

# Computation of operational and environmental benchmarks for dairy farms through the five-step LCA+DEA method

Diego Iribarren<sup>1,\*</sup>, Almudena Hospido<sup>2</sup>, M. Teresa Moreira<sup>2</sup> and Gumersindo Feijoo<sup>2</sup>

<sup>1</sup>Madrid Institute for Advanced Studies in Energy (IMDEA Energy Institute), Unit of Energy Systems Analysis, 28933 Mostoles, Spain

<sup>2</sup>University of Santiago de Compostela, Department of Chemical Engineering, 15782 Santiago de Compostela, Spain

\*diego.iribarren@imdea.org

**Abstract** While Life Cycle Assessment (LCA) is a methodology to assess the environmental aspects and potential impacts associated with a product, Data Envelopment Analysis (DEA) is a linear programming methodology used to quantify in an empirical way the comparative productive efficiency of multiple similar entities. The joint application of both techniques has been recently proposed as a five-step approach aimed at providing an eco-efficiency verification tool that relies on the quantification of operational benchmarks in order to determine the associated environmental targets for multiple homogenous units. This study deals with the use of the five-step LCA+DEA method over a wide sample of dairy farms located in Galicia (NW Spain). Total operational reductions of up to 38% were found, leading to environmental impact reductions above 20% for each of the impact categories subject to evaluation.

## 1 Introduction to the case study

As impacts from livestock-related systems are considered a major environmental issue [1], Life Cycle Assessment (LCA) has been widely used to evaluate the environmental impact of livestock products [2]. In particular, Hospido et al. [3] carried out a simplified LCA of the Galician (NW Spain) milk production system (production and processing).

Galicia produces over 2 million tons of raw milk per year, involving more than 37% of the Spanish dairy farming production, and around 1.3% of the European

milk production rate [4]. The present study focuses on the eco-efficiency analysis of dairy farming in Galicia from a wide sample of farms [5].

For those case studies where multiple input/output data have to be available for a high number of facilities, Lozano et al. [6] and Iribarren [7] have recommended the use of LCA+DEA methodology, which is a methodological approach based on the joint implementation of LCA and Data Envelopment Analysis (DEA).

DEA is a linear programming methodology to quantify the comparative productive efficiency of multiple similar entities. Each homogenous entity subject to evaluation is named Decision Making Unit (DMU). On the basis of LCA and DEA synchronicities, LCA+DEA methodology combines these techniques so that a tool for the operational and environmental benchmarking of multiple DMUs is provided. Interestingly, this approach avoids the use of average inventory data and allows eco-efficiency verification [6-10]. Eco-efficiency refers here to the delivery of competitively priced goods that satisfy human needs while progressively reducing environmental impacts of goods and resource intensity throughout the entire life cycle to a level at least in line with the Earth's estimated carrying capacity [11].

## **2 Materials and methods**

This study performs an eco-efficiency assessment of Galician dairy farming by using LCA+DEA methodology over a sample of 72 farms [5]. The use of an LCA+DEA approach - which prevents data variability concerns and enriches the interpretation of the results derived from the individual application of LCA or DEA - is encouraged due to the high number of DMUs to be handled [12].

Specifically, the five-step LCA+DEA method was used in order to compute the environmental benchmarks linked to efficient farming practices [7,8]. This approach involves the following stages: (i) Life Cycle Inventory (LCI) of each dairy farm, (ii) Life Cycle Impact Assessment (LCIA) of each farm, (iii) DEA for the sample of DMUs, (iv) LCIA of the target farms, and (v) interpretation of the results according to the traditional eco-efficiency concept. While step (iii) entails the establishment of operational target values (operational benchmarking), step (iv) results in the environmental benchmarking of each farm. Finally, step (v) compares current and target environmental impacts, therefore providing a quantitative measure of the environmental consequences of operational inefficiencies in dairy farming.

As regards system boundaries, all life cycle stages up to the farm gate were taken into account. Nonetheless, the scope of DEA differs from that of LCA. In this

respect, LCA items involved a wide range of aspects, whereas DEA elements were limited to the most relevant aspects. On the one hand, the LCA study included feed, chemicals, water and energy input flows along with those outputs relating to production (raw milk, as well as meat as coproduct) and to waste streams that undergo further treatment (i.e. municipal solid waste and silage plastic waste) or emissions that are directly released to the environment (methane, nitrous oxide, ammonia and wastewater). On the other hand, the DEA study involved a reduced number of items: water, silage plastic, diesel, electricity and a set of feed items as selected inputs, and raw milk, wastewater and direct emissions to air as chosen outputs.

Primary data were collected directly from the farms through questionnaires, while secondary data for background processes were taken from the ecoinvent database [13].

