

LINKING ECONOMIC AND ENERGY MODELLING WITH ENVIRONMENTAL ASSESSMENT WHEN MODELLING THE ON-FARM IMPLEMENTATION OF ANAEROBIC DIGESTION

Muskolus, A.⁽¹⁾, Salter, A.M.⁽²⁾ and Jones, P.J.⁽³⁾

(1) School of Biological Sciences, University of Southampton, Bassett Crescent East, Southampton, SO16 7PX, UK

(2) School of Civil engineering & the Environment, University of Southampton, Highfield, Southampton, SO17 1BJ, UK

(3) Centre for Agricultural Strategy, School of Agriculture, Policy and Development, University of Reading, PO Box 237, Whiteknights Road, Reading, RG6 6AR, UK

ABSTRACT

In order to determine the effects of the introduction of AD within a farming environment it is necessary to take into account all of the potential factors affecting on-farm biogas production in an integrated way. One of the problems faced by those trying to build integrated models is that the drivers for environmental, economic and energy production often conflict with one another and may be incompatible. This paper considers some of these drivers and how the three approaches, for economic, environmental and energy assessment may be integrated in order to address conflicts between them.

KEYWORDS

Anaerobic digestion, Integrated farming, Economics, Environment, Energy

1. INTRODUCTION

A number of authorities have recognised the contribution that agriculture makes to greenhouse gas (GHG) emissions through the production of livestock and livestock manures. GHGs also result from the use of land fill and decomposition of green and organic wastes. Anaerobic Digestion (AD) has been identified as having a role to play in reducing these emissions (see, for example, EC, 2005; FAO, 2006). This potential role, including the use of anaerobic digesters on-farm, is recognised in many EU and subsidiary national policy initiatives in support of GHG reduction and the promotion of renewable energy. The capability of anaerobic digestion to use organic wastes and a wide range of plant materials also enables the production of biomass based renewable energy whilst avoiding conflict with food production and with the potential to enhance crop yields.

In order to determine the potential effects of the introduction of AD within a farming environment it is necessary to take into account all of the potential factors affecting on-farm biogas production in an integrated way. One of the problems faced by those trying to build integrated models which consider all of these factors is that the drivers for environmental, economic and energy production often conflict with one another and may be incompatible.

This paper briefly examines some of the issues relating to the economic, environmental and energy aspects of on-farm energy production using AD and methods that can be used for modelling or assessment. Each of these areas is considered individually, followed by an

assessment of how the methods may combine or conflict, and how this might impact upon an integrated farm-based model.

2. ECONOMIC MODELLING

The economic modelling of AD cannot meaningfully be done in isolation, but rather has to place the activity into the physical, commercial, social, market, policy and regulatory context within which it will operate in practice. This context forms an extremely complex set of interacting factors which both impact upon the AD activity and are impacted by it. Any economic modelling exercise must reduce the dimensionality of this context in order to be practicable, while simultaneously capturing its essential determinants, so that the representation of the system functions adequately. As the focus of this enquiry is farm-based AD, a key component of this context has to be the farm business within which AD operates. The nature and scale of this problem in large part determines the choice of modelling approach. Since the 1960's Mathematical Programming techniques have been widely used to model farm-level management decisions (see, for example, Glen, 1987), although other approaches are available. Mathematical Programming is a method for solving a problem where one function (the objective) is maximised, or minimized, while other functions (the constraints) are satisfied. Linear Programming (LP) is the most commonly used form. In this case the maximised objective would be the profit of the whole farm business, subject to constraints on, amongst other things, the availability of farm resources. Modelling would be based on a traditional activity analysis framework (see, for example, Hazel and Norton, 1986) with the deployment of AD as a novel land using activity, competing for farm resources with the more 'traditional' land uses.

