New Energy Technologies In Agriculture

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1. Introduction

Agriculture is an energy industry, providing energy in the form of food for human consumption. The economic incentive to famers is usually to maximise the income from the land which they manage, either through use of crops, animals, or a mixture of the two. Modern methods use many energy inputs to facilitate this food production.

Rising energy prices in recent years have had a significant effect in raising the costs of agricultural inputs, threatening profitability as well as contributing to high global food prices. Diminishing fossil fuel resources place uncertainty over whether high levels of food production can be maintained. This report aims to consider three aspects: where the true energetic costs of agriculture arise; what solutions could be implemented; and the barriers to introducing new technologies.

The best solution at a farm level will depend very much on the farm's circumstances. This report will consider farms in the UK setting, but the discussion will not yield specific answers as the differing geographies of farms means no "one size fits all" answer exists. However, the important variables when considering each technology will be clarified.

This study will consider experience from the Peak District National Park, where a community-led group and participating farmers aim to introduce new technologies to improve sustainability in agriculture.

2. Identifying Energy Inputs

It is useful to consider first how energy flows through agricultural systems. To begin, when the sun shines upon farmland, the input of solar energy allows plants to build up nutrient stores and grow. Sometimes these plants can be immediately harvested for human consumption; or on other occasions it is animals that eat the plants, absorbing the energy and using some of it to grow and then finally the energy passes to humans in the form of animal products and meat.

This simple description considers only the central energy flow, which is applicable to wild plant and animal food chains too. Energy flows in agriculture are much more complex, with the aim of ensuring that the food yield is much higher than they would naturally be. A farmer works to ensure that the food crops are not overgrown with weeds; that they do not succumb to parasites; that they are provided with the nutrients needed to optimise growth; and that they can be harvested with minimal cost. Meeting each of these requirements requires effort and energy inputs from the farmer. Much of the increased yields of recent decades has come from methods consuming fossil fuel, over a period in which they have been relatively cheap.

Fossil fuels are now used to power farm machinery, make artificial fertilisers and chemical pesticides, generate electricity and create many other resources used on farms. Perhaps surprisingly, the energy return on investment(EROI), a measure of the energy in the food output compared to the non-renewable energy input, has fallen significantly while agriculture has developed from subsistence to modern methods. The yields of crop per unit area are a lot higher, but the use of fertiliser and fuels for machinery mean high levels of energy input. Research by Coley estimates that, by the time foods reach the shopping basket, a typical UK diet has an embodied energy of 5.75 times that derived from the food[1], meaning an EROI value of 0.17. Table 1 contains a list of estimated EROI values for various food products, the figures come calculated by Gerald Leach in 1976[2], apart from the values for ethanol production which are based on recent calculations[3].

Table 1 A list of calculated Energy Return on Investment figures. Figures sourced from [2] unless otherwise stated.

Farming Method	Energy Return On Investment (EROI)
Typical Subsistence Crops	13-38
US cellulosic ethanol production	4.40-6.61[3]
UK wheat	3.5
UK potatoes	1.6
US corn ethanol production	0.84-1.65[3]
UK white bread (at bakery door)	0.51
UK milk	0.37
UK broiler poultry	0.1
UK fishing fleets	0.05

Much of this energy intensity resulted from low fuel prices which meant that machines could do a lot of work at greater speed and low running costs compared to human or animal labour. The price of oil remained at around $1.5 per barrel during the 1950s and 1960s which roughly equates to 6000 hours of human labour[2], so it should be no surprise that mechanisation was a priority.

Calculations of EROI figures exclude the amount of solar energy that falls onto the farm, considering only the energy inputs which have a cost to the farmer. This may seem strange, particularly since the solar energy would be the biggest energy input by far, but it is constant and has no cost to the farmer, and as such is not an energy investment.

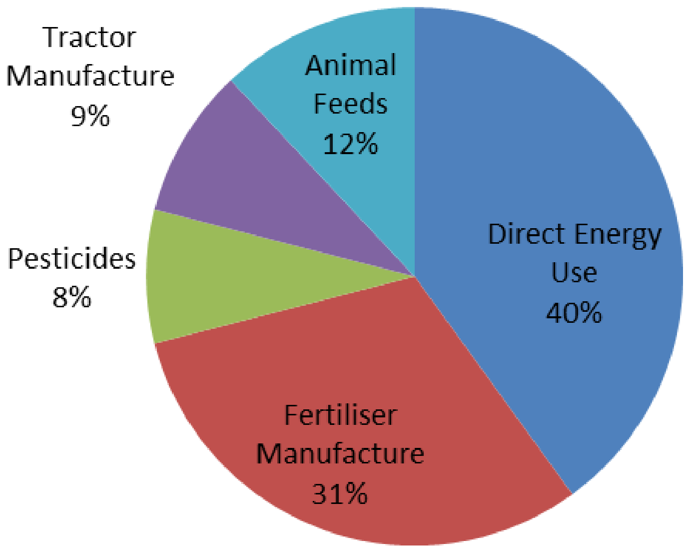

Figure 1 The estimated proportions of energy inputs to UK agriculture in 2004. [4]

