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Economic Value of Greenhouse Gases and Nitrogen Surpluses: Society vs Farmers' Valuation

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Abstract

Livestock supply must challenge the growth of final demand in the developing countries. This challenge has to take into account its ecological effects since the dairy and livestock sectors are clearly pointed out as human activities which contribute significantly to environmental deterioration. Therefore, livestock activity models have to include desirable and undesirable outputs simultaneously. Using this perspective, we implement a Data Envelopment Analysis model to evaluate shadow prices of outputs under contradictory objectives between the society and the farmers. Our results highlight the current debate about the negative or positive shadow prices of the undesirable outputs in efficiency frameworks. Furthermore, we show that farmers are able to reduce pollution significantly if society accepts to balance farmers' opportunity cost. Finally, we observe that the initial levels of CO_2 tax are in line with farmers' valuation while the current tax evolution tends to reach the value of pollution targeted by the society.

JEL Classification: Q51, Q57

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1. Introduction

Since the beginning of the new century, there has been a proliferation of major reports regarding the collective awareness of the sustainability as well as the exploitation of natural resources (World Bank, 2008; Millennium Development Goals, 2008). These reports mainly emphasize the necessary changes in the use of natural resources as well as their impact on the environment including biodiversity, global warming, and water supply. Among the different sectors involved requiring attention is agriculture which appears to relate human activities to the environmental deterioration. Indeed, the Food and Alimentation Organization (Steinfeld et al, 2006) estimates that livestock is responsible of 18% of total anthropogenic emissions of greenhouse gases (GHG). Moreover, agriculture and livestock interfere directly in the nitrogen cycle and contribute for 70% in the 7-8 million tons of N_2O (Nitrous Oxide) anthropogenic emissions. This environmental impact of livestock production is more important as developing countries enter in a “nutritional transition” and increase their consumption of meat particularly beef as well as dairy. The challenge is to increase livestock production in order to meet the demand for beef and dairy products (enough to feed nine billion people in 2050) within the objective of sustainable production systems. One way for researchers to lead their research on sustainable development of livestock is to apply the methodological advances of the Data Envelopment Analysis (DEA) (Charnes et al., 1978). One of the major benefits is that DEA provides a tool to assess the whole production system and the different environmental impacts generated by the given technology.

Even though the classical DEA model is used to maximize outputs (given inputs) or minimize inputs (given outputs), Koopmans (1951) suggested that it is possible in a technology production to also generate undesirable outputs (Scheel, 2001). The mathematical formalization of the undesirable outputs integration in the DEA models have been subject to many debate (for example: Hailu and Veenman, 2001; Färe and Grosskopf, 2003; Kuosmanen, 2005).

Beyond the debates cited above, Kuosmanen and Matin (2011) demonstrate a dual formulation of a DEA model, via a rigorous integration of the weak disposability of the undesirable outputs and the introduction of a correlation factor between the desirable production and the undesirable. By applying the model of Kuosmanen and Matin (2011) on a data set of the dairy sector in La Reunion’s island (French overseas department in Indian Ocean), we aim to give an economic valuation of undesirable production. Given a close collaboration between economists and agronomists within the French national research agency program ("Environmental Efficiency and livestock productions for sustainable development"), a data set was provided that includes simultaneously production system data (milk production, labor, pasture land) and environmental indicators such as nitrogen balance.

A Life Cycle Assessment (LCA) provided the Carbon Footprint of the farms, expressed in equivalent CO_2 of all the greenhouse gases emitted. In order to quantify the varying appreciation of pollution from the point of view of two stakeholders in the dairy industry (farmer and society), we model a directional distance function to fit the different objectives sought. In the first part of the paper, we introduce briefly the methodological details needed to implement a DEA model with undesirable outputs and the specificity of a sectoral analysis (possibility of reallocation). In the second part, we focus on the data set and more specifically on the methodology used to generate the environmental indicators. Shadow prices for desirable and undesirable outputs are presented according to each models and stakeholders' point of view, and the absolute shadow values are derived comparatively to the market price of the milk in La Réunion. Finally, we demonstrate the profit for each stakeholder if the reduction of inefficiency is made coupled with a discussion on the case study. We conclude the paper with comments regarding the methodology used here as well as its applicability in future work of agronomy and economics.

