decrease milk price (Lips and Rieder, 2005; Bouamra-Mechemache et al., 2008). In Ireland, for example, milk production has the potential to increase by 50% by 2020 (DAFM, 2010) if farmers respond to national policy frameworks and are encouraged by the abolition of European Union milk quotas in 2015, whereas milk price is expected to decrease by 33% (Lips and Rieder, 2005). Milk production systems in Ireland, therefore, will continue to focus on cost control and maximizing the amount of milk that is produced from grazed grass. The potential of Irish soils to grow grass throughout the year and success in utilizing grass are key factors affecting output and profitability of dairy production systems (Shalloo et al., 2004).

Efficient use of energy is one way to improve the cost competitiveness of the Irish dairy sector. At this moment, electricity costs on Irish farms are around 1.5% of the cost price of milk sold (Upton et al., 2011), but they are expected to increase because of introduction of dynamic electricity pricing. Besides a potential cost reduction, reducing electricity consumption has an environmental benefit, because electricity consumption has been shown to represent 25% of total energy use on pasture-based dairy farms in New Zealand (Wells, 2001). Hence, understanding electricity consumption trends will have the potential to reduce overall energy use and reduce production costs.

The new Irish electricity grid infrastructure is proposed by the Commission for Energy Regulation (CER) and implies a pricing system based on the electricity demand on the national grid, resulting in higher electricity rates during peak periods of consumption and lower rates during off-peak periods. The peak period is typically from 1700 to 1900 h. If dairy farmers carry

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out their evening milking during these peak periods they will be exposed to increases in energy costs. This dynamic pricing structure could, however, also present opportunities to reduce overall energy costs if equipment is managed intelligently to optimize energy use in off-peak periods (currently from 0000 to 0900 h). By 2020, about 80% of all electricity consumers are expected to be connected to the smart grid (CER, 2011). The electricity demand on the national grid not only varies during the day (i.e., peak in the evening), but also across seasons (i.e., peak in the winter; EirGrid, 2012). To use energy cost-effectively, therefore, dairy farmers need insight into the variation in electricity consumption during the day and across the year. To our knowledge, no research has been published that studied on-farm daily and seasonal electricity consumption profiles while providing detailed equipment electricity consumption information. This information, however, is required to identify strategies that reduce energy costs and that use electricity efficiently (i.e., aimed at a reduction in electricity use per kilogram of milk sold while maximizing its use in off-peak periods).

The main objective of this study, therefore, was to document electricity use per kilogram of milk sold from the farm and to identify strategies that can reduce its overall use while maximizing its use in off-peak periods. We assessed average daily and seasonal trends in electricity consumption on 22 Irish dairy farms, through detailed auditing of electricity-consuming processes. To determine the potential of identified strategies to save energy, our second objective was to assess total energy use along the production chain of Irish milk. We therefore performed a life cycle energy assessment of total energy use on 22 Irish dairy farms.

MATERIALS AND METHODS

Data Collection

We selected 22 commercial dairy farms from a database of advisory clients within Teagasc (Ireland), which are referred to as study farms. Selection criteria included availability of financial information, data on herd size, and the ability and willingness of the farmer to collect and maintain accurate data. All data were collected for 2011. All inputs and outputs necessary to compile the life cycle energy assessment were recorded using a combination of manual recording and wireless data transfer. General farm data were collected using a survey, including farm area worked and detailed information on farm infrastructure (e.g., type and size of milking equipment, milk-cooling equipment, manure-handling equipment, machinery, and winter housing facilities).

Monthly questionnaires were completed by each farmer. Data collected were quantity and type of fertilizer used, quantity of diesel or fuel oil consumed, area of land worked by contractors, amount and type of concentrate feed purchased, forage/manure/slurry imported or exported from the farm, quantity and type of farm chemicals used, and a stock take of all animals on the farm. To assess actual consumption of, for example, fertilizer or feed, opening and closing balances were obtained at the beginning and end of the monitoring period. In addition to these data, milk production and composition information was gathered from the milk processors.

Electricity consumption was recorded using a wireless monitoring system supplied by Carlo Gavazzi (Carlo Gavazzi Automation SpA, Lainate, Italy). Energy analyzers of type EM24 DIN together with Digi Connect wireless WAN cellular routers were used to measure and transport the electricity consumption data. Powersoft logging and recording software (Carlo Gavazzi Automation SpA) was used to record cumulative energy use (kWh) every 15 min for each electricity-consuming process behind the farm gate. Domestic electricity use was measured separately and subtracted for the dairy farm measurements.

