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Metrics and indices to assess the life cycle costs and greenhouse gas impacts of a dairy digester

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ABSTRACT

This paper aims to propose consistent Life Cycle Assessment and Life Cycle Costing metrics and indices and to test them to assess an anaerobic digester on a dairy farm.

The method is based on a graphic representation of the environmental Life Cycle Impact and economic Life Cycle Cost Differentials. Performance indices are the Internal Rate of Return (discount rate that makes the total cost differential over the lifetime equal to zero), the Breakeven Price of Electricity (unit price of electricity that makes the total cost differential over the life time equal to zero) and the Impact Savings Ratio (the total impact reduction divided by the detrimental impacts generated).

A dairy digester producing electricity, chosen as case study yields a substantial carbon footprint reduction close to 0.2 kg CO_{2e} per liter of milk (25% improvement of milk carbon footprint), corresponding to a high Impact Savings Ratio of 34–37. Life Cycle Cost Differentials ranges from −$545 (most favorable) to $808 (least favorable) per cow, depending on electricity price, heat recovery and upfront grant. Economic performances are reflected in the Internal Rates of Return (IRR), that range from −1% to 12%. The Breakeven Price of Electricity ranges from $0.07 to $0.13 per kWh.

The effective economic performance is measured by choosing the discount rate equal to the Weighted Average Cost of Capital of the stakeholder. Comparing the IRR to his target rate of return enables the decision maker to check whether its own economic targets are met.

1. Introduction

Life Cycle Costing (LCC) evaluates the cost of a product along its life cycle. It is an approach consistent with environmental Life Cycle Assessment (LCA), given that both LCC and LCA studies refer to a consistent definition of the product system in the goal and scope definitions (Hunkeler et al., 2008; Swarr et al., 2011). All costs incurred within the system boundaries have to be assessed, including those incurred for research and development, raw materials, manufacturing, labor costs, services (e.g. insurance), use stage and disposal. LCA and LCC often compare alternative scenarios, assessing differences in impacts and costs between these alternatives.

A first issue when comparing results of both approaches is the evolution of impacts and costs, especially for scenarios that require long-term investment, such as the installation of a digester on a farm. The combined LCA and LCC approach needs to compare costs and impacts over multiple years. In order to compute multiannual impacts, by default, LCA sums up the impacts over the product lifetime since all generations are attributed equal value (no discounting hypothesis – (Hellweg et al., 2003)). For economic methods such as LCC, costs are usually discounted using the Net Present Value (NPV) approach (Hunkeler et al., 2008; Swarr et al., 2011) and the inter-temporal evolution needs to be explicitly described and represented. For such representation, Schwab Castella et al. (2009) and Simões et al. (2013) have proposed combined graphical representation of absolute life cycle costs and impacts, but these do not reflect the temporal evolution over the lifetime.

Another point of concern with LCC is the choice of the time value for money, also known as the discount rate. Swarr et al. (2011) states that this rate depends on the stakeholder's perspective, whether they be consumer, government or manufacturer; in the latter case, a lower bound can be determined as the Weighted Average Cost of Capital of the company. A discount rate equal to the Weighted Average Cost of Capital reflects well the company's effective performance and profitability, since the company starts to make profit only if the Costs of Capital are covered. Whether to

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select a higher discount rate requires further thoughts to ensure consistency between LCA and LCC. Setting a higher discount rate corresponds to an economic target (the desired level of profit) and not to the effective economic performance (the economic profit or loss at effective cost of capital). This deviates from the way the environmental performance is measured in LCA, which is clearly estimated and reported as an effective difference in impact, independently from the environmental target (e.g. 10% minimum impact reduction). There is therefore a need to further discuss the choice of the discount rate and provide a clear differentiation in LCC between effective economic performance and economic targets.

In complement to absolute costs metrics, several indices have been developed to help characterize economic performances. The most commonly used approach in manufacturing and service industries when measuring economic performance of an investment is the internal rate of return (IRR). The IRR is the value of the discount rate that makes the Net Present Value (NPV) equal to zero. The higher the IRR, the more profitable the investment. One advantage of the IRR approach is that, unlike NPV, it does not depend on the discount rate. However, this approach has two main problems. First, in a few cases with large expenses that lead to negative cash flows in later project stages, the approach can be unstable, yielding multiple IRR values (Cannaday et al., 1986). More critical is the implicit assumption that interim net revenues are reinvested at a rate equal to the IRR. In cases of very profitable projects with high IRR, this overestimates the profitability, as those cash flows are more likely to be reinvested at the company's reinvestment rate (Beaves, 1988). Thus it will be of interest to test whether these two problems can be avoided using the alternative Modified Internal Rate of Return (MIRR) proposed by Kierulff (2008).

