# Environmental impact assessment of milk production: is a simplified tool possible?

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## Abstract

The aim of this study was to develop a simplified tool for estimating Climate Change (CC) associated to milk production at farm level that can be easily used by farmers. An accurate environmental impact assessment of milk production is the first step to select the best mitigation strategies to make milk production greener. Most studies in this field use Life Cycle Assessment (LCA) to estimate various environmental impacts of milk production at the farm level. LCA is a robust method, although time consuming. However, the current need of the sector is to start extensive estimation of environmental impact of milk production in dairy farms, at least for the Climate Change (CC) category, to set up a starting point for measuring future improvements. The study was performed on 54 dairy cattle farms located in Northern Italy. A complete LCA analysis was performed, and some performance data were recorded in the last 3 years. The latter were retrieved from the national fertility database managed by the National Breeders Association of Holstein, Brown, and Jersey (ANAFIBJ, Cremona, Italy) and consisted of production, management, and fertility data (i.e. pregnant cows at 120 d, and milk sold per Livestock Unit, LU), and genetic indices (i.e. Health and Economic Index - IES, predicted Methane Emission Index - pCH4). On average, the number of lactating cows in the selected farms was 232.2 (min 56, max 817), Fat and Protein Milk production (FPCM) per lactation was 9591±1357 kg. The inclusion of soybean meal, in the ration of lactating cows, was on average 10.7±5.28%. The CC impact was estimated starting from IPCC 2019 equations for modelling $CH_4$ and $N_20$ emissions related to the on-farm processes, while for off farm ones, data from databases were used (Agrifootprint and Ecoinvent). The EF 3.0 method was used for CC estimation. Average CC of the farms in the dataset was 2.00±0.31 kg $CO_2$ eq/kg FPCM. Subsequently, multivariate analyses were performed using R and SAS software using CC, farm characteristics and performance data. The Principal Component Analysis (PCA) was performed to find a multidimensional relation between variables.

With the aim to find an equation for estimating CC (CC_es) using few variables, easy to be collected at farm level, a linear model with stepwise selection was used. Starting from a collinearity test, variables with high VIF (Variance Inflation Factor) were excluded from the dataset. Stepwise procedure (Ordinary Least Squares, OLS) was used to select the best parameters for CC_es. Variables selected were presence of biogas, percentage of soybean meal in the ration, IES and CH4 indexes, age at first calving, pregnant cows at 120 d, and milk sold per LU. Adjusted $R^2$ of the equation was 0.63. Validation of the equation was performed by randomly selecting 15 farms from the database 1,000 times to test the equation, and the average correlation coefficient

between CC_es and CC was 0.77. From PCA, CC resulted inversely related with biogas presence, percentage of replacement animals on total LU and percentage of cows pregnant at 120 days after calving. The last two parameters are linked with an efficient farm management, characterized by a limited ratio between unproductive (heifers and open cows) and productive animals and by fertility efficiency. The mitigation effect of the presence of biogas was very high. The IES index also showed negative correlation with CC_es, On the other hand, while increasing percentage of soybean meal in the ration resulted an increased value of CC_es. Fertility efficiency parameters i.e. pregnant cows at 120 d, and milk sold per LU were inversely proportional to CC_es.

*Keywords: lca, tool, milk, cow, management, environmental impact.*
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## Introduction

In literature a generally accepted method for estimating the environmental impact of animal products on a global perspective is the Life cycle assessment (LCA), thanks to its power to include in a holistic assessment the environmental impacts of processes and products (Guerci *et al*., 2013). However, LCA represents a high time-consuming method, making it a method of difficult application in the field, especially for assisting farmers in identifying GHG mitigation strategies to be implemented at farm level. For this reason, a simplified tool for the evaluation of Climate Change (CC), that considers all the farm management aspects, together with genetic and phenotypic parameters, related to animal and farm efficiency, may be useful for improving the environmental sustainability of the milk production sector.