Data Processing

Raw data from electricity monitoring were exported to spreadsheets and subsequently used to compute trends in electricity consumption of individual farms. To determine electricity costs of individual farms, we combined data on electricity use with day and night tariffs (day tariff was 0.18 €/kWh; night tariff was 0.08 €/kWh from 0000 to 0900 h). Furthermore, data obtained from questionnaires, dairy processors, and the wireless electricity monitoring system were used to perform a life cycle energy assessment.

Life Cycle Energy Assessment

We performed a single-issue life cycle assessment (**LCA**) by quantifying the total energy use according to the International Organization for Standardization (ISO, 2006). The 4 stages of an LCA are goal and scope, inventory analysis, impact assessment, and interpretation of results (ISO, 2006).

Goal and Scope Definition. The LCA related, in this case, energy use to a functional unit, which is the main function of a production system expressed in quantitative terms. The main function of our system was production of milk. To allow a comparison of our results with those presented in the literature (Wells, 2001; Cederberg and Flysjö, 2004; Hartman and Sims, 2006; Williams et al., 2006; Basset-Mens et al., 2009; Thomassen et al., 2009; O'Brien et al., 2012), we used multiple functional units: kilograms of ECM (Sjaunja et al., 1990; Yan et al., 2011), kilograms of fat- and protein-corrected milk (**FPCM**; CVB, 2000), kilograms of milk solids (**MS**), liters of milk, and kilograms of milk.

The system boundary was defined from cradle to farm gate, which implies that energy use was quantified for all processes involved up to the moment that milk left the farm gate, including production and transport of concentrates, roughage, seeds, herbicides, and chemical fertilizer. Such a cradle-to-farm gate LCA, therefore, resembles quantification of the direct (i.e., energy use on-farm) and indirect energy use (i.e., energy needed to produce farm inputs) of milk (De Boer, 2003).

Besides milk, our production system also yielded meat from culled cows and calves. In such a multiple-output situation, the energy use of the system had to be allocated to these various outputs. We used economic allocation, implying that the energy use was allocated to the various outputs based on their relative economic value (i.e., 88.3% to milk and 11.7% to culled cows and calves).

Life Cycle Inventory. In the second stage, the inventory analysis, energy used in each production process was collected. For each product consumed by a dairy farm, an energy conversion factor was determined, including the amount of energy related to the production and transport of each unit of this product. The energy conversion factors for chemical fertilizers, herbicides, and ingredients of purchased concentrates were based on the international LCA Ecoinvent 2.0 database (Ecoinvent, 2010). All applicable data quantities were converted to a common unit for international comparisons. For energy, this unit is the megajoule or gigajoule.

For the composition of concentrate feed used on each farm, a standard 16% CP feed was chosen. Feed formulation was obtained from several feed suppliers (Supplementary Table S1, available online at http://dx.doi.org/10.3168/jds.2013-6874). Yan et al. (2013) used the same methodology for feed composition analysis. The energy content per tonne of DM (MJ/t of DM) of the standard concentrate was calculated using Ecoinvent 2.0 (Ecoinvent, 2010) and feed conversion tables from NRC (2001). Conversion factors for liquid fuels and factors about efficiency of electricity generation were taken from Howley et al. (2009), which provided local data for the distribution efficiency of the Irish electricity supply network. Hours worked in the field for each contractor operation, including plowing, manure spreading, and fertilizer spreading, was recorded and a corresponding fuel usage was applied according to Witney (1996). Fuel used in transport of feed, fertilizer and forage to the farm were included by incorporating the distance traveled from suppliers to the farm. With knowledge of the weight of material transported, conversion factors from Bone et al. (1996) were applied to determine liters of fuel consumed in transportation. Lubricants including gear oil and transmission oil were also included. Production of medicines and machinery were excluded due to their small overall impact (Cederberg, 1998).

Other energy inputs in this study consisted of seeds used for reseeding grassland, which contained a mixture of grass seed and clover seed. Purchased forage consisting of silage, hay, straw, and whole crop wheat was also included. Herbicides and minerals (mainly precalver minerals) were included. Forages were converted to tonnes of DM using tables from NRC (2001). All quantities were converted to megajoules using the Ecoinvent 2.0 database (Ecoinvent, 2010).

Impact Assessment and Interpretation of Results. The impact assessment stage was where we processed the data collected in the life cycle inventory phase. Raw data were processed to compute total energy use from cradle to farm gate of milk production on a sample of Irish dairy farms using the common unit of energy, the megajoule.