Figure 1 shows the results of an assessment of energy inputs carried out by ADAS in 2004[4]. The results show the large contribution of direct energy use (including diesel fuel and electricity at 40%), and also the large embodied energy input (31%) from using manufactured fertilisers. We now look at the contributions from each major input in more detail. Technological solutions to energy-dependency will be explored in the following section.

2.1 Diesel Use

Diesel use is vital for Western agriculture, allowing heavy machinery to work the land and make it suitable for cultivation, as well as carrying out the harvest and moving materials around the farm site. The trends in Western machinery have been towards bigger and more powerful machinery, able to work more land in less time. Particularly in the UK, the ability to undertake a faster harvest using bigger machines makes it easier to take advantage of a period of nice weather to complete a harvest, resulting in lower losses due to bad weather.

Diesel is also used for road vehicles to transport animals and goods to the market place. This can be a significant energy use in rural locations. The high energy density and convenience of liquid fuels make them a valuable commodity to agriculture. So the industry is vulnerable if fuel prices increase.

2.2 Electricity Use

Electricity is used on farms to drive electrical motors, for example driving pressure washing equipment. Also, since the rural location of farms means they are rarely connected to the gas grid, electricity can be used to heat water. The heating of water is energy intensive, particularly in dairy farms where hot water is used regularly to maintain the hygiene levels in the milking parlour. During harsh winters a lot of electrically heated water may be used to thaw frozen pipes on farm as well as at water troughs in the fields. Alternatives providers of heating are wood- or coal-burning stoves, but the price of coal and wood has risen in recent years too.

Government policy is currently creating a positive environment for investing in gas-fired power stations, but natural gas prices are volatile, having tripled since 2000. So further rises in electricity prices are entirely possible.

2.3 Fertiliser

Artificial fertilisers have a high embodied energy as a lot of natural gas is used in their manufacture. The main industrial process involved is called the Haber-Bosch process. This fixes nitrogen from the atmosphere into ammonia which is then processed to make fertiliser compounds containing ammonium and nitrate. Natural gas is used in this process to supply hydrogen through the steam reformation reaction, and also to heat the reactions so that the necessary temperatures and pressures can be maintained.

Artificial fertilisers allow for control of nutrient levels in the field which can be adjusted to give the best yields for each crop by adjusting the levels of potassium and phosphorus that is available to the crop.

2.4 Pesticide Use

Pesticides are mostly based on organic molecules that are derived from oil, so the input of oil to their production represents embodied energy. However, as seen in Figure 1 this embodied energy is relatively small by comparison to other factors. The use of pesticides is important to keep yields high while maintaining low labour costs. Using less pesticide will have environmental benefits and save money too, but the relatively small energy use means that pesticide use is probably sustainable despite increasing fossil fuel prices.

2.5 Tractor Manufacture

The energy inputs to manufacture machinery are high, suggesting that a slower turnover of machinery would save energy. However, older machinery is likely to be less efficient than new machinery and, as mentioned earlier, more powerful modern machinery may be beneficial for maximising yields.

2.6 Animal Feedstuffs

12% of the energy inputs to agriculture are embodied in animal feeds, and remember this is averaged between farms that have livestock and arable farms that do not. This suggests that for farms carrying livestock nearly half of their energy inputs may arise from animal feed. The significant use of feedstuffs is also demonstrated in research by the Food and Agriculture Organisation which suggests approximately 70% of the carbon footprint of meat production of monogastric animals(e.g. pigs and poultry) comes from the use of feedstuffs[5]. Statistics from the Food and Agriculture Organisation, represented in Figure 2, show that UK farm produce is dominated by animal produce when ranked by value, even though the tonnage of wheat produced is greater than that of milk.

Animals on UK farms often need high-protein foods to supplement their diets. Europe only grows enough high-protein crops to supply around a third of the dietary needs of these animals[5]. As a result a high volume of soya, the main high-protein crop traded internationally, is imported into Europe to feed farm animals. The meats in a typical European diet requires the use, on average, of one kilogram of soya per week per person[12].