## Material and methods

The study was performed on 54 dairy cattle farms located in Northern Italy. A complete LCA analysis was performed, and some performance data were recorded in the last 3 years. The latter were retrieved from the national fertility database managed by the National Breeders Association of Holstein, Brown, and Jersey (ANAFIBJ, Cremona, Italy) and consisted of production, management and fertility data (i.e. pregnant cows at 120 d, and milk sold per Livestock Unit, LU), and genetic indices (i.e. Health and Economic Index - IES, predicted Methane Emission Index - pCH4).

### *Life Cycle Assessment*

The goal of this LCA study was to quantify the CC of 1 kg of fat and protein corrected milk (FPCM), that was used as functional unit. At farm level, the allocation was performed between milk and meat, using a physical method (IDF International Dairy Federation, 2015). System boundaries considered were from cradle to farm gate, and all the inputs and output involved in the productive processes were considered. For the assessment, primary data collected at farm were used as much as possible. Secondary data from databases (Ecoinvent and Agri-footprint databases) and proxy were also used. Emissions of greenhouse gases in air were estimated by using IPCC 2019 guidelines. After classification, characterization was performed through EF 3.0 method. The life cycle impact assessment was performed by using the software SimaPro V 8.3.

## Statistical analysis

The complete data set was analysed using SAS 9.4 (2012; SAS Institute Inc., Cary, NC), computing descriptive statistic (Proc MEANS). Multivariate analyses were performed using SAS software 9.4 (2012; SAS Institute Inc., Cary, NC), using CC, farm characteristics and performance data. A Principal Component Analysis (PCA, Proc PRINCOMP) was performed to find a multidimensional relation between variables. With the aim to find an equation for estimating CC (CC_es) using few variables, easy to be collected at farm level, a linear model with stepwise selection was used. Starting from a collinearity test, variables with high VIF (Variance Inflation Factor) were excluded from the dataset. Stepwise procedure (Ordinary Least Squares, OLS) was used to select the best parameters for CC_es. Validation of the equation was performed by randomly selecting 15 farms from the database 1,000 times to test the equation, and the average correlation coefficient between CC_es and CC was calculated.

## Results

The results of summary statistics performed on 54 dairy cattle farms of Northern Italy are shown in Table 1.

On the average, the number of lactating cows in the selected farms was 232, Fat and Protein Milk production (FPCM) per lactation was 9591 kg, with an average percentage of fat and protein of 3.83 and 3.40, respectively (Table 1). The inclusion of soybean meal, in the ration of lactating cows, was, on the average 10.7%. Average values collected for IES and CH4 indexes were 161 and 100, respectively. Age at first calving was, on the average, for the 54 farms of the sample, 26.9 months, while percentage of pregnant cows at 120 d was, on the average 58.3%. Average value of milk sold per LU was 6239 kg (Table 1).

Average CC of the farms in the dataset was 2.00±0.31 kg $CO_2$ eq/kg FPCM.

In Figure 1 results of PCA are shown.

From PCA (Figure 1), CC resulted inversely related with biogas presence, percentage of replacement animals on total LU and percentage of cows pregnant at 120 days after calving. The last two parameters are linked with an efficient farm management, characterized by a limited ratio between unproductive (heifers and open cows) and productive animals and by fertility efficiency. IES index also resulted to be inversely

*Table 1. Summary of descriptive statisti*

| Variable | Unit | Mean | Std | Min | Max |
|---|---|---|---|---|---|
| Lactating cows | n | 232 | 186 | 56.0 | 817 |
| FPCM[1] per lactation | kg | 9591 | 1357 | 6754 | 13284 |
| Fat | % | 3.83 | 0.23 | 3.28 | 4.23 |
| Protein | % | 3.40 | 0.12 | 3.02 | 3.70 |
| Soybean meal in the ration | % | 10.7 | 5.28 | 0 | 22.5 |
| IES index[2] | | 161 | 159 | -93.6 | 733 |
| CH4 index[3] | | 100 | 1.42 | 97.1 | 105 |
| Age at first calving | month | 26.9 | 2.47 | 23.0 | 34.7 |
| Pregnant cows at 120 d | % | 58.3 | 9.25 | 37.0 | 73.0 |
| Milk sold per LU[4] | kg | 6239 | 827 | 4494 | 8093 |

