European Journal of Operational Research 232 (2014) 643–653

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

A multiple criteria decision making approach to manure management systems in the Netherlands

Solomie A. Gebrezgabher [a,*], Miranda P.M. Meuwissen [b], Alfons G.J.M. Oude Lansink [b]

[a] International Water Management Institute, PMB, CT 112, Cantonments, Accra, Ghana
[b] Business Economics, Wageningen University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 31 December 2012
Accepted 5 August 2013
Available online 22 August 2013

Keywords:
Multiple criteria decision making
Multiple objective programming
Compromise programming
Goal programming
Analytical hierarchy process

ABSTRACT

The intensification of livestock operations in the last few decades has resulted in an increased social concern over the environmental impacts of livestock operations and thus making appropriate manure management decisions increasingly important. A socially acceptable manure management system that simultaneously achieves the pressing environmental objectives while balancing the socio-economic welfare of farmers and society at large is needed. Manure management decisions involve a number of decision makers with different and conflicting views of what is acceptable in the context of sustainable development. This paper developed a decision-making tool based on a multiple criteria decision making (MCDM) approach to address the manure management problems in the Netherlands. This paper has demonstrated the application of compromise programming and goal programming to evaluate key trade-offs between socio-economic benefits and environmental sustainability of manure management systems while taking decision makers' conflicting views of the different criteria into account. The proposed methodology is a useful tool in assisting decision makers and policy makers in designing policies that enhance the introduction of economically, socially and environmentally sustainable manure management systems.

1. Introduction

The intensification of livestock operations in the European Union has caused increasing environmental impacts on the soil, the water and the air (Jongbloed & Lenis, 1998). Within the European Union, it is estimated that agriculture contributes 49% of CH_4 emissions and 63% of N_2O emissions (Sommer, Petersen, & Moller, 2004). Most of CH_4 emissions originate from livestock manure during storage while most N_2O emissions originate from field application of animal manure (Sommer et al., 2004). In order to abate these environmental hazards, a series of environmental regulations and directives have been implemented. The EU nitrate directive aims at reducing water pollution caused by nitrate from agriculture and the EU air quality directive sets limits on the emission of ammonia and nitrogen oxides to the atmosphere (Oenema, 2004). Manure management is becoming increasingly important in order to reduce environmental impacts (Karmakar, Lague, Agnew, & Landry, 2007). Manure management is defined as a decision-making process at all stages, i.e. from collection of manure in animal houses till after field application that aims to combine profitable agricultural production with minimal nutrient losses from manure (Chadwick et al., 2011; Karmakar et al., 2007; Sommer et al., 2009).

The extent and impact of the manure problems became clear in the 1970s and especially, the 1980s (Langeveld et al., 2007). The problem is still a pressing issue today as it has long been difficult to implement effective strategies to change manure management practices. Alternative environmentally acceptable disposal routes with potential financial benefits are manure processing technologies that provide energy and manure products (Burton & Turner, 2003; Melse & Timmerman, 2009). However, these alternative manure processing technologies are not without problems. Although the main objective of manure processing is to reduce the environmental impact, not all of the technologies achieve a reduction in pollution (Petersen et al., 2007) and most of the technologies are considered to be too expensive for the livestock farmer to adopt (Burton, 2007). Consequently, a socially acceptable manure management system that simultaneously reduces environmental impacts while accounting for the socio-economic welfare of both farmers and society is needed (De Vos, Weersink, & Stonehouse, 2002).

Manure management involves a number of decision makers with different and often conflicting perceptions of what is acceptable in the context of sustainable development. Different interest groups attach different values to each of the economic, social and

* Corresponding author. Tel.: +233 302 784753; fax: +233 302 784752.
E-mail address: s.gebrezgabher@cgiar.rog (S.A. Gebrezgabher).

0377-2217/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2013.08.006

environmental objectives, and rank priorities differently. For instance, for the farmer, keeping manure disposal cost at a minimum is important while for the environmental organizations, reducing environmental impacts is more important. This calls for an integrated approach to modelling manure management systems that encompasses multiple objectives of decision makers. The traditional model of optimizing a single objective function over a set of feasible solutions is not enough to capture the complexity of the decision-making processes. In the presence of multiple and conflicting objectives, multiple criteria decision making (MCDM) methods are appropriate tools to support decision making (Pohekar & Ramachandran, 2003; Romero & Rehman, 2003).

