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ENERGY USE IN ORGANIC FOOD SYSTEMS

by
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SUMMARY

Agriculture and food systems play an important role in fossil fuel consumption and climate change because of their significant energy use and because of agriculture's potential to serve as a sink for the negative externalities of energy use and a source for renewable energy. Comparing organic and non-organic production in terms of energy use is crucial to understanding the energy inefficiencies of different food systems and their potential for reducing energy consumption and mitigating environmental impacts especially of climate change.

Based on existing research, this paper considers the environmental efficiency of energy use in organic and non-organic agricultural systems, with implications on the natural and socio-economic environment of organic production methods as compared to non-organic production.

Because organic and non-organic food systems maintain separate but parallel supply and transport chains, it is important to include in the analysis of energy consumption not only agriculture production but also post-harvest practices and distribution networks and the energy consumption therein. Conventional agriculture production utilises more overall energy than organic systems due to heavy reliance on energy intensive fertilisers, chemicals, and concentrated feed, which organic farmers forego.

Other production practices such as irrigation, use of heavy machinery, and use of heated greenhouses are high energy consumers and are utilised by both organic and conventional operations. Organic systems, with exceptions, however, use less of these energy-demanding implements. Organic systems partly compensate for the decreased fossil-fuel based energy used on a farm with generally higher labour requirements and higher returns on labour.

Little information is available regarding concrete differences between organic and conventional processing, packaging, storage, and distribution; however, there is some indication that organic systems may offer less energy intensive methods than their conventional counterparts.

With lower energy inputs, organic systems contribute less to greenhouse gas emissions and have a greater potential to sequester carbon in biomass than conventional systems. The energy efficiency of organic agriculture is attractive for bioenergy production as the aim of this renewable fuel source is to reduce dependency of fossil fuel energy and mitigate environmental damage caused by emissions.

Because organic agriculture relies less on external inputs, human labour needs are increased. Organic agriculture can provide employment opportunities supported by price premiums and decreased costs for purchasing inputs; however, in some circumstances, additional labour is unavailable or could burden overworked demographics.

Agriculture's role in both climate change and non-renewable resource consumption needs a more prominent position in the global discussion of curbing greenhouse gas emissions and reducing dependency on oil. Designing a food label to display the energy used in the production, packaging, and distribution of products may offer incentives to streamline energy use and educate consumers; however, standards are needed for measuring energy consumption in food systems.

INTRODUCTION

Scope

Agriculture and food systems rely on a variety of energy sources, including renewable and non-renewable resources such as fossil fuels as well as human and animal labour. Energy is used not only in planting, cultivating, and harvesting of crops and animal products, but also in the manufacture and transport of inputs such as pesticides, fertilisers, and machinery and in processing, packaging, and distribution of final products. This paper focuses on non-renewable sources of energy such as fossil fuels and others (such as electricity and natural gas) at all points of the production, processing, packaging, storage, and distribution stages of agricultural and food products and inputs.

Through examples and by synthesizing research, this paper analyses the environmental efficiency of energy use in organic and non-organic agricultural systems and food chains, with implications on the natural and socio-economic environment, including human energy use (labour) of organic production methods as compared to non-organic production. Criteria for comparing organic and non-organic agricultural systems are explored, as are options for labelling agricultural products to reflect the energy consumption of their production.

Energy and food systems

Energy consumption is gaining attention on a global scale as dwindling fossil fuel stores inspire exploration of renewable energy sources and as the negative impacts of energy by-products begin to affect climate. Food is often overlooked in regards to energy use, although there is growing awareness of the inefficiencies of energy expenditures in food systems.

Agriculture alone is a relatively small user of energy. However, when considering energy use in all of the stages of food production and distribution, from the manufacturing and transport of farm inputs to the processing, storage, and dissemination of final products, the whole food system makes up a large percentage of energy consumption in many countries. In the United States, the operations of food systems, including agricultural production, food processing, packaging, and distribution, account for 19 percent of the national fossil fuel energy use (Pimentel, 2006). Fossil fuel consumption by food systems in developed countries often rivals that of automobiles.

Energy resources are tightly linked with the development of the agriculture sector, both in terms of input costs and output prices. Energy is a particularly significant input in so-called ‘industrial’ food and farming systems, with farm systems based on synthetic external inputs and producing for the processing or global markets (i.e. several manufacturing stages and long transport distances). This is usually economically advantageous for such systems in times of cheap energy, as has been the situation for several decades. However, this also makes such systems susceptible to rising to energy prices or unstable energy supplies, a drawback that may become important in the future.

With many small-scale farmers and large rural populations, developing countries face the challenge of developing their farming base without the benefit of large financial investment and economies of scale. Currently, this often means foregoing or limiting the use of expensive fossil fuel-based energy inputs, such as fertiliser, in favour of dependence on manual labour.

In these countries, achieving higher local yields especially in times of drought, more diverse and nutritious diets, and a reduced dependency on unsustainable water sources for irrigation while at the same time maintaining energy efficiency in agriculture through restricted external and synthetic inputs is a necessary step in alleviating rural poverty and improving health and in establishing a stable, productive, and sustainable agricultural system.

The use of energy resources in agriculture is also important for climate change. Agricultural production can be both a source and sink of fossil energy use emissions such as carbon dioxide. Agriculture not only contributes to the problem of over consumption of fossil fuels and production of greenhouse gases, but it can also potentially mitigate greenhouse gas emissions and reduce the major climate change impacts, such as flooding and food shortages caused by drought. The method of agricultural production determines to a large extent the amount of energy used in cultivation of crops or animal husbandry. Given the limited opportunities to reduce energy use within a farming system and given the fact that most energy consumption occurs off the farm in the production and transport of the inputs, farming methods are probably the most significant area of flexibility where efficiency can be introduced.

Increasingly, agriculture is also now being looked to as a source of energy. Bioenergy crops, or agricultural products which can be converted to solid or liquid fuel, can offer a lower carbon emitting source of energy. In particular, interest and investment in biofuels, liquid transport fuels produced from arable crops, is gaining momentum especially in the policies of industrialized countries and the markets of developing nations. The development of biofuel technology has intensified the need to examine energy use in agricultural production systems, as the suitability of biofuels depends on the overall energy efficiency with which potential biofuel crops can be grown, processed, and distributed and the existence of other environmental impacts. This is a complex and developing area of study and this report does not attempt to analyse this subject, but it briefly comments on the potential for organic farming to contribute to improved bioenergy production.