Inventory data had to be allocated to the different products (milk and meat). Feed inputs (concentrate, grass silage, maize silage, alfalfa, corrector, straw, hay and grass) and direct livestock emissions to air ( $\text{CH}_4$ ,  $\text{N}_2\text{O}$  and  $\text{NH}_3$ ) were exclusively quantified for productive dairy cows and, consequently, they were entirely attributed to milk. However, for the remaining flows, individual allocation factors were computed for each farm according to milk and meat production rates and their respective economic turnovers. An average economic allocation factor of  $0.92 \pm 0.04$  was computed for milk.

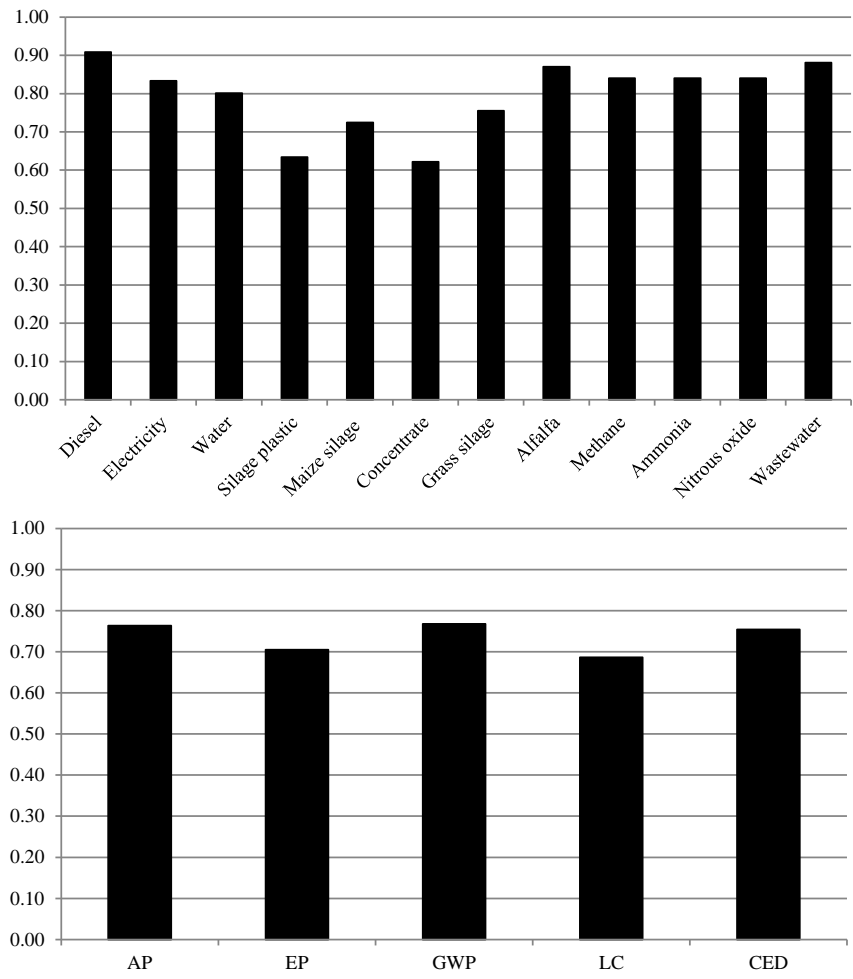
### **3 Results**

The LCIs of the dairy farms were implemented into SimaPro 7 to attain the environmental characterization (i.e., the LCIA) of each farm. Acidification (AP), eutrophication (EP), global warming (GWP), land competition (LC) and cumulative non-renewable energy demand (CED) were the categories evaluated. The first four categories were quantified through the CML method, while CED was evaluated according to Hischier et al. [14].

Additionally, the DEA matrix with the selected inputs and outputs was implemented into an optimization model. As a result, efficiency scores were computed (1 for the efficient farms, and  $< 1$  for the inefficient units) and target operating points defined. An input-oriented slacks-based measure of efficiency model with constant returns to scale was used, which led to a considerably high number of DMUs deemed efficient: 31 farms.

Moreover, the target operating points derived from DEA entailed a modification of the original LCI data, which resulted in new environmental characterization

values when performing the LCIA of each target facility. Thus, target environmental values were calculated. From a whole sample perspective, Figure 1 shows the ratio between target and current values for the operational items subject to minimization and the impact categories assessed. As inferred, average operational reductions ranged from 9% (for diesel) to 38% (for concentrate). If these operational reductions were achieved, then the average environmental improvement would range from 23% (for GWP) to 31% (for LC).



