RESEARCH REVIEW: Monitoring and Management of Energy and Emissions in agriculture

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Contents

1. Introduction

The dependence of our food and farming industry on fossil fuels has been an issue for many years. B.M Green (1978) voiced concerns with the publication of 'Eating oil' nearly 30 years ago, which used the 1973 oil crisis to highlight the vulnerability of our food system. This report was updated by Jones (2001), who concluded that far from becoming less reliant on oil in the interim period, we have never been more so. He cited a number of issues that have led to the current position, including:

- The modernisation of agriculture and introduction of the CAP
- A shift away from local supply chains towards a more international system that has become increasingly global
- Good infrastructure that has enabled food to be moved long distances at low cost.
- The expectation of the majority of the population of cheap plentiful food
- IMF and World Bank policies promoting food production for export and opening up of domestic markets to food imports from poorer countries

The production, processing and distribution of food is one of the three main purposes worldwide for which oil is used (Fleming 2001). Pretty et al (2005) estimated that agricultural or food products account for 28% of all goods transported in UK. The blockading of oil refineries and distribution depots by farmers and hauliers in 2000 gave an inkling of the vulnerability of the system; almost immediately bread milk and sugar were rationed and the chief executive of Sainsbury's wrote to the prime minister of the day warning that stores would be out of food in 'days rather than weeks'. The consequences of a more prolonged disruption of supplies can scarcely be imagined. And yet, Jones concludes, 'we are totally reliant on one finite resource; an energy source that causes enormous levels of pollution during is production, distribution and use'.

One of the key changes since the first eating oil report is a growing realisation of the impact of greenhouse gas (GHG) emissions, primarily from the burning of fossil fuels, on the global climate. Climate change issues are now at the heart of UK environmental policy, and its implications are perhaps greater for the food and farming industry than for any other. An assessment of the impact of climate change by DEFRA (undated a) concluded 'Droughts, storms, heavy prolonged rainfall and inter-seasonal variation are components of weather that are already within the experience of most farmers; it is the increased frequency of such events under future climate change that presents the greater risk to farm businesses …It is estimated that the [hot dry] summer of 1995 cost the industry about £457 Million in increased costs and reduced income.' Conversely, the cost of the cool wet summer of 2007 has yet to be estimated but it will be substantial. These are not losses that can be sustained were such conditions to become a regular occurrence, and this estimate does not even attempt to quantify the associated ecological and environmental damage.

Clearly, there are steps that farmers can take to tackle and adapt to the changing circumstances. However, these must go hand in hand with actions to reduce the burden of greenhouse gases, and the use of fossil fuels that generate them. It is here that organic farming has an important contribution to make, both in terms of reduced energy input and in increased carbon sequestration (Pimental et. al, 2005)

2. Objectives and scope of the review

The primary purpose of this review is to collate the results of research into energy use and emissions in organic farming, and to provide advisors with an analysis of the results, access to the data used and a review of the benchmarking methodologies available. The review will inform those working in the development of benchmarking tools and advising farmers on practices to improve their performance.

Specifically it will:

- Identify organic management practices to reduce energy inputs and minimise the global warming potential of the system
- Identify appropriate auditing methodologies
- Facilitate access to input data (energy use and emissions figures for agricultural activities) which can be used in the development of an auditing tool
- Summarise the energy and emissions levels found in organic farming systems and comparable conventional systems.

3. Organic management practices reducing energy inputs and emissions

Efficient use of energy has long been a key aim of organic farming, and is written into the IFOAM principles (IFOAM 2005). In recent years, a number of studies have identified specific organic management practices that contribute achieving this goal (Allen et al, 2007; Bos et al, 2007; Boisdon & Benoit, 2006; Cormack & Metcalfe, 2000; Pimental et al, 2005; Pimentel, 2006; Robertson, et al, 2000; Williams et al 2006; Pretty and Ball, 2002)

The main factor is reduced use of purchased inputs in particular fertilisers, pesticides and compound feeds. These products consume large amounts of energy in their manufacture, distribution and use (Cormack and Metcalfe, 2000; Williams et al 2006, University of Florida, 1991). On the other side of the coin, organic management also helps to increase the amount of carbon sequestered (Pretty and Ball 2002; Robertson et al., 2005; Pimentel et al 2005). These benefits are brought about by a number of management practices including:

- Use of leguminous plants in crop rotations to fix nitrogen and the efficient use of composts, manures and slurries. This eliminates the use of synthetic fertilisers, and increases the capacity of the soil to sequester carbon.
- Use of rotations; mulches; mechanical/hand weeding; stale seed beds; and other non chemical approaches to weed management to eliminate the use of herbicides
- Use of rotations; cultural controls; crop covers and mulches; resistant varieties; predators and pathogens of pests; and other non chemical approaches to pest management reduce or eliminate the use of insecticides, acaricides and mollusicides
- Use of rotations; resistant varieties; good crop hygiene; avoidance techniques and other non chemical approaches to reduce or eliminate the use of fungicides
- Maximising production from feed produced on farm; appropriate stocking rates; and breed selection to minimise the quantity of bought in feed
- Minimising summer fallows and periods with no ground cover to maintain soil organic matter stocks