Knowledge about energy use in agriculture and the food system is essential in developing sustainable food production systems and it is clear that current knowledge is far from complete. Some studies have been conducted that explore the multifaceted sources and uses of energy in agriculture at the farm level, including the manufacturing and utilisation of agrichemical inputs, production of machinery, and construction of infrastructure. More studies, however, are needed for all sectors of the food system in different countries and in different production systems. There are also currently few studies of energy use further downstream in the food chain in food processing, packaging, storage, and distribution. Such work is needed in order to better understand the main sources of energy expenditures are in the different sectors, stages, and systems, to assess the comparative value of different production systems, and to develop other solutions to further increase efficiency while avoiding negative impacts.

In this analysis, it is important to consider not only how much energy is consumed, either directly or indirectly, throughout the food production system but also how that efficiency is measured, which is crucial for evaluating different methods of production and in improving inefficiencies.

Definitions

Organic agriculture represents a broad set of practices that emphasize farming based on ecosystem management, integrated cropping and livestock systems, diversity of products, and reliance on natural pest and disease control without the use of synthetic inputs. The objectives of organic agriculture are to produce sustainable and healthy food through harnessing natural biological and ecological processes. The Codex Alimentarius Commission (2001) defines organic agriculture as "a holistic production management system which promotes and enhances agro-ecosystems health including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, cultural, biological, and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system". An organic agricultural system is therefore designed to rely on renewable energy sourced as much as possible from on-farm or natural local systems. Although organic agriculture adheres to certifiable standards, farmers have the flexibility to enhance the ecological and sustainable practices of their farms beyond what the standards require.

Conventional agriculture is used in this paper to reference any non-organic farming system and encompasses a wide range of agricultural methods including high external input agriculture, integrated production management, traditional pastoral systems, precision agriculture, and conservation agriculture, among others.

Energy can be broadly defined as the capacity to do work. As it can neither be created nor destroyed, energy is conserved and transferred within a closed system. The various forms of energy (kinetic, potential, electrical, thermal, etc.) can be converted, at least partially, from one to another and 'used' to perform work. In an agricultural context, energy in the form of fossil fuel, electricity, natural gas and human labour is used to operate machinery, manufacture inputs, cultivate soils, control plants, pests, and animal disease, dry and cool crops, heat and ventilate glasshouses, and heat and light livestock housing.

Energy in agriculture is typically evaluated under two overlapping and complementary measures: energy consumption for both direct and indirect energy expenditures and energy efficiency. **Energy consumption** is used to refer to the basic data on farm and farm input energy expenditure which is measured as the total energy used per unit of land over unit of time. Typically, researchers convert all fossil fuel and sometimes also human labour, to a standard unit of energy, either joules or calories, measured per hectare for one year (Mendoza, 2002, Williams *et al*, 2006, Bos *et al*, 2007, MAFF, 2000).

Energy efficiency is the ratio of energy use per unit of crop or per calorie produced, usually joules per tonne or joules per calories. Energy efficiency is used to standardize comparisons between a variety of crops and to normalize higher or lower yields for a given production method (Refsgaard *et al*, 1998). This is the measure used in this report to compare the energy use of organic and non-organic systems. Examining efficiency in terms of non-renewable energy consumption does not fully capture the total energy use on a farm. Importantly, organic agriculture additionally harnesses the energy of natural ecological and biological processes to carry out or assist with a range of key agricultural functions, including soil structure, nutrition, water supply, plant pest control, animal parasite and disease control.

Again, as these do not have the negative impacts of fossil fuel use, these are considered broader impacts, on biodiversity and animal welfare, which are not addressed in this report.

Human labour expenditures often differ significantly between organic and non-organic agricultural systems. Although usually considered as a separate type of input than energy, human labour is occasionally evaluated as another energy input on the grounds that human energy can be used to partially replace fossil energy. Human labour is also not comparable to the conventional fossil fuel inputs for the purpose of this report, as it does not in itself negatively contribute to climate change or energy security issues. Human labour is therefore treated in this report as a social impact of substituting fossil fuel energy use, rather than as an energy input.

A **Life Cycle Analysis (LCA)** is a comprehensive assessment of a given product for the purpose of detailing environmental impact, energy use, or economic cost-benefit analysis. LCAs cover a broad range of sectors that directly and indirectly contribute to the final product, which makes them a valuable tool for pinpointing inefficiencies and comparing production methods. However, LCA was developed for industrial products and does present some difficulties when applied to energy use in agriculture.

Factors limiting the analysis of energy use in agricultural systems

Many factors can be considered when comparing organic and conventional agricultural systems; however, a significant challenge to conducting a practical and replicable comparison of organic and conventional farming is that neither system is homogenous. Although conventional can be defined as the negative of organic, conventional farming encompasses a wide range of production methods. Farms will vary depending on the crop produced, location and size of the farm, climate, and the individual choices of the farmer. As Kasperczyk *et al* note, “there is no clearly defined system of conventional farming, which ranges from high-input intensive systems to near-organic systems” (2006).

Likewise, organic agriculture, although adhering to basic standards, differs in its implementation from highly organized ecological systems to large-scale monocropping or concentrated livestock operations similar in many ways to conventional agriculture, save for the absence of synthetic pesticides, fertilisers, and veterinary drugs (e.g. orchards where crop rotations are impossible or extensive livestock systems).

Comparing any complex system to another is a challenge. It should be noted that while energy use is an important criterion for evaluating farming systems sustainability, it is only one difference in the impacts of the two systems. There is an extensive body of research devoted to many environmental, social, and economic comparisons of organic and conventional agricultural systems. Various studies have compared the nutritional levels, yield, net income, quality of farmers’ lives, and a variety of environmental impacts such as farmland biodiversity, soil quality, nutrient leaching, global warming potential, area of land used, and production in years with extreme weather conditions such as drought (Lotter, 2003; Kasperczyk *et al*, 2006; Stolze *et al*, 2000). This analysis does not aim to tackle the myriad factors on which these two systems can be compared. Instead, it focuses on comparing organic and conventional agriculture in terms of energy consumption and efficiency.

Nevertheless, because farming systems are multi-functional, analyses of just one impact are of limited value without a broader consideration of the other costs and benefits of the system.

Therefore, the quantitative analysis of energy expenditures and efficiencies is often coupled with a qualitative analysis that measures individual and societal benefits of farming practices. Organic has additional intangible benefits that are impossible to directly compare to a conventional system such as improved ecosystems which result from balanced nutrient and energy flows, as well as maintenance of living countryside, opportunities for skilled agricultural labour, stewardship of the land and natural resources, animal welfare, and strengthening rural communities. These qualitative benefits may indirectly influence energy expenditures and probably provide additional incentives for individual or government adoption of certain methods over others; however, these issues are discussed only insofar as they are directly relevant to energy consumption.