[1] FPCM, Fat and Protein Corrected Milk
[2] IES index, Health and Economic Index
[3] CH4 index, Methane Emission Index
[4] LU, Livestock Unit

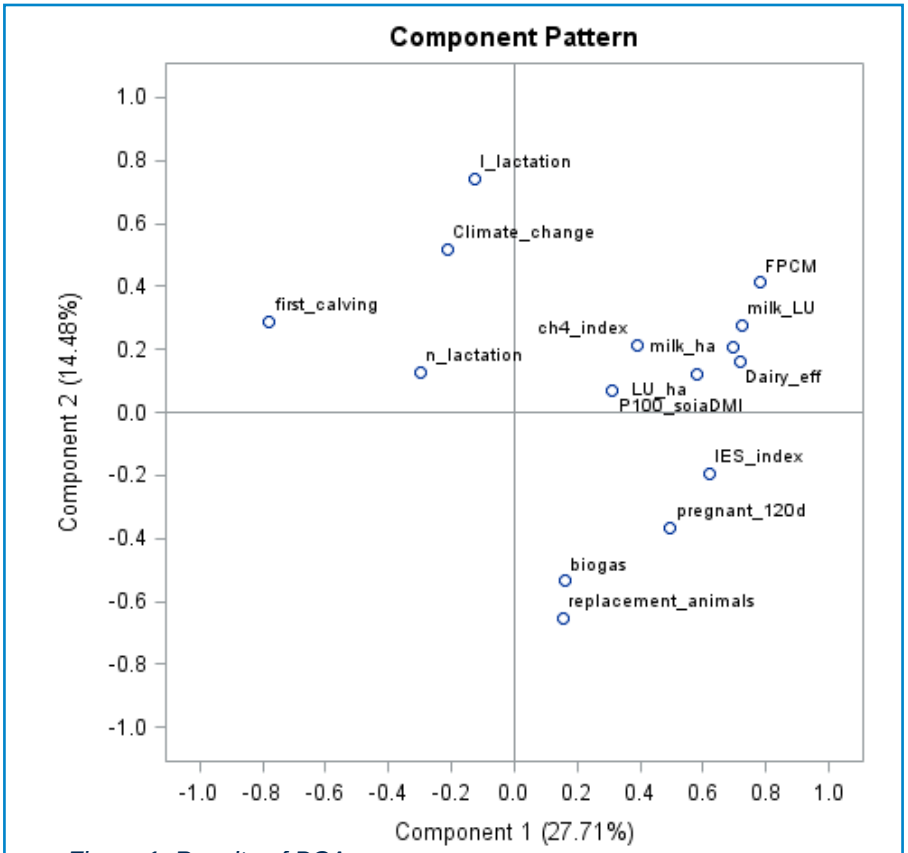


*Figure 1. Results of PCA.*

related to CC. On the contrary, PCA highlighted a positive correlation between CC and age at first calving, number of lactations and length of lactation (Figure 1).

Variables selected for the estimation of CC (CC_es) (Table 2) were presence of biogas, percentage of soybean meal in the ration, IES and $CH_4$ indexes, age at first calving, pregnant cows at 120 d, and milk sold per LU. Adjusted $R^2$ of the equation was 0.63, and the average correlation coefficient between CC_es and CC was 0.77.

The mitigation effect of the presence of biogas was very high. The IES index also showed negative correlation with CC_es, On the other hand, while increasing

*Table 2. Variables selected for the estimation of CC.*

| Variable |
|---|
| Biogas |
| Percentage of soybean meal in the ration |
| IES index[1] |
| CH4 index[2] |
| Age at first calving |
| Pregnant cows at 120 d |
| Milk sold per LU[3] |

[1] IES index, Health and Economic Index
[2] CH4 index, Methane Emission Index
[3] LU, Livestock Unit

percentage of soybean meal in the ration resulted an increased value of CC_es. Fertility efficiency parameters i.e. pregnant cows at 120 d, and milk sold per LU were inversely proportional to CC_es.

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