4. Quantifying the contribution of organic farming

4.1 Basis of measurements and comparison

The extent to which these practices contribute to an overall reduction of energy inputs and greenhouse (GHG) emissions has been the subject of much debate and of a growing body of work. Quantifying the benefits of organic farming in this context is perhaps rather more difficult than it would first appear for a number of reasons:

4.11 The complexity of organic systems

It is relatively easy to allocate energy costs and associated emissions to particular enterprises for most conventional systems. Organic systems, on the other hand, tend to be much more integrated and it is therefore more difficult to attribute particular inputs and costs to specific enterprises. This can make it difficult to draw direct comparisons. This was clearly illustrated by a recent study at Cranfield University (Williams et al 2006), which compared a conventional arable system to a stockless organic arable rotation. They assumed that at any one time, a proportion of the land in the organic system was under fertility building crops and effectively out of production. However, this has drawn criticism from a number of quarters (Soil Association, 2006) because only a small minority of UK organic farmers actually operate this system. The vast majority of organic arable enterprises are part of a mixed farming system, and farmers graze or make silage from the fertility building ley. Thus the land, far from being out of production, is an integral part of a milk and/or meat production system. The effect of not taking this into account was to inflate the energy and global warming potential (GWP) burdens by around 50%.

4.12 Standard methodologies and units of measurement

The second issue is that there is no agreed methodology for quantifying the inputs and environmental burdens. The basis on which comparisons are made differs from study to study. In the papers reviewed for this document, figures are quoted variously in terms of per unit area, per unit output and even per head of livestock. Since it is possible to arrive at different conclusions depending on which measure you use there tends to be a strong correlation between the units used and the views of the author. There is also little agreement in the literature as to what should be included in these assessments, particularly with regard the indirect and embodied energy. For instance most agree that the energy used to manufacture a tractor should be included. However some studies also take into account the energy used to extract and process the raw materials that made the tractor, and so on.

4.13 Variation within datasets

The third issue relates to the nature of the data itself. Energy use varies widely from farm to farm, in both organic and conventional systems, and this is reflected in the data sets generated by many studies (Williams et al 2006, CALU 2007, Carbon Trust 2005, 2006 and 2007). This presents certain statistical challenges, which require larger sample sizes to arrive at scientifically robust conclusions. Since the total number of organic farms is very much smaller than that of conventional farms this is a particular problem for the organic sector.

4.2 Quantifying energy inputs

4.21 Cropping systems

Cormack and Metcalfe (2000) showed significant reductions in total energy use (per hectare) in organic compared to conventional systems for a range of cropping systems. The reduction varied from crop to crop as detailed in Table 1. On a per tonne of product basis, the generally lower yields for organic meant the energy efficiency advantage was diminished, but in most cases organic systems still had a lower energy burden. The notable exception was carrots, where organic systems used about 27% more energy per tonne, largely because of the high energy cost of flame weeding. However, they noted that energy inputs calculated per tonne of product are closely related to the yields achieved, and this in turn depends and a wide range of factors. For instance, on good soils, organic yields tend to be higher and therefore the difference between the two systems is smaller – and the reverse would be true on poorer soils.

Crop	**Comparison of energy inputs**	
	Per Ha	Per Tonne Product
Winter wheat	60% less	30% less
Potatoes	45% less	14% less
Carrots	59% less	27% More
Cabbage	47% less	35% less
Onion	31% less	7% less
Calabrese	70% less	40% less
Leeks	60% less	

Table 1: Energy use in organic crops relative to conventional systems (From Cormack and Metcalfe 2000)

In most cases the savings were attributed to a reduction in synthetic fertiliser use but reduced pesticide use particularly for calabrese, onions and carrots was also an important consideration. The energy associated with pesticide use in potatoes was significant (although less than in conventional systems) probably due to the use of copper based fungicides against blight.

Williams et al (2006) also identified energy savings of 27% (per tonne) in organic compared to conventional wheat used than conventional systems (broadly similar to Cormack and Metcalfe, 2000), but found very little difference for potato. They noted that organic winter wheat systems used 3 times as much land and argued that this would lead to increased leaching, carbon emissions linked with ploughing and cultivation and other associated environmental burdens. However, as discussed in 4.11, the integrated nature of organic systems means that these burdens are usually carried by a number of enterprises, rather than being allocated to a single crop.

4.22 Livestock systems

In terms of livestock, Cormack and Metcalfe (2000) estimated that upland organic sheep systems used 26% less energy than conventional systems, due mainly to a reduction in bought in feed. For beef sucklers, they identified a saving of 80% due to a combination of lower energy input in silage making (presumably due to no synthetic N fertiliser use) and reduced feeding of concentrates. Williams et. al (2006) identified significant savings for lowland organic beef and sheep systems (35% and 20% respectively per tonne of product), but attributed the difference more to reduced fertiliser inputs rather than less bought in feed. In France, Boisdon and Beniot (2006) also identified a 45% reduction in organic (lowland) systems and Piemental (2006) working in USA, estimated that producing a kilogramme of beef on good organic pasture used half the energy compared to an intensive grain fed (feedlot) system.

