**Università degli Studi di Perugia**

Department: SCIENZE AGRARIE, ALIMENTARI E AMBIENTALI (DSA3)

# Analisi dell'efficienza ambientale nel settore bovino da carne

15/6/2023

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# FRAMEWORK

- Cecchini, L., Romagnoli, F., Chiorri, M., & Torquati, B. (2023). **Eco-Efficiency and Its Determinants: The Case of the Italian Beef Cattle Sector.** *Agriculture*, *13*(5), 1107.

agriculture

MDPI

*Article*

## Eco-Efficiency and Its Determinants: The Case of the Italian Beef Cattle Sector

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**Abstract:** In recent years, eco-efficiency assessment has proven to be an effective tool to reduce the environmental damages of agricultural activities while preserving their economic sustainability. Hence, this paper aims to assess the eco-efficiency of a sample of 148 beef cattle farms operating in the extensive livestock system of Central Italy. The analysis is based on Farm Accountancy Data Network (FADN) economic data in the year 2020 and includes, as environmental pressures, farm expenditure for the use of fuels, electricity and heating, and fertilizers. A two-stage approach was implemented: in the first stage, an input-oriented DEA model including slack variables was used to quantify farm eco-efficiency scores and determine the polluting inputs' abatement potentials. In the second stage, the influence of possible influencing factors on eco-efficiency scores was tested using a regression model for truncated data. The analyzed farms were found to be highly eco-inefficient, as they could abate their environmental pressures, on average, in a range from 56% to 60% while keeping the value of their global production constant. Fertilizers and fuel consumption were identified as the least efficiently operating inputs, with potential reductions in terms of the related expenditures fluctuating between 9% and 42%. Farms showing a high-intensity livestock system, a low labor intensity, and a larger farm area were recognized as the most eco-efficient. Environmental and animal welfare subsidies were found to not affect eco-efficiency, while a negative influence was estimated for a single farm payment, which does not seem to be an incentive mechanism for farms to operate efficiently.

**Keywords:** eco-efficiency; livestock farms; data envelopment analysis; model approaches in estimating greenhouse gases (GHG); truncated regression

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**Citation:** Cecchini, L.; Romagnoli, F.; Chiorri, M.; Torquati, B. Eco-Efficiency and Its Determinants: The Case of the Italian Beef Cattle Sector. *Agriculture* **2023**, *13*, 1107. https://doi.org/10.3390/agriculture13051107

Academic Editor: Christos Karelakis

Received: 6 April 2023
Revised: 17 May 2023
Accepted: 21 May 2023
Published: 22 May 2023



### 1. Introduction

Agricultural activities play a pivotal role in providing access to food, supporting farmers' incomes, and strengthening the resilience of many rural communities, while ensuring a large part of ecosystem services, including biodiversity and landscape conservation.

Nevertheless, this sector is recognized as one of the most responsible for contributing to the deterioration of human and natural ecosystems, as its negative impacts include pollution and degradation of soil, water, and air.

Within the agricultural sector, livestock activities are definitely the ones most responsible for the production of greenhouse gases (GHG), as they contribute significantly to the emissions of carbon dioxide ($CO_2$), methane (CH4), and nitrogen oxide ($N_2O$) [1–3]. In the livestock sector, the largest share of polluting emissions relies on cattle production systems, accounting for 65% [4]. In addition, cattle livestock farming contributes significantly to environmental pollution by affecting water quality and is responsible for more than half of the anthropogenic emissions of N and P [5].