RESULTS

General Farm Characteristics

Figure 1 shows the average lactation profile for the study farms relative to the average Irish dairy farm lactation profile. The study farms represent 0.14% of the specialized dairy farm population and supplied 0.24% of the national milk in 2011. Table 1 shows the details of the study farms in terms of scale and production. The study farms operated grass-based milk production systems with spring calving herds. The seasonality of this production system in terms of milk output is visible in Figure 1. The average fat content of the milk supplied was 4.23% (SD of 0.16%), whereas the average protein content was 3.60% (SD of 0.11%). In 2011, the national average fat content was 3.97% (SD of 0.23%) and protein content 3.39% (SD 0.15%; (CSO, 2012).

Energy Analysis

Table 2 presents the total energy used, expressed per functional unit (diverse units), and the contribution of different processes along the life cycle per kilogram of MS. Total energy use averaged 31.73 MJ/kg of MS, ranging from 15.28 to 49.00 MJ/ kg of MS. About 57% of this energy use was accounted for by the application of chemical fertilizers (range of 40–80%). Other signifi-

Table 1. Average production parameters for study farms compared with national average figures (Lalor et al., 2010; Hennessy et al., 2011; CSO, 2012)

Parameter	Minimum	Mean	Maximum	National average
Farm area (ha)	43	76	142	57
Number of cows (herd size)	47	118	290	66
Stocking density (LU/ha)[1]	1.68	2.27	3.45	1.77
Milk production (× 1,000 L/yr)	255	559	1,329	316
Milk production (t of MS/yr)[2]	21	44	109	24
Nitrogen application rate (kg of N/ha per year)[3]	86	194	278	86
kg of concentrate fed/100 kg of milk produced	0.49	1.19	2.06	NA[4]

[1]LU = livestock units.

[2]MS = milk solids.

[3]N = fertilizer N.

[4]NA = not available.

cant energy consuming processes included production and transport of purchased concentrate feed at 21% (range of 8–36%), electricity at 12% (range of 8–21%), and liquid fuels such as diesel, petrol, and kerosene at 8% (range of 1–15%). Other items such as seeds and herbicides represented a small portion of total energy use 2% (range of 0–15%).

Fertilizer Application. Large differences existed in the chemical fertilizer application rates in this study (Table 1). The mean energy input by chemical fertilizer was 17.96 MJ/kg of MS (range of 10.54–30.71 MJ/kg of MS).

Concentrate Feed. The average farm fed 1.19 kg of concentrate per 100 kg of milk produced, (range of 0.49–2.06 kg of concentrate/100 kg of milk).

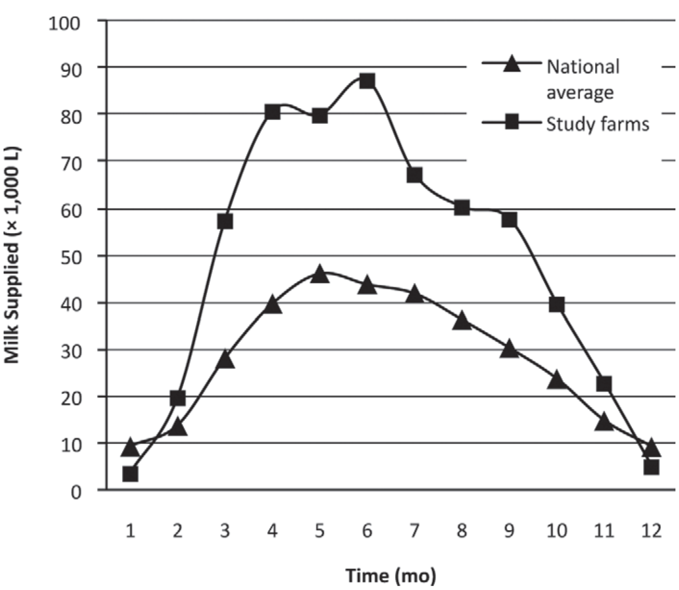

Figure 1. Mean milk production profile of the 22 study farms relative to the national average lactation profile for specialized dairy farms (CSO, 2012).

Fuel, Lubricants, and Other Energy Inputs. Fuel used on the farm accounted for 66% of the total fuel energy input and amounted to 1.68 MJ/kg of MS. These inputs were specifically diesel (97.5% of on-farm fuel use), gear oil and transmission oil (1.3%), and kerosene (1.2%). Fuel used by contractors accounted for 31.7% of fuel use and transport of feed, fertilizers, and forage to the farm accounted for just 2.3% of fuel use. Other energy inputs amounted to 0.77 MJ/kg of MS (range of 0–5.08 MJ/kg of MS).