For dairy, Cormack and Metcalfe (2000) estimated organic systems use 80% less energy per cow, largely attributable to reduced reliance on bought in feeds. However, other workers are rather more conservative. Boisdon and Beniot (2006) calculated that organic systems used 41 % less energy per hectare and Williams et al (2006) quoted similar reductions (39%) on a per litre basis, but again noted the associated increase in land use.

Organic poultry production uses more energy than non-organic systems. For meat, energy costs can be 24% higher than in caged systems and 8% higher than non-organic free range systems (per tonne) (Williams et al 2006). This is related to a number of factors including: much smaller flock sizes and therefore higher fixed costs per bird; a higher food conversion ratio; longer growing periods; and higher slaughter weights. Organic eggs also require more energy than either free range (4% more) or caged (14% more) systems, and this is related to the smaller flock sizes, and therefore larger overheads (Williams et al, 2006).

Organic pig systems use 14% less energy than conventional indoor and outdoor systems (Williams et al, 2006), mainly due to a reduction in bought in feed.

4.23 Direct energy inputs

In general terms, the direct inputs (those that occur on the farm itself, and are under the control of the farmer), are similar for organic and conventional systems. Cormack and Metcalfe (2000) showed this to be case for upland beef and sheep systems (calculated on a per head basis), and Pimentel (2006) showed that they were practically identical for maize and soybean in USA. However there are a number of instances where significant differences have been identified. For dairy, direct inputs tend to be higher for organic systems. This is related to lower yields on the one hand and similar storage and heating costs on the other, leading to higher costs per litre produced.

The horticulture sector is more complex as the situation varies widely from crop to crop. Weed susceptible crops (e.g. carrots, onions, leeks) require more direct energy inputs per kg of product in organic compared to conventional systems, mainly due to the increased number of passes with mechanical weeders and especially the energy demands of flame weeders where they are used (Cormack and Metcalfe, 2000; Bos et al 2007). For less susceptible crops such as potatoes, direct energy inputs are very similar in conventional and most organic crops (Williams et al 2006, Cormack and Metcalfe 2000). However, there are some organic systems that burn off the haulms, and in these cases the direct energy inputs are likely to be significantly higher than in conventional systems (Bentley Fox, 2004)

Organic tomatoes also use considerably higher amounts of energy per tonne, and this is due almost entirely to heating and lower yields in organic systems mean that more glasshouse space has to be heated to obtain the a tonne of produce (Cormack and Metcalfe, 2000; Williams et al, 2006).

4.3 The global warming potential of organic farming

Agriculture plays a major role in the flux and cycling of a number of key greenhouse gasses, including Carbon Dioxide (CO_2), Nitrous Oxide (N_2O) and Methane (CH_4). In this respect it differs significantly from other industries, where emissions tend to be dominated by CO_2. N_2O accounts for a large proportion of emissions from many cropping systems - about 80% of the GWP in wheat crop for instance, but it does vary from crop to crop. CO_2 emissions tend to be highest in crops that require heating, such as greenhouse tomatoes, or cold storage for example potatoes Thus, in relation to agriculture, is it more relevant to talk about a carbon – nitrogen footprint as opposed to a simply a carbon foot print (FAO 2001).

The gasses in question have very different global warming potential, but are usually expressed as CO_2 equivalents. One tonne of methane has the same effect as 21 tonnes of CO_2, and N_2O is 310 times as powerful as CO_2 by the same measure (IPCC, 2006). The relative GWP proportions (in terms of CO_2 equivalent) emitted by agriculture, forestry and land use are given in Table 2 and the main agricultural processes that generate emissions and the type of gas involved are summarised in Table 3.

Gas	GWP (tonnes of CO_2 equivalent)
Carbon Dioxide	39%
Methane	26%
Nitrous Oxide	35%

Table 2: Global warming potential of key greenhouses gases. DEFRA 2001

Life stage of cattle	Process generating emission	Type of emission
Production of animal feeds	Manufacture & transport of nitrate fertiliser; animal feed; manufacture and use of machinery	CO_2, N_2O emissions from grazing land and fodder crops
Animal housing and maintenance; associated machinery	Heating; lighting; production of building materials; associated machinery	CO_2, N_2O from housing and pasture
Digestion	Enteric fermentation; manure management	CH_4, N_2O
Slaughtering , processing	Machinery; cooking; leather production; cooling; lighting, pumping (dairy); slaughter house building materials and construction	CO_2
Transport storage	Transport; cooling; lighting	CO_2
Domestic consumption	Cooling; cooking	CO_2
Waste disposal	Transport	CO_2, N_2O
Slurry and manure	Storage; management and spreading	CO_2 CH_4