Although the study of energy consumption in agriculture is gaining momentum, most research focuses on energy use during only the production phase and does not look beyond to examine the energy intake of agricultural products further downstream. Life Cycle Analyses assess energy and environmental impacts for particular agricultural products under specific production methods and attempt to address all stages of the 'life cycle' of the product. If the product is an agricultural product, then the analysis ends at the farm gate; if it is a food product, then it attempts to examine the full range of issues throughout the production, processing, packaging, storage, and distribution stages of the food product. However, although several LCAs have been done for organic and non-organic agricultural products, few have been done for the final food product. These topics are broadly explored, pulling from scientific research, policy reports and comparative analyses focusing specifically on comparing energy use between organic and conventional food systems.

For the purposes of simplicity and for comparison, energy output of crop yield is measured in total calories or mega-joules; this one-dimensional quantification of energy output ignores the varied nutritional contents of agricultural products. Obviously, producing a variety of foods with different vitamin and mineral content is vital to nutritional well-being despite the relative energy inefficiencies of certain foods when compared to others. Because of this limitation, this analysis focuses more on comparing energy efficiency of different production methods for any given crop rather than comparing the energy efficiencies between crops themselves.

When reviewing research and literature for this analysis, the emphasis was on presenting a representative sample of research to encompass the broad range of farms that fall under agriculture's purview. For example, both small and large-scale farming operations are discussed, as are annual and perennial cropping systems, agro-forestry, and integrated systems. Although this analysis features research from around the world, there are noticeable gaps, such as the lack of substantive research on energy consumption in agriculture in many developing countries. When information was available on developing countries, however, it is included.

ENERGY CONSUMPTION IN THE FOOD SYSTEM

Organic and non-organic food systems maintain separate but parallel supply and transport chains in most industrial countries and, increasingly in developing countries, as organic products are exported to the global market. It is therefore important to extend the analysis of energy consumption beyond the harvest of the crop or animal product to examine distribution networks and the energy consumption therein. Cold supply chains, storage for seasonal crops, and international shipment of agricultural products, all demand significant energy and should be included in the energy footprint of food systems. Unfortunately, little comprehensive research has been conducted comparing conventional and organic systems in their various post-harvest stages of processing, storage, and transport to final point of sale.

This section explores the contributing factors to energy consumption throughout the entire food chain beginning with on-farm production of the food and following it through processing, packaging, transportation, storage and finally distribution. Where empirical data is not available, reasonable speculation on energy use is presented and questions for further debate are raised.

Production

When examining energy use in food systems, it is logical to begin with the activities involved in growing crops and raising livestock. Agricultural systems utilize both, direct energy from on farm activities such as operating machinery and maintaining infrastructure, and indirect energy, from the manufacture and transport of inputs. Different production methods drastically alter the amount of energy needed to grow a particular crop or raise livestock.

Nitrogen fertiliser

Nitrogen fertiliser is cited as the biggest energy sink in non-organic production. Not only is nitrogen fertiliser produced from the raw materials of fossil fuel but the conversion process to usable fertiliser is energy intensive (Soil Association, 2006, 2007). The production of one tonne of nitrogen fertiliser utilises one to one and half tonnes of equivalent petrol. In productions, like grains, in which high amounts of synthetic nitrogen fertilizers are applied, about half of the total energy (direct and indirect) needed is the energy used for the manufacture of the nitrogen fertilizers. Compared to such conventional production systems, the energy use in organic agriculture is therefore about half. (Aubert, *personal communication*). According to the Soil Association (2006), the largest portion of energy utilized in conventional agriculture - on average, 37 percent of the total energy - is synthetic pesticides and mineral fertilisers, particularly nitrogen, and to a lesser extent, phosphorous, and potassium. Refsgaard *et al* (1998) found that energy consumption through the use of fertilisers accounted for anywhere from 25-68 percent of total energy use depending on the type of crop and growing conditions.

According to a research project from the British Ministry of Agriculture, Fisheries and Food, the energy input per hectare in organic farming is 40 percent of the energy input in conventional farming for wheat production, 54 percent for potatoes, 50 percent for carrots, 65 percent for onions, 27 percent for broccoli (MAFF, 2000). A comparative study conducted in Canada of two crop rotations (wheat-pea-wheat-flax and wheat-alfalfa-alfalfa-flax) cultivated organically and conventionally concluded that the energy use was 50 percent lower with organic than with conventional management. Even though the energy output was 30% lower under organic, the energy efficiency (energy produced /energy used) remains better in organic agriculture. (Hoeppner, 2006).

Conventional agriculture’s energy inefficiency is directly tied to the high energy consumption of producing and transporting synthetic pesticides and fertilisers used to grow these crops. Organic agriculture utilizes manure, legumes, and other natural sources of nitrogen, which replace the fossil fuels to manufacture synthetic nitrogen fertiliser with a natural biological processes. Legumes fix atmospheric nitrogen naturally in their root-nodules by the activity of micro-organisms. Water and other plant nutrients are supplied via the active soil biology of organic systems; soil microbes break down and cycle minerals from soil rock particles, decaying plant matter, manure, and compost to the plant roots. This natural symbiosis of soil microfauna and crops is suppressed in many non-organic systems with less biologically active soils. On either conventional or organic farms, when animals produce some or all of the fertiliser needed for crop production, the energy expenditures are greatly reduced.

Because of its reliance on natural fertilisers, organic agriculture often performs relatively better in terms of energy efficiency (measured as the ratio of energy input per unit of crop output) despite lower yields. In the majority of field trials and studies of operating farms, the increase in yield for conventional production over organic did not offset the energy used in the fertiliser to produce that gain (Stolze *et al*, 2000). In an analysis of conventional rice farming in the Philippines, one expert concluded that increases in rice yield come with a 6 to 25 fold increase in energy consumption predominately because of fertiliser used to achieve incremental gains in crop yield (Pretty, 1995).

Researches Nguyen and Haynes (1995) have compared low-input conventional and organic integrated sheep and arable crop farms in New Zealand for their energy efficiency. Because of reduced reliance on synthetic fertilisers and chemicals in the conventional system, the researchers found similar energy efficiency ratios for organic and conventional farms, with the organic slightly better in two of the three pairs of comparisons. Organically produced tea in an integrated agro-forestry system has also been found to save energy compared to a conventional counterpart, by relying on biological fertilisers such as manure and crop residue instead of synthetics (Jianbo, 2006).

