ISIS Press Release 15/10/08

Organic Agriculture and Localized Food & Energy Systems for Mitigating Climate Change

How the world can be food and energy secure without fossil fuels. Dr. Mae-Wan Ho

Invited lecture at ***East and Southeast Asian Conference-Workshop on Sustainable Agriculture, Food Security and Climate Change***, Waterfront-Insular Hotel, Davao City, Philippines, 12-14 October 2008.

Current agriculture and food system responsible for at least a quarter of global greenhouse emissions

Agriculture contributes directly about 6.1 Gt CO_2e (carbon dioxide equivalent) a year to global greenhouse emissions, mainly as methane (3.3 Gt) and nitrous oxide (2.8 Gt). This is approximately half of global emissions of these gases due to human activities, or 10-12 percent of global greenhouse emissions [1]. But if we take the agriculture and food system as a whole, every other sector in the pie chart contributes. Agriculture itself uses energy on farm for machinery, heating, cooling and irrigation, and off farm for make fertilizers, pesticides, and drugs. Food is processed and packaged, transported and distributed, imported and exported across the globe by transnational food giants. Roads are constructed for access and transport, buildings are erected for storage, processing and distribution. Wastes arising from agriculture and the food industry have to be treated. And most of all, forests are cut down at a great rate to be converted into agricultural land.

Greenpeace International factored in some of the major indirect contributions to agriculture, and estimated that 8.5 -16.5 Gt CO_2e are emitted, i.e., between 17- 32 percent of global emission [2]. Land conversion to agriculture, or deforestation, is the biggest contribution and is predicted to accelerate as 'bio-energy' crops are competing for land with food crops [3] (Biofuels: Biodevastation, Hunger & False Carbon Credits, *SiS* 33). But what has been left out is the global commodity trade, which has greatly increased the carbon footprint and energy intensity of our food consumption, and at tremendous social and other environmental costs. A UK government report on food miles estimated the direct social, environmental, and economic costs of food transport at over £9 billion each year, or 34 percent of the £26.2 billion UK food and drinks market [4] (Food Miles and Sustainability, *SiS* 28).

A conservative estimate that takes all indirect contributions into account comes to 34 percent (see Table 1). I shall try to justify that and show not only how we can avoid most of the emissions but also be food and energy secure without using fossil fuels.

Table 1. Contributions of Industrial Agriculture and Food System to Global Greenhouse Emissions

Sector		*Explanation*
Agriculture	11.0 %	Mostly methane and nitrous oxide

Landuse change	9.0 %	Deforestation for agriculture
Industry	3.0 %	Fertilizer manufacture, machinery, food industry
Energy	2.0 %	Direct use on farm, machinery, heating, cooling, irrigation
Transport	4.0 %	Food transport & distribution
Processing & packaging	2.0%	
Buildings & infrastructure	2.0 %	Storage, processing & distribution
Waste	1.0 %	Food and packaging wastes
Total	34.0%	

There is much scope for mitigating climate change and reversing the damages of the current agriculture and food system, and this is corroborated by scientific and empirical evidence indicating that organic agriculture and localised food and energy systems can potentially save more than 50 percent of global greenhouse emission and energy use [5, 6] (Mitigating Climate Change through Organic Agriculture, *SiS* 37; Food Futures Now *Organic *Sustainable *Fossil Fuel Free , ISIS publication). New data/estimates have appeared since so I propose to refine the calculations.

Organic agriculture and localized food and energy systems not only mitigate climate change, but also involve major adaptations to climate change [6] such as increasing agricultural biodiversity and resilience to climate extremes, increasing stability of food and energy supply in climate emergencies, reducing dependence on water against drought, increasing percolation of flood water against soil erosion, and increasing habitats for wildlife against species extinction.

