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Can spatial reallocation of livestock reduce the impact of GHG emissions?

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ABSTRACT

Historically, concentrated livestock production and, consequently, manure production and management have resulted in considerable environmental impacts in many parts of Europe. The region selected for the current case study was Belgium which is characterized by input-intensive animal production within a geographically concentrated land area. In this study, the effect of a reduction in manure pressure through spatial distribution of CO_2 equivalent emissions was investigated and the impact on the carbon footprint verified through a consequential life cycle approach. This was accomplished by investigating the marginal spatial impact on CO_2 emissions of a decrease in manure pressure. An economic and environmental optimization was conducted using mathematical linear programming and the main differences between both approaches determined. The results of the model simulations show that, while the economic optimum is achieved by maximizing the transport of raw manure until fertilization standards are fulfilled and subsequently processing the excess manure, the environmental optimum, from a carbon footprint point of view, is achieved by separating all manure, as this strategy causes the least CO_2 emissions, mainly due to the limited manure storage time. Moreover, the analyses indicate that rearrangement of the spatial distribution of livestock production in Belgium will not substantially decrease CO_2 emissions. As the study demonstrated that manure storage is the main contributor to the carbon footprint, solutions should instead be sought by changing these storage systems. This article contributes to the methodology of the consequential life cycle approach by linking carbon footprint analysis with an economic model that simulates manure disposal decisions driven by legal constraints and market forces.

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1. Introduction

Intensive livestock production is widely regarded as having a detrimental impact on the environment (Sage, 2012; Steinfeld et al., 2006; Meers et al., 2005) due to livestock supply chains requiring significant inputs of feed, energy and water, production of CH_4, NH_3 and other emissions, and pollution risks arising from inefficient waste management practices (McAuliffe et al., 2016). While research into whole-system pig production indicates that feed production generates the greatest environmental pressure, on a localized scale, waste management becomes more problematic, with the main concerns being global warming from greenhouse gas (GHG) emissions, aquatic eutrophication and acidification from ammonia emissions (Lopez-Ridaura et al., 2009; Sandars et al., 2003). More specifically, large amounts of GHG emissions, such as CH_4 and N_2O, relating to manure storage and its application on crop land create a substantial environmental burden (Loyon et al., 2007; Lopez-Ridaura et al., 2009; Rigolot et al., 2010; De Vries et al., 2012). There is a need for a detailed assessment of overall environmental impacts from pig manure management, incorporating available technologies applied at different handling stages in order to reduce the environmental burden (Prapaspongsa et al., 2010).

One tool for assessing the environmental performance of complex systems, such as pig production, is life cycle assessment (LCA). This has often been applied in the case of pig production (McAuliffe et al., 2016). The LCA literature distinguishes two types of LCA: the attributional approach to environmental impact calculation (also called the accounting or descriptive approach) attempts to provide information on the share of global burden that can be associated with a product and its life cycle (Sonnemann and Vigon, 2011), while the consequential approach is designed to generate information on the consequences of actions (Ekvall and Weidema, 2004).

Livestock waste-related, and mostly attributional, LCAs have received widespread attention in the EU in recent years, possibly due to the Water Framework Directive targets in 2015. Waste management is the most localized concern for pig production, due to the N and P content of animal manure and, hence, technologies have been developed to reduce risks associated with traditional manure management techniques, such as anaerobic digestion, biological treatment of manure and manure separation (McAuliffe et al., 2016).

However, the existing literature reports conflicting results for the optimal solutions for pig waste management. According to McAuliffe

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et al. (2016), the general consensus from the research was that treated manure or slurry generated a lesser burden than untreated manure. There were, however, exceptions, such as Lopez-Ridaura et al. (2009), who found that traditional slurry spreading had less impact than aerobic treatment, while Bayo et al. (2012) suggested spreading was preferable to constructed wetlands. Moreover, since these types of studies apply LCAs of GHG emissions for specific areas and animal products, and use different approaches, scopes and functional units, it makes them very hard to compare and draw consistent conclusions (Weiss and Leip, 2012).

In Belgium, the main bottleneck for manure management is the strong geographical concentration of livestock and manure production in the province of West Flanders and the northern part of Antwerp (Van der Straeten and Buysse, 2013). To adhere to targets in the Water Framework and Nitrates Directive, raw manure is currently exported from zones with high manure pressure to zones with low pressure until fertilization standards are fulfilled, to minimize the economic cost, after which the manure surplus is processed. On the one hand, calls have been made to reduce the high manure pressure and related environmental effects by reducing, relocating and more evenly distributing livestock production (Werkgroep voor Rechtvaardige en Verantwoorde Landbouw, 2013). On the other hand, based on the literature, one could argue that a high livestock density increases manure processing and, therefore, reduces the environmental impact of manure management.

