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Finding the right compromise between productivity and environmental efficiency on high input tropical dairy farms: A case study

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ABSTRACT

This study focused on the trade-off between milk production and its environmental impact on greenhouse gas (GHG) emissions and nitrogen surplus in a high input tropical system. We first identified the objectives of the three main stakeholders in the dairy sector (farmers, a milk cooperative and environmentalists). The main aim of the farmers and cooperative's scenarios was to increase milk production without additional environmental deterioration but with the possibility of increasing the inputs for the cooperative. The environmentalist's objective was to reduce environmental deterioration. Second, we designed a sustainable intensification scenario combining maximization of milk production and minimization of environmental impacts. Third, the objectives for reducing the eco-inefficiency of dairy systems in Reunion Island were incorporated in a framework for activity analysis, which was used to model a technological approach with desirable and undesirable outputs. Of the four scenarios, the sustainable intensification scenario produced the best results, with a potential decrease of 238 g CO_2-e per liter of milk (i.e. a reduction of 13.93% compared to the current level) and a potential 7.72 L increase in milk produced for each kg of nitrogen surplus (i.e. an increase of 16.45% compared to the current level). These results were based on the best practices observed in Reunion Island and optimized manure management, crop–livestock interactions, and production processes. Our results also showed that frontier efficiency analysis can shed new light on the challenge of developing sustainable intensification in high input tropical dairy systems.

1. Introduction

Milk production has been increasing steadily for the last 50 years. The United Nations reported an increase in world production from 344.2 million metric tons (MMT) in 1961 to 719.2 MMT in 2010 (FAOSTAT, 2013) representing an average annual growth rate of 1.51%. Boosted by livestock production policies, this increase followed the world demographic growth trend (1.69% per year) over the same period (United Nations, 2010). In the past, livestock production policies were mainly assessed using an efficacy criterion defined as the ratio of observed production to the production targets. More recently, the expected continuous growth of livestock production linked with population growth trends (i.e. a predicted world population of nine billion in 2050) has been called into question in major reports due to potential environmental deterioration. A Food and Agriculture Organization report (FAO, 2010) including a life cycle assessment pinpointed the significant amounts of greenhouse gas (GHG) emissions caused by the dairy sector (from 1.3 to 7.5 kg CO_2-e per kg of fat and protein corrected milk). In the Millennium Ecosystem Assessment (MEA, 2005), nitrogen was also identified as a major issue in livestock production, since the nutrient balance is generally positive (nitrogen leaks into the natural environment) in industrialized countries, whereas it is

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mostly negative in South America and Africa (decline in soil fertility; Cobo et al., 2010). Finally, the MEA identified 15 ecosystem services out of the 24 that are threatened, mainly by the worldwide intensification of agriculture that is causing global warming, pollution, and over-exploitation (Steinfeld et al., 2006). More specifically, the dairy sector is characterized by high costs for both storage and transport due to the high perishability of milk (Knips, 2005). These costs have a significant impact on life cycle assessment. On the other hand, milk production is also a steady source of income and milk products are a source of nutrients for 750 million people, mainly in developing countries, and production is expected to increase by 25% in these countries by 2025 (FAO, 2013).

The efficient use of inputs in the production process and the mitigation of the potential negative environmental impacts of dairy production consequently raise a number of questions. We define efficiency as the achievable maximum output from a given level of inputs, or alternatively, the minimum level of inputs needed to produce a given level of outputs. In addition, a distinction can be made between good/desirable outputs, i.e. those that produce a positive income, and bad/undesirable outputs such as detrimental emissions, that have to be considered as social costs. The FAO recently published its “Global Agenda of Action in Support of Sustainable Livestock Sector Development” in which one of the three main themes was “Closing the Efficiency Gap”. In it, the FAO (2012a) states that “Initially, a Global Agenda of Action will focus on the improvement of resource-use efficiency in the livestock sector to support livelihoods, long-term food security and economic growth while safeguarding other environmental and public health outcomes”. Clearly both productivity and environmental efficiency have to be taken into account in the assessment of current policies, and the best solution would be a continuous increase in milk production with a concomitant decrease in undesirable environmental impacts, in a process called “sustainable intensification” of dairy systems as defined by Godfray et al. (2010).