While the Intergovernmental Panel on Climate Change (IPCC) failed to mention organic agriculture or localised food systems for mitigating climate change [1, 7], its counterpart on agriculture, the International Assessment of Agricultural Science and Technology for Development (IAASTD) has concluded that a fundamental overhaul of the current food and farming system is needed to get us out of the food (and fuel) crisis, that small scale farmers and agro-ecological methods are the way forward, and GM crops will not play a substantial role [8, 9] ("GM-Free Organic Agriculture to Feed the World", *SiS* 38). Earlier in 2002, a United Nations Food and Agriculture Organisation (FAO) report said that organic agriculture enables ecosystems to better adjust to the effects of climate change and has major potential for reducing agricultural greenhouse emission [10].

Reducing direct and indirect energy use in agriculture

The FAO report [10] found that organic agriculture performs better than conventional agriculture, both with respect to direct energy consumption (fuel and oil) and indirect consumption (synthetic fertilizers and pesticides). This has been amply confirmed since [5, 6]. The most important energy saving comes from *not* applying nitrogen fertilizers, which typically account for well over half of the energy consumed. .

In the UK, the total energy for agriculture is estimated at 2.7 percent of national energy consumption [11] and 1.8 percent of national greenhouse emission [12]. This is much lower compared with the estimate for the United States (see below). Nitrogen fertiliser is the single biggest input, accounting for 53.7 percent of the total energy use. Thus, phasing out nitrogen fertilizer would save 1.5 percent of national energy consumption and one percent of national greenhouse emission (not counting the nitrous oxide from N fertilizers applied to the fields).

Another way to estimate the energy saving is from the energy it takes to produce one kg of N fertilizer, which is 107.38 MJ on average [13]. UK farmers use about 1 million tonnes of N fertilisers each year; which require 107.38 PJ energy, or 1.5 percent of the national energy consumption of 160 Mtoe (mega tonne of oil equivalent) [14], exactly as estimated above.

World use of N fertilizers went up more than 8 fold between 1960 and 2005, from 11 Mt N to 91 Mt N, requiring 9.772×10^{18} J to produce, or 2.3 percent of the world energy consumption of 422×10^{20} J in 2006 [15], contributing 1.3 percent of world greenhouse emission.

David Pimental and colleagues at Cornell University New York in the United States estimated that the country's agriculture and food system uses 19 percent of the total fossil energy burnt in the US [16]: 7 percent for agricultural production (including fertilizers, pesticides, drugs, etc), 7 percent for processing and packaging, and 5 percent for distribution and food preparation. Adding the 5 percent due to deforestation would bring agriculture's contribution to 24 percent. Note that energy required for buildings and infrastructure, waste treatment, and export/import are not explicitly included.

Pimentel also estimated that US farmers invest on average 2 units of fossil fuel energy to harvest a unit of energy in crop [17]; i.e., the US uses twice the amount of fossil energy than the solar energy captured by all the plants. Corn is a high-yield crop and delivers more energy in the harvested grain per unit of fossil energy invested than any other major crop.

Counting all energy inputs in an organic corn system, the output over input ratio was 5.79 (i.e., 5.79 units of corn energy are obtained for every unit of energy spent), compared to 3.99 in the conventional system [17]. The organic system collected 180 percent more solar energy than the conventional. There was also a total energy input reduction of 31 percent, or 64 gallons fossil fuel saving per hectare. If 10 percent of all US corn were grown organically, the nation would save approximately 200 million gallons of oil equivalents, or 1.8 Mt CO_2e.

Based on the above considerations, I estimate the energy use of the current global agriculture and food system in Table 2.

Table 2. Contributions of Industrial Agriculture and Food System to Global Energy Consumption

Sector		*Explanation*
Agriculture	4.0 %	Farm machinery, lighting, heating, cooling, irrigation
Landuse change	5.0%	Deforestation for agriculture
Industry	4.0 %	Fertilizers, pesticides, & drugs manufacture, farm machinery
Transport	5.0 %	Food transport & distribution
Processing & packaging	5.0%	
Buildings & infrastructure	2.0 %	Storage, processing & distribution