Pesticides and chemicals

Conventional agriculture has a wide range of agrichemicals at its disposal for use as pesticides, herbicides, fungicides, and insecticides. Like fertilisers, the energy burden of these agrichemicals stems mainly from their manufacture and transport, with a relatively small amount of energy used in their application. Because of the diversity of synthetic chemicals and annual variation in their application, an average energy burden of production and transport is generally used (Saunders *et al*, 2006). Although the energy consumption of fertilisers typically outweighs that of agrichemicals in conventional systems, chemical pesticides are themselves a significant contributor to the energy inefficiency of many conventional operations.

A Life Cycle Analysis of energy efficiency in Greek olive groves found energy expenditures in conventional groves far exceeded the organic systems both on a per hectare basis and per tonne of olives. The indirect energy expenditures in the production of chemical sprays and fertilisers depressed the energy efficiency of conventional groves compared to organic groves that utilized biological pest control, cover crops to suppress weeds, and additional field labour (Dessane, 2003).

Energy Efficiency of Organic Agriculture in the UK

Sector	UK production t/yr, 2005 [1]	Non-organic energy use/t, (MJ) [5]	Organic energy use/t as % of non-organic (MJ)[5]	Total UK energy use (MJx10[9])	Total UK energy use if all organic (MJx10[9])	Change in energy use if all organic (MJ x10[9])
Milling wheat	6,177,000[2]	2,460	**71%** (1,740)	15.20	10.75	-4.45
Oilseed rape	1,902,000	5,390	**75 %** (4,020)	10.25	7.65	-2.6
Potatoes	5,815,000	1,260	**102%** (1,280)	7.33	7.44	0.11
Carrots	718,500	600	**75%** (450)	0.43	0.32	-0.11
Cabbage	262,700	900	**28%** (250)	0.24	0.07	-0.17
Onion	404,500	1,250	**84%** (1,050)	0.51	0.42	-0.08
Calabrese	86,900	3,700	**51%** (1,900)	0.32	0.17	-0.16
Leeks	49,800	950	**42%** (400)	0.05	0.02	-0.03
Beef	763,000	27,800	**65%** (18,100)	21.21	13.81	-7.4
Sheep	321,000	23,100	**80%** (18,400)	7.42	5.91	-1.51
Pig meat	671,000	16,700	**87%** (14,500)	11.2	9.73	-1.47
Milk	13,883,000 (unit = cubic m)	2,520	**62%** (1,560)	34.99	21.66	-13.33
TOTAL (excluding poultry, eggs & tomatoes)				109.15	77.95	-31.2 **Average (typical) energy reduction: 29%**
Poultry meat	1,542,000[3]	12,000	**132%** (15,800)	18.5	24.36	5.86
Eggs	537,000 (unit = 20,000 eggs)	14,100	**114%** (16,100)	7.57	8.65	1.08
Tomatoes (long season glasshouse)	82,684[4]	122,000	**130%** (159,000)	10.09	13.15	3.6
TOTAL (all sectors)				145.31	124.11	-20.66 **Average energy reduction: 15%**

(Azeez, 2007, from MAFF/Defra data)

Mechanisation

Farming practices and the use of machinery greatly influence energy use on individual farms. Mechanical weeding, pesticide application, greenhousing, and flame weeding are all high energy use practices that can significantly affect a farm’s energy consumption and efficiency. Organic carrot and potato production are both cited in various studies as having high energy inputs per unit of output because of mechanical weeding (Stolze *et al*, 2000; Williams *et al*, 2006; Bos *et al*, 2007).

Precision agriculture and zero (or minimal) tillage farming are methods of conventional agriculture that are often presented as environmental alternatives to standard conventional agriculture. Precision agriculture focuses on the careful allocation of fertilisers based on testing of soil nutrients; no tillage practices emphasize cultivation of crops without disturbing the soil through ploughing. Environmentally, these methods have been shown to reduce soil erosion and minimize nutrient runoff; however, from an energy conservation perspective their benefits are less clear.

Low or no till systems decrease direct energy inputs but can increase indirect energy by requiring more herbicides, pesticides, and other chemicals (Smolik *et al*, 1995). Seen in a more global perspective (that is beyond a given farm), no tillage systems are often crop monocultures which entail off-farm degradation through intensive livestock systems that make use of energy intensive feed, let alone direct pollution externalities.

Little evaluation of energy use in precision agriculture has been conducted; however, studies have consistently shown that application of any synthetic nitrogen fertiliser reduces energy efficiency when compared to organic systems that use manure or legumes as a nitrogen source (Aubert *et al*, 2003; Soil Association, 2006; Kasperczyk *et al*, 2006; Pimentel, 2006). A study from the Netherlands suggests that precision technology can reduce fertiliser input without sacrificing yields, but energy use in this system has not been evaluated (Koopmans *et al*, 2005).

Irrigation

Pump irrigation is another energy-intensive agricultural practice, one that is utilized by both organic and non-organic farms. While some methods of irrigation are more energy efficient that others, overall energy use for irrigation is largely determined by depth from which water is pumped, climate, and crop type. Organic agriculture has been shown to decrease irrigation need because the higher soil organic matter generated by organic practices retains water better than the soil from conventional systems (Fan *et al*, 2005).

Concentrated Feed

When calculating energy consumption from livestock products, energy efficiency of feed must be considered. As noted above, crop production uses a substantial amount of energy; therefore, feeding livestock grain (especially conventionally grown grain) reduces their energy efficiency considerably. Even beef cattle that are fed a mixture of grain and grass forage throughout their lives (which is typical of conventional systems) use twice as much energy per kilocalorie of protein produced than grass-fed beef (Pimentel, 2006). Partly because of the efficiency in their conversion of feed, the impact of energy used in feed production for poultry is less dramatic (Pimentel, 2004). For this reason, broiler hens have been shown to be less energy efficient on organic farms than conventional farms in the UK; the opposite has been demonstrated for pigs (Williams *et al*, 2006; MAFF, 2000).

Conventional systems typically rely on an off-farm supply of concentrated feed, while organic systems more often source their livestock forage locally or produce it directly on the farm. Conventional livestock feed is often produced in the most intensive form of agricultural production, which relies heavily on synthetic chemical and fertiliser input (Willeke-Wetstein, 1998) and because livestock consumes large amounts of silage, grain, and grass, the energy inefficiency of conventional crop production is magnified. An FAO report estimates that almost two thirds of energy consumption in conventional livestock is attributed to production, processing, and transport of feed (de Haan *et al*, 1997).