2. Methodology and model choice

In the past, DEA linear programs often included undesirable outputs as inputs to minimize. However, this approach did not rigorously integrate the weak disposability assumption. Pittman (1983) addressed this issue by treating desirable and undesirable outputs separately. Färe et al. (1989) expanded on the Pittman's approach by proposing a new way to impose weak disposability. The imposition of weak disposability was achieved by replacing the classic inequality applied on undesirable outputs by an equality and a radial contraction factor (Färe et al., 1989). By assessing weak disposability in this way, good and bad outputs can only be reduced proportionately. Moreover, the equality used to treat undesirable outputs means that the shadow price of pollution can be either positive or negative in the dual formulation. Hailu and Veenman (2001) propose an alternative way to model the undesirable outputs and reintegrate the inequality on them treating bad outputs as inputs. Therefore the shadow price on bad outputs is non-positive (bad outputs are considered as a cost) which seems more intuitive. Färe and Grosskopf (2003) comment on this result by insisting on the necessity to model bad outputs with the weak disposability assumption as defined by Shephard (1974). This abatement parameter has been the object of a debate (Kuosmanen, 2005; Färe and Grosskopf, 2009; Kuosmanen and Podinovski, 2009) to determine if it must be firm specific or common to all firms.

Kuosmanen (2005) demonstrated that considering an individual abatement factor and a suitable substitution of variables allow the linearization of the envelopment program. In subsequent work, Kuosmanen and Matin (2011) suggest a dual formulation allowing an economical interpretation of weak disposability. We used this general approach and customize the model to analyze the relationship of good and bad outputs in the dairy sector of Reunion Island.

2.1 Model customization

The specification of our model is related to the scale of analysis. The objective is to assess the global environmental impact of the whole dairy sector in Reunion Island. We therefore conduct our analysis at an industry level by considering the industry technology as the sum of firms' technologies.

In the mathematical model, we considerate a set of N Decision Making Units (DMUs) producing G desirable outputs and B undesirable outputs with I inputs, associated with the following index sets:

$\aleph = \{1, \ldots, N\}$, $\mathcal{G} = \{1, \ldots, G\}$, $\mathcal{B} = \{1, \ldots, B\}$ and $\mathcal{I} = \{1, \ldots, I\}$
with, $\mathbf{y^G} = \left(y^1, \ldots, y^G\right) \in R_+^G$, $\mathbf{y^B} = \left(y^1, \ldots, y^B\right) \in R_+^B$, $\mathbf{x^I} = \left(x^1, \ldots, x^I\right) \in R_+^I$ the quantities of desirable outputs, undesirable outputs and inputs respectively.

With these notations, the production technology can be defined as:

$$T = \left\{\left(\mathbf{x^I}, \mathbf{y^G}, \mathbf{y^B}\right) \in R_+^{I+G+B} : \mathbf{x^I} \text{ can produce } \left(\mathbf{y^G}, \mathbf{y^B}\right)\right\} \tag{1}$$

To assess the efficiency of the sector and not the individual efficiency of each farm, we aggregate the N technologies (Li, 1995). It should be pointed here that sector efficiency is not directly equal to the sum of the individual efficiencies. At the sectoral level, resource reallocation is feasible among the most efficient firms, therefore, sector efficiency is always greater than the sum of individual firms' efficiencies. Formally, we consider the global dairy sector as a compound of N firms, each of them belonging to T. The aggregate technology is derived from the individual technology properties and can be expressed as the sum of theses individual technologies. Li (1995) further demonstrated that, under the convexity assumption, the aggregate technology of the sector is defined as in (2).

$$T^S = \sum_{n \in \aleph} T = N \times T \qquad (2)$$

We model a directional distance function used in the classical DEA assessment where undesirable outputs are considered. This function allows us to measure the inefficiency of a DMU with radial or non-radial distance according to the determined value chosen for each vector composing the directional distance function (DDF). In this case, we define our DDF as:

$$D(\mathbf{x^I}, \mathbf{y^G}, \mathbf{y^B}; \mathbf{d^G}, \mathbf{d^B}) = \sup\left\{\alpha \middle/ \left(\mathbf{x^I}, \mathbf{y^G} + \alpha\, \mathbf{d^G}, \mathbf{y^B} - \alpha\, \mathbf{d^B}\right) \in T^S\right\} \qquad (3)$$

And with: $\mathbf{d^G} \in R_+^G$, $\mathbf{d^B} \in R_+^B$

The DDF allows the specification of a non-zero direction vector $\left(\mathbf{d^G}, \mathbf{d^B}\right)$ which defines a direction for each DMU to be compared to the efficiency frontier. In our study, we used two specific directions to evaluate the efficiency of the dairy sector, considered under the point of view of two stakeholders: farmer and society. The modeling from these varying points of view is deduced by the different values of the directional distance vector relying on each stakeholder's motivation. Model specifications are detailed below.