Electrical Energy Inputs. The major processes of electricity consumption were milk cooling (31%), water heating (23%), milking (20%), pumping water (5%), and lighting (3%), and other miscellaneous consumption such as winter housing systems, air compressors, and backing gates consumed 18% of the electrical energy. All farms were nonirrigated. Electricity used in the dairy milking shed accounted for almost 80% of the total electrical energy used. Table 3 presents a more detailed analysis of the electricity consumption results.

Altogether 42.34 Wh of electricity was used per liter of milk produced (range of 23.03–76.29 Wh/L). In total, 62% of all electrical energy used by the farms in this study was on the higher-cost day tariff. Costs are presented in Table 3. The average cost of electricity on the study farms in 2011 was €0.0051/L of milk produced (range of €0.0026–0.0087/L).

Milking Machine. All farms engaged herringbone milking plants, with 2 stalls per milking unit and were fitted with oil-lubricated centrifugal vane vacuum pumps without variable speed control. Milking parlor size varied from 8 to 24 milking units; the average number of cows per milking unit was 9. The milking machine consumed 20% of the total electrical energy. This consists of the vacuum pumps and the milk pump. Electrical energy consumption of the milking machine was 8.44 Wh/L of milk harvested, with a range from 4.38 to 13.78 Wh/L.

Table 2. Total energy consumption [mean with SD in parentheses, minimum (Min), and maximum (Max)] per energy input category, expressed in various units, for 22 study farms in 2011

Energy input category	Energy consumption						
	GJ/farm	MJ/kg of MS[1]	MJ/L	MJ/kg of milk	MJ/kg of ECM	MJ/kg of FPCM[2]	% of total
Fertilizer							
Mean (SD)	789.92 (315.24)	17.96 (6.25)	1.41 (0.50)	1.37 (0.48)	1.34 (0.47)	1.34 (0.47)	57 (11)
Min	226.78	10.54	0.87	0.85	0.81	0.81	40
Max	1,428.95	30.71	2.44	2.37	2.30	2.3	80
Concentrates							
Mean (SD)	288.14 (96.50)	6.55 (2.57)	0.52 (0.19)	0.50 (0.19)	0.49 (0.19)	0.49 (0.19)	21 (7)
Min	138.18	2.17	0.18	0.17	0.16	0.16	8
Max	504.31	11.87	0.95	0.92	0.89	0.89	36
Electricity							
Mean (SD)	172.19 (73.83)	3.91 (1.06)	0.31 (0.08)	0.30 (0.08)	0.29 (0.08)	0.29 (0.08)	12 (3)
Min	67.68	2.25	0.18	0.18	0.17	0.17	8
Max	395.58	6.75	0.53	0.53	0.50	0.50	21
Fuel							
Mean (SD)	111.62 (65.29)	2.54 (1.32)	0.20 (0.10)	0.19 (0.10)	0.19 (0.10)	0.19 (0.10)	8 (3)
Min	3.55	0.04	0.00	0.00	0.00	0.00	1
Max	291.40	6.18	0.48	0.46	0.46	0.46	15
Other							
Mean (SD)	33.83 (62.27)	0.77 (1.11)	0.06 (0.09)	0.06 (0.08)	0.06 (0.08)	0.06 (0.08)	2 (3)
Min	0.00	0.00	0.00	0.00	0.00	0.00	0
Max	297.57	5.08	0.39	0.39	0.39	0.39	15
Total							
Mean (SD)	1,395.71 (414.38)	31.73 (7.72)	2.50 (0.61)	2.42 (0.59)	2.37 (0.58)	2.36 (0.58)	100
Min	484.14	15.28	1.25	1.21	1.15	1.15	—
Max	1,973.47	49.00	3.90	3.79	3.67	3.67	—

[1]MS = milk solids.

[2]FPCM = fat- and protein-corrected milk.

Milk Cooling. On all but one farm milk was cooled in the first instance by a precooling system, consisting of a plate heat exchanger, followed by final chilling in a direct expansion (**DX**) milk cooling tank. Four farms used an ice builder (**IB**) milk cooling system. We observed that the IB systems delivered an energy efficiency of 19.22 Wh/L (range of 16.00–21.77 Wh/L), whereas the DX systems achieved 11.19 Wh/L (range of 6.38–15.89 Wh/L). The IB systems ran on day tariff for 30% of their operating times, whereas the DX systems used 70% day tariff electricity.