Indeed, the enhancement of the sustainability of agricultural activities represents one of the most crucial challenges identified by the policy agendas. For example, at the European level, the Common Agricultural Policy (CAP), accordingly to the European Green

# Eco-Efficiency and Its Determinants: The Case of the Italian Beef Cattle Sector

## STATE OF ART

- The agricultural sector has the most significant impact with a contribution of 11% of total global GHG emissions (IPCC, 2022).
- Within the agricultural sector, livestock activity contributes 14.5% of GHG emissions, through the emission of carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), globally (Opio et al., 2013).
- The contribution of cattle production to polluting emissions equal to 65% (Mariantonietta et al., 2018).
- Cattle livestock farming is responsible for more than half of the anthropogenic emissions of N and P

# STATE OF ART

- Politicians and scientists have increasingly focused their attention on assessing the undesirable outputs of agricultural and livestock systems
- Eco-efficiency assessment have been increasingly implemented in production contexts where conflicting economic and environmental goals exist.
- The concept of eco-efficiency was first proposed in 1990; its definition is given by the following ratio:

**Eco−efficiency** = Product or service value/Environmental impact

- Eco-efficiency is an instrument to analyze sustainability, as it deals with solutions able to encourage farms become responsible in relation to the environment, while preserving profits, in a cost-effectiveness perspective

# OBJECTIVES

- Although these approaches have been widely adopted to estimate the eco-efficiency of livestock farms, most of them have focused on the dairy sector without providing a direct quantification of the excessive use of polluting inputs (slack)

- A two-stage DEA model incorporating slack variables was implemented, based on the Farm Accountancy Data Network (FADN) database, according to the following three objectives:

(i) to assess the eco-efficiency of 148 beef cattle farms located in central Italy through Data Envelopment Analysis (DEA), by considering the use of fuels, electricity and heating, and the use of fertilizers as polluting inputs;

(ii) to quantify the abatement potentials for the considered polluting inputs;

(iii) to test for the influence of possible explanatory variables on the eco-efficiency.

# METHODOLOGY- INTRODUCTION

- To evaluate productive performances two main quantitative indicators exist:

➢ **Productivity:** the ratio between the quantity of output, y, obtained from production, and the quantity x of the input used.

➢ **Efficiency:** expresses a comparison between observed productivity of a certain Decision Making Units (DMUs) (such as farms) and maximum possible productivity.

A DMU is technically efficient if the increase in output can only occur if it is reduced at least another output or if at least one input is increased

# METHODOLOGY

- DEA is a non parametric method that uses mathematical programming techniques to determine the relative efficiency of similar decision-making units
- Its nonparametric approach favours its flexibility of application, since it is not necessary to explicitly specify *a priori* a production function
- The basic formulation of DEA assumes a monotonous relationship of linear proportionality between input and output (Charnes et al., 1994), and returns an efficiency score ranging from 0 to 1.
- The eco-efficiency is expressed in relative terms related to best observable performance within the sample.
- Input orientation
- Environmental pressures were considered as technical inputs of the model

## FIRST STAGE. DEA MODEL

- Two traditional (CCR and BCC) DEA models were implemented, respectively assuming constant return to scale (CRS) and variable results to scale (VRS):

$$\mathrm{Max}_{\theta_o,\lambda_k}\ \theta_o$$

s.t.

$$\sum_{k=1}^{K} \lambda_k x_{ik} + s_i^- = x_{io}, \forall\, i = 1,2,\dots,I;$$

$$\sum_{k=1}^{K} \lambda_k y_{jk} - s_j^+ = \theta_o y_o, \forall\, j = 1;$$

$$\lambda_k, \geq 0, k = 1,2,\dots,\mathrm{K}$$

$$s_i^- \geq 0, i = 1,2,\dots,\mathrm{I}$$

$$s_j^+ \geq 0, j = 1 \qquad (1)$$

- The optimal solution of the CCR and BCC model represents, respectively, the technical eco-efficiency ($\mathrm{TEE_o}$) and the “pure” technical efficiency ($\mathrm{PTEE_o}$) of the DMU under evaluation.
- By taking the ratio between $\mathrm{TEE_o}$ and $\mathrm{PTEE_o}$, it is possible to compute the scale efficiency.

# DATA

- **148** meat-producing cattle farms from Central Italy (Abruzzo, Lazio, Marche and Umbria regions)

- Farm-level data, referring to the year 2020, were obtained from Farm Accountancy Data Network (FADN)

- **One** year time horizon

- Technical input variables included in the analysis were proxied in terms of related **expenditures**

- **Four inputs**: fuel costs (€); electricity and heating costs (€); fertilizer costs (€); livestock units (LSU).

