Computers and Electronics in Agriculture 135 (2017) 216–221

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

Dairy Energy Prediction (DEP) model: A tool for predicting energy use and related emissions and costs in dairy farms

Giuseppe Todde *, Lelia Murgia, Maria Caria, Antonio Pazzona

Department of Agraria, University of Sassari, Viale Italia 39, 07100 Sassari, Italy

ARTICLE INFO

Article history:
Received 5 July 2016
Received in revised form 2 February 2017
Accepted 15 February 2017
Available online 24 February 2017

Keywords:
Milk
Direct energy consumption
Greenhouse gases
Linear model

ABSTRACT

The need of reducing energy consumption in agriculture through more efficient working methods came first into focus in the 1970s as a consequence of oil crisis and the sharp increase of the energy price. Today, besides the economic issues, other aspects connected to a large use of fossil energies are becoming prominent: the depletion of nonrenewable resources and the pollution of the environment. The consumption of direct energy, as fuels and electricity, in dairy farming is a source of greenhouse gas emissions and contributes significantly to increasing the carbon footprint of milk.

The objectives of this study were: (a) to build linear models to estimate the consumption of diesel fuel and electricity in dairy farms; (b) to develop a calculation tool in order to assess efficiency indicators associated to energy consumption, emissions of carbon dioxide and energy costs in dairy farms.

Data used in the model development were collected from 285 dairy farms located in southern Italy. Two linear regression models were developed using total fuel (TF, kg year^{-1}) and electricity consumption (TE, kW h year^{-1}) as responses and total number of heads, total number of lactating cows, milk produced, and cultivated land as primary independent variables. Model's parameters were then implemented in a spread sheet to develop the Dairy Energy Prediction (DEP) tool. Entering some basic information about dairy farms characteristics, DEP is able to predict diesel fuel and electricity consumptions, to list several Energy Utilization Indices (EUIs), to estimate carbon dioxide emissions from energy uses (kg CO_2-eq), to evaluate the costs of energy purchase. DEP may be used by farmers, to evaluate the energy performances of their farms, and by researchers and stakeholders to compare the impact of different energy scenarios (i.e. LCA studies, economic evaluation, environmental assessment, etc.). DEP tool is available online at this link: http://bit.ly/DEPTOOL.

1. Introduction

The identification of agricultural practices with higher energy efficiency is a challenge that began years ago. In the 1970s, as a result of the sharp increase of oil price, the need of reducing the fossil energy consumption has lead to propose several methodologies of energy analysis applied to agriculture (Odum, 1971; Pimentel et al., 1973). More recent Life Cycle Assessment (LCA) studies include the non-renewable energy flows in the evaluation of the overall sustainability of agricultural products from cradle to farm gate (Pelletier et al., 2011; Rotz et al., 2010). Fossil energy consumptions in agriculture are usually divided in direct and indirect: the first ones refer to fuels and electricity that are directly converted in unit of energy at farm level; the second ones refer to the cumulative energy embodied in all inputs used in the production process. The knowledge of the energy usages is crucial for reducing the production costs and improving the environmental sustainability of food production through less energy intensive practices.

Specifically for dairy farming, the scientific literature shows different methodologies to assess and include energy inputs into environmental analysis. Data source comes both from national statistics on energy consumptions (Basset-Mens et al., 2005; Capper et al., 2009; FlysjÖ et al., 2011; Henriksson et al., 2011) and from the collection of direct measures on sampled farms (Murgia et al., 2013; Thomassen et al., 2009; Van der Werf et al., 2009; Murgia et al., 2008; Schils et al., 2006; Kristensen et al., 2011; Haas et al., 2001).

Other studies estimated the fuel use through simulation models when calculating carbon dioxide emissions (Rotz et al., 2010). Upton et al. (2014) defined a mechanistic model for assessing electricity consumption, related CO_2 emissions and costs on a monthly basis. Sefeedpari et al. (2014) modelled electricity and fuel use on

* Corresponding author at: Viale Italia 39, 07100 Sassari, Italy.
E-mail address: gtodde@uniss.it (G. Todde).

http://dx.doi.org/10.1016/j.compag.2017.02.014
0168-1699/

50 Iranian dairy farms, using an adaptive neural-fuzzy inference system technique.

Moreover, the prediction of the direct energy demand of dairy production based on the analysis of farm energy bills is not enough accurate. For instance, diesel purchase receipts do not take into account the mechanized operations carried out by contractors. Diesel and electricity costs often refer to other farm activities besides milk production (i.e. farms with dairy cows and sheep or swine or poultry), so that it is very difficult to identify the specific requirements of milk production.

The energy efficiency of dairy farms is closely linked to different management methods and to the production intensity (Todde et al., 2016; Gelasakis et al., 2012; Alvarez et al., 2008; Usai et al., 2006). Efficiency indices, expressed as units of energy consumed per cow or per mass of milk, have been calculated in numerous studies carried out in different European dairy production systems (Martinho, 2016; Huysveld et al., 2015; Bos et al., 2014; Upton et al., 2015; Guerci et al. 2013; Kraatz, 2012; Rossi and Gastaldo, 2012; Murgia et al., 2008; Edens et al., 2003; Jäkel, 2003). The differences in farm technology and in milk yield per cow affect significantly the energy efficiency indicators. As a consequence, these indices can often result not enough accurate when used to estimate the fuel and electricity consumptions of individual farms.