Water Heating. Of the 22 farms in this study, 20 farms used electrical-powered water heating systems; all were the pressurized cylinder type. The remaining farms used oil-fired boilers to heat their water for milking plant washing. Diesel and kerosene used for this purpose were included in the fuel energy analysis section. Over 45% of water heating was carried out on the day tariff even though all farms had night tariff available for this purpose. Water heating consumed 9.83 Wh/L of milk sent to the dairy processor (range of 3.30–14.30 Wh/L).

Other Electrical Inputs. Other miscellaneous equipment consumption across all farms was 7.54 Wh/L, with a range of 2.02 to 19.23 Wh/L. Figure 2 shows that "other" electrical energy consumption increased from November to February, corresponding to periods where farm animals were housed indoors, resulting in electrical consumption by motorized manure scrapers and lights.

Table 3. Breakdown of electricity consumption per liter of milk produced, including cost of electrical energy consumed and tariff distribution profile by percentage of day rate tariff usage

Item	Electricity consumed (Wh/L)	Cost of electricity (€/L)	% of day rate tariff usage[1]
Milk cooling	13.02	0.0016	60
Water heating	9.83	0.0011	45
Milking	8.44	0.0011	71
Lighting	1.37	0.0002	89
Other	7.54	0.0010	69
Water pumping	2.13	0.0003	38
Total	42.34	0.0051	62

[1]Percentage of electricity consumed from 0900 to 2400 h.

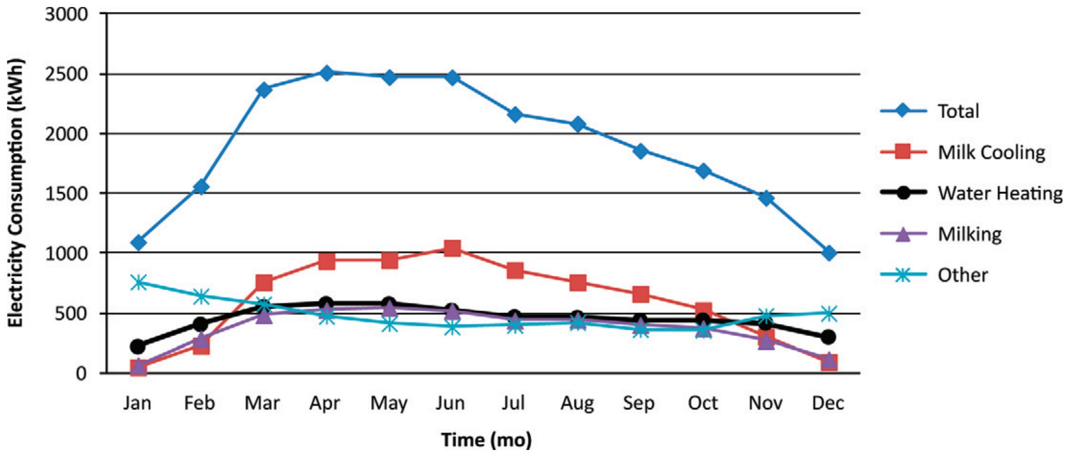

Figure 2. Monthly electrical energy consumption (kWh) for 22 farms over 12 mo for all major energy-consuming processes. Color version available in the online PDF.

Electricity Consumption Trend Analysis

Daily Electricity Consumption Trends. The profile of electrical energy consumption trends from day to day followed a sinusoidal pattern (Figure 3); large peaks in consumption were a result of the morning and evening milkings. Figure 3 shows the average electrical demand of the study farms for June 14 and 15, 2011. These days were chosen as representative days during peak milk production to illustrate the nature of the electricity consumption profile. Consumption peaks were present from 0700 to 1200 h and again from 1630 to 1930 h; these peaks can be attributed to the twice per day milking routine used by the study farmers.

Seasonal Electricity Consumption Trends. The seasonal effect of electricity consumption followed the milk production curve due to the fact that over 80% of consumption was by equipment associated with milk harvesting. Consequently, 20% of electrical energy consumption was independent of the amount of milk produced. Figure 2 shows the seasonality of kilowatt-hour consumption by month. It is evident that electricity consumption by milk cooling equipment, water heating plant, and the milking machine pumps were linked to milk production, as they followed the milk production curve (Figure 1). Consumption of other items was decoupled from milk production and increased from November to February.

