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An efficiency-based concept to assess potential cost and greenhouse gas savings on German dairy farms

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ABSTRACT

This article investigates potential savings of costs and greenhouse gas (GHG) emissions for a sample of 216 dairy farms in northern Germany using Data Envelopment Analysis. Tradeoffs between a cost-efficient and a GHG-efficient production are identified. For this purpose, an environmental-economic farm model is used, which allows 'pricing' the input with market prices and CO_2 equivalents, respectively. Uncertainty of CO_2 equivalents and volatility of input prices are taken into account and therefore efficiency scores are in the form of ranges. The results reveal that the sample farms are more GHG-efficient than cost-efficient. We estimate potential cost savings between 37.2% and 57.4% and potential savings in GHG emissions between 24.9% and 41.3%. Cost and GHG emission reductions are complementary across a wide range: by moving from the status quo to cost-efficient production, at least 87.5% of the GHG saving potential would be tapped. Unlocking the remaining reduction potential comes at a shadow price (abatement cost) of about €165/t CO_2 equivalent. From an input allocative point of view, a change from cost-efficient production to GHG-efficient production requires reductions in nitrogen use and an extension of diesel use. Compared to the sample average and the cost-efficient farms, GHG efficient dairy farms are characterized by a higher share of legumes and a longer effective lifetime of cows.

1. Introduction

Environmental protection, efficient use of resources and reduction of greenhouse gas (GHG) emissions (carbon dioxide, methane and nitrous oxide) belong to the prominent economic, environmental and socio-political objectives in Germany and many other countries (BMELV, 2009). Germany has committed itself to GHG emission reductions of 40% by 2020 compared to 1990 (BWT and BMU, 2007). Agriculture is called upon to contribute to achieving these goals (BMELV, 2011a, 2011b). The agricultural sector accounts for roughly 11% of total GHG emissions in Germany, approximately 54% of total methane emissions, and 76% of total nitrous oxide emissions. Cattle farms have been identified as a key source of methane emissions (Deutscher Bundestag, 2007; Umweltbundesamt, 2012). Consequently, dairy farms are increasingly faced with a tradeoff between profitable and climate-friendly production (BMELV, 2009; Hagemann, 2011). There is thus a need to investigate potential savings in costs and GHG emissions and assess the tradeoffs between these two objectives. Previous studies on GHG mitigation and abatement costs mainly focused on the agricultural sector as a whole, representative model farms or case studies (e.g. Osterburg et al., 2009; Moran et al., 2010; Beukes et al., 2010; Crosson et al., 2011; Briner et al., 2012). However, quantifying potential savings and abatement costs requires a research design that is based on single farms and takes into account the heterogeneity of resource settings (Stewart et al., 2009).

This paper aims to shed light on these issues by estimating the cost and GHG efficiency of 216 specialized dairy farms from northern Germany. Specific objectives of the paper are: to estimate for the sample farms the potential savings in costs and GHG emissions at constant output level; to quantify tradeoffs and complementarities between cost-efficient and GHG-efficient milk production; to estimate the costs of GHG abatement at the farm level; and to highlight the process characteristics of cost-efficient and GHG-efficient farms.

The empirical analysis is based on Data Envelopment Analysis (DEA). DEA is a well-established and widely applied method for measuring the efficiency of farms (e.g. Latruffe et al., 2004; Breustedt et al., 2011). Compared to other methodologies such as cost accounting, DEA offers the advantage of including non-monetary inputs and outputs in the analysis of total factor productivity (Coelli et al., 2005). The input-oriented specification of DEA allows the analyst to estimate the largest potential savings in costs and GHG emissions while keeping output

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constant. This model specification reflects farmers' objective to minimize production costs (or GHG emissions) for a constant level of milk output constrained by the (former) milk quota. In order to obtain cost and GHG efficiency estimates, we 'price' the inputs with both their market prices and their CO_2 emission factors (measured as CO_2 equivalents — henceforth CO_2eq). This approach allows us to distinguish between inefficiencies caused by physical wastage of resources (inputs) on the one hand and inefficient combinations of inputs given their prices or CO_2 emission factors on the other. DEA models further allow complementarities and tradeoffs between cost-efficient and GHG-efficient production to be identified and GHG mitigation costs to be estimated at the farm level. In pricing the inputs, we take into account the volatility of input prices and the uncertainty of CO_2 emission factors and thus obtain GHG saving potentials and abatement costs in the form of ranges rather than point estimates.

The remainder of the paper is organized as follows. Section 2 reviews the literature on how environmental effects can be integrated into efficiency analysis. Section 3 sets out the efficiency measurement framework of the article. Section 4 describes the data. Section 5 presents and discusses the empirical results. Section 6 concludes.