In this context, the aims of this study were: (a) to develop linear models to estimate the consumption of diesel and electricity for milk production at farm level; (b) to build a useful tool in order to predict performance indices related to energy consumption, emission of carbon dioxide and costs in dairy farms.

2. Materials and methods

Data collected through the energy audit of 285 conventional Italian dairy cow farms, located in southern Italy (Sardegna, Basilicata, Calabria, Puglia e Sicilia), was used to develop linear models in order to predict electricity and diesel consumptions for milk production. Farms involved in this study were mostly located in hills (49%) and valley (40%) where the cow breed principally raised was Holstein. Most of the farms were specialized in milk production (76% of farms) with a herd management mainly based on barn confinement (55%). The average herd dimension was 127 heads with 58 milking cows producing about 495 tonnes of milk per year. The cultivated land was an average of 44 hectares per farm; 48% irrigated for producing grass hay and grass silage on spring, and corn silage in late summer, while the production of grains was marginal. Further characteristics on the management of investigated farms have been described in a previous study by Todde et al. (2016).

The annual energy averagely consumed in farms accounted for 13,120 kg of diesel fuel and 16,250 kW h of electricity. The variability of energy consumptions among the farms was very high, as shown in Table 1. A detailed energy auditing was performed, on a yearly basis, to allocate the electricity and diesel consumptions among the different on-farm activities connected to milk production excluding all energy consumptions related with other enterprises within the farm. All the electrical equipment operating at farm level were inventoried, reporting the power requirements and their usage time (hours per day, days per year) to calculate the annual electricity consumption. The outcomes were then compared to the electricity bills to evaluate the conformity of the results.

On-farm fuel consumptions were inventoried for field operations, slurry management and feeding practices. To estimate the diesel consumption due to each operation, the usage time of the tractor, the rated power and the specific motor load were considered. The fuel consumption at partial load (Q) was derived from the following equation (Grisso et al., 2004):

Q = (0.22 X + 0.096) x Ppto ($L\,h^{-1}$), which considers the rated power of the machinery (Ppto, kW) and the estimated fraction (X, decimal) of the rated power being used during field operations. Values from 0.30 to 0.65 were set for the different operations A conversion factor of 0.835 $kg\,L^{-1}$ was applied to transform the equation result in kg of diesel.

2.1. Statistical analyses

Statistical analyses were carried out in R Studio (version: 2.15.2). Two linear regression models were developed using total fuel (TD, kg $year^{-1}$) and electricity consumption (TE, kW h $year^{-1}$) as responses and total number of heads, total number of lactating cows, milk production (kg FPCM), and land area (hectares) as primary independent variables.

$$\boldsymbol{Y_i} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 X_{1i}} + \cdots + \boldsymbol{\beta_p X_{pi}} + \boldsymbol{e_i}$$

$\boldsymbol{Y_i}$ = observed diesel (kg) or electricity (kW h) consumption in i-th farm.
$\boldsymbol{i}$ = 1, 2, 3,. . ., 285 farms.
$\boldsymbol{\beta_0}$ = intercept.
$\boldsymbol{\beta}$ = fixed effect of independent variables.
$\boldsymbol{X_{1i}}$ = total number of heads in i-th farm.
$\boldsymbol{X_{2i}}$ = total hectares of land in i-th farm.
$\boldsymbol{X_{3i}}$ = total kg of milk produced in i-th farm.
$\boldsymbol{X_{pi}}$ = total number of lactating cows in i-th farm.
$\boldsymbol{e_i}$ = residual error $N(0, I\sigma_e^2)$.

Variables selection was not based on stepwise method since the high correlation among the independent variables was observed. To avoid multicollinearity a correlation matrix was set, as a variable selection method, in order to identify the correlation among the independent variables and the dependent variables.

Second and third order polynomial terms of total number of heads and number of lactating cows were tested through Akaike Information Criterion (AIC) and Variance Inflation Factor (VIF). AIC is a measure of the relative quality of a set of models; lower AIC values represent models which minimize the information lost. VIF identifies the correlation between variables; values lower than 10 are considered not affected by multicollinearity.

Moreover, a binary variable was tested to represent the presence (1) or the absence (0) of mechanized feeding operations that

Table 1
Data summary of the audited farms.

Data observed	Minimum	Mean	Maximum	SD	N.
Diesel (kg $year^{-1}$)	489	13,120	92,430	±13,299	241
Electricity (kW h $year^{-1}$)	1085	16,250	91,420	±13,581	273
Heads (N)	6	127	1320	±142	285
Milking Cows (N)	2	58	600	±62	285
Milk (t $year^{-1}$)	15	495	5323	±608	285
Land (ha)	3	44	338	±43	285