In order to come to a clear conclusion on the matter, in this study, we use the concept of consequential LCA (Ekvall and Weidema, 2004) to explore the spatial distribution of CO_2 equivalent (eq.) emissions from pig manure management in Belgium. The consequential LCA is selected in preference to an attributional approach because consequential modeling estimates how flows to and from the environment will change as a result of different potential decisions (Curran et al., 2005; Sonnemann and Vigon, 2011), such as, in this case, the spatial reallocation of livestock production. In this study, however, we do not conduct a complete LCA of all the flows created by manure management. First of all, we limit ourselves to those flows that contribute to the carbon footprint (CF), i.e. the GHG emissions from manure into the atmosphere in the form of CO_2, CH_4, and direct and indirect N_2O and NO_x. Secondly, since in Belgium pig production creates the greatest environmental pressure, only the GHG emissions from concentrated pig production are taken into account.

In this study, we answer the following question: 'Can spatial reallocation of livestock production in Belgium reduce the impact of GHG emissions?' This question is translated into three research objectives: 1) conduct an economic (cost minimization) and environmental (GHG minimization) optimization for three manure management strategies, which are, in this case, pig manure transport, treatment and separation, in Belgium, 2) determine the main differences between both approaches, and 3) determine the consequential CF of a decrease in manure pressure (i.e., wider distribution of pig production). As a basis for our calculations, we use a linear programming model that simulates manure disposal decisions driven by legal constraints and market forces, to which we link CF calculations in order to investigate the impact of spatial reallocation.

2. Methodology

In this section, we first describe the assumptions upon which the LCA calculations are based, followed by a description of the linear programming model in which we insert the LCA data and conduct the consequential LCA.

Fig. 1 provides an overview of the manure management system upon which the life cycle as well as the manure allocation calculations are based and explains how both approaches are combined. We will come back to this figure in the various sections of the methodology.

The basic assumption of the model is that different types of animals produce manure with a different nutrient content. The nutrient content can be altered by managing the manure in different ways, such as manure separation or biological treatment. To apply manure to the field, fertilization standards have to be adhered to. These standards depend on the crop type. The LCA calculations determine the environmental impact of each manure management strategy, focused here on GHG emissions, while the manure allocation model (MAM) allows us to determine the optimal spatial manure allocation depending either on economic optimization (allocation cost minimization) or on environmental optimization (CF minimization). It is important to note that, with regard to the environmental optimization, we only take into account the management of pig manure, while for the economic optimization we consider all existing livestock in Belgium.

2.1. Functional unit and system boundaries

The functional unit is the total amount of pig manure produced on an annual basis in each municipality in Belgium. System boundaries, indicated in Fig. 1 by the black dotted line, are set starting from manure production to the arrival of the (processed) manure at its final destination. The life cycle stages involved are manure production, storage, processing, transport and, finally, application to the land. The life cycle and boundaries of our assessment are presented in Fig. 1, together with a representation of the MAM (see Section 2.4). The system boundaries

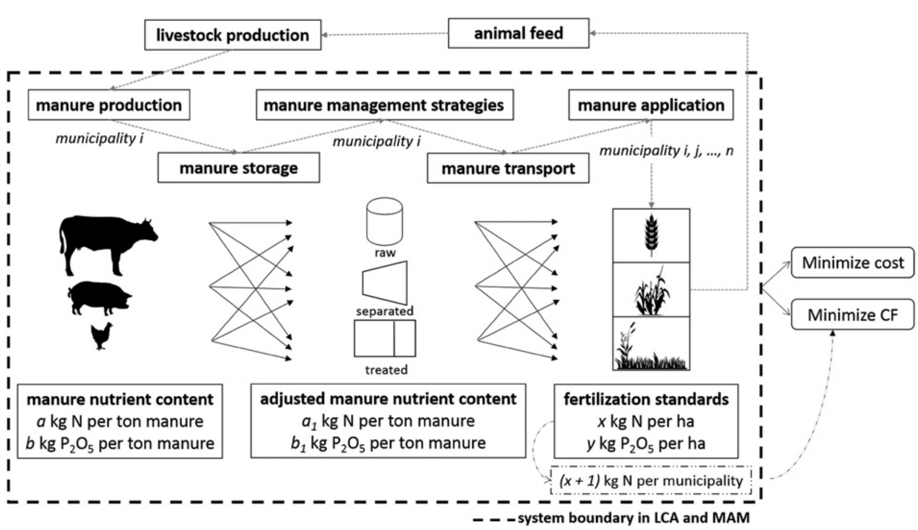

Fig. 1. Manure management system with system boundaries and manure management strategies.

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