- **Output**: Global production value (€)

# SECOND STAGE - TOBIT REGRESSION MODEL

- To quantify the effect of possible influencing factors on farms' eco-efficiency, a Tobit model was implemented by considering the scores obtained from the first-stage models as the dependent variable (CRS and VRS).

$$y_k^* = X_k Z + q + \varepsilon_k$$

Where:

- $y_k^*$ represents the DEA scores obtained from the first stage, observed for values ranging from 0 to 1, and censored otherwise;
- $X_k$ is the vector of explanatory variables;
- Z is a vector of parameters;
- q is the unknown intercept;
- $\varepsilon_k \sim iidN\ (0,\sigma^2)$ is the statistical error.

# SECOND STAGE – EXPLANATORY VARIABLES

The following farm factors were considered according to similar previous studies:

- ✓ farm size, in terms of surface area dedicated to livestock activities;
- ✓ intensity of the production system, in terms of both the value of global value and labor employment;
- ✓ the amount of Common Agricultural Policy (CAP) subsidies, by explicitly considering those for animal welfare and environmental aspects.

| | Farm Area | Intensity of Farming | Labor Hours Per Livestock Unit | Farm Payment | Animal Welfare Subsidy | Environmental Subsidy |
|---|---|---|---|---|---|---|
| MEAN | 27.66 | 3875 | 82.62 | 7604 | 1280 | 3925 |
| DV. ST. | 42.98 | 11,386 | 131.47 | 10,626 | 4692 | 5560 |
| MIN | 0.30 | 76.92 | 0.56 | 0.00 | 0.00 | 0.00 |
| MAX | 344.20 | 113,032 | 1000 | 107,012 | 33,100 | 56,417 |

# RESULTS

Technical, "pure" technical, and scale eco-efficiency (n = 148)

| | Technical Eco-Efficiency (TEE) | | | "Pure" Technical Eco-Efficiency (PTEE) | | | Scale Eco-Efficiency (SEE) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Eco-Efficiency Range** | Mean | n. | % | Mean | n. | % | Mean | n. | % |
| **0.00–0.19** | 0.095 | 59 | 40% | 0.098 | 50 | 34% | 0.111 | 5 | 3% |
| **0.20–0.39** | 0.285 | 40 | 27% | 0.399 | 35 | 23% | 0.271 | 1 | 1% |
| **0.40–0.59** | 0.486 | 20 | 13% | 0.641 | 17 | 11% | 0.444 | 10 | 7% |
| **0.60–0.79** | 0.678 | 11 | 7% | 0.839 | 12 | 8% | 0.680 | 13 | 9% |
| **0.80–0.99** | 0.929 | 8 | 5% | 0.987 | 7 | 5% | 0.929 | 105 | 70% |
| **1** | 1.000 | 11 | 7% | 1.000 | 28 | 19% | 1.000 | 15 | 10% |
| **Total** | 0.396 | 148 | 100% | 0.439 | 148 | 100% | 0.850 | 148 | 100% |
| **No. of farms with Constant Returns to Scale (CRS)** | | | | | | | | 15 | 10% |
| **No. of farms with Increasing Returns to Scale (IRS)** | | | | | | | | 133 | 90% |

- The involved farms were found to be highly eco-inefficient
- possible reductions of polluting inputs ranging from 56% (VRS) to 60% (CRS)
- Quite high scale eco-efficiency
- 133 farms (90%) showed increasing returns to scale
- Results in line with those reported in other studies.