Several comparative studies confirm the energy efficiency of organic livestock systems. Research in the UK concluded that organic dairy cow production utilised only 22 percent of the energy from conventional production because in the organic systems cows mainly ate grass whereas the conventional cows were fed predominately with corn silage, grain and soybean cake (MAFF, 2000). A study from Finland found that the energy consumed by dairy cows was 4,4 gigajoules per 1000 litre of milk produced in organic systems and 6,4 gigajoules in conventional production (Grönroos, 2006).

Impact of Organic Agriculture on the Environment and Economic Performance of Croatia

A study from the University of Essex Centre for Environment and Society, with the support of FAO, examined the potential environmental impact of wide-scale conversion to organic farming in Croatia as it compared to base-line conventional farming data. The study looked at a broad range of "farm upstream linked sectors" such as energy production and supply, manufacturing of agrichemical inputs, trade, transport, research, education, and advisory, veterinary, and administrative services of agriculture in Croatia. To assess the economic impact of organic farming, the researchers adjusted the gross farm income to account for environmental damage to air, water, and soil.

The study concluded that conversion of 100 percent of Croatia's farmland to organic agriculture would result in cutting energy use to 38 percent of the current base-line energy consumption. The study calculated that fertiliser manufacturing, transport, and application accounted for 4.6 percent of the national energy consumption. Conversion to organic agriculture of 10, 25, 50, or 100 percent of the land would reduce national energy consumption by a measurable degree. The study also concluded that conversion to organic farming would result in "decreased environmental degradations and associated costs" provided that the yields generated from organic agriculture did not fall below 50 percent of the conventional baseline yields.

Because organic agriculture replaces fossil fuel-dependent inputs with farmer knowledge and labour, an obstacle to converting Croatia's farmland from conventional to organic is lack of farmer education on ecological agricultural practices. By emphasizing farmer training and dissemination of organic farming techniques, the Croatian government could help its country reap the economic and environmental benefits of large scale conversion to organic farming systems.

(Znaor *et al*, 2007)

Greenhouses

Some northern countries are relying more on greenhouse production to extend growing seasons of high-value vegetables. Tomato farming, which is often done in heated greenhouses for off-season production, is very energy demanding in comparison to field crops. Because energy consumption is dominated by heating and electricity costs for the greenhouse and establishment of the infrastructure, organic and non-organic systems performed very similarly, with small differences arising based on variety of tomatoes cultivated.

Additionally, in the controlled environment of the greenhouse, organic and non-organic systems both utilize biological pest control, which decreases the amount of synthetic pesticides applied in the non-organic systems. The energy used in this specialized production of tomatoes is comparatively less efficient than other forms of agriculture, whether organic or conventional; therefore, any energy savings in switching production methods would be marginal at best (Williams *et al*, 2006). Although not required by organic standards, organic producers are increasingly foregoing the use of heating in greenhouses.

Human labour

In most organic systems, the energy saved from reduced inputs is compensated for by an increase in human labour. Although energy is not simply transferred from synthetic inputs to human labour, low-inputs systems such as organic agricultural on average require additional manpower when compared to high-input conventional systems. Estimates vary and depend on climate, crops, and size of the operation; however, the Soil Association calculates that organic farming provides 32 percent more employment per farm than conventional agriculture in the UK (Soil Association, 2006); in Denmark, a conversion from conventional to organic increases labour needs by 35 percent (Barthelemy, 1999).

A study from Turkey examined raisin production on 82 conventional and organic farms and concluded that human labour inputs were higher on average for organic farms. Even factoring in energy for human labour, however, organically produced raisins consumed less overall energy (23 percent on average) and had a better input-to-output energy efficiency ratio than conventional production (Gündogmus *et al*, 2006). In addition to weeding, cultivating, and plant and animal maintenance activities (which are largely performed by machinery and chemicals in conventional systems), organic farmers plant cover crops, spread manure, and produce compost. Developing and maintaining an integrated agro-ecosystem requires additional labour from the farmer, who has the knowledge and skills to perform this work and cannot be easily replaced by mechanization.

Post Harvest

Processing

The amount of energy used for grading, sorting, cooking, preserving, canning, and otherwise processing raw products into consumable goods differs little between organic and conventional systems. Unfortunately, this topic has been only narrowly explored for specific commodities and has focused, typically, on those that require little processing (i.e. milk). The salient issue is whether organic foods overall are less processed than conventional foods. Although organic products are perceived as less manipulated, their expansion into mainstream markets and competition with processed conventional foods may be erasing any prior disparities.

Some post-harvest processing may be influenced by organic principles and therefore use more sustainable, less energy consumptive practices; evidence for this is limited, however. A study of arable cropping operations in the Netherlands concluded that drying and storage of grains consumed almost half of the total energy of production and post-harvest handling in conventional systems (Bos *et al*, 2007). Organic farms that used solar power for drying had a lower energy burden.

Packaging

Packaging for transport and to reduce food spoilage is another area little explored beyond Life Cycle Analyses of a few specific products. Even LCA studies have marginalized or ignored packaging, preferring to study packaging separately from the activities surrounding raw commodities. Like processing, the central question when comparing energy use is whether organic products use less energy intensive packaging than conventional products. Again, organic agriculture's emphasis on minimal environmental impact may lead the industry as a whole to use less packaging, employ more recycled materials, and use more biodegradable supplies; however, the energy impacts of how (or if) packaging of organic products differs from conventional are still unclear.

Packaging can be a substantial, and often hidden, energy consumer in the food system. An evaluation of the energy use of a conventionally produced can of sweet corn in the United States found that the energy used for packaging exceeded the combined energy used in production, processing, and transportation (Heller *et al*, 2000). The issue of energy use in packaging, however, is complicated because of both minimal packaging standards set by food safety regulations and also the trade off between packaging and food spoilage. Additionally, unlike many agricultural inputs such as fertiliser and agrichemicals, packaging requires an assessment of upstream energy in the manufacturing process as well as a downstream analysis of energy in disposal of used packaging. These additional complexities make it an essential but cumbersome study subject in the overall energy consumption of food systems.

Stonyfield Farm Packaging of Organic Products

Stonyfield Farm, an organic yogurt manufacturing and distribution company based in the United States, monitors the environmental impact of their packaging materials and attempts to limit the energy consumed in the production and disposal of containers. After commissioning Life Cycle Analyses of the primary and secondary packaging of their products, Stonyfield Farm replaced the materials from which their yogurt containers were made and eliminated plastic lids on smaller containers in order to lessen the environmental impact involved with their production and disposal. In addition to modifying packaging materials, Stonyfield Farm is researching renewable and biodegradable sources of packaging materials. Their actions on the issue of packaging represent one way to incorporate organic principles of environmental stewardship into other areas of the food system beyond production.