Table 3: Key processes generating greenhouse gasses in agriculture. From Bentley-Fox (2006)

4.31 Emissions

There is relatively little work on emissions, although a number of papers have been published recently on the subject. The most detailed work has been done in relation to milk production. Bentley Fox (2006), in an audit the Commonwork Organic Farm showed that emissions per litre of milk were lower than for a number of conventional systems, but noted that it was difficult to draw direct comparisons since each project used slightly different methodologies and made different assumptions – an issue discussed in some detail in section 4.1. Bos et al (2007) also calculated that for dairy systems, GHG emissions were 65% higher in conventional systems on a per hectare basis, mainly due to reduction in energy CO_2 related emissions. However, they noted than on a per litre basis, CH_4 emissions were not significantly different for the two systems. Allen et al (2007) also identified a reduction in total emissions in organic systems on a per litre basis (5 -9% less depending on the system), but did not concur with Bos et al (2007) regarding CH_4 emissions, arguing that lower yields per cow meant more methane was emitted per litre of milk produced. Williams et al. appear to take the latter view. They calculated that the GWP of organic systems was 14% higher which they attributed mainly to increased CH_4 emissions, presumably on the same basis as Allen et al, although this was not explicitly stated.

Williams et al 2006 calculated slight reductions in the GWP for organic compared to conventional systems for a number of products including bread wheat (3%), Oil seed rape (5%), potatoes (7%). For poultry and tomatoes, the GWP was higher in organic systems, and presumably this is due to the CO2 emissions related to the higher energy inputs identified in section 4.2.

Work into beef systems presents a rather confusing picture. Williams et al 2006 showed that organic lowland beef production systems have a substantially (14%) higher GWP than conventional system despite having a much lower energy input, and it is not clear from the input data as to why this should be.

There is also a great deal of debate over how much N_2O is actually emitted from agricultural systems, both organic and conventional, and how this should be measured. One might expect that due to reduced fertiliser use, emissions of this gas would be significantly lower in organic systems, and indeed Allen et al (2007) found this to be so. However, Bos et al (2007) reported similar N_2O emissions per litre of milk in the two systems, arguing that gain made in organic systems by reduced fertiliser use are offset by higher grazing intensity and more frequent ploughing in organic systems.

4.33 Sequestration of organic systems

Sequestration is difficult to measure, and this is probably why there is relatively little work in this area compared to emissions. Ball and Pretty (2002) identified a number of mechanisms and measures for increasing carbon sinks including:

- Replace inversion ploughing with conservation and zero tillage systems
- Adopt a mixed rotation with cover crops and green manures to increase biomass additions to the soil
- Adopt agro forestry in cropping systems to increase above ground standing biomass
- Minimise summer fallows and periods with no ground cover to maintain soil organic matter stocks
- Use soil conservation measures to avoid soil erosion and loss of soil organic matter.
- Apply composts and manures to increase soil organic matter stocks

The Rodale Institute's 23 year Farming systems trial (Pimental et al 2005) compared organic (with animal manures and stockless) and conventional maize and soybean production in the USA. Over the period of the trial, soil carbon in the organic systems increased from about 2% to about 2.5%, while the soil carbon in the conventional system remained static at about 2%. Since the above ground carbon inputs were similar for organic and conventional systems, the increase in the organically managed soils is due to their ability to retain the carbon better. This led to an annual increase 981 Kg/ Ha and 574 Kg/ Ha for the manured and stockless systems respectively compared to 293 Kg/ ha for conventional crops.

4.33 Total GWP of organic systems

While a certain amount of work has been carried out on emissions and sequestration individually, there seem to be few studies that bring the two together to assess the net contribution to GWP (i.e. Carbon emissions- carbon sequestration) for specific systems. Robertson et al (2000) achieved this by monitoring four management systems over a period of 10 years. The systems were: High input; low input (but not organic); reduced tillage; and organic. They looked at a number of crops including a Soybean/ wheat/ soybean rotation, alfalfa and poplar coppice. They also examined 'natural' (unmanaged) systems at various stages of succession.

They found that the perennial crops (alfalfa and poplar) had a neutral or mitigating impact on GWP, as did the natural systems in the early stages of succession. This is largely due to high levels of carbon sequestration (32 – 44g Carbon/ m^2/year for the crops and 60g/m^2/yr for the early succession eco system) combine with low levels of Nitrogen inputs.

However, they concluded that all the annual cropping systems made a net positive contribution to global warming, which would appear to contradict Pimental et al (2005)..The net GWP of the no till system was lowest (14g CO_2 equivalents/ m^2/year), followed by the organic and low input systems (41 and 63g CO_2 equivalents/ m^2/year respectively) and the high input conventional systems the highest at 114 CO_2 equivalents/ m^2/year. The no till system has the highest sequestration rate 30g Carbon/m^2/year). The low input and organic systems sequestered approximately a third of that (8 and 11g/ m^2/year respectively). However, production related emissions meant that these systems still caused a net increase in GWP. They noted that N_2O emissions were very similar among all the cropping systems, suggesting that the net availability of N was the key factor determining emissions of N_2O, and the source, whether from inorganic fertilisers or as result of biological N fixing, is less important. This would appear to support the conclusions of Bos et al (2007) as discussed in 4.31.