Much of the soya will have been grown on expansive farms in places such as the US or South America. The higher land availability caused by lower population density in these regions means that the farming methods do not need to be as energy intense (e.g. less fertiliser need per unit area). However, there is an energy penalty for transporting between continents and as global demand for food grows these land resources will come under growing pressure meaning the international prices will rise. So the energy embodied in these feedstuffs look vulnerable to rises in fossil fuel prices as well as demand from a growing global population in coming decades.

The droughts in the United States in the summer of 2012 have driven the price of corn and other commodities very high, and they serve as a reminder that importing such vast quantities of feed from the Americas has sustainability issues attached too.

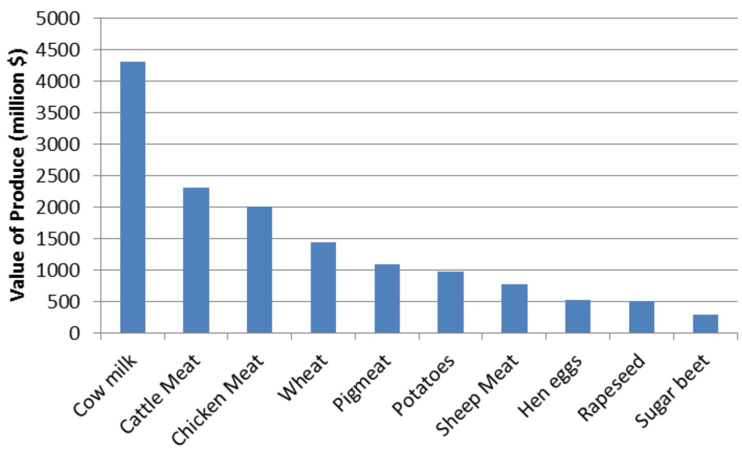

Figure 2 International value of UK agricultural produce[6].

3. Possible Solutions

No single solution will apply to all farms, but this paper aims to explore a range of options available and discuss advantages and disadvantages. Investment decisions will be difficult since food and energy commodities are both volatile making forecasts difficult. The long-term sustainability of farm operations should be considered against a backdrop of a growing global demand for commodities alongside increasing scarcity of natural resources.

3.1 Energy Efficiency

Like in the domestic sector, reducing the amount of energy that is wasted is often the easiest way to reduce bills. For example, the big energy expenditure form transport can be reduced through economical driving techniques. Heat losses from buildings can be reduced by improving the glazing levels and eliminating draughts, then animals will consume less feed to keep themselves warm.

A positive first step is to improve monitoring of energy use. For example some electricity suppliers provide in home display screens which allow electricity use to be monitored in real time. Some farms just have a single electricity meter covering both the farm and domestic dwellings; this makes electricity consumption harder to control. Better awareness of energy use, and what it is being used for, is a very positive step.

3.2 Altered Livestock Levels

From an energetic viewpoint, energy losses are high at each step in the food chain. This is why Table 1 shows that meat production gives a much lower energy return on investment than crop production. A farmer needs to consider whether the price of meat produced reflects the cost of the inputs used to produce it. The geography of the farm will affect this, for example animals grazing on a hillside that could not possibly be harvested is probably the best way of producing food in that circumstance. In other circumstances, land may be convertible from animal fodder crops to human food crops and this may make sense if the financial penalty for energy use in meat production is not rewarded by the market price of meat.

3.3 Biofuels

Can a farm grow enough biofuel to power its own tractors? More specifically, can the energy output from an "energy crop" be sufficient to provide the energy needed to fuel the tractor that ploughed the land as well as make the artificial fertiliser that helped the crop to grow. The answer is determined by the value of the Energy Return on Investment (EROI). An EROI value of 1.0 is effectively a 'break-even' point. If an arable farmer dedicates a quarter of their crop land to grow biofuels, and the fertiliser and fuel inputs are broadly the same on both crops, then an energy return on investment of 4.0 is needed for self-efficiency in energy terms.

Research to estimate the EROI of ethanol production in the United States has given answers in the range 0.84-1.65 for corn-derived ethanol and 4.40-6.61 for cellulose(plant-fibre) derived ethanol[3]. The energy return on investment for whole-crop biofuels(e.g. cellulose derived ethanol) is much higher as the energy embodied in the whole plant is used. However on farms where livestock are kept the other parts of the plant are often used to make straw bedding for animals. Growing biofuels will reduce the capacity of the farm to grow food. Does it make sense to import more food and grow more fuel or the other way round?