# RESULTS

Input eco-efficiency (IEE) of the involved farms ($n$ = 148).

| Variable | Min | | Max | | Mean | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | VRS | CRS | VRS | CRS | VRS | CRS | VRS | CRS |
| Expenditure on fuels | 0.00 | 0.01 | 1.00 | 1 | 0.65 | 0.58 | 0.37 | 0.35 |
| Expenditure on fertilizers | 0.00 | 0.10 | 1.00 | 1 | 0.82 | 0.80 | 0.28 | 0.29 |
| Expenditure on electricity and heating | 0.04 | 0.11 | 1.00 | 1 | 0.93 | 0.91 | 0.21 | 0.21 |
| Livestock Unit | 0.33 | 1.00 | 1.00 | 1 | 0.97 | 1.00 | 0.09 | 0.00 |

- low efficiency levels were detected relating to the use of fertilizers and to fuel consumption
- potential reductions in terms of the related expenditures ranging from 18% to 42%
- LSU and electricity management do not seem to represent critical points

# RESULTS

## Tobit regression models estimates

| Variable | Technical Eco-Efficiency (TEE) | | | Pure Technical Eco-Efficiency (PTEE) | | |
|---|---|---|---|---|---|---|
| | Coef. | | p-Value | Coef. | | p-Value |
| Intensity of livestock system (Global production per LSU) | 0.0034 | *** | 0.000 | 0.0036 | *** | 0.000 |
| Farm payment | −0.00063 | ** | 0.012 | −0.00064 | ** | 0.038 |
| Farm area | 0.024 | *** | 0.000 | 0.036 | *** | 0.000 |
| Labor intensity (Hours per LSU) | | | | 0.0012 | *** | 0.006 |
| _cons | 0.242 | *** | 0.000 | 0.165 | *** | 0.003 |
| Log pseudolikelihood | −15.362 | | | −57.562 | | |
| Number of obs | 148 | | | 148 | | |
| F-statistics | 12.52 | | | 12.49 | | |
| Prob > F | 0.000 | | | 0.000 | | |
| Number of censored observations | 11 right-censored observations | | | 28 right-censored observations | | |
| Pseudo R2 | 0.7161 | | | 0.4142 | | |

# RESULTS

Marginal effects (MEs) of significant variables from the Tobit regression models.

| Variables | Technical Eco-Efficiency (TEE) | | Pure Technical Efficiency (PTEE) | |
|---|---|---|---|---|
| | MEs for the Expected Value of TEE Conditional on Being Uncensored | MEs for the Unconditional Expected Value of TEE | MEs for the Expected Value of PTEE Conditional on Being Uncensored | MEs for the Unconditional Expected Value of PTEE |
| **Intensity of livestock system (Global production per LSU)** | 0.00317 | 0.00328 | 0.00537 | 0.00611 |
| **Farm payment** | −0.00058 | −0.00060 | −0.00050 | −0.00057 |
| **Farm area** | 0.022 | 0.023 | 0.028 | 0.032 |
| **Labour intensity (Hours per LSU)** | - | - | −0.009 | 0.010 |

- ✓ Intensive and well-structured production processes could positively impact eco-efficiency
- ✓ Farm payment does not seem to represent an effective incentive to promote eco-efficiency
- ✓ Larger farm size allows farms to more easily afford investments for environmental efficiency improvement
- ✓ Environmental subsidies and animal welfare subsidies seemed to have no significant effects

# CONCLUSION - 1

- Fertilizers and fuel consumption were identified as the least efficiently operating inputs, with significant potential reductions in terms of the related expenditures
- Improvement measures involving inputs management aimed at reducing their use to achieving efficient frontier are needed
- Farms operating scale does not seem to be a critical issue
- The exact quantification of the impact-reduction potentials represents valuable information for farmers, who may implement targeted and costless improvement actions

# CONCLUSION - 2

- Farms showing a high-intensity livestock system, a low labor intensity, and a large farm area were recognized as the most eco-efficient.
- Environmental and animal welfare subsidies were found to not affect eco-efficiency

Productivity was identified as the main factor affecting eco-inefficiency

- ✓ the need to provide for specific investment measures aimed at promoting “green” technologies, rather than subsidies based on farm area
- ✓ providing training and advisory programs with the purpose of heightening farmers’ knowledge about eco-efficient practices