(Stonyfield Farm, 2007)

Storage

Because organic products cannot utilise synthetic preservatives, fungicides, and other chemicals that maintain quality during long-term storage, organic food systems differ from conventional systems in their options for, and use of, long-term storage of products. The use of refrigeration and natural or synthetic pest and fungal control are energy consumptive practices in both organic and conventional systems that contribute to the energy footprint of a product. For those crops that are not stored for out of season consumption, the obvious trade-off is more frequent transportation.

A recent report from New Zealand compared energy consumed in the production and transport of apples and onions to the UK with the same products produced and stored in the UK for sale in the off-season. The study found that cold storage for six to nine months of apples and onions grown in the UK consumed slightly more energy per tonne of crop than transporting these same products from New Zealand (Saunders *et al*, 2006). Because New Zealand's production methods, although not organic, had a lower energy consumption level due to better farming practices, the overall energy burden from New Zealand crops was significantly lower than the conventionally grown products in the UK.

Distribution

The discussion concerning the energy burden of transportation is often distilled to examining the distance food travels from the farm to the consumer, or the 'food miles' of the product. The true energy expenditures of transportation, however, are much more complex. Method of transportation, fuel and loading efficiency of vehicles, and consumer travel all factor in to the final analysis of energy consumption for food products. Transportation energy must be considered along with energy costs of production, processing, packaging, and storage of products, as higher energy expenditure for transportation can be offset by lower energy use in one of these other arenas.

A modelling study in the UK looked at the energy expenditures of seven different methods of transporting agricultural products to distribution centres (MAFF, 2000). Using transportation to a large unit distribution centre as its baseline, the model concluded that delivery to or pick up by a nearby packing centre cut transportation costs by 37-43 percent, as did supplying a local wholesaler for local shops. Smaller scale farms delivering to a co-operative shipping centre increased energy consumption slightly, while imported products from other countries dramatically increased energy expenditures (MAFF, 2000).

Although sophisticated transportation networks operate with a certain level of energy efficiency, sourcing food from local growers drastically cuts back on the distance food travels and, potentially, the energy used in transportation. Decreased food miles may not necessarily translate into reduced energy consumption, however; a report from the UK Department for Environment, Food, and Rural Affairs (Defra) noted that although transportation energy may be reduced by locally sourcing food, "the reduction in transport may be offset to some extent by the use of smaller vehicles or lower load factors" (2005). Although there is a movement within the organic sector towards more local and regional food systems, organic products continue to be sourced from all corners of the globe. Whether organic agricultural products in general are distributed in a tighter geographical circle than conventional products and whether this reduces the energy use in transportation are questions for further research.

Energy expenditures of consumers' travel to and from markets should also be factored into energy analysis, as the benefits of reduced transport of local products may be overshadowed by increased travel by consumers. A study from the UK discovered that the distance food travels within cities has increased 27 percent in the last fifteen years, a fact that the researchers attribute mostly to an increase in consumer travel to, and from, markets (Defra, 2005).

Re-localizing Food Systems for Food Security in Cuba

Cuba provides an important case study of the role of organic and low energy input agriculture in food security. As a result of reduced food imports coupled with limited access to fuel and agrichemical products after the fall of the Soviet Union, Cuba experienced an agricultural and food security crisis. The policies and programmes the Cuban government implemented to counter this crisis focused on low-input, and often organic, food production with an emphasis on local food systems and diversified production. The result has been a decentralized food system that largely meets the nation's food needs and does so with minimal chemical and fertiliser inputs. Furthermore, "[d]uring the crisis, it was the small, diverse farmers that were able to maintain the domestic food supply; the large monocultural farms lacked such resilience."

By focusing food security not just on increased yield but on maintaining rural livelihoods and investing in urban agriculture, Cuba created a food system based on small scale agriculture, integrated systems, and local markets. During the fuel crisis, the Cuban government restructured farms by dividing some large farms into smaller parcels distributed to rural producers and cooperatives. Although large scale monocrop farms still operate, an emphasis was placed on growing a greater variety of fruits and vegetables on small plots. Local markets were encouraged to flourish through state-sponsored farmers' markets and direct sales from farmers to local stores.

Cuba managed to reduce fuel consumption in its agricultural sector dramatically and rapidly by reducing (and in some cases eliminating) synthetic inputs and transportation of food, especially within Havana. Such a drastic transition may not be practical or possible in other countries; however, Cuba provides valuable lessons on wide scale reduction of non-renewable energy in a national agricultural system.

(Wright, 2005, 2007)

IMPLICATIONS

Climate relevance

When considering whole food systems, the consequences of energy use cannot be separated from the analysis of energy expenditure. The purpose of reducing dependency of agricultural systems on non-renewable energy sources is twofold: to shift reliance from dwindling supplies of fossil fuel to renewable energy sources and to mitigate negative effects of energy consumption from greenhouse gas emissions.

Carbon emissions and sequestration

Agriculture is unique in that as a system it not only produces greenhouse gases from energy consumption but also provides a sink for these emissions. Agriculture has the potential to internalize many of the negative effects of its own energy consumption and thereby diminish the environmental impacts. Carbon, which is emitted in the form of carbon dioxide as a result of fossil fuel consumption, can be sequestered in soil organic matter and plant biomass.

Organic agriculture has a greater potential to sequester carbon in biomass and soil than most forms of conventional agriculture. Organic agriculture, especially on farms where cover cropping, grazing on pastures, and establishing permanent hedgerows and buffer zones are utilized, increases carbon sequestration. Application of manure, compost, and crop residues, which are vital to the maintenance of soil fertility in organic systems, has been proven to increase soil organic carbon in amounts unparalleled by conventional methods (SARE, 2001; Fan *et al*, 2005).

Marriott and Wander (2006) analyzed soil samples from nine farming system trials that were started in the USA between 1981 and 2000. The soil organic carbon concentrations were 14 percent higher in organic systems than in conventional ones. The Rodale farming systems trial, that began in 1981 in Pennsylvania, USA, compared manure and legume-based organic agriculture systems to a conventional system based on mineral fertilizers. The organic and conventional systems had similar soybean and maize yields whereas the organic system showed an increase in soil carbon of 574 kg per ha in the legume-based and 981 kg ha-1 in the manure-based system. The 23-year study from the Rodale Institute in USA showed that organically managed grain production sequestered 15-28 percent more carbon in the soil than equivalent conventional production (The Rodale Institute, 2003).