Two options are possible for the modeling of bad outputs. First we can use the model of Färe et al. (1989) which uses an equality sign on the undesirable output in the primal formulation, which in turn corresponds to an unconstrained shadow price for the bad in the dual program. The possibility to have a positive price assigned to the bads has been criticized by Hailu and Veenman (2001). However they consider the bad as a usual input in order to achieve an inequality in the primal program and imposing a non-positive shadow price for the bad in the dual program. Our formulation takes on another approach namely that to keep bads as outputs we model the joint production between desirable and undesirable outputs explicitly while constraining the shadow price to be non-positive. We describe both formulations respectively in programs (4) and (5).

Unconstrained shadow prices of bad outputs

Primal

$$\max_{\lambda,\mu,\eta} \lambda$$

$$N\sum_{n\in\mathcal{N}} \mu_n y_n^g \geq \sum_{n\in\mathcal{N}} y_n^g + \lambda \delta^g \quad \forall g\in\mathcal{G} \quad (u_g)$$

$$N\sum_{n\in\mathcal{N}} \mu_n y_n^b = \sum_{n\in\mathcal{N}} y_n^b - \lambda \delta^b \quad \forall b\in\mathcal{B} \quad (v_b)$$

$$N\sum_{n\in\mathcal{N}} (\mu_n+\eta_n) x_n^i \leq \sum_{n\in\mathcal{N}} x_n^i \quad \forall i\in\mathcal{I} \quad (w_i)$$

$$\sum_{n\in\mathcal{N}} (\mu_n+\eta_n) = 1 \quad (u_g)$$

$$\mu_n \geq 0 \ \forall n\in N$$

$$\eta_n \geq 0 \ \forall n\in N$$

λ unconstrained

Dual

$$\min_{\delta,u,v,w} \delta - \left[\sum_{g\in\mathcal{G}}\left(u_g\sum_{n\in\mathcal{N}} y_n^g\right) + \sum_{b\in\mathcal{B}}\left(v_b\sum_{n\in\mathcal{N}} y_n^b\right) - \sum_{i\in\mathcal{I}}\left(w_i\sum_{n\in\mathcal{N}} x_n^i\right)\right] \tag{4}$$

$$N\left(\sum_{g\in\mathcal{G}} u_g y_n^g + \sum_{b\in\mathcal{B}} v_b y_n^b - \sum_{i\in\mathcal{I}} w_i x_n^i\right) \leq \delta, \ \forall n\in\mathcal{N} \quad (\mu_n)$$

$$N\left(-\sum_{i\in\mathcal{I}} w_i x_n^i\right) \leq \delta, \ \forall n\in\mathcal{N} \quad (\eta_n)$$

$$\sum_{g\in\mathcal{G}} u_g \delta^g + \sum_{b\in\mathcal{B}} v_b \delta^b = 1 \quad (\lambda)$$

$$u_g \geq 0, \ \forall g\in\mathcal{G}$$

v_b unconstrained, $\forall b\in\mathcal{B}$

$$w_i \geq 0, \ \forall i\in\mathcal{I}$$

δ unconstrained

Non-positive constrained shadow prices of bad outputs

Primal

$$\max_{\lambda,\mu,\eta} \lambda$$

$$N\sum_{n\in\mathcal{N}} \mu_n y_n^g \geq \sum_{n\in\mathcal{N}} y_n^g + \lambda \delta^g \quad \forall g\in\mathcal{G} \quad (u_g)$$

$$N\sum_{n\in\mathcal{N}} \mu_n y_n^b \leq \sum_{n\in\mathcal{N}} y_n^b - \lambda \delta^b \quad \forall b\in\mathcal{B} \quad (v_b)$$

$$N\sum_{n\in\mathcal{N}} (\mu_n+\eta_n) x_n^i \leq \sum_{n\in\mathcal{N}} x_n^i \quad \forall i\in\mathcal{I} \quad (w_i)$$

$$\sum_{n\in\mathcal{N}} (\mu_n+\eta_n) = 1 \quad (u_g)$$

$$\mu_n \geq 0 \ \forall n\in N$$

$$\eta_n \geq 0 \ \forall n\in N$$

λ unconstrained

Dual

$$\min_{\delta,u,v,w} \delta - \left[\sum_{g\in\mathcal{G}}\left(u_g\sum_{n\in\mathcal{N}} y_n^g\right) + \sum_{b\in\mathcal{B}}\left(v_b\sum_{n\in\mathcal{N}} y_n^b\right) - \sum_{i\in\mathcal{I}}\left(w_i\sum_{n\in\mathcal{N}} x_n^i\right)\right] \tag{5}$$

$$N\left(\sum_{g\in\mathcal{G}} u_g y_n^g + \sum_{b\in\mathcal{B}} v_b y_n^b - \sum_{i\in\mathcal{I}} w_i x_n^i\right) \leq \delta, \ \forall n\in\mathcal{N} \quad (\mu_n)$$