One of the criticisms levelled against Mathematical Programming is that it is data demanding, requiring a consistent set of input-output coefficients (for each model activity) and detailed information on farm resources. The lack of availability of such data is often an obstacle to the construction of farm models. In constructing farm-based models it is often necessary therefore to use multiple sources of data, drawn from official datasets, independent surveys and other farm management publications and care needs to be taken to ensure consistency between sources. While serviceable input-output data can usually, with effort, be obtained for the main land using agricultural activities, more problematic is obtaining data for minor agricultural enterprises and non-agricultural activities, particularly when they are relatively novel, as is the case with AD. A particular problem for AD is that some of the inputs to the activity are farm wastes and these have traditionally been overlooked in surveys and other farm data collection exercises, as they have been perceived to have very low economic value.

In Mathematical Programming a single objective is maximised, i.e. farm profit (usually expressed as a Gross Margin or some form of Net Margin). The advantage of this approach, as opposed to just accounting for the profit margin attributable to AD, is that it captures any indirect effects that AD may have on other farm enterprises, both in terms of profit margins and management decisions. This could mean, for example, that AD may not enter the model solution at all, in spite of being profitable, because to do so would negatively affect other enterprises and so reduce whole-farm Net Margin. The converse is also possible. The limitation of this approach is that it does not directly account for other farming objectives, such as lifestyle (i.e. maximising leisure time of the farmer and family), or environmental goals. There may also be specific non-profit goals for the AD enterprise itself, in addition to the general farming goals. Subsidiary goals can be accounted for in the modelling through the use of constraints. For example limitation of the amount of inorganic fertilizer that can be imported onto the farm, as would be the case under a certified organic system. The limitation of the use of constraints to reflect other farming goals is that they can only approximate the

effects of more general objectives. However, the main difficulty in capturing non-profit farming goals in economic models lies in actually knowing what they are and how significant they are relative to one another.

An important consideration when modelling AD is the market and policy context. Experience has shown that when enterprises are economically marginal they are much more heavily influenced by changes in market conditions and also much more dependent on policy support. This is even more the case where new and untested technologies are concerned. As the policy and market environment for AD is changing rapidly, a multi-scenario approach would be preferable, i.e. modelling AD under a range of policy and market assumptions. When there is uncertainty over likely future market and policy conditions, it may be useful to carry out a sensitivity analysis to identify price threshold and policy settings that determine the feasibility of AD. It should also be remembered that the agricultural policy and market environments are also subject to change and scenarios should reflect this.

3. ENVIRONMENTAL IMPACT ASSESSMENT

Biogas production on farms is likely to affect the environment in a number of ways. The most direct effects may result from the spreading of liquid or solid digestion residues on land. While digestate can provide a valuable fertiliser for crops, it can also be the cause of environmental nitrogen and phosphorus enrichment. On a full life-cycle basis, the digestion of livestock manures, and the spread of digestate on land has the potential to reduce CH₄ and N₂O emissions. However, but the spreading of digested energy crops leads to additional ammonia emissions and so are likely to be incompatible with current policy objectives to reduce nitrogen and phosphorus leaching and gaseous emissions from agriculture. Emission abating measures include reducing the amounts of digestate spread per hectare or using injection application equipment.

While the direct emissions of NH₃, CH₄, and N₂O from digestate application have been measured (Clemens et al., 2006) and can be used in models, the indirect environmental effects of AD are more difficult to quantify and are often not considered at all. If crops are grown specifically for AD, this new production goal is likely to change farming practices. Under these circumstances a new biomass-quantity-optimised production focus will accompany a change in cropping pattern, leading to altered sowing/harvesting dates and possibly even a two-cultivation system with significant changes in field operation times. The environmental effects of these are manifold and complex and would therefore be difficult to generalize in the modelling of biodiversity impacts.

'Planned' biodiversity, comprises the crops and/or livestock the farmer chooses to produce. 'Unplanned' biodiversity, constituting all other biota in the system may either be economically beneficial, for example insects which pollinate the crop, or damaging, such as pathogens, pests and weeds. Unplanned biodiversity may become part of farm planning, in the sense of that they are actively promoted or eliminated. Such management is directed towards elimination or promotion of either population processes (e.g. pest control) or ecosystem processes (e.g. N fixation). These approaches are associated with species diversity and functional group diversity, respectively (Brussaard et al., 2007).