DISCUSSION

General Farm Characteristics

It is evident that the study farms had a much higher milk output than the national average farm and, therefore, were not representative of Irish dairy farms in 2011. The study farms represented the larger-than-average modern dairy farm, with a higher stocking density per ha (i.e., more intensive). Milk output and hence herd size will increase in the future if farmers respond to the potential for expansion in milk production identified in the Food Harvest 2020 report (DAFM, 2010). Results of this study and hence the conclusions drawn are, therefore, relevant for larger and more intensive dairy farms.

Comparisons with Other Studies

Table 4 presents total energy use per unit of milk production from selected international studies. These countries represent a variety of milk-production systems and climatic conditions; hence, the large differences across studies. Comparisons were made to assess

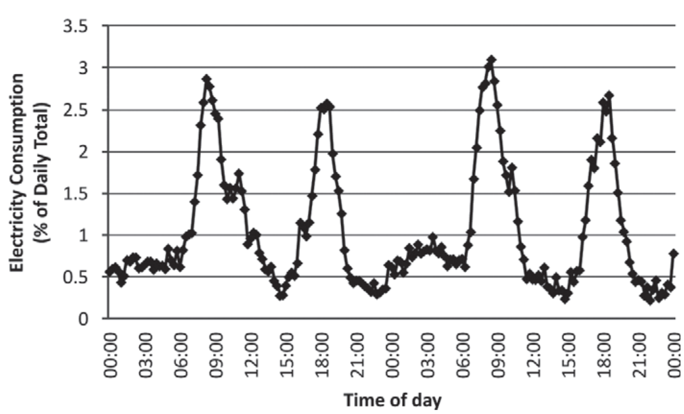

Figure 3. Average percentage of daily electricity consumption for 22 commercial farms in Ireland from June 14 to 15, 2011; data points are at 15-min intervals.

how results of this study fit within the range in the literature.

Based on data of 150 dairy farms in New Zealand, Wells (2001) computed an average total energy use of 24.60 MJ/kg of MS, of which 38% was related to fertilizers, 21% to liquid fuels, 20% to electricity, and 21% to other items. Basset-Mens et al. (2009) computed a total energy use for a national average New Zealand farm of 1.51 MJ/kg of milk. The current Irish study assessed an average total energy use of 31.73 MJ/kg of MS or 2.42 MJ/kg of milk. The higher average values in the current study are explained mainly by a higher input of chemical N fertilizer per hectare of, on average, 198 kg of N/ha per year. Farms studied by Wells (2001) applied 85 kg of N/ha per year, whereas Basset-Mens et al. (2009) assumed a value of 114 kg of N/ha per year.

Based on data of 8 dairy farms, Cederberg and Flysjö (2004) reported 2.7 MJ/kg of ECM, of which 50 to 60% was required for cultivation and transportation of purchased feed. Based on data of 119 farms, Thomassen et al. (2009) reported 5.3 MJ/kg of FPCM, of which 56% was required for cultivation and transport of purchased feed.

The current study reported only 2.37 MJ/kg of ECM or 2.36 MJ/kg of FPCM, which is in line with results of O'Brien et al. (2012), who found that energy use per kilogram of FPCM was lower in grass-based (2.3 MJ/kg of FPCM) than in confinement systems (3.9 MJ/kg of FPCM).

Electricity-Consumption Analysis

Electricity use was a significant consumer of energy and accounted for 12% of total energy use and 60% of the direct energy use. This study quantified the breakdown of electricity usage by component, within day and between seasons, as well as compared the usage of electricity on night and day tariffs on a subset of commercial dairy farms. In effect, 80% of the electricity use was related to heating water, cooling milk, and running the milking machine. These fundamental operations are common across all milk production systems, not just grass-based systems. Hence, efficiency figures and recommendations described in relation to these operations should be applicable to other global milk producers. This information will contribute to the energy efficiency and cost-reduction agenda at the farm level.

Daily Electricity-Consumption Trends. Figure 4 shows the demand on the national grid for the same 2 d that are presented in Figure 3 (EirGrid, 2012). The cyclical nature of the load on the national grid is visible.

