Applied Energy xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Electricity & direct water consumption on Irish pasture based dairy farms: A statistical analysis

P. Shine [a], T. Scully [b], J. Upton [c], L. Shalloo [c], M.D. Murphy [a,*]

[a] Department of Process, Energy and Transport Engineering, Cork Institute of Technology, Cork, Ireland
[b] Department of Computing, Cork Institute of Technology, Cork, Ireland
[c] Animal and Grassland Research and Innovation Centre, Teagasc Moorepark Fermoy, Co., Cork, Ireland

HIGHLIGHTS

- 39.85 Wh and 7.43 l of water consumed per litre of milk produced.
- No cost savings due to milk cooling load shifting capabilities on day/night rate.
- Pre-cooling milk with ground water saved 21% milk cooling electricity consumption.
- Pre-cooling milk with ground water increased parlour water consumption by 41%.
- Water usage depends more upon farm processes than milk production and stock.

ARTICLE INFO

Article history:
Received 25 November 2016
Received in revised form 27 June 2017
Accepted 15 July 2017
Available online xxxx

Keywords:
Electricity
Water
Dairy farming
Statistical analysis
Agricultural sustainability

ABSTRACT

With the abolishment of the European Union milk quota system in April 2015, the Irish government has targeted a 50% increase in milk production by 2020 over 2007–09 levels. Resulting milk price volatility and environmental constraints are forcing farmers to produce milk at lower costs with a lower overall environmental footprint. This entails using less energy and water resources to maintain commercial competitiveness and to reduce the environmental consequences of the production. This paper presents a detailed analysis of electricity and direct water consumption of 58 pasture-based, Irish commercial dairy farms. Data was acquired through a remote monitoring system installed on each farm in 2014 alongside corresponding milk production, stock, infrastructural and managerial data. The results derived from the analysis of this data allow key drivers of both electricity and water consumption to be understood with the ultimate aim of generating data to develop footprint models, to achieve a reduction in electricity and water use and to improve the cost efficiency of Irish pasture based dairy farms. The analysis showed electricity use of 39.84 Wh L_m^{-1} and water use of 7.43 L_w L_m^{-1} for the period Jan - Dec 2015. Dairy farm processes directly associated with milk production (milk harvesting and milk cooling) were responsible for 47% of overall electricity consumption. Milk cooling systems which utilised ice chiller units or ice bank milk tanks consumed 32% greater Wh L_m^{-1} for milk cooling compared with direct expansion milk tanks. This increase in consumption was met with a 25% decrease in day-time hours consumption due to their load shifting capabilities resulting in no difference in milk cooling related cost per L_m when under a day and night electricity tariff structure. Mean milk cooling electricity savings of 21% were achieved across farms with the incorporation of ground water through a plate heat exchanger for milk pre-cooling. However, in an open loop system, this resulted in a 41% increase in parlour water consumption. Electricity consumption was found to be largely associated with milk production, herd size (total dairy cows) and the number of lactating cows. Water consumption was found to be largely correlated with milk production and moderately correlated with herd size and the number of lactating cows. Decreased correlation strengths for water consumption compared to electricity suggests consumption is less dependent on milk production and stock numbers and more dependent on managerial processes, environmental conditions and farm infrastructure. Results and methodologies from this analysis will facilitate the development of adaptive predictive and optimisation methodologies for dairy farming electricity and water consumption.

* Corresponding author at: Department of Process, Energy and Transport Engineering, Cork Institute of Technology, Bishopstown, Co. Cork, Ireland.
E-mail address: michaeld.murphy@cit.ie (M.D. Murphy).

http://dx.doi.org/10.1016/j.apenergy.2017.07.029
0306-2619/

Nomenclature

DSM	demand side management
DX	direct expansion milk tank
DX_{GW}	DX with milk pre-cooling with ground water
DX_{ICW}	DX with milk pre-cooling with ice cold water and/or ground water and/or
E&W	electricity and direct water
ES	effect size
gW	ground water
HzHW	frequency of hot wash
IB	ice bank milk tank
IB_{GW}	ice bank milk tank with ground water
FPCM	fat and protein corrected milk
L_m	litre of milk
L_w	litre of water
n	number of instances
p	P value
PHE	plate heat exchanger
r	correlation coefficient
R^2	coefficient of determination
SD	standard deviation
SEM	standard error of the mean
VSD	variable speed drive
IQR	inter-quartile range