5. Energy in transport and distribution of food

Food transport to supply the UK population in 2002 accounted for an estimated 30 billion road kilometres, generating 19 million tonnes of CO_2 (10 million of which was emitted in the UK (DEFRA 2005). Road is the dominant mode of transport for food, with sea, rail, air and internal waterway making a negligible contribution. Almost half of the estimated vehicle kilometres are accounted for by cars, that is to say the transport of food from the retail outlet to the home. Goods vehicles in the UK account for 35% of road km (19% HGVs and 16% in LGVs) and a further 12 % overseas (DEFRA 2005).

Food transport systems are dominated by the multiple retailers, which market 76% of organic products (Soil Association 2006) and about 85% of all food sold in the UK (DEFRA 2005).,This has resulted in centralisation of the purchasing and logistical operations. Most food is now distributed through a network of abut 70 Regional Distribution Centres (RDCs) each serving a large geographical areas. This has considerably lengthened the last link in the chain from warehouse to store, although the consolidation of retailer controlled deliveries may well have reduced the total vehicle kilometres travelled (DEFRA 2005).

However, any reduction in this part of the chain is offset by increases in traffic upstream of the RDC. Where previously small suppliers were only able to supply their local branch store, the development of the RDCs meant that now they are able to gain access to the entire chain. This expanded their markets considerably, but also meant that their produce now travelled proportionately further. Ironically, the RDCs have made it virtually impossible for them to deliver to their local stores (with the possible exception of bread, milk and other so called morning goods). This leads the logistical anomalies that most of us are by now familiar with – Sandwich companies supplying shops next door via an RDC 50 miles away, Welsh carrots being driven to East Anglia for washing and preparation and back again for sale and so on. The debate on the efficiency of these systems is passionate and on going. Detractors argue that trucking produce 100 miles to effectively move it 10 cannot possibly be efficient, while supporters point to better levels of vehicle utilisation at aggregate level (DEFRA 2005).

As noted above about three quarters of organic food is distributed via this system. However, the proportion of food sold through other outlets is growing rapidly. In 2005 sales through producer-owned outlets (box schemes, mail order, farm shops, farmers markets etc.) increased by 11% and those from non-producer owned businesses (independent shops, box schemes etc) increased by 38%. By comparison, sales through multiples increased by less than 1% (Soil Association 2006). At individual level products clearly travel considerably less distance compared to centralised systems, and from this perspective there are considerable benefits. However, there is still much debate over whether overall, this model, which tends to involve more, shorter, trips is more efficient in terms of energy and emissions than a more centralised system that makes fewer, longer journeys (DEFRA Undated b).

6 Review of audit tools

There are a number of existing audit tools or systems under development that could be built on or adapted to make them more applicable organic systems. Many are very simple, and are designed to help farmers benchmark their business with regard to energy use and/ or emissions of greenhouse gases and to identify areas where savings and improvements can be made. They therefore tend to focus on direct inputs (that is the aspects under the direct control of the farmer), and are designed to be simple to use and interpret. Many (CALU 2007, SAVEFuel and Refuel) use electricity and fuel bills to get a good indication of the energy demand of the business over all. Other, more sophisticated calculators have been developed to determine the inputs in to individual farm operations They take into account factors such as the type of machine, the power of the tractor, work rate and even the distance from the farm yard to the field.

Carbon Accounting for Land Managers (CALM)
Developed by: Country, Land and Business Association (CLA) www.cla.org.uk
Contact: Tanya Olmeda-Hodge tanya.olmeda-hodge@cla.org.uk, Tel: 0207 2350511.

This tool is currently under development, and is due to be released in September 2007. The focus will be on direct inputs (derived from fuel and electricity bills), the associated emissions, and their GWP and identifies opportunities for energy savings in a 'check list' format. It does not take into account the indirect energy input involved in the manufacture, distribution and use of purchased inputs. It does, however, include renewable energy sources, and their contribution to reducing carbon emissions.

Environmental benchmarking

This is a DEFRA funded project (OF0348), still in progress (Sue Fowler, Pers Comm). It aims to assess viability, not only in financial terms, but also in energy terms. The products from an energetically viable system contain more energy than is consumed by their production (excluding the input of solar energy) without depleting soil fertility. It calculates energy inputs over energy outputs measured as percentage, using the following data:

- All purchases and sales, including of fossil fuels and electricity, descriptions and quantities
- Standard data for gross energy of all above
- Routes to market
- Distance to slaughter/sale for each
- Weight of produce sold through each

Food Carbon Calculator
http://www.foodcarbon.co.uk/carbon_emissions.html
This tool looks at energy from a consumer perspective, and attempts to calculate the emissions (rather than energy directly) of individuals based on their weekly food purchases. It uses standard figures for different products (beef, chicken, potatoes, carrots, apples, bananas, milk, cheese) based on where they are sourced from and whether or not they are organic. The figures include production, storage and distribution costs, but not transport from the shop/ store to the home. It is a useful guide from a consumer point of view but is of limited use in a farming context. It is also incomplete in terms of the range of products consumed.