The peak in electricity consumption on the study farms occurred during the time intervals when demand on the grid was highest. In a dynamic electricity-pricing

Table 4. Compared energy consumption (MJ) assessment of milk production of selected studies, gathered by functional unit

Study	Study case	Country[1]	FU[2]	Subset	Total energy	Direct energy	Indirect energy
Wells (2001)	150 commercial farms	NZ	kg of MS	Average	24.60	10.80	13.80
Wells (2001)	150 commercial farms	NZ	kg of MS	Irrigated	33.60	17.80	15.80
Wells (2001)	150 commercial farms	NZ	kg of MS	Nonirrigated	21.60	8.90	12.70
Hartman and Sims (2006)	62 dairy farms	NZ	kg of MS	Total	47.00	24.40	22.60
This study	22 dairy farms	IRE	kg of MS	Total	31.73	6.45	25.28
Basset-Mens et al. (2009)	Average dairy farm	NZ	kg of milk	Total	1.51	NA[3]	NA
This study	22 dairy farms	IRE	kg of milk	Total	2.42	0.49	1.93
Thomassen et al. (2009)	119 dairy farms	NL	kg of FPCM	Total	5.30	0.80	4.50
O'Brien et al. (2012)	1 research farm	IRE	kg of FPCM	Total	2.30	NA	NA
This study	22 dairy farms	IRE	kg of FPCM	Total	2.36	0.48	1.88
Cederberg and Flysjö (2004)	8 farms production <7,500 kg of ECM/ha	S	kg of ECM	Total	2.70	NA	NA
This study	22 dairy farms	IRE	kg of ECM	Total	2.37	0.48	1.89
Williams et al. (2006)	Nonorganic	UK	L of milk	Total	2.52	NA	NA
This study	22 dairy farms	IRE	L of milk	Total	2.50	0.51	1.99

[1]NZ = New Zealand; IRE = Ireland; NL = the Netherlands; S = Sweden; UK = United Kingdom.
[2]FU = functional unit; MS = milk solids; FPCM = fat- and protein-corrected milk.
[3]NA = not available.

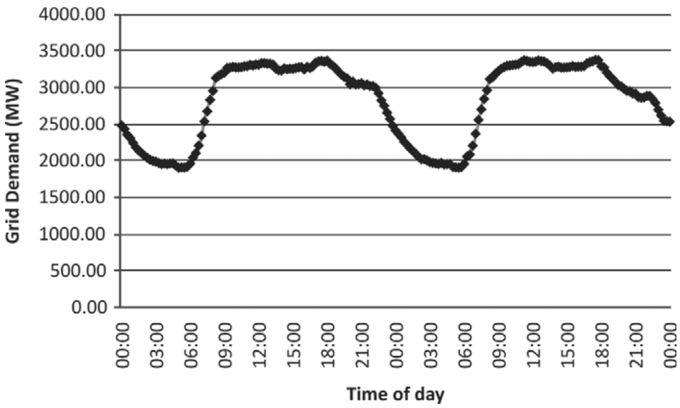

Figure 4. Demand on the Irish electricity grid in megawatts from June 14 to 15, 2011; data points are at 15-min intervals.

environment, these times would correspond to periods of higher electricity costs. Peak demand on the grid occurred between 1700 and 1800 h. This peak demand was 78% higher than the lowest demand interval, which occurred between 0500 and 0600 h. Consequently, the lowest-cost electricity would be available at this time.

Seasonal Electricity-Consumption Trends. The demand on the national grid also experiences a seasonal effect. Figure 5 shows the demand on the national grid in megawatts from January 2010 to December 2011, inclusive (EirGrid, 2012). Peak demand occurred in December 2010, with the weakest demand in July 2011. The peak was 30% higher than the trough. In a truly dynamic electricity-pricing scenario, this seasonal effect would result in a higher electricity price in winter months compared with summer months. The Irish milk-production system produces milk from grazed grass, which requires a spring calving pattern, resulting in higher energy use during the summer months (Figure 2). This may present an opportunity to farmers with spring-calving herds to optimize calving patterns to reduce electricity consumption during winter months when electricity prices are likely to be higher.

Options for Reducing Electricity Consumption and Electricity Costs

Electricity-consumption analysis of both daily and yearly consumption patterns show that dairy farmers could be exposed to higher electricity prices if a pricing structure is implemented that varies tariffs according to the load on the national grid. The results of this study pertaining to electricity consumption trends and their relationship to the demand profile on the national grid may be of relevance to dairy industries internationally. Estonia, Finland, France, Ireland, Italy, Malta, the Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom are all classified as dynamic movers in relation to the implementation of smart grid infrastructure. These countries have a clear path toward a full rollout of smart metering. Either the mandatory rollout is already decided, or major pilot projects are paving the way for a subsequent decision (Hierzinger et al., 2012). Other countries such as Australia and New Zealand have recognized smart metering as a method of improving resource use efficiency and have carried out some early-stage feasibility studies and cost-benefit analysis calculations (DRET, 2008; Energy Federation of New Zealand, 2010). Many of these countries have well-established milk-production industries that may be able to use smart grid infrastructure to their advantage by taking note of some of the findings of this study.