3.4 Renewable Energy Generation on Farms

Many renewable energy resources are diffuse, sunlight and wind for instance, and the main land use in the UK is agriculture and so it makes sense for farmers to be aware of good ways to harness renewable energy. We now explore the main renewable technologies that could be implemented on farms.

3.4.1 Wind

The cheapest form of renewable electricity generation is onshore wind. Farmers with land that is exposed to high winds may be sitting on a valuable resource. The power a wind turbine can produce is roughly proportional to the size of the circle swept out by the rotating blade; therefore a wind turbine twice the area will produce roughly four times as much power. Also, with increasing height from the ground, wind speeds also increase as there is less turbulence due to obstructions on the ground. However, larger wind turbines mean greater cost and more visual impact for the local community, and so a suitable compromise should be reached.

It is necessary that wind turbines are situated a decent distance from trees, buildings and other obstructions to ensure a good flow of the wind to the turbine; poor flow will reduce the power output. The output from wind turbines is intermittent, so a back-up power supply is needed, however if the turbine is connected to the grid then the intermittency is not managed by the turbine owner and the feed-in-tariff generates income proportional to the energy generated.

3.4.2 Solar

Producing electricity from solar panels is the most expensive form of renewable energy, but the costs of solar panels have been falling fast. The incentives provided by Government have been cut significantly, so this will affect the economics. Also worth considering is the use of solar thermal panels; the principle here is to use the solar energy to heat water running through the panel. If a significant amount of energy is used on the farm for hot water then this may be a useful resource and the technology is much cheaper. With solar thermal panels it should be acknowledged that the greatest heat production will be in summer, so finding sufficient demand at those times may be difficult.

3.4.3 Micro Hydropower

A site with consistent water flow will give most certainty over financial return on investment; sites with high flow rates and a large drop in water level will give the greatest power output. The output will vary with rainfall levels and so be seasonal, tending to give higher output in winter than summer. The cost of connecting the point of generation to the point of electricity consumption may be high. A typical 5kW domestic scheme may cost £20k-£25k[7]. Developers need to be aware of the necessary permits required from the Environment Agency, and alterations to the design may be required.

3.4.4 Biomass

Unmanaged woodlands could be an energy resource for the farmer, providing wood which can be used for heating in wood-burners[8]. Rededication of land for willow or miscanthus crops may be problematic, requiring new harvesting techniques, but they may help to take advantage of marshlands that are unsuitable for grazing or cropping.

3.5 Anaerobic Digesters (AD)

Animal manure produced on farms gives off methane, anaerobic digesters use bacteria to break down organic molecules in the waste in order to quicken release of this methane which can then be captured inside the digester and burned as a biogas fuel. Burning this biogas rather than releasing to air significantly reduces the greenhouse gas impacts; another advantage is the production of energy from waste. The breakdown of organic molecules by the bacteria also means that the nitrogen availability is higher in the digestate output from the digester than is the case in manure, typically over 90% available compared with 30% for raw slurry and this can reduce artificial fertiliser use by 50% or more, even in manure-only systems[9]. However, these systems can easily cost £100k or much more depending on specification, and the system will have a lifespan of up to 30 years so the maintenance and running costs should be worked out carefully.

Co-digesting of energy crops or food wastes will increase the biogas outputs but also increase the number of environmental permits. The inclusion of these more volatile feedstocks also increases the need to supervise the system Manure-only systems can work but economic viability will depend on many factors. A *Toolbox* document prepared by the Methanogen Ltd for Sustainable Youlgrave, and for the wider use by farmers considering AD systems, provides a thorough understanding of the issues to consider and there are more details at the end of this document[9].

4. Barriers to Implementing New Technologies

Introducing these new technologies often requires significant investment, and the financial positions of farms may make these unviable. We will discuss financing, but also other problems that may prevent a project being completed as these are important to know before committing to a project. It is worthwhile for farmers to visit examples of where these technologies have been implemented and ask the developers about the problems they faced, to be certain that they are doing the right thing.

4.1 Motivation

Developing some of these technologies may take many years to plan, get approval and find financing for. The traditional culture in agriculture often means unwillingness to try new things, and if new technologies are to be introduced then there is a need for someone who is willing to manage the process and feel positive despite setbacks that will occur. This could be a group of individuals sharing a vision but without individuals steering the project forward then the project will fail. Such projects should be seen as part of long-term developments of the farm that may have high cost in the short term but benefits in the long term. There are potential problems here in that the average age of farmers is increasing in the UK and as a result the appetite for long-term planning will be less[8].