Footprinter
Developed by: Best Foot Forward, www.footprinter.com
Contact: Craig Simmonds Mail@Bestfootforward.com, Tel 01865 794586

This is a web-based tool that connects over the internet to Best Foot Forward's EcoIndex™ database. A free trial model is available from the website. At present there are sections on the company profile (no employees, office space, unit manufactured etc), transport and utilities, and food section is currently under development.

It has not been developed specifically with agricultural businesses in mind, and some of these factors might, in their current form be difficult to relate to a farm situation. However, the system can be customised, both in terms of simplifying the auditing process and amending/ adding to the database and the new food section could provide a good basis on which to work. Craig Simmons has indicated they would be interested developing a suitable system. **Forum for the Future**

Contact Claire Skinner, c.skinner@forumforthefuture.org.uk

This spreadsheet tool has been developed to assist dairy farmers to examine a farm's energy use and greenhouse gas emissions. The tool suggests ways to reduce energy use and greenhouse gas emissions, with the aim of pinpointing cost savings. The tool was piloted with four dairy farms. It generates headline indicators for comparison between farms including:

- Total energy cost per litre of milk produced
- Estimated energy savings possible through efficiency measures
- Total greenhouse gas emissions per litre of milk, per cow and per hectare

It also includes estimates of some key in direct inputs, including fertilisers and imported animal feeds.

Farmers are able to use the spreadsheet tool to gauge the effects of changing specific practices. By altering baseline data, it can demonstrate variations in greenhouse gas emissions. The tool could be developed further and, for example, could be used as the basis for activities and discussion within dairy benchmarking groups.

KBTL Calculator
http://www.ktbl.de/dieselbedarf/index.htm).

This is a web based calculator which determines the fuel requirement, and hence the energy demand, of a number of specific agricultural and horticultural operations. It appears to one of the best of its type, but is currently only available in German. The full version would need to be paid for. A free trial version available from website.

Managing Energy and Carbon
Developed by Centre for Alternative Land Use (CALU) and ADAS.
www.calu.bangor.ac.uk

This tool calculates direct on-farm inputs for fuel and electricity bills, relates energy use to GHG emissions and identifies opportunities for energy savings in a 'check list' format. The user can compare their usage to standard figures for different enterprises, based on data from 900 farms in England and Wales. This tool takes a very broad brush approach to the issues. It is a useful tool for taking a superficial look at the issues, but is not sufficiently powerful to look at the issues in great detail

SAVEFuel and Refuel

Developed by SAC
Contact: Rod McGovern 01224 711107, rod.mcgovern@sac.co.uk

These are two pieces of Software were developed by SAC to support their consultancy services. SAVEFuel quantifies existing farm energy use and compares it with benchmarks and targets. Potential savings are identified and ranked by cost/benefit with an outline plan for implementation. REFuel assesses the potential for on-farm production of renewable energy, looking at options for producing energy from renewable sources such as wind, hydro, solar heat, photovoltaics, energy crops and animal wastes. The software enables technical feasibility studies to be carried out and also provides economic assessments (including payback) of opportunities for renewable energy production. The software is not in the public domain, but SAC has expressed a willingness in principle to work to develop a system specific to the organic sector.

7. Potential sources of data

This section identifies published papers and reports that could potentially provide raw data that could be inputted in an audit tool (Table 5), including:

- Indirect energy for manufacture and distribution of inorganic Nitrogen fertilisers
- Indirect energy for manufacture and distribution of Phosphate fertilisers
- Indirect energy for manufacture and distribution of pesticides (Herbicides, fungicides, insecticides and acaricides)
- Indirect energy for manufacture and distribution of farm machinery
- On farm fuel demand (specific operations)
- Carbon emissions
- Carbon sequestration
- Renewable energy
- Enterprise specific data for arable, beef & sheep, dairy, horticulture, pigs, poultry)

	Fertiliser	Pesticides	Machinery	Transport	Fuel demand	Emissions	Sequestration	Ren. energy	Arable	Beef &	Dairy	Horticulture	Poultry	Pigs	Other
Allen et al 2007	✓	✓	✓			✓					✓				
Bos et al, 2007						✓			✓		✓	✓			
Bentley-Fox, 2004	✓		✓		✓				✓						
Bentley-Fox, 2006						✓			✓	✓	✓	✓			✓
Carbon Trust, 2004												✓			
Carbon Trust 2005													✓		
CALU, 2007					✓	✓		✓	✓	✓	✓	✓	✓	✓	
Cormack & Metcalfe 2000	✓	✓	✓	✓	✓				✓	✓	✓	✓			
DEFRA 2005				✓		✓									
FAO 2001						✓									
Pimentel et al, 2006					✓				✓	✓	✓	✓			✓
Pimentel et al, 2006						✓	✓		✓						
Robertson et al, 2000						✓	✓		✓						✓
University of Florida 1991	✓	✓													✓
Williams et al 2006	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	