Further research is required to quantify the financial impact of possible smart grid rollout on commercial farms based on differing smart metering approaches; however, a 3-pronged approach to maximize the efficiency of energy usage in the context of smart metering will be required. First, decoupling large energy users such as milk cooling and water heating from milking times and shifting them to off-peak periods will be required. Milk cooling has the largest electrical energy consumption (31% of total electricity consumption) on Irish dairy farms. Over 60% of milk cooling electricity consumption currently occurs on the more expensive day rate tariff. Using a milk-cooling system that decouples the cooling load from these peak tariffs would be useful in mitigating the impact of a smart-metering electricity-pricing scenario, because cold energy could be generated when electricity is cheap. The IB system in the current study used more electricity per liter of milk cooled than the alternative DX systems; however, IB systems can be an effective tool to decouple the

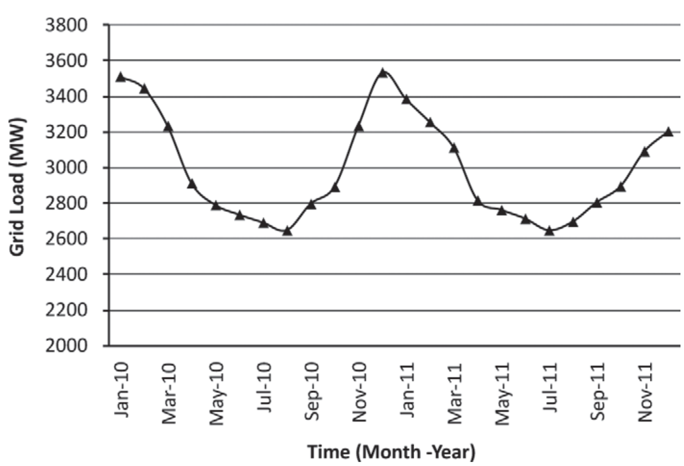

Figure 5. Demand on the Irish electricity grid in megawatts from January 2010 to December 2011.

milk-cooling load from milking times by shifting the load to off-peak periods, but only if they are set up and managed correctly (MDC, 1995). This practice, together with optimized use of a plate heat exchanger with ground water, would reduce energy use and energy costs associated with milk cooling. This strategy of shifting the load to the off-peak rates would reduce on-farm energy costs both in a day/night and a dynamic electricity-pricing scenario.

Second, in the longer term, a farmer must decide whether to alter the calving pattern and, thus, the seasonality of milk supply to avoid producing milk when the demand and ultimately the price will be at peak (December and January). In a spring-calving grass-based system, the electricity demand should be the lowest at this point, as most cows are not lactating. Further research is required to investigate the effect of calving pattern (including spring versus autumn calving) on the energy demand and energy costs of milk production in various dynamic electricity-pricing scenarios.

Third, efficiency gains and lower energy costs can be realized through application of energy-efficient technology. For example, scope may exist to reduce the electricity consumed by vacuum pumps through the application of variable speed drive technology. However, adoption at the farm level is low. Similarly, no studies are available that quantify the use of solar thermal water-heating systems or solar photo voltaic cells, or micro wind turbines in the Irish dairy environment. Some of these systems have been shown to be an effective solution on French and New Zealand dairy farms (Morison et al., 2007; Institut de l'Élevage, 2009). However, given the difference in climate, due to changes in latitude, country-specific data are required.

Future Analysis of Electricity Consumption

This study has shown the need for a model to be developed around electricity usage on dairy farms. This model should be integrated with a whole-farm model similar to those that currently exist (e.g., the Moorepark Dairy Systems Model; Shalloo et al., 2004). Options around calving pattern (autumn vs. spring), milking frequency, and the integration of smart metering could be evaluated on energy consumption and energy costs across a range of herd sizes and production systems.

CONCLUSIONS

This study presents novel data regarding daily and seasonal electricity consumption trends from 22 commercial dairy farms in Ireland. On average, a total of 31.73 MJ was required to produce 1 kg of MS, of which 20% was direct and 80% was indirect energy use. Electricity accounted for 60% of the direct energy use and appeared centered around milking. Over 60% of daily electricity was used at peak periods. To improve the competitiveness of milk production in a dynamic electricity-pricing environment, therefore, management changes and technologies are required that decouple energy use during milking processes from peak periods. Combining technology that decouples energy use from milking times with energy efficient technology can, therefore, improve the economic and environmental competitiveness of the milk-production sector.

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