Waste	1.0 %	Food and packaging wastes treatment
Total	26.0 %	

It is important to dispel the myth that organic agriculture yields less than conventional agriculture. A comprehensive review of 293 studies worldwide found that organic agriculture out yields conventional by a factor of 1.3 in the major crops compared, and that more than enough nitrogen can be provided by green manure alone, amounting to 171 percent of synthetic N fertilizer used currently [19, 20] (Scientists Find Organic Agriculture Can Feed the World and More, *SiS* 36). And in Ethiopia, the world's largest single study of its kind comparing organic and conventional agriculture in farmers' fields over a period of seven years found that composting increased yields two to three-fold, and outperformed chemical fertilizers by 30 percent [21] (Greening Ethiopia for Food Security & End to Poverty, *SiS* 37).

Lower greenhouse gas emissions

Figure 1 gives the greenhouse gas contributions of agriculture estimated in Greenpeace International's report [2]. It can be seen that N fertilizers come top at 2.128 Gt CO_2e a year. More than 50 percent of fertilizers applied to the soil end up in the atmosphere or in local waterways, giving rise to the potent greenhouse gas nitrous oxide with global warming potential of 289 compared with CO_2. In addition, 410 Mt CO_2e a year is due to the energy used in producing the fertilizers. The second biggest direct emitter in agriculture is livestock, in particular beef cattle and sheep, emitting l.792Gt CO_2e of methane, a greenhouse gas with global warming potential of 23. Nitrous oxide and methane are also emitted from livestock manure and from burning biomass at 0.413 Gt CO_2e and 0.672 Gt CO_2e respectively. Flooded rice paddy fields releases 0.516 Gt CO_2e of methane. The remaining emissions come from fossil fuel use for farm machinery and irrigation, making up a total of 6.638 Gt CO_2e for agriculture.

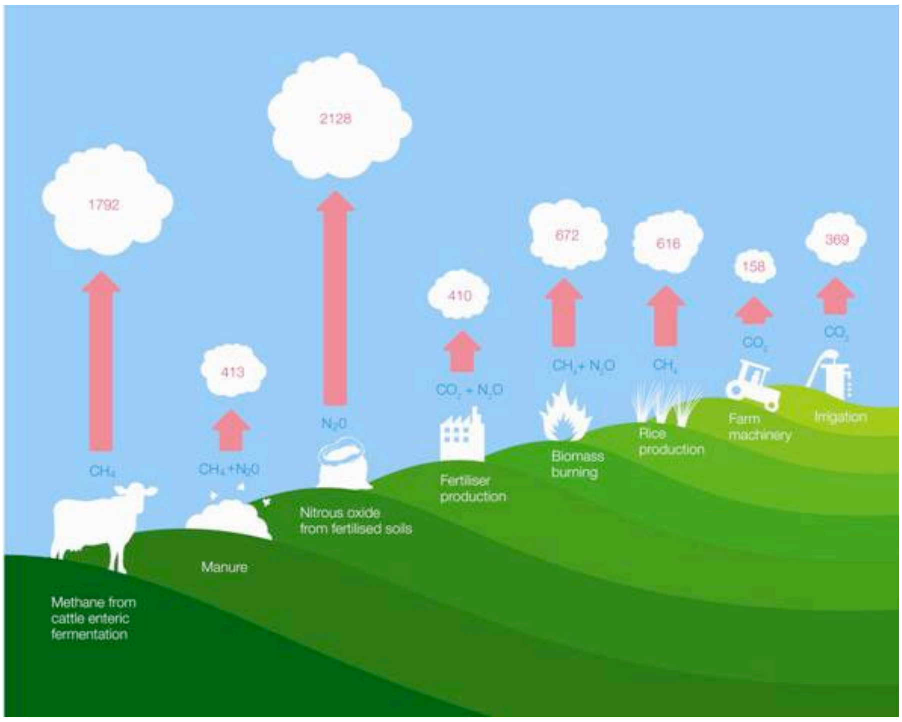

Figure 1. Greenhouse emission from agriculture in Mt CO_2e

The most effective on-farm measure for mitigating climate change and one that is eminently practicable is to phase out all N fertilizers. The direct emissions from N fertilizers are responsible for 3.8 percent of global greenhouse emissions. In addition, production of N fertilizers incurs 0.413 Gt CO_2e a year, or 0.7 percent global greenhouse emission, less than the 1.2 percent estimated directly from the world's N fertilizer use (see above).