Table 5:Summary of data sources on energy inputs and GHG emissions

Allen et al, 2007

This study focuses on emissions from organic and conventional dairy enterprises, based on analysis of 72 farms. The following data are available in spread sheet format, but require permission from Kite Consulting Ltd for wider distribution. Inputs are quantified both in terms of energy and emissions

- Direct inputs (diesel and electricity) for organic & conventional systems
- Fertiliser
- Pesticides
- Dairy chemicals
- Bedding
- Machinery
- Buildings
- Fencing
- Feed
- Methane emissions (enteric and slurry)
- N_2O emissions

Bos et al 2007
http://orgprints.org/9961/
This paper compares the energy inputs and GHG emissions from organic and conventional systems (arable, dairy and vegetables) in Netherlands. The following data is supplied for each of the enterprises:

- Total energy use
- Proportion of direct and indirect energy costs
- GHG emissions and GWP

Bentley–Fox 2006

This is a GHG audit for the Commonwork zero (fossil) energy farm. Most the data relating energy use is taken from Cormack & Metcalfe 2000. Emissions data includes:

- Total emissions from UK agriculture and contribution of each GHG
- Total emissions from farm (from internal and external sources)
- Savings (in terms of energy and emissions) from using heat recovery units and ice tanks, energy efficiency checks for vehicles.
- Emissions from specific field operations (FYM and slurry spreading, Silage making, combining, ploughing, sowing and weed management)
- Impact of specific management practices (including reduced tillage, reduced stocking rates, stocking rates).

- Potential contribution of wind, solar, biomass, ground source heat pumps, biogas, biodiesel, and bioethanol, in terms of energy generated and the resulting reduction in emissions.

- Standard figures for transport related emissions

Bentley-Fox 2004
http://orgprints.org/10322/
This is an audit of energy inputs into the organic arable system at Sheepdrove organic farm, and maps out energy demand for several rotations including: winter wheat; spring wheat; spring barley; spring oats; white clover; red clover; spring beans; including options for undersowing the cereal crops. Data on the energy demand for the following operations is presented:

- Soil improvements
- Ploughing & cultivation
- Seed transport & Sowing
- Rolling
- Undersowing
- Combining,
- Post harvest cultivation
- Grain transport, drying & cooling
- Baling

Spreadsheets generated from this project could feed into an auditing tool

CALU, 2007
http://www.calu.bangor.ac.uk/Technical%20leaflets/Energyauditmanual.pdf
This tool calculates direct on-farm inputs and provides some benchmark figures for arable, horticulture dairy, pigs, poultry, beef & sheep. The data presented is superficial (farm totals) and not specific to organic systems. However, it is supported by a large data set (900 farms), the detail of which may be useful to generate conventional benchmark figures.

Carbon Trust, 2005
http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=ECG089&metaNoCache=1
This publication includes benchmark figures for pig production systems, and recommendations for energy saving measures. It takes a very broad brush approach, but may be useful if total energy inputs for conventional systems are needed to benchmark organic systems against

Carbon Trust, 2004
http://www.carbontrust.co.uk/Publications/publicationdetail.htm?productid=ECG091&metaNoCache=1
This publication includes benchmark figures for protected horticulture and recommendations for energy saving measures. As noted for pigs, it takes a very broad brush approach but may be useful if total energy inputs for conventional systems are needed to benchmark organic systems against.

Cormack & Metcalfe, 2000
http://orgprints.org/8169/01/OF0182_181_FRP.pdf

This paper compares direct and indirect energy inputs in organic and conventional systems for arable, beef & sheep, dairy and horticulture. This is a key reference and the source of much information quoted in subsequent work. Specific data includes:

- Energy use for manufacture of fertilisers (less comprehensive than Williams et al, 2006)
- Energy in manufacture and distribution of pesticides
- Energy inputs (per Ha and per tonne of produce) for arable and vegetable crops (conventional and organic)
- Transport and distribution costs
- Drying machinery, pesticides, fertilisers and seed
- Proportion of direct and indirect costs for livestock enterprises
- Direct and indirect energy inputs for organic an non organic systems (whole farm basis) for livestock, vegetables and dairy

The spreadsheet generated as part of this project could form the basis of an auditing tool, However, DEFRA feel that in its current form the, data is misleading and were not willing to provide access to them.