4.2 Extra Costs

There are costs associated with preparation for planning consent and applying for environmental permits if necessary. There are costs for connection to the national grid if electricity generation capacity is to be connected

4.3 Project Finance

Finding the money from farm balance sheets will often be difficult, so it is important to seek opportunities for funding, and also to understand incentive schemes. For example the Government through its Heat Strategy aims to use the Renewable Heat Incentive to “support substantial deployment of biogas” including anaerobic digestion schemes[10].

Often in agriculture the older generations keep control and do not necessarily share information on the state of farm finances with the younger generations, this may inhibit decisions beneficial to long-term financial planning[8]. The volatile nature of food and fuel prices also means that making predictions is difficult.

The ways of reducing costs for developments should be actively considered. For example, farmers in the Peak District are currently exploring a supervised self-build AD project in order to reduce costs while retaining the supplier’s guarantees over the operation of the machine.

4.4 Local Opposition

As much as possible, projects should consider the wishes of the local community, suitable measures should be taken to address their concerns. They should be engaged at an early stage to ensure that their concerns are met and that they feel involved in the process especially if there is to be local disruption during building and operation of any new technology. It is worthwhile having some fairly firm ideas to discuss with the community in order to answer questions about how big a wind farm would be, for example, but also not to have made a final decision and keep your options open to change in response to what they say.

Farmers should search for possible “win-win” scenarios, for example for local communities to offset their own emissions if they are interested to do so. Also, communities could have financial involvement through issues of shares in order to help raise funds and share out profits; this would then reduce the money that a farmer needs to invest in the new system.

4.5 Regulations

It is probably best to seek professional advice if the regulatory framework is unclear; particularly if receipt of incentives is dependent upon certain criteria e.g. the applicability of sustainability criteria for energy crops used in AD is currently under consultation by the DECC.

The Sustainable Youlgrave community has encountered problems with regulations when the farmers there were hoping to introduce anaerobic digestion systems. Their case is a demonstration of how a community has been well-motivated towards change and knowledgeable of the technology options but regulations have inhibited developments.

For example, recycling volume targets for waste management companies mean that they do not want to provide a community anaerobic digester with food waste. Planning authorities took a negative view towards waste processing inside the national park even though it would have helped with the viability of the project. The general reluctance for local authorities to use this new technology to help with waste processing makes the coalition government’s target for a “huge increase” for anaerobic digestion[11] difficult to achieve.

5. Conclusions

It has been made clear in this paper that agriculture in the UK is highly dependent upon energy inputs that are vulnerable to price increases. There are high embodied energies in the fuel, the electricity, the fertilisers and the electricity used on farms. The significant use of imported feedstuffs for raising livestock represents a large energy input too, and leave UK agriculture exposed to volatility in international food commodity prices which are under pressure from growing global populations as well as extreme weather events such as the US drought of the summer of 2012. These extreme weather events are set to become more likely in the scientific climate projections for coming decades[7].

There is a range of solutions that can be used by farmers to generate their own electricity, or their own biogas fuel. Energy efficiency should come first as a simple way to avoid pointless energy wastage where possible and save money. Better monitoring of energy use on farms is also a good step to help identify where energy bill costs are coming from and how they can be reduced. Some of the technologies are much more complicated than others, for example anaerobic digestion has many variables to consider when deciding upon how it will function. The specifics will depend upon the farm type, but it is important to remember that the systems should only be implemented when they provide tangible benefits to the farmer such as easier waste management or a diversified source of income.

Furthermore, even if a farmer is keen to implement a new system there can be barriers to success. Not least of these barriers is finding finance for the project. However, there can be clever solutions like distribution of shares to help raise capital whilst bearing in mind that the farmer should ultimately have the casting vote over what he is committed to. It is also important to check which incentives are likely to be applicable and to make sure they are taken advantage of.

Finally, it is worth emphasising that there are many organisations that are committed to helping agriculture become more sustainable and these organisations should be looked to for advice. The National Farmers Union has written reports about sustainable methods, the National Non-Food Crops Centre provides valuable information about the production of fuel crops, FarmingFutures.org.uk provides information for farmers in a way that is easy to understand. As part of the Sustainable Youlgrave project, an Anaerobic Digestion ‘toolbox’ document was produced to detail the choices to make when considering AD projects. All these sources of information can be found on the internet along with many more helpful organisations.

Useful Links

www.FarmingFutures.org.uk, www.sustainableyoulgrave.org,
www.nfuonline.com/our-work/environment/renewable-energy/

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