Environmental indices analogous to IRR or MIRR are not commonly used and decision making might benefit from those indices to complement, in parallel to the economic performance, the assessment of environmental performances. Some indices such as the Greenhouse Gases (GHG) Abatement Cost link economic and environmental absolute values, measuring the cost of reducing one unit weight of GHG (Rehl and Muller, 2013). This cost is conceptualized and computed for a large number of GHG reduction opportunities in McKinsey and Company (2009). It is primarily informative for decision making in unprofitable cases where GHG mitigation induces more costs than profits.

The adequacy of different approaches and indices need to be tested and illustrated by studying a practical case, selected as a digester for dairy. Anaerobic digestion systems for livestock manure have steadily grown in the US over the last ten years, providing substantial reductions of GHG emissions in two ways. First, they reduce methane emissions by capturing and burning biogas that would otherwise escape to the atmosphere from the waste management system. Second, they can generate energy and enable reduction of the use of fossil fuels, thus further avoiding emissions of greenhouse gases. However, despite a potential number of 2645 U.S. dairy farms with herd sizes large enough to support anaerobic digesters, only 126 systems were in operation in 2010 (United States Environmental Protection Agency, 2010). Digesters are significant investment expenditure for a farmer, and even though they produce electricity or biogas that provides a steady source of revenue, their long-term profitability are project dependent. Public funds are often necessary to make the project profitable and these vary in type and amount depending on state regulations, initial grants, subsidized loans and/or electricity feed-in tariffs (United States Environmental Protection Agency, 2010; Wang et al., 2011). In terms of maintenance costs and runtime efficiency, long-term experience with electricity production from anaerobic digesters is still scarce (Anderson et al., 2013). Recent case studies have shown that digesters initially run at lower capacity than expected, and that adjustments are then needed (Princeton Energy Resources International, 2009). In addition, maintenance costs are challenging to assess and vary over years: over a typical 20 year investment lifetime, heavy maintenance is necessary on the electricity generation device (Lazarus and Rudstrom, 2007). The profitability of a digester system also depends on the outputs: according to Rehl and Muller (2013), a combined heat and power system is more profitable than a system producing only biogas, or a system producing only electricity. Revenues from the recycling of processed manure solids as stall bedding material may also significantly improve the profitability (United States Environmental Protection Agency, 2012; Gooch et al., 2006). Since digesters bring substantial reduction in GHG emissions, involve long term investment and operation over multiple years, and since their profitability strongly depends on the local economic context, it represents an ideal case to test and illustrate a consistent comparison of life cycle environmental impacts and economic costs.

This paper addresses these different needs by proposing combined LCA and LCC metrics and testing them to assess an anaerobic digester on a dairy farm. We will focus on four main specific objectives:

- To consistently compare absolute environmental and cost performances cumulated over the lifetime of the equipment, with income and expenses occurring at different points of the life cycle, and to complement their interpretation with performance indices.
- To apply the approach to study the life cycle cost and carbon footprint performances of an anaerobic digester.
- To demonstrate the respective influence of discount rate, electricity unit price, up-front public grants and co-product revenue sources through scenario and sensitivity analyses.
- To discuss the role of the discount rate from producer and public perspectives.

2. Methods

2.1. Framework for life cycle cost and impact of the anaerobic digester

To assess environmental and cost performance of a digester over its lifetime, we adopt a consistent life cycle impact and cost assessment approach, adding additional indices that complement the environmental and the economic absolute values.

Fig. 1 presents the general assessment framework. The functional unit is defined as the treatment of farm manure for one cow over the lifetime of the digester. The life cycle cost is assessed from a farmer's perspective. Data on investments, operation, maintenance, energy generation and labor hours are collected for both the reference system open slurry manure storage and the new digester system. Those quantities, combined with emissions rates and prices, enable the computation of the difference in impact (ΔLC Impact$_i$) and cost (ΔLCC_i) between the digester and the reference system for each year *i*. The impact differences for each year are directly summed over the lifetime to provide the total life cycle impact differential (ΔLC Impact$_{total}$). The total Life Cycle Cost Differential (ΔLCC_{total}) is equal to the sum of the net present values of yearly life cycle cost differentials over the lifetime. Regarding the discount rate, Swarr et al. (2011) recommends Weighted Average Cost of Capital to be a lower bound, this cost of capital being equal to the weighted average of the long term interest rate of the debt and the long term cost of equity. For a farmer who may not need to remunerate external investors, this cost of capital may be close to the long term interest rate of the