. Earlier studies showed that greenhouse emission would be 48-66 percent lower per hectare in organic farming systems in Europe [22], and were attributed to no input of chemical N fertilizers, less use of high energy consuming feedstuffs, low input of P, K mineral fertilizers, and elimination of pesticides.

Many experiments have found reduced leaching of nitrates from organic soils into ground and surface waters, which are a major source of nitrous oxide. A study reported in 2006 also found reduced emissions of nitrous oxide from soils after fertilizer application in the fall, and more active denitrifying in organic soils, which turns nitrates into benign N_2 instead of nitrous oxide and other nitrogen oxides [23].

Should we all be vegetarians?

The next biggest emitters of greenhouse gas are livestock, especially beef cattle and sheep. Vegetarians, including the Chair of IPCC [24] have been quick to seize on this observation to proselytize against eating meat. But vegetarianism is not the answer.

Cattle and sheep - like the herds of bison and wild buffaloes that previously roamed the earth - are ecologically adapted to feed on grass and recycle essential nutrients in the biosphere. Grass grows on more marginal lands that are not so productive for crops. Furthermore, grasslands sequester a lot of carbon in the soil. Tropical savannas have a carbon stock underground four times as big as that above ground, while temperate grasslands have more than 30 times as much carbon stock in the soil as above it (see Table 3} [2], and sequester as much C as tropical forests. So organic pastures maintained as permanent meadows are strong mitigators of greenhouse emission.

Table 3. Global carbon stocks in vegetation and top 1 metre of soils

Biome	Area	Carbon Stocks (Pg CO_2-eq)			Carbon stock concentration (Pg CO_2-eq M km^{-2})
	M km^2	Vegetation	Soils	Total	
Tropical forests	17.60	776	791	1566	89
Temperate forests	10.40	216	366	582	56
Boreal forests	13.70	322	1724	2046	149
Tropical savannas	22.50	242	966	1208	54
Temperate grasslands	12.50	33	1080	1113	89
Deserts and semideserts	45.50	29	699	728	16
Tundra	9.50	22	443	465	49
Wetlands	3.50	55	824	878	251
Croplands	16.00	11	468	479	30
Total	151.20	1706	7360	9066	60

Source: IPCC 2001, Land use, land use change and forestry.

IPCC Chair Pauchauri (citing FAO source) attributes 80 percent of greenhouse emission from agriculture to livestock production, which takes up 70 percent of all agricultural land. However, the estimated 1.792 Gt from livestock (Fig. 1) is just 26.0 percent of greenhouse emission from agriculture, so where is the missing 44 percent of emission due to livestock? It is mostly concealed in the allocation to N fertilizers used in growing crops for feeding the livestock. Hence, organic, extensive livestock production would save substantially greenhouse emission for agriculture, allowing more cropland to revert to natural biodiverse meadows that would sequester a great deal more carbon [25] (Dream Farm 2 a Work of Art, *SiS* 40).

It is generally recognized that meat consumption is excessive in the developed countries and that the intensive livestock industry is at least both environmentally and ethically indefensible. (The health impacts of meat consumption are contested [26], and most likely conflated with the impacts of pesticide residues and hormones in non-organic beef.) Reducing meat consumption and halving the number of livestock would cut greenhouse emission by 1.6 percent in addition to the 3.8 percent from phasing out N fertilizers, making an impressive total of 5.4 percent of global greenhouse emission saved.