$$N\left(-\sum_{i\in\mathcal{I}} w_i x_n^i\right) \leq \delta, \ \forall n\in\mathcal{N} \quad (\eta_n)$$

$$\sum_{g\in\mathcal{G}} u_g \delta^g + \sum_{b\in\mathcal{B}} v_b \delta^b = 1 \quad (\lambda)$$

$$u_g \geq 0, \ \forall g\in\mathcal{G}$$

$$v_b \leq 0, \ \forall b\in\mathcal{B}$$

$$w_i \geq 0, \ \forall i\in\mathcal{I}$$

δ unconstrained

In the primal formulation of the two programs, the endogenous variables are λ, μ and η. y^g, y^b and x^i represent the data on quantities corresponding respectively to the amount of milk produced, undesirable outputs: nitrogen surplus, greenhouse gases, and inputs: cattle, feed, labor, and land. As we explained above, the model is a sectoral analysis and it explains why we evaluate the sectoral DMU defined as the sum of individual DMUs

$\left(\sum_{n\in N} y_n^g, \sum_{n\in N} y_n^b, \sum_{n\in N} x_n^i\right)$ in the right hand side (RHS) of the DEA linear program. The primal program seeks to maximize the good output while minimizing the bads through the λ variable. Parameters d^b and d^g are the components of the directional distance vector, chosen to fit stakeholder's point of view in inefficiency reduction. Specification of the directional distance vector will be discussed in the next subsection but we note that both the directions chosen for society and farmer are output-oriented models.

On the left hand side (LHS), the technology is defined as linear combinations of existing DMUs through the μ variable. The sectoral technology we use is defined as the sum of the individual technologies and equal to N times the individual technology, since the latter is convex. The η variable is used to model the jointness of the production of good and bad outputs even if after some transformations it relies on the input constraint (see Kuosmanen and Matin (2011) for the linearization of this technology). As stated above, our model is defined under a variable returns to scale assumption (VRS).
In the dual formulation, u, v, w are endogenous variables and correspond to the shadow prices related to the constraints of the primal program. The d is a variable which can be interpreted as the maximum shadow profit. As in the primal model, our variables are given by our dataset. In the dual, the objective function seeks to minimize the difference between the evaluated shadow profit for the sector and the optimal profit by finding the best shadow prices for outputs and inputs.

Comparison of (4) and (5) highlights the impact of choosing either an inequality or an equality on undesirable outputs in the primal formulation. Actually, we see that the equality in the primal program in (4) implies that v_b is unconstrained in the dual version, while the inequality in the primal program in (5) imposes non-positivity of v_b in the dual formulation. In order to explore the consequences of this difference, we present in subsection 3.1 (Table 2) the results of each model.

The models presented in (4) are very close to Kuosmanen and Matin (2011) but with the main difference that they are defined at the sectoral level. The models given in (5) allow us to impose the non-positivity constraint of the shadow price on bad outputs. In the latter case the value related to the bads is considered as a cost, which is more intuitive. For estimation purpose these models have been implemented in GAMS (GAMS 23.4.) and are available upon request.

2.2 Context of the dairy sector and stakeholder's point of view to reduce inefficiency

The data used in our study were derived from dairy herds on Reunion Island (an overseas Department of France located off the east coast of Madagascar Island). The island has a rapidly expanding dairy industry located in distinct geographic region all at altitudes which result in a temperate climate suitable for dairy production. As the milk yield increased quickly (mainly due to genetic and feeding improvements), new structures appeared in the sector including agricultural development, supply, and technical support which in turn led to technical sophistication and increase in the dairy production. Simultaneously, a strong population growth significantly increased the demand in dairy products. In 2006 at its highest level, the dairy sector produced 24.6 million liters of milk and supplied 15% of the local demand. In 2007, the milk production has decreased to less than 20 million liters and 10 % of the farmers have stopped dairy farming.

Due to chronic shortage of forage, high proportions of concentrate are generally incorporated into the diets of lactating cows (i.e. 40–70%). As all of the raw materials used to make feeds are imported, the carbon footprint allocated to livestock production increase as feeds supplies increase (obviously because transportation requires fossil fuels that increase the amount of CO_2 in the atmosphere).

Thus, stakeholders must face the challenge of recovering the growth in milk production within the context of societal concern for environment standards. As we described it in the previous section of this paper, we have decided to analyze the objectives of the two stakeholders differently in order to increase the economic and environmental efficiencies of the dairy farms in La Réunion. We can summarize our hypothesis for each stakeholder so as to understand why each of the specifications of the directional distance vector specified in (4) is derived.