In this paper, we propose an activity analysis model (Koopmans, 1951; Baumol, 1958), which models a production process that transforms a set of inputs into good and bad outputs. Our framework allows us to include the main features of the dairy sector. First, as underlined by the FAO in “Closing the efficiency gap”, the bulk of producers continue to use practices that are often extremely inefficient. We consequently wanted a frontier estimation that identifies the best observed practices compared to more standard and econometric approaches. Second, since the dairy production process is clearly multi-dimensional, inputs such as cattle, feed, land, labor or capital need to be linked with good outputs such as milk, and with bad outputs including GHG emissions and nitrogen surplus. We therefore needed an approach that made it possible to include this multi-dimensionality in a model setting based on physical quantities without using a dual framework in which prices are needed to perform cost benefit analyses. Following Farrell (1957), who proposed an applied framework for the activity analysis model of Koopmans (1951), Data Envelopment Analysis[1] (DEA) was shown to be an appropriate way to estimate production frontiers. In DEA, bad outputs can be easily included as a joint product of milk output, and therefore play an active role in the efficiency measurement.

Finally, the model also includes the role of the stakeholders in the dairy sector. We identified three stakeholders, who, in the model, are named ‘Farmers’, a dairy ‘Cooperative’, and ‘Environmentalists’, whose objectives and behaviors differ with respect to productivity and environmental issues. These three stakeholders are representative of the current attitudes to livestock production in Reunion Island. While farmers want to increase their income because of the high price of inputs, the cooperative primarily wishes to increase local production and is ready to encourage farmers to use more inputs. Moreover, as emphasized by Knips (2005), cooperatives play a very particular role in the dairy sector. As most individual farmers would be unable to produce enough milk to directly supply a processing plant, dairy farmers have to sell their milk to a cooperative that pools the milk and transports it to the processing plant. In return, the cooperative guarantees farmers their daily production will be purchased. This specific characteristic of the dairy cooperatives explains why we chose to include the cooperative's scenario in our paper. On the other hand, the environmentalists wish to limit the impact of livestock production on the environment, which is also expressed as an economic objective to protect tourism, this being based on a unique natural environment (Reunion Island is on the UNESCO World Heritage list). Schematically, each scenario can be described as a different livestock development pathway rooted in the particular features of the dairy sector in Reunion Island:

- To increase the efficiency of livestock production to achieve a higher level of productivity despite the high cost of inputs imported into Reunion Island, and land scarcity (the Farmers' scenario).
- To promote the economic development of the livestock production sector and develop dairy systems to increase local milk production (the Cooperative's scenario).
- To increase the attractiveness of Reunion Island to tourists based on its remarkable natural assets and, to this end, limit the environmental externalities of livestock production as much as possible (the Environmentalist's scenario).
- To explore a possible compromise approach to livestock production that can satisfy both the need to preserve the environment and fulfill the demand for dairy products with local production (sustainable intensification scenario).

By considering specific objective functions for each stakeholder, we designed different scenarios to analyze the trade-off between production and environmental concerns. In addition to the behavior of the three stakeholders, we also modeled a sustainable intensification scenario, with an increase in milk production combined with minimization of its environmental impacts. Our model setting relies on the use of directional distance functions and undesirable outputs in frontier efficiency models like those developed by Picazo-Tadeo and Prior (2009), Macpherson et al. (2010), Picazo-Tadeo et al. (2012) or Yu-Ying Lin et al. (2013).

Here we describe the application of the model to the dairy sector in Reunion Island, a French overseas region located in the Indian Ocean. Since the creation of the milk cooperative in 1962, milk production in Reunion Island has increased steadily in response to the growing local demand for local products, mainly driven by genetic improvement, specialized production systems, and the increasing use of feed concentrate. Reunion Island's dairy system is an interesting case as it is representative of the high input systems that are currently emerging in tropical regions. Because it is small, Reunion Island also has to face serious environmental concerns such as natural resources conservation, land scarcity, and ecosystem weaknesses due to the fact it is an island. Reunion Island thus provides an ideal opportunity to analyze the interplay of stakeholders' objectives and to find a satisfactory compromise between productivity and environmental efficiency using a DEA model that explicitly considers milk production and the associated GHG emissions along with nitrogen surplus.

[1] For an introduction to Data Envelopment Analysis, we refer the reader to Fried et al. (2008).