Agriculture produces greenhouse gases through many practices including soil tillage, fertiliser application, and manure handling; utilisation of fossil fuel energy in the manufacturing of synthetic inputs, however, contributes the most greenhouse gas equivalents in cropping operations and is the second largest greenhouse gas contributor besides methane emissions from animals on livestock farms (Wightman, 2006). Because organic agriculture prohibits the use of these chemical pesticides and fertilisers, the greenhouse gas emissions in organic systems are already significantly lower than in conventional systems (Kotschi *et al*, 2004). Reduced offsite production and transportation of concentrated feed for organic livestock systems also decreases carbon emissions for organic production when compared to conventional (Kotschi *et al*, 2004).

Agriculture is uniquely positioned to maximise energy use through renewable resources. Plant production already harnesses solar energy; agriculture makes effective use of this trapped energy when cover crops are used as fertilisers for the next crop rotation and when perennial and hedgerow are planted in agro-ecosystems. Most importantly, organic systems seek to establish closed (or at least semi-closed) energy systems, based on energy use efficiency and biomass recycling.

Bioenergy

Biofuels present an opportunity to further utilise captured solar energy and minimise the external energy inputs needed for agricultural systems. However, a central issue in the viability of biofuels is the energy consumed in the production, processing, and transportation of agricultural products for those biofuels. Energy generated in fuel must vastly exceed energy expended in growing and processing the fuel crops in order for biofuels to effectively displace—or even significantly supplement—gasoline and diesel as an energy source. If this energy surplus can be accomplished, biofuels could potentially close the energy cycle for agriculture (i.e. all of the energy used on the farm is also produced on the farm). However, with current fossil-fuel intensive technologies for feedstock production (e.g. mechanized monocultures using synthetic agricultural inputs), biofuels defeat the purpose of being climate-friendly or being a sustainable method of fuel production.

Because of its reduced energy inputs, organic agriculture is the ideal production method for biofuels. Unlike the cultivation of staple food crops, in which energy efficiency is just one of many environmental and nutritional aspects of production, biofuels are measured primarily by their energy efficiency. Organic agriculture offers a favourable energy balance because of its lower energy requirements. As the aim of biofuels is to reduce dependency on non-renewable energy sources and to mitigate environmental damage of fossil fuel emissions, organic production of biofuels furthers these goals in a way that conventional agriculture does not.

Social relevance

Although environmental consequences of excess energy consumption certainly have societal implications, the ramifications of additional labour inputs in organically managed systems are more direct impacts which are largely unexplored. The increased labour requirements of organic systems present both opportunities and liabilities, depending on the employment sector of the society in which they are located. Job creation can be a boon for societies with high unemployment rates and depressed rural economies.

In the developed world, an increase in labour often is coupled with an increase in cost of production. Organic agriculture has been able to support the increase in labour through a price premium on organic products and decreased expenditures for manufactured inputs; however, the manual labour needed to fill these jobs is inadequate in many countries. A declining interest in farming in developed nations coupled with high employment rates translates to a shortage in labour supply for agriculture in general, including organic agriculture. Many organic operations, like their conventional counterparts, rely on immigrant labour to fill the gap (Soil Association, 2006).

In an interesting set of calculations, the human labour needed to harvest food requires energy from food intake to perform the physical activity required for agricultural work. For the most complete analysis, then, the kilocalories required for a worker to perform his farming tasks should be calculated and added to the energy expenditures of the overall food system. An estimate of total daily calories needed for a physical active, 58 kilogram man in his twenties was calculated at 2910 kilocalories or 12 309 kilojoules, roughly equivalent to the production of 18 percent of a kilogram of ammonium nitrate fertiliser (Boedeker, *personal communication*; Pimentel, *personal communication*). Even less research, however, has ventured into this area as issues quickly arise regarding if kilocalories should be calculated only for hours worked or for the regular maintenance of each agricultural worker; if all labour in the various stages of manufacturing inputs, production, and distribution should be similarly included; and how to account for differences in energy requirements based on sex, age, and physical exertion of each labourer.

Although increased labour can employ surplus workers, not all countries have such human capital to spare. High rates of HIV/AIDS and violent conflict have emaciated the working-age population in many African countries and placed extra burdens on the rest of the work force. In many developing countries, women, who are often in charge of farming as well as child rearing and caring for the elderly, often do not have labour to spare on increased agricultural work. Labour intensive organic production is not ideal in these situations.

However, considering that in developing countries 70 percent of the population is rural and depends, either directly or indirectly on farming, organic agriculture represents a major employment opportunity, with better return on input of labour where markets can be accessed. It can also present opportunities for flexible labour hours (i.e. during non-peak seasons) and can potentially provide price premiums for some commodities, which can generate much needed income for these families without requiring excessive labour. Labour in organic systems tends to be based more on knowledge and skills than in conventional farming and therefore provides better quality employment.

Because of its emphasis on small-scale, integrated systems, organic agriculture has the potential to provide less tangible benefits in the quality of life for poor farmers. Organic farming eliminates exposure to harmful chemicals for both the farmer and the farming family. Production of more crop types integrated with animal care limits the amount of isolated or drudgery work—repetitive and tedious labour—and replaces those tasks with lighter, more varied activities. The diversification of organic systems mitigates crop loss and financial risks for farming families and creates a more predictable environment, allowing farmers to spread out tasks more effectively throughout the year.

Financial viability in a true organic system results from an emphasis on diversity in crop production and income generation such that some products are sold as cash commodities while others are sold to niche markets as high quality, value added, or rare/unique products. Through product pluralism, farmers and farming communities benefit from a diversification of risks, a wider range of products for home consumption, and the ability to access different, new, and emerging markets.

As the agrarian population ages, organic agriculture is bringing in an influx of younger farmers to the profession in both Europe and North America (Theriault, 2006; Soil Association, 2006). Agriculture in developed nations has seen a steady decline in number of farmers and number of farms in the past fifty years (Barthelemy, 1999; USDA, 1997); however, the growth in organic farms has countered the trend in the past few years (USDA, 2005; Barthelemy, 1999). Organic agriculture draws non-farmers to the profession at a higher rate than conventional farming, indicating that organic farming can be a useful tool in agrarian revitalization and preservation of rural communities.