Farmer's perspective. The main economic issue for the farmers (heavy feed charges, land scarcity, structural debt) is production optimization for increasing profits. We assume that they only attempt to increase milk production by increasing productivity without increasing undesirable outputs. However, because there are no penalties or advantages to better manage the pollution related to production, they have no interest to decrease pollution levels. In this context, for the sector, the projected direction to the efficiency frontier can be expressed as follows:

$$\left(\mathbf{d^g}, \mathbf{d^b}\right) = \left(\sum_{n \in \aleph} y_n^g, 0\right) \qquad (6)$$

Society perspective. We assume that society only seeks to minimize the various impacts of agricultural activities on environment, i.e. decrease the emissions of GHG or nitrogen surpluses generated by livestock production and preserve tourism attraction, water quality and landscapes. This objective must not be in contradiction with dairy activities and the quantity of labor generated by the dairy industry. So, the direction chosen for society is to minimize the bad output production while maintaining the level of production of the desirable output:

$$\left(\mathbf{d^g}, \mathbf{d^b}\right) = \left(0, -\sum_{n \in \aleph} y_n^b\right) \qquad (7)$$

2.3 Environmental indicators methodology

Two undesirable outputs are considered in this paper: the nitrogen surpluses and the amount of GHG. The emission of GHG has become a very sensitive subject as a de facto tradeoff between economic growth and environmental protection. The amount of GHG emitted by each study farms was estimated using a life cycle assessment approach (Thevenot et al., 2011). We use the method PLANETE (Bochut et al, 2010), based on the ISO standards 14040 specific of Life Cycle analysis to allocate emissions, define the system boundaries, and the time scale. Even though it is common to use the term “Carbon Footprint” when only GHG are considered in an environmental impact analysis, we use the term LCA in this paper, because Carbon Footprint is a special case of LCA provide by PLANETE. Using this method allows us to quantify the major GHG emissions associated with dairy farming (including those related to the production and transport of inputs like fertilizer, pesticide, and feed), namely, carbon dioxide, methane and nitrous oxide, and included all animals related to milked cows, including replacement animals and calves. The GHG amounts are set to the unity of equivalent CO_2 (eq. CO_2) as a function of their "global warming power" (PRG). Based on various energy coefficients and emissions factors specific to each livestock production, the environmental indicators are used to determine the value of environmental degradation in the case of Reunion Island.

The second environmental indicator elaborated from our dataset is the whole-farm nitrogen balance, defined as the difference between farm nitrogen exports and imports. The nitrogen balance is apparent since nitrogen losses by leaching in soil and gaseous emissions are not taken into account. Nitrogen remaining on farm is considered in this study as a bad output as it results in releasing nitrogen into the environment (groundwater pollution) and increased costs for management, and as such it is often used as an environmental indicator in efficiency analysis (Reinhard, 1999).

2.4 Data set description

Detailed data on 51 dairy farms were gathered in 2007 from accounting available from a local management center. The sample covered 49% of the entire dairy farm population and accounted for 60% of the milk production collected in 2007 by the dairy sector (14.6 billion liters of milk). The sample was compiled by experts to be representative of the diversity in dimensions (including land endowments, herd, and milk production) (Alary et al., 2002).

In addition to the undesirable outputs already defined above, the technology production is characterized by a desirable output: the milk production. Although farmers optimize their production system with different kinds of outputs (agro-tourism, meat, and forage), we consider only milk production in our study as it accounted for a large part of the farmers' income.

Four relevant inputs were considered, land endowment, herd size, food charges and active labor. Land endowment (hectares) includes the forage crops surfaces, grassland and surfaces of buildings (barn, milking parlour…). Herd size was expressed in livestock unit (LU) i.e. adult cow equivalent, on the basis of live weight, in order to facilitate the aggregation of livestock from various ages, not only cows in lactation (one dairy cow is one LU while an heifer under 1 year old is 0.3 LU). Feed charges were expressed in kilograms (Kg) of dry matter and took into account both concentrates and fodder purchased by the farmer. Active labor on the farm was given in working hours and included the farmer and his associates, his family and the internship student in agricultural school. Descriptive statistics and the units of measurement are given in table 1.