**Fig.1: Ratio target to current values for operational items and environmental impacts**

## 4 Discussion

Average current environmental impacts per litre of raw milk were 9.0 g SO<sub>2</sub> eq for AP, 4.3 g PO<sub>4</sub><sup>3-</sup> eq for EP, 7.7 kg CO<sub>2</sub> eq for GWP, 0.9 m<sup>2</sup>a for LC and 3.8 MJ eq for CED. These results are in accordance with previous literature in this field [2]. Moreover, coefficients of variation ranged from 18% to 31%, which stresses the appropriateness of having used an LCA+DEA approach since this procedure handles individual values rather than average data.

Furthermore, LCA+DEA approaches provide environmental studies with an economic perspective through the translation of the operational benchmarking into economic savings [8,10,12]. This potential significantly improves LCA capability for decision making. As regards dairy farming, relevant operational reductions for the inefficient farms should be accomplished by dairy farmers to attain an efficient operational performance that leads to a more profitable economic and environmental profile. The conversion of current and target operational values into economic figures according to market prices for the most relevant inputs led to estimate savings of up to 0.13 € per litre of raw milk for the 41 (out of 72) inefficient farms.

## 5 Conclusions

The application of the five-step LCA+DEA method to dairy farming proved to facilitate the computation of operational and environmental benchmarks for a wide sample of farms. When compared to the single use of LCA, the main advantages of LCA+DEA methodology include the avoidance of standard deviation concerns, the quantification of economic savings and the verification of the traditional eco-efficiency concept.

Above 40% of the Galician dairy farms were deemed efficient. Furthermore, for those facilities found inefficient, target operational values were benchmarked. The environmental characterization of the target operating points proved that efficient farming practices would lead to reduced impacts. In this respect, average operational reductions of up to 38% were found, which resulted in impact reductions above 20% for every category as well as in increased economic profits.

## 6 References

- [1] Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C, *Livestock's long shadow: environmental issues and options*, FAO, 2006.
- [2] de Vries M, de Boer IJM, Comparing environmental impacts for livestock products: A review of life cycle assessments, *Livestock Science*, Vol. 128, No. 1-3, 2010, 1-11.
- [3] Hospido A, Moreira MT, Feijoo G, Simplified life cycle assessment of Galician milk production, *International Dairy Journal*, Vol. 13, No. 10, 2003, 783-796.
- [4] <<http://www.fega.es>>, (Accessed 17.11.2010).
- [5] Iribarren D, Hospido A, Moreira MT, Feijoo G, Benchmarking environmental and operational parameters through eco-efficiency criteria for dairy farms, *Science of the Total Environment*, Vol. 409, No. 10, 2011, 1786-1798.
- [6] Lozano S, Iribarren D, Moreira MT, Feijoo G, The link between operational efficiency and environmental impacts - A joint application of Life Cycle Assessment and Data Envelopment Analysis, *Science of the Total Environment*, Vol. 407, No. 5, 2009, 1744-1754.
- [7] Iribarren D, *Life Cycle Assessment of mussel and turbot aquaculture - Application and insights*, University of Santiago de Compostela, 2010.
- [8] Vázquez-Rowe I, Iribarren D, Moreira MT, Feijoo G, Combined application of Life Cycle Assessment and Data Envelopment Analysis as a methodological approach for the assessment of fisheries, *The International Journal of Life Cycle Assessment*, Vol. 15, No. 3, 2010, 272-283.
- [9] Lozano S, Iribarren D, Moreira MT, Feijoo G, Environmental impact efficiency in mussel cultivation, *Resources, Conservation and Recycling*, Vol. 54, No. 12, 2010, 1269-1277.
- [10] Vázquez-Rowe I, Iribarren D, Hospido A, Moreira MT, Feijoo G. Computation of operational and environmental benchmarks within selected Galician fishing fleets (NW Spain), *Journal of Industrial Ecology*, 2011, in press.
- [11] Schmidheiny S, *Changing Course - A global business perspective on development and the environment*, World Business Council for Sustainable Development, 1992.
- [12] Iribarren D, Vázquez-Rowe I, Moreira MT, Feijoo G, Further potentials in the joint implementation of Life Cycle Assessment and Data Envelopment Analysis, *Science of the Total Environment*, Vol. 408, No. 22, 2010, 5265-5272.
- [13] Frischknecht R, Jungbluth N, Althaus HJ, Doka G, Heck T, Hellweg S, et al., *Overview and Methodology - ecoinvent report No. 1*, Swiss Centre for Life Cycle Inventories, 2007.
- [14] Hirschier R, Weidema B, Althaus HJ, Bauer C, Doka G, Dones R, et al., *Implementation of life cycle impact assessment methods - ecoinvent report No. 3*, Swiss Centre for Life Cycle Inventories, 2009.