Farmers producing crops for AD in Europe have tended to grow maize as feedstock due to its high biomass yield. However, while maize may fit the bill from an economic perspective, it is by no means ideal from the environmental point of view, as it requires high fertiliser inputs and the bare soil between rows promotes soil erosion. Maize also provides few habitats for birds, insects and small mammals. When maize comes to dominate arable rotations, it has the potential to significantly reduce biodiversity. This could be abated by a number of means,

including limiting the share of maize in a crop rotation, limiting field sizes and providing corridors for wildlife moving between habitats. However, these management options are unlikely to be funded under current CAP Pillar II agri-environment schemes and are likely to be associated with reduced machinery efficiency, leading to higher energy input and therefore higher AD feedstock costs. The magnitude of this loss in efficiency largely depends on farm structure.

Biodiversity promoting measures may not affect smaller low input farms with mixed farm systems to the extent that they would larger, more specialist farms. In this case an indicator related to field sizes is a suitable measure to implement and transmit information from the environmental assessments to the economic and energy modelling.

Changing the farm management system to grow crops specifically for use in a digester can significantly influence environmental outcomes. The economic need for high yields of biomass per hectare can lead to pressure to convert grassland to arable crops such as maize, as this is usually more productive. This conversion is associated not only with reduced biodiversity, but also with carbon release from the soil due to cultivation. All these factors need to be accounted for in the environmental assessment.

Many environmental effects cannot be quantified in a 'generalised' assessment, as they depend on site-specific conditions. What can be achieved, however, is a representative assessment which ranks relevant agronomic factors according to their environmental significance. For example, in terms of the impact of maize on biodiversity, the relevant agronomic factors might be:

- the percentage of maize in a rotation
- the size of individual fields
- the presence of catch crops
- the presence of hedges and field boundaries providing nesting sites
- the presence of habitat-connecting corridors
- reduced pesticide application
- harvest times in relation to breeding requirements

Once each of these factors has been ranked according to the significance of each for biodiversity (and factor-values allocated accordingly), a specific farm situation can be assessed by scoring each of the above factors according to whether they are addressed on the farm or not. Multiplying both values and summing the products to provide whole-farm scores would allow between farm and between scenario comparisons.

4. ENERGY MODELLING

The main drivers for renewable energy production come from the requirement to replace limited fossil fuel sources, provide energy security and combat climate change. Figures published in the World Energy outlook 2008 (IEA, 2008) suggest that fossil fuel use for energy production could increase to 17010 million tonnes oil equivalent (Mtoe) by the year 2030. Directly linked to this increase in energy use is the increase in global warming as a result of the emissions produced through the combustion of these fossil fuels. According to the WEO (IEA, 2008) global energy-related CO₂ emissions will increase from 28 Gt in 2006 to 41 Gt in 2030. Renewable fuels can be considered in terms as replacements for these including wind, wave and solar power. In this paper we are concerned with biomass as a source of energy, particularly through farm based anaerobic digestion. When assessing any form of renewable energy it must also be considered in terms of its sustainability. Can more energy be produced than is used (from fossil fuel sources) in the generation process? Also,

can the yield of energy be achieved year on year and can this be done without adversely affecting the landscape, soils, air and water quality and biodiversity? In terms of climate change can the energy be produced without generating any more CO₂ than is taken up by the biomass used as feedstock for the process?

An indicator of the sustainability of an energy production process can be determined from the energy balance which can be calculated for any given energy modelling scenario by using life cycle analysis methods. These calculations take into account both energy directly used, in the form of diesel, oil, gas and electricity but also indirectly used. Energy used directly in the cultivation of crop based feedstock materials and the generation process includes the fuel required for the production of crop based biomass, the transport of this biomass to the digester, the heat and electricity requirements of the digester and any further processing of the biogas and digestate produced. Energy used indirectly includes that consumed in the production of the inputs to the biomass cultivation such as the manufacture and transport of fertilizers and sprays but also occurs in the manufacture, delivery and maintenance of tractors and machinery, and in the construction of buildings and the digester. Having calculated all these energy requirements they can then be compared with the energy value of the fuel produced and any substitution of energy resulting from the replacement of fossil-fuel-derived energy and material sources. If the energy value of the fuel produced is greater than the energy put into production then the balance is positive and is sustainable from an energy perspective. If the input energy is greater than the energy value of the fuel produced then the process is unsustainable and should be reconsidered.