Table 1
Data sets: units and descriptive analysis (n=51)

Input (x) / Output (y)	Units	Mean	Standard deviation	Min	Max
Milk production (MP) : y^g	Tons of milk	285.8	140.5	83.7	669.4
Nitrogen surplus (NS) : y^{b1}	Kg of nitrogen	6090.8	3673.5	1371.5	21780.4
Greenhouse gases (GHG) : y^{b2}	Tons of gas (eq. CO_2)	488.4	244.1	148.6	1149.6
Adult bovine unit (LU) : x^1	Livestock unit	61.4	26.3	27	131.2
Feed charges (FC) : x^2	Tons of dry matter	231.9	114.1	69.19	525.1
Total labor (L) : x^3	Total labor (h)	7414.8	3398.2	2190	18158
land endowment (LE) : x^4	Surface (Ha)	22,2	16,0	3	72

The indicators in Table 1 and, in particular, the standard deviations show that the sample reflected the large diversity of farms on the island, also in term of size. Along with heterogeneity in production, we also note a similar heterogeneity in nitrogen surpluses and greenhouse gases emissions. The variation of the size of farms is taken into account in our DEA framework because we use a variable returns to scale model which controls for the size of DMUs.

3. Results

3.1 Shadow price of undesirable outputs according to stakeholder's points of view and models used

The two models we specified above have been computed to test the two stakeholders' points of view and the influence on the price of desirable and undesirable outputs. We also illustrate in Table 2 the results obtained if the price of the undesirable outputs is constrained i.e., if an inequality was specified in the primal model.

Table 2
Shadow price of the undesirable outputs expressed in % of the milk shadow price

	Model without constraint on undesirable outputs price (4)		**Model constraining a non-positive price (cost) of undesirable outputs (5)**	
	Nitrogen surplus	Greenhouse gas	Nitrogen surplus	Greenhouse gas
Farmer	0.62%	-6.73%	0%	0%
Society	-5.34%	-40.86%	-5.34%	-40.86%

For example, if the price of the milk is 100€ per ton, the cost of the Nitrogen Surplus for the society is 5.34 € per Kg.

As shown in Table 2, the results for the society are similar irrespective of which model is used. Conversely, we observe a major difference in the farmers' point of view which is due to whether or not the constraint on the price of undesirable outputs is specified in the linear programming problem. When price is not constrained, nitrogen output results in a positive price. This means that there exist valuations or worth attached to this undesirable output. Other shadow prices are negative indicating costs for the farmer or the society. In this model, we also observe that one ton of greenhouse gases costs the farmer 6.7 % of the ton of milk value. In other words, if he has to pay for the production of GHG, he would have to increase the price of milk or reduce charges to keep the same milk price and pay the GHG emissions. Since price cannot be positive, we interpret that model assigns a zero price for nitrogen production.

Given this interpretation, the set of prices for desirable and undesirable outputs and the global score of the program are changed. Thus, the price of the GHG is impacted by the model structure and hence this output does not incur further costs to the farmer. The positive price of nitrogen appears to be counter-intuitive and therefore, we refer back to the definition of nitrogen surplus to explain this finding. The nitrogen surplus is the difference between all inputs and outputs on farm. A positive balance or surplus reflects inputs that are in excess resulting in diffuse pollution through the loss of nutrients to bodies of water, to air as ammonia and other greenhouse gases. But, the positive valuation of this output allows us to explore a new hypothesis. The nitrogen "lost" can, for example, be stocked in soil and be released later through the forage production. The manure many farmers used to fertilize their forage crops almost never appears in the nitrogen balance. We can also assume that nitrogen has been stocked in a manure pit throughout the year and again does not account for the nitrogen output of the year. The valuation of a nitrogen surplus can also be explained by capitalization of dairy cow or other livestock. Buying replacement animals constitute an important input in nitrogen and it results a high nitrogen surpluses. However, this nitrogen will be rentable for the production system as it allows an increase in milk production in later time periods. Again, we can only apply this case from the farmers' point of view because his only objective is to increase the milk production with an inefficiency reduction of his production system. In other words, the nitrogen presents in the farm (nitrogen surpluses) will be optimized and used most efficiently (this way, the NS is positively appreciated).

Conversely, society focuses on a pollution reduction and has no interest in valuing nitrogen in this production process. Our findings (Table 2) demonstrate that society places a higher price on pollution than the farmers. This result makes intuitive sense as the undesirable outputs are the only direction chosen by the society to assess the inefficiency of the sample.

3.2 Market price of milk and cost of the pollution

The prices shown in Table 2 are relative prices indexed on the milk price calculated by the DEA linear program. In Réunion Island, the price paid to the dairy farmers for fresh milk does not depend on fat and protein content but is indexed to microbiological quality. Since cases of penalties were unusual, we considered that the price of milk was unique for all farmers, i.e. 0.56€ (approximately 0.73$) per liter of milk. With this specification, the set of prices can be described as in Table 3 which presents the findings using the model with the undesirable output price unconstrained.

Table 3
Estimated shadow prices of nitrogen surplus and greenhouse gas based on the market milk price in Reunion Island

	Milk (€/T)	**Nitrogen surplus (€/Kg)**	**Greenhouse gas (€/Ton)**
Farmer	560.00	3.45	-37.69
Society	560.00	-29.93	-228.83

From the farmer's point of view we find similar results as given in Table 2, i.e. each Kg of nitrogen surpluses earned the farmer an additional 3.45 € (Table 3). This finding can be interpreted as the value of the nitrogen potential stock on the farm.