1. Introduction

With projected GDP (Gross Domestic Product) growth within developing countries fuelling a 20% forecasted increase in global consumption of milk & dairy products by 2050 [1], the European Union milk quota system was abolished in April 2015. In preparation, the Irish government identified potential for a 50% increase in milk production by 2020 over 2007–09 levels [2]. The sustainability of the increased production must be met with consideration regarding the use of natural resources to ensure future sustainable growth of Ireland's dairy industry [3]. Concurrently, farmers may be exposed to increased electricity costs with the implementation of time-of-use pricing systems which charge according to a day/night/peak structure [4]. Similarly, increased costs may result from plans outlined in the Water Services (No. 2) Act 2013 which aim to monetize public supply and waste water in Ireland for the provision of water services [5]. With milk price volatility in a now open market, famers are therefore required to produce milk at lower costs with a lower overall environmental footprint through using fewer energy and water resources to maintain commercial sustainability. In response, this study focuses on the influence of dairy farm production, stock, infrastructural and operational characteristics as well as environmental conditions on electricity and direct water (i.e. on farm blue water abstractions) (E&W) consumption to provide farmers with the knowledge to optimize E&W resources. This information is necessary from both environmental and milk production cost effectiveness perspectives.

Current research in the area of energy sustainability on Irish dairy farms includes that of Upton et al. [6], finding that electricity made up 12% of total energy demand per litre of milk, from cradle to farm gate on 22 Irish dairy farms. While Upton et al. focused on total energy demand, this study focuses on both E&W together on Irish pasture based dairy farms. More information is needed on this particular aspect as an inextricable link exists between milk production, electricity and water whereby milk production, E&W consumption and related costs can be influenced by the farmer through management practices and equipment choices. Hence, it would be valuable for associations between E&W and key components of the dairy farm system to be represented through mathematical models with a small number of high prediction yielding empirically derived coefficients in order to better represent E&W uses within dairy farms. No such empirical models exist for both E&W consumption prediction on Irish dairy farms. E&W demand will increase along with farm size, therefore there is potential for reduction in resource usage efficiency per litre of milk as farm facilities may not be optimally sized for milk production increases. For example, Upton et al. [7] reported a 24% increase in Wh L_m^{-1} by increasing dairy herd size from 45 to 88 cows on Irish dairy farms. Moreover, the higher electricity consumption of a facility, the increased potential for demand side management (DSM), and thus greater opportunity for cost savings for farmers in time-of-use or real time electricity pricing environments with suitable control systems installed. This is particularly relevant when an ice bank milk cooling system with load shifting capabilities is employed [8,9]. Increased DSM integration may reduce the frequency of wind curtailment thus improving the reliability and sustainability of a future Irish electricity power system with high wind penetration as described by Finn et al. [10].

Research into water consumption on Irish farms includes the on-farm treatment of soiled water [11] at both the farm and catchment levels while Murphy et al. [12] present dairy farm water foot printing at the system level (i.e. cradle to farm gate). Murphy et al. found 690 $L_w\,kg^{-1}$ fat and protein corrected milk (FPCM) to be required for the overall production of milk (green water plus blue water) with on-farm blue water requiring 5.3 $L_w\,kg^{-1}$ FPCM on average. Internationally, Cardot et al. [13], Murphy et al. [14] and Meyer et al. [15] specifically investigate the drinking water intake of dairy cows. While on farm blue water includes drinking water consumption, there has been little or no work to date to attribute overall direct water use (drinking plus parlour plus miscellaneous) by production, practice or technology on farm which is the focus on this paper, with an ultimate objective of being able to use the information to provide guidance to reduce water use. Understanding variances in water consumption may offer on-farm benefits regarding the protection of borehole water supplies and optimizing infrastructural equipment for a cost effective water system. Concurrently, governing bodies may use this information in calculating the impact of dairy farming on natural resources for improving the marketability of Irish dairy exports to international markets [3].

This paper aims to determine E&W usage efficiencies and consumption breakdowns for a group of Irish farms while focusing on the milk production - electricity - water nexus. Investigating the influence of milk production, stock numbers, infrastructural equipment, managerial procedures and environmental conditions on E&W usage will aid the subsequent empirical prediction of monthly E&W consumption. Concurrently, this paper aims to increase the understanding into the relationship between E&W consumption and different on farm practices and technologies. The techniques undertaken take into account dataset spread and homogeneity of variances for the accurate determination of relationships between E&W and potential predictive variables and investigating differences in usage efficiencies between multiple categories of dairy farms.

2. Materials and methods

This analysis was carried out through the sub-metering of E&W on 58 commercial dairy farms, primarily based in the Munster

Please cite this article in press as: Shine P et al. Electricity & direct water consumption on Irish pasture based dairy farms: A statistical analysis. Appl Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.07.029