To evaluate the economic and environmental sustainability of manure management systems and to support decision making, different types of methods based on either mathematical programming or simulation methods are used. The mathematical programming models are either single objective optimization models or multiple objective programming models. Giasson, Bryant, and Bills (2002) used a multiple objective programming model to support decision making with respect to manure allocation decisions at farm level. Alocilja (1997) developed a compromise programming model for phosphorus management for a dairy-crop operation by simultaneously minimizing excess phosphorus from manure and cost of feed. Stonehouse, De Vos, and Weersink (2002) used a mixed integer programming model to develop a decision-making tool for assessing the technical, environmental and economic performance of alternative manure-handling systems in the context of a whole farm planning model. Others used a linear programming model to optimize farm profitability by introducing the environmental aspects of manure management as constraints (Gebrezgabher, Meuwissen, Prins, & Oude Lansink, 2010; Hadrich, Wolf, Black, & Harsh, 2008). In addition to mathematical programming models, previous studies have used simulation methods. Kruseman et al. (2008) developed a micro-simulation model called manure and ammonia model (MAMBO) of livestock and agriculture to model the mineral flows within the sector and the resulting emissions. The simulation model is used as a tool to evaluate policies on non-point source emission. Van der Straeten, Buysse, Nolte, Lauwers, and Claeys Dand Van Huylenbroeck (2010) developed a simulation model for spatial optimization of manure allocation. Despite the wide range of studies on manure management problems, the integration of economic, social and environmental criteria, taking decision makers' preferences into account has not been addressed.

The objective of this study is to develop a decision-making tool to assess the economic, social and environmental sustainability of manure management systems. This paper examines trade-offs between economic, social and environmental impacts of manure management and integrates views from different decision makers. The methodology applied in this study can be used as a tool to assist decision makers and policy makers in designing policies that enhance the introduction of economically, socially and environmentally sustainable manure management systems.

The remainder of this paper is organized as follows. Section 2 introduces the MCDM modelling framework. Section 3 provides a brief description of manure processing technologies considered in this study, the case study and the data sources. Results are given in section 4. Conclusions and implications are given in section 5.

2. Modelling framework

Multiple criteria decision making is a well-known branch of decision making which deals with the process of making decisions in the presence of multiple and conflicting objectives (Pohekar & Ramachandran, 2003). MCDM thus seeks to assist the decision maker in identifying feasible alternative solutions that attempt to reach a balance among the multiple objectives. This task can be formulated as a multi-objective problem by applying a compromise programming (CP) to find the best compromise solution. Fig. 1 depicts the modelling framework for manure processing systems.

First, criteria to measure the economic, social and environmental objectives are determined. By integrating the necessary input information for each of the manure processing systems considered, a pay-off matrix is constructed to enable decision makers to understand trade-offs among the different criteria. After the weights to the criteria that reflect their relative importance are determined, the best compromise solution is determined.

2.1. Compromise programming

Compromise programming (CP) belongs to the class of multiple criteria analytical methods called "distance-based" methods (Romero & Rehman, 2003). It is an extension and a complement to other MCDM technique, the multi-objective programming (MOP) which seeks to solve the problem of simultaneous optimization of several criteria. This is done by identifying the set that contains Pareto efficient solutions for all the criteria. This can be stated as:

$$\begin{aligned} &Eff \quad Z(y) = [Z_1(y), Z_2(y), \ldots, Z_n(y)] \\ &s.t.: \quad F[Z_1(y), Z_2(y), \ldots, Z_n(y)] \end{aligned} \tag{1}$$

where y is a vector of decision variables, $Z_j(y)$ is the mathematical expression for the jth criteria, *Eff* means the efficient solution and F is the feasible set that contains Pareto efficient solutions for all the criteria. The MOP attempts to generate the efficient set which is a subset of the feasible set (El-Gayar & Leung, 2001). Once these efficient solutions are identified, they can be further analyzed using compromise programming to find the best compromise solution.

Compromise programming defines the best solution as the one in the set of efficient solutions with the smallest distance from an ideal point (Romero & Rehman, 2003; Zeleny, 1982). The first step in CP is to construct a pay-off matrix which shows the ideal and anti-ideal values for each of the criteria by optimizing each of the criteria separately over the efficient set. The pay-off matrix shows the degree of conflict between criteria. The ideal point is used as a reference point in CP as the aim is to obtain a solution by choosing a point in the efficient solution which is closest to the ideal value. To achieve this, a distance function is introduced as a proxy measure for human preferences with regards to achieving a solution closest to the ideal value. The normalized distance, d_j, between the jth criteria and its ideal assuming a maximization problem is given by:

$$d_j = \frac{Z_j^* - Z_j(y)}{Z_j^* - Z_{*j}} \tag{2}$$

where Z_j^* and Z_{*j} are the ideal and anti-ideal values for the jth criteria respectively. The normalization factor is the absolute deviation between the ideal and anti-ideal solution and is used to obtain consistent results when the criteria are measured in different units (Zeleny, 1982).

In order to obtain the set of efficient solutions nearest with respect to the ideal point, the following CP model is proposed (Zeleny, 1982; Yu, 1973):

$$L_p(W) = \left[\sum_{j=1}^{n} W_j^p \left[\frac{Z_j^* - Z_j(y)}{Z_j^* - Z_{*j}}\right]^p\right]^{1/p} = \left[\sum_{j=1}^{n} (W_j d_j)^p\right]^{1/p} \tag{3}$$

where p is a metric defining the family of distance functions which reflects the importance attached to the deviation of each criterion