DEFRA 2005
http://www.defra.gov.uk/farm/policy/sustain/fiss/pdf/report-food-transport-may2007.pdf
This is an analysis GHG emissions associated with transport/ distribution of food from the farm gate to consumer's home in the UK, including:

- Distances travelled and associated emissions for Road (HGV, LGV, Car), Rail, Air, Sea, Inland waterways
- Proportions of UK produced and imported food, and relative distances and associated emissions in the UK and abroad
- Consumption data
- Farm gate retail prices and size of market

It also includes case studies for particular products (tomatoes, imported organic wheat including analysis of energy savings in production vs energy consumed in transport)

FAO 2001
http://www.fao.org/docrep/004/Y2780E/y2780e00.HTM
This document includes global estimates of nitrogen emissions (Ammonia, NO and N_2O) from agricultural land. It is not specific to organic systems, but includes good data on:

- Standard emission data for various fertiliser types
- N application rates
- Ammonia volatilisation rates for various factors
- Total emissions on regional basis (e.g. Canada, USA, S. America etc)

Pimental et al, 2006

This document is a summary of the Farming Systems Trial at Rodale which compared organic and conventional maize and soybean production systems over a period of 23 years. Data includes:

- Total energy inputs per Ha
- Soil carbon sequestration

Pimentel et al, 2000
http://www.organic-center.org/reportfiles/ENERGY_SSR.pdf
This paper compares energy inputs in organic and non- organic production systems for beef, dairy, soybean, maize, dairy, oranges, rice, field vegetables in the USA. It is potentially useful, but some of the crops are clearly not relevant to the UK. For each enterprise, organic and non organic data is available for:

- Energy ratios
- Labour
- Machinery
- Fuels
- Manufacture and distribution of inputs (fertilisers, pesticides seeds)
- Standard application/seed rates
- Electricity costs
- Sequestration rates (organic and non organic arable systems)

Robertson et al
This paper presents the results of a 10 year study in the USA, monitoring emissions and sequestration in production systems of varying intensity (High input and low input conventional; reduced tillage; and organic). It also includes unmanaged vegetation at various stages of succession. Crop systems are Soybean/ wheat rotations; alfalfa; and poplar coppice. For each system, there is data available on:

- Above ground net primary production (ANPP)
- N availability
- N. Mineralisation potential
- Organic carbon (% and kg/m^2)
- Change in carbon (g/m^2/year)
- GWP of each system

University of Florida, 1991
Detailed data on energy requirements of specific types of the following inputs:

- Nitrogen, phosphorous and potassium bearing fertilisers
- Pesticide active ingredients (some of which are no longer in use)

- Pesticide packing and formulation
- Plastic mulches and greenhouse covers

Williams et al, 2006

This study measures the environmental burdens of 10 commodities (bread wheat, potatoes, Oil seed rape, beef, sheep, pigs, poultry meat, eggs and milk) and compares conventional and organic systems. While there are some concerns about the validity of the model, in terms of how burdens are calculated, the underlying data is sound, and this document is a key source of information including:

- Work rates for fuel usage for key field operations (including factors to adjust for soil type)
- Main characteristics of typical tractors, other self propelled and trailed machinery (power, work rate, embodied energy)
- Embodied energy and emissions for manufacture and transports of all main fertilisers and soil amenders Burdens of composting residues,
- Grain storage requirements
- DM contents (used for calculating emissions)
- Distances travelled and methods of transport for imported feeds
- Energy consumption in feed processing
- Burden of building and maintaining buildings
- Inputs (organic and non organic) for dairy, pig, eggs, sheep, beef

8 Conclusions

While a large and growing body of work continues in this area, there is very little agreement as to the contribution organic farming makes to the reduction of energy use and GWP of food production. As discussed is section 3.1 this is largely down to inconsistencies in methodology and the basis of measurement. This is true for energy inputs and emissions and sequestration data. With regard the GWP, more work is clearly needed on the sequestration side of the equation, and studies that take into account the net contributions to GWP (rather than just energy and emissions data) would be a significant step forward in our understanding of the situation. The picture also remains unclear at the distribution and logistical level, and there is clearly a good deal of mileage left in the local vs centralised systems debate.

As to the future direction, there are currently a number of proposals under development. Jones (2001) bought many of the issues discussed thus far together and proposed a model for sustainable food supply chains. A full discussion of this is beyond the scope of this review, but in essence, he advocates:

- A move away from large scale, specialist production toward local diverse production systems. This will shorten the distance from between procurers and consumers
- A move towards low input sustainable systems such as organic farming and permaculture
- A move away from international sourcing and centralised distribution and implement a ‘near for far’ substitution policy

- The revitalisation of local markets
- The reintroduction of usable packaging schemes
- Increase the proportion of local ingredients sourced by the catering trade and local authorities

DEFRA is also taking a number of the issues on board and is working with the Dairy Supply Chain Forum's Sustainable Consumption and Production Taskforce to develop a so called ‘roadmap’ towards a more sustainable dairy industry. It uses life cycle analysis to complete a "cradle to grave" picture of the environmental impacts of a product, and highlight areas where efforts can effectively be concentrated to reduce those impacts. It is still a work in progress, but a first draft is due for publication in November 2007.

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