Unlike farmers, society assigns the highest price to the greenhouse gases (-228.83 €/Ton versus -37.69 €/Ton). Our finding highlights society's value for decreasing pollution and the relatively minor importance given by farmers who focus on the dairy production.

3.3 Potential economic improvement under the two points of view

Table 4
Potential economic gain according to objectives in inefficiency reduction

	Milk(€)	Nitrogen Surplus (€)	Greenhouse gas (€)	Potential profit (PP)(€)	PP/ turnover
Farmer	2,306,401			2,306,401	28.25%
Society		4,235,848	2,597,236	6,833,085	83.70%

The economic gain for each point of view shows that society could have the maximum profit increase with a decrease in NS and GHG emissions (Table 4). The profit improvement in this case represents 83.7% of an approximate turnover of the sample (total of the milk income, i.e. total milk production × 0.56€). From the farmer's point of view, we observe a small profit increase only if he does not have to pay for pollution and if his only objective is to optimize his production by improving efficiency in his production system.

We can also propose an interesting interpretation of these findings (Table 4). The farmer can legitimately improve profits by 28.25% of the actual turnover if he does not have to pay any fee for pollution produced on his farm. If society reduces the inefficiency through an undesirable outputs decrease, its profit increases by 6,833,085 € which in turn enable to pay 2,306,401€ to farmers as compensation. This compensation could be interpreted as an opportunity cost for the farmer in lost profits from not increase milk production but without any obligation to pay a pollution emissions fee. In terms of economics welfare, this trade-off between society and the farmer is Pareto Efficient.

3.4 Comparison with observed CO_2 prices in industrial countries

In table 5, we compare our results with different CO2 tax rates observed in two European countries. Sweden is one of the most sensitive European countries to environment issues. In 1991, a tax on CO2 is established at 27€/ton, which is equivalent to the current evaluation of the price of CO2 by a French expert group (Quinet, 2009). This value is close to our results obtained for the farmer's point of view. Currently, the price of CO_2 in Sweden is 114€/Ton whereas the price of CO2 in France is projected to reach 100€/Ton in the next twenty years. These prices are similar to those observed in our study from society's point of view.

To generate appropriate comparisons between Réunion Island and France, we calculated the price of greenhouse gases in Réunion using the milk price recorded in France (Table 5). The GHG price obtained in this way is closer to the observed price. However, this price is not realistic given the breeding context in Réunion (inputs imported, land scarcity).

Table 5
Estimated price of CO_2 and observed price in European countries (negative prices indicate taxes or pollution costs)

	Estimated CO2 price(€/Ton)			**Sweden (€/T)**[**]		**France(€/T)**[***]	
	Milk price 0.56€/L	Milk price 0.33€/L[*]	**Year**	1991	2011	2010	2030
Farmer	-38	-22		-36/-38[****]	-114	-32	-100
Society	-229	-134					

[*] *Average milk price for farmers in France (FranceAgrimer Report 2011).*
[**] *CO_2 tax rates (Ministry of the Environment Sweden report: 20 years of carbon pricing in Sweden 1991-2011).*
[***] *Recommended level of the CO_2 tax rates (Quinet, 2009).*
[****] *The current price was 27 € in 1991 prices. We express here this price in 2010 prices.*

4. Concluding remarks on methodology and undesirable outputs in agronomy

Many studies (Lozano et al, 2009; Vazquez-Rowe et al, 2010) have explored the combination of the life cycle analysis (LCA) and the Data Envelopment Analysis. Thanks to a close collaboration between economists and agronomists we are able to develop a DEA methodology incorporating undesirable outputs. As the different stakeholders of an economic sector rarely agree with the different way to raise efficiency, we demonstrated via the directional distance function that these two points of view can be reconciled (Boussemart et al., 2011). Indeed, win-win situations are frequently highlighted in eco-efficiency as inefficient firms can improve their eco-efficiency by a reduction of undesirable outputs, given their levels of inputs and desirable outputs (Picazo-Tadeo et al., 2011). Van Meensel et al. (2010) also emphasize the economic-environmental win-win situation for pig finishing by simultaneously reducing nitrogen emission and production cost thanks to feed conversion. In this context, our results (Table 4) underline the role of stakeholder's point of view in implementing prices on undesirable outputs in a win-win perspective. Differences between stakeholder's objectives turned out to be very significant as the price of nitrogen surpluses vary from a value of 3.45€/Kg to a cost of 29.93€/Kg and the greenhouse gases vary from 37.69€/Tons to 228.83€/Tons. These results could be a powerful tool for livestock development as stakeholders assess, ex-ante, the impact of their perspective on the reduction of the inefficiency. Indeed, they assign different prices on undesirable outputs especially if livestock systems incur high pollution costs.