GHG and other emissions can be linked directly to energy production and use. It is therefore possible to calculate the emissions of the fuel production process and compare those with the fossil fuel equivalents. For a fuel to be deemed sustainable the emissions of greenhouse gases from its generation should be minimal and preferably negative compared to fossil fuel equivalents. In order to achieve this the use of fossil based fuels and fertilisers in the crop production and energy generation process must be kept to a minimum. In terms of AD emissions of GHG's must also be minimised through ensuring that fugitive emissions are reduced and the use of digestate as a fertiliser is as efficient as possible and does not lead to nitrate leaching and emissions of N₂O.

5. INTEGRATION

Previous farm-based AD modelling exercises have been centred on existing AD plants for which 'real' data has been available over a number of years, making it possible to define site-specific models which can be validated by comparison with observed practice. Such approaches are limited in terms of a general application to predict farm income and potential environmental effects that might accompany changes of existing farm practices to those associated with a switch to energy production. In attempting to model farm-based AD, the whole farm must be represented and techniques adopted that allow all the different drivers and outcomes to be considered. This type of approach allows for scenario-based exploration of different strategies designed to maximise the synergies and overcome the conflicts between the various drivers and outcomes. For example the use of maize as a feedstock material for AD is encouraged by economics, i.e. it is high yielding and a good source of biogas, but has many negative attributes from an environmental perspective. It can be hard to reconcile the economic and environmental assessments directly, as the drivers are often in apparent opposition.

By adopting a whole-farm modelling approach, scenarios can be explored that place emphasis on each of the different drivers, so that the outcomes can be assessed. Is the aim of

the introduction of AD to produce as much income as possible regardless of environmental impacts? Is the aim to maximise the production of sustainable energy or is the aim to reduce environmental impact by reducing the use of fossil fuels in the production of energy and in the fertilisers used for crop growth? As outlined above, deriving whole-farm implications for the introduction of AD, the modelling process involves three distinct approaches as shown in Figure 1. Each of the approaches can be applied in isolation, however integration can be achieved by using the outcomes of each approach to provide input to the others.

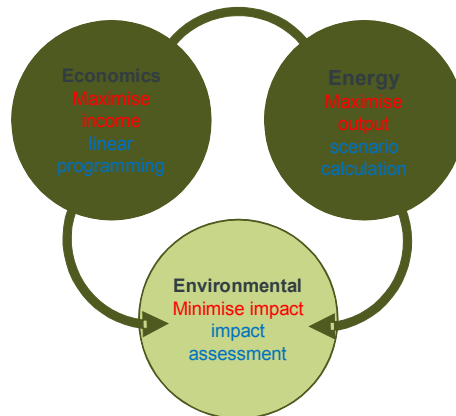


Figure 1: Three modelling/assessment approaches

For example, an initial assessment can be made based on optimising the farm arrangements from an economic perspective using a range of possible digester sizes. This in turn affects the energy production and potential amount of digestate generated. The storage and application of the digestate and the resulting changes made to the cropping system will have environmental impacts which can be assessed. Suggestions for alternative cropping systems will affect the potential energy production and related emissions which can then be fed into the economic assessment. Similarly the application of fertiliser is governed by climatic, crop and soil considerations may affect the potential economics of the digester. Restrictions on the application of the digestate may result in the requirement for alternative processing options such as drying and waste water processing. These require energy, thereby reducing the output and finance to set up and maintain leading to reduced income.

It is often assumed that farmers take decisions on the type of AD technology that they require, together with its scale, based solely on the pre-existing supply of feedstock. In actuality the selection of appropriate AD technology and scale will be very much dependent on the farming system i.e. the choices made on livestock farms with a good supply of slurry will be very different from those made on organic, mixed or arable farms. This in turn affects the models selected and resulting assessments. By using the three linked assessment methods outlined here, it is possible to capture and explore the effects of the often contradictory drivers and resultant. economics, environmental and energy impacts. It is then possible to develop an overview of the potential effects of the introduction of AD in an integrated farming system which can then be validated against real data.

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