With the rapid decline of farming as a profession in developed nations, rural economies and communities have suffered a similar deterioration both economically and socially. Organic farming presents a market-based solution to revitalize dying rural areas in North America and across Europe. The additional jobs on organic farms, and the higher income generation of organic farms that support these extra jobs, bring in much needed funds to rural economies and help reverse the drain of rural populations.

Human Labour Use in Uganda's Organic Fields

In 1994, the Swedish International Development Agency implemented a programme to assist smallholder farmers in Africa access international organic markets. The programme, named the Export Promotion of Organic Products from Africa (EPOPA), focuses on using organic production and principles to increase and stabilise income for farmers and farming communities, improve livelihoods, and reduce environmental damage. EPOPA has been operating in Uganda for thirteen years and has provided 40 000 smallholder farmers with access to organic markets. A recent evaluation of the programme demonstrated that farmers experienced increase yields, better food security, higher incomes, improved livelihoods, and that organic management reduced soil erosion.

(Burke, 2007)

Labelling

In the last decade, there has been a proliferation of labels proclaiming the environmental and social benefits of the farming methods for different products. Labels range from the regulated organic label to the various voluntary humane animal care certifications and country of origin labels. Labelling is a valuable method to inform consumers about agricultural practices, animal welfare standards and working conditions of the farm labourers. Labelling attempts to inform on production processes that reincorporate externalities into the final product so that consumers can base their purchasing choices on the impact the product has on the environmental and social welfare of the growers. By educating the public about these issues, the label pressures other producers, manufacturers, and sellers to improve the standards under which their own products are produced.

Growing public concern about fossil fuel consumption and greenhouse gas emission has prepared the way for the emergence of labels that measure environmental impact of products beyond the farm gate; however, the complexity of the food distribution system make tracking the complete energy use of food difficult, due to the myriad of direct and indirect energy expenditures that contribute to a product's final arrival on a supermarket shelf.

Criteria for assessing energy use in agricultural production need to be outlined and standardized for Life Cycle Analyses so that comparisons among production methods and products are meaningful. Some of the disparities in LCAs arise from whether or not to include extraction of raw materials used in the manufacturing of inputs, how to weigh different sources of energy (e.g. fossil fuels versus electrical energy), and if analysis should end at the farm gate, at point of sale, or upon arrival at consumers' homes. With standardized criteria for energy consumption in LCAs, labelling of products based on energy consumption would be feasible.

The measuring of energy consumption in food products will only be effective if standards are defined for which direct and indirect energy aspects of the food system are tracked and how energy consumption is calculated. The standards should be designed to highlight differences in energy use for different methods of production, processing, and distribution; however, it may be difficult to develop a comprehensive label that is transparent to consumers and still encompasses the complexities of energy use in agricultural systems.

Greenhouse Gas Emissions Labelling of EOSTA

In an effort to develop a more inclusive environmental label, the company EOSTA designed a CO_2 emissions label which tracks how much carbon is used in the transport and storage of organic fruits and vegetables from developing countries'farms to a warehouse in central Europe. Although by no means a comprehensive measure of the carbon burden of their products, the CO_2 emissions label is an innovative start to tackling this complex issue. EOSTA is pairing the carbon label with three other rating systems that in turn assess the quality of the product, the social welfare of the producers, and ecological practices on the farm in order to make the various aspects of the food system more transparent. Although the type of labelling that addresses the entire food system is still in its infancy, it holds great potential for presenting consumers with a complete view of how their food purchases impact the environment.

(Nature & More, 2007)

CONCLUSIONS

Despite the complexities, uncertainties, and gaps in knowledge regarding energy consumption in both conventional and organic agriculture, a few general conclusions can be drawn. Typically, organic agriculture uses 30 to 50 percent less energy in production than comparable non-organic agriculture. Though organic agriculture on average uses energy more efficiently, it often requires an indirect trade-off of energy intensive inputs with additional hours of human labour—approximately one third more than conventional agriculture.

Whether the reduction in energy on the production side is maintained through the post-harvest processing, packaging, transportation, storage, and final arrival on consumers' plates is an issue for further exploration. Particularly, the question of how and if post-production handling of organic products differs from that of conventional products should be investigated. In keeping with organic principles, the environmental impact of all stages of organic agricultural products needs to be evaluated and efforts made to mitigate harmful effects of non-renewable energy use in production and post-harvest processes.

Organic agriculture holds a great potential for pioneering energy reducing practices through the framework of organic standards. Organic principles, which emphasize environmental stewardship, farm-level self-sufficiency, and incorporation of externalities can be leveraged to develop strategies for limiting use of fossil fuel-based energy in organic agriculture. Especially in the areas of post-production handling, innovations in the organic supply chain to decrease energy consumption can influence parallel conventional sectors.

Conventional agriculture does not have a similar set of regulations and standards from which to launch an energy-saving initiative. Market pressures, rising fuel costs, and government policies will affect how conventional agriculture uses and limits energy in the future. Developments in technology will continue to reduce fertilizer and chemical usage as application methods become more precise. Organic agriculture, in the meantime, can pave the way in identifying energy inefficiencies and developing alternative practices to reduce energy consumption in the food system.

Agriculture's role in both climate change and non-renewable resource consumption needs a more prominent position in the global discussion of curbing greenhouse gas emissions and reducing dependency on oil. Agriculture, and especially organic practices, offers possibilities for carbon credits through sequestration as well as emissions reductions through better energy efficiency; but little framework has been developed either through international agreements or national policies to capture these opportunities. Unfortunately, the production of agricultural products for bioenergy may be at odds with ecological management to reduce greenhouse gas emissions, as more land and environmentally unfriendly practices may be used for the cultivation of bioenergy crops. Given agriculture's role as both a mitigating and exacerbating factor in climate change, policies should be established for addressing conflicting aims and creating solutions that do not cause environmental degradation.

Future research should be aimed at building the basis for energy reducing technologies and policies that prioritize energy efficiency in all stages of the food system. Life Cycle Analyses of energy use throughout the food system are crucial in identifying energy wastes and providing models for reduction of non-renewable energy. Renewable energy offers potentially viable alternatives in agricultural production, processing, and distribution; however, further development is needed.

With non-renewable energy sources waning and a global, mounting concern over greenhouse gas emissions, reducing the food system's energy burden is imperative. Organic agriculture already uses less fossil fuel based inputs and has a better carbon footprint than standard agricultural practices. Organic operations provide promising possibilities for further energy reductions throughout the food system. Organic production can point the way to wisely balancing energy efficiency with economic and environment factors in all stages from production to consumption, which will ultimately determine both the social and financial viability of adopting energy saving practices.

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