This paper also highlights the methodological issue associated with undesirable outputs in the DEA program. As undesirable outputs are defined as pollution, it appears that there should be a constraint on their prices in the dual formulation of the problem which is equivalent to an inequality constraint in the primal program. Thus, the program can only calculate a positive price, synonym to a cost for the DMU.

4.1 Undesirable outputs in Agronomy

Our findings illustrate that undesirable outputs must be treated carefully, especially in the agronomic research. We point out that even though nitrogen surpluses are considered as pollution, it also can be stocked in a pit or even in the soil and then be applied later in the production process. The nitrogen flows are subject to very different practices in the livestock production system and it makes them difficult to treat in the optimization model. Many studies demonstrated that organic manure plays a significant role in the crop-livestock systems in Africa (Landais, 1993). Therefore, assigning prices to organic material as a natural fertilizer or as pollution requires more finesse in allocating nitrogen as either a positive input or undesirable output. The nitrogen balance could be improved in farm by integrating nitrogen surpluses in soils for regeneration and/or stocking them for a postponed use. If the price of GHG is correctly defined as in our case study, the same issue could occur with the valuation of methane emission of livestock as in the biogas industry. The reflection on GHG global assessment in dairy farm is currently extended to the CO_2 sequestration by grassland. The DEA approach could be implemented to this whole-farm analysis.

4.2 Price of carbon dioxide

Estimation of CO_2 price has become a major research topic since the third conference of the parties to the UNFCC established Kyoto's Protocol in 1997. In order to achieve the GHG reduction prescribed by the Protocol, environmental taxes were expected to be a promising approach to motivate firms to become more environmentally friendly. A first approach to assess the GHG impact on the global warming was to try to quantify these impacts including measures of sea-level rise, ocean acidification, and extreme weather, but this approach promptly appeared unwieldy. Another approach could include focusing on one measure such as carbon dioxide. However, even on one measure, Ha-Duong (2009) demonstrated that different concepts of CO_2 prices can vary based on the chosen approach (avoided climate change price, cost of CO_2 reduction, social value of CO_2, shadow price and market price). In our paper, a shadow price of CO_2 is measured thanks to an activity analysis framework. Compared with the Färe et al. (1993) initial approach in which case both an output distance and revenue functions were used to derive CO_2 shadow price, our framework relies on the specification of stakeholder's preferences thanks to different directions.

We also expand on Färe et al. (1993) and the subsequent work of Harkness (2006) wherein the authors identified the mean value of CO_2 emissions cost 30.25 €. Gupta (2005) also evaluated the price of CO_2 reporting higher costs of between 57.39 € and 80.7 € (according to model specificity).

In contrast to these results, we have explored two extremes valuation of CO_2 by choosing specifically the undesirable output direction (society's point of view) or the desirable output direction (farmer's point of view), respectively 37.69 € and 228.83 €. Of course society is assumed to focus on GHG emissions reduction and gives high value to GHG emission while farmers who wish to increase milk production evaluate at a lower level the undesirable outputs. Regarding environment policy of two European countries (Table 5), Sweden (early invested in eco taxes) and France (a country which has not implemented yet carbon tax), a global tendency can be highlighted. It seems that government establishes CO_2 tax preferentially under the farmer point of view. In other words, they evaluate the price of CO_2

in accordance to a milk production raise. Nevertheless, the evolution of the CO_2 price tends to reach the price given by the society in our study which appears to be the real optimum price. In 2006, the energy agency of Sweden estimated a reduction of 2.5 billion tons in greenhouse gases emission (Millock, 2010), comparing to a non-CO_2-tax scenario. Scandinavian countries have demonstrated that environmental taxes were not contradictory to economic growth, and instead they could generate considerable incomes (5.8 billion euros in 2007 in Sweden). As discussed earlier, win-win situations are possible and result from environmental tax policies. For instance, environmental taxes are compensated by a decrease in labor taxes inducing this way unemployment reduction (Speck, 1999). Overall, regarding the new FAO's (2011) recommendations on livestock efficiency and food security, our study emphasizes the dual economical interpretation of dairy production productivity by taking into account the cost of undesirable emissions. In the ongoing debate about the inequity of environmental taxes between developing and developed countries (Chapman and Khanna, 2000), our paper shows that combination of Life Cycle Assessment and frontier analysis is a promising approach to define ranges of undesirable outputs costs in different agronomic context.

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