2. Environmental effects in efficiency analysis

Studies that considered environmental effects in efficiency analysis can be traced back to Pittmann (1983) and Färe et al. (1989). A variety of methodological approaches to measure environmental efficiency was subsequently established (Reinhard et al., 1999; Zhou et al., 2008; Song et al., 2012). Negative environmental effects like GHG emissions or nutrient surpluses are mostly modelled as input, inverse output or weak disposable input/output (e.g. Färe et al., 1996; Tyteca, 1997; Oude Lansink and Bezlepkin, 2003). In most of these studies, environmental effects are modelled as additional variables, which extend the technology set by adding further dimensions of discrimination. This approach was criticized by Coelli et al. (2007) because it lacks recognition of the first law of thermodynamics (the law of conservation of matter and energy). To address these shortcomings, Coelli et al. (2007) introduce the material balance principle into non-parametric efficiency measurement. Environmental effects of the inputs are taken into account in the measurement of efficiency in an analogous manner as price information rather than being introduced as a separate variable. Minimization of the inputs 'priced' with nutrient contents is the objective function of Coelli et al. (2007) approach, which implicitly includes minimization of nutrient surpluses. Environmental efficiency thus equals the ratio of the minimized nutrients and observed nutrients at constant output (Coelli et al., 2007). This approach allows environmental efficiency scores and cost efficiency scores to be compared and contrasted: cost-efficiency when inputs are priced with their market prices, and environmental efficiency when 'pricing' inputs with their environmental impact factors.

Blancard and Martin (2014) apply this approach to estimate the energy efficiency of French arable farms. However, application of the materials balance principle is afflicted with conceptual problems when energy or immaterial environmental effects such as GHG emissions are to be included in efficiency analysis (Lauwers, 2009). One reason is that the CO_2eq emission factors used to 'price' the inputs do not reflect the physical composition of the GHG but their immaterial climate effects. A further reason is that certain inputs (such as energy) cannot be balanced since there is no material relationship between energy and agricultural products. In addition, GHG emissions do not become part of the products as is the case for fertilizers, which means that the 'removal of GHG emissions with the crop' cannot be computed. Finally, GHG emissions cause environmental harm from the first unit of CO_2eq discharged into the atmosphere. By contrast, fertilizers from the farm-gate inwards harm the environment only when there is a surplus that is not absorbed by the crops. Coelli et al. (2007) argue that, for this reason, compilation of material balances is inappropriate when it comes to GHG. They conclude that only those GHG emissions are relevant for efficiency analysis that results from the production process of inputs and the on-farm application of inputs.

Nonetheless, the idea of Coelli et al. (2007) to 'price' inputs with CO_2eq factors is still suitable for the purpose of this paper because GHG efficiency is defined as the ratio of the minimum possible and the actually observed GHG emissions at any given output level. CO_2eq emission factors are calculated in the style of cradle-to-grave approach (Guinèe et al., 2002; Cederberg and Stadig, 2003). As Blancard and Martin (2014) do for energy, we take into account the uncertainty of CO_2eq emission factors by 'pricing' the inputs with the lowest, the average and the highest emission factors found in the literature.

As indicated above, the 'pricing' approach allows us to determine input combinations that are appropriate for cost minimization and GHG minimization, respectively; it further enables observed inefficiencies to be attributed to their two underlying causes: (1) physical wasting of inputs and (2) combining the inputs in a way that is not appropriate for cost or GHG minimization. While the 'pricing' approach has been applied in the literature (Coelli et al., 2007; Blancard and Martin, 2014), we extend the literature on two counts. First, we distinguish between physical wasting of inputs due to pure technical inefficiency and due to scale inefficiency. This allows us to estimate input and GHG savings that can be reaped in the short-term and those that can only be realized in the long run (after readjustment of scale size). Second, we use the DEA framework to derive shadow prices for GHG abatement by shifting the farms' input mix from the cost minimum to the GHG minimum (Coelli et al., 2007). We interpret these shadow prices as marginal abatement costs.

3. Methodological approach

3.1. A dairy farm as an environmental-economic model

The empirical analysis is based on Data Envelope Analysis (DEA). The DEA framework models dairy farms as productive units that transform inputs into outputs. Fig. 1 depicts the input–output-system of a dairy farm. The inputs that can be adjusted in the short run are electricity, diesel, nitrogen, concentrates and cows ($x_1 - x_5$). These are transformed via husbandry processes into revenues y_1 as the model's output variable. The cows input includes both purchased cows and those reared on farm. We assume that there are no other short-run variable inputs with significant effects on the output variable (Rasmussen, 2010; Sauer and Latacz-Lohmann, 2015). We further include in our analysis labor, agricultural land and buildings as quasi-fixed inputs whose levels cannot be changed in the short term (Gubi, 2006; Breustedt et al., 2011). In the DEA model, these variables are treated as non-discretionary inputs for which no reductions are demanded. Inclusion of these inputs takes account of the farms' periphery and avoids unjustifiable discrimination (Dyson et al., 2001).

The transformation process in Fig. 1 describes a farm's 'technology', and every output–input ratio represents a farm's productivity. A farm's efficiency is determined by the ratio of its observed productivity and its maximum possible productivity. The input-oriented DEA model is capable of estimating the maximum possible reduction of emissions and costs while keeping output unchanged in the status quo. This yields estimates of cost and GHG efficiency for each of the 216 sample farms. Inefficiencies can result from physical wastage of inputs (technical inefficiency) or inefficient combinations of the inputs with regard to their prices (cost inefficiency) or emission factors (GHG allocative inefficiency).

To estimate cost efficiency it is sufficient to price the inputs with a compatible set of prices, e.g. market prices or farm-specific opportunity costs. Estimating GHG allocative efficiency requires pricing the inputs with CO_2eq emission factors. These account for GHG released during both the production process of the inputs and their application on