.It is also possible that moving away from grain and concentrate-fed to a predominantly grass-fed organic diet may reduce the level of methane generated, although that has yet to be investigated. Mike Abberton, a scientist at the Institute of Grassland and Environmental Research in Aberystwyth, suggested that a diet consisting of a mixture of rye grass bred to have high sugar levels, white clover, and birdsfoot trefoil could reduce the quantity of methane produced [27]. A study in New Zealand had found that methane output of previously grain and concentrate-fed sheep could be 50 percent lower while on the alternative diet. The small UK study did not achieve that level of reduction, but found nevertheless that "significant quantities" of methane could be prevented from getting into the atmosphere. Growing clover and birdfoot trefoil could help naturally fix nitrogen in organic soil as well as reduce livestock methane.

Saving forests from agriculture contributes most to mitigating climate change

The Stern Review on the Economics of Climate Change, commissioned by the UK Treasury and published in 2007 [28], highlighted the fact that 18 percent of global greenhouse emission (2000 estimate) comes from deforestation, and that halting deforestation is by far the most cost-effective way to mitigate climate change, and for as little as $1/ t CO_2 [29] (see The Economics of Climate Change, *SiS* 33).

Converting tropical forests to croplands releases an estimated 200 t CO_2e/ha a year to the atmosphere over a period of 30 years [30, 31] (Saving and Restoring Forests Saves Far More Carbon Emissions than Biofuels, *SiS* 37). In contrast, restoring tropical cropland to forest will sequester 175 t CO_2e/ha a year, about ten times the emission saved by growing corn to make ethanol on the most optimistic estimate.

Clearly, saving forests from agriculture would constitute the largest contribution of the sector to mitigating climate change. It would prevent emissions of 5.9 Gt CO_2e a year, or 10.6 percent of global emissions. Boreal forests (near the Arctic North) are the richest carbon stocks, averaging 1.49 Gt CO_2e/ha, compared with 0.89 Gt CO_2e/ha for tropical forests, and 0.56 CO_2e/ha for temperate forests (see Table 3) [2]. A new study also overturned previous misconceptions that old forests no longer grow sufficiently to sequester any carbon [32]. Instead, the net primary productivity of forests is found to improve with age up to about 80 years and then only slowly decline. Forests 200 years old and older sequester on average 8.8 t CO_2e/ha a year, about twice as much as the best cropland.

There is also much scope for converting existing plantations to sustainable agro-forests and to encourage the best harvesting practices and multiple uses of forest plantations [33, 34] (Multiple Uses of Forests, Sustainable Multi-cultures for Asia & Europe, SiS 26)

Carbon sequestration in organic soils

Soils are an important sink for atmospheric CO_2, but this sink has been increasingly depleted by conventional agriculture, and especially by converting tropical forests into agricultural land.

Organic agriculture helps to counteract climate change by restoring soil organic matter content as well as reducing soil erosion and improving soil physical structure. Organic soils also have better water-holding capacity, which explains why organic production is much more resistant to climate extremes such as droughts and floods and serves as important adaptation to climate change [35] (Organic Agriculture Enters Mainstream, Organic Yields on Par with Conventional & Ahead during Drought Years, *SiS* 28).

Organic matter is restored through the addition of manures, compost, mulches and cover crops. The Sustainable Agriculture Farming Systems (SAFS) Project at University of California Davis in the United States [36] found that organic carbon content of the soil increased in both organic and low-input systems compared with conventional systems, with larger pools of stored nutrients. Similarly, a study of 20 commercial farms in

California found that organic fields had 28 percent more organic carbon. This was also true in the Rodale Institute trials, where soil carbon levels had increased in the two organic systems after 15 years, but not in the conventional system [37]. After 22 years, the organic farming systems averaged 30 percent higher in organic matter in the soil than the conventional systems [35].

Every kilogram of soil organic matter absorbs 20 times its weight in water; hence organic soils have much greater water retaining capacity [38]. In addition, increased soil organic matter opens the structure of soil, improving water percolation by 25 to 50 percent, and reducing run-off and soil erosion.

In the longest running agricultural trials on record of more than 160 years, the Broadbalk Experiment at Rothamsted Experimental Station in the UK, manure-fertilized farming systems were compared with chemical-fertilized farming systems [39]. The manure fertilized systems of oat and forage maize consistently out yielded all the chemically fertilized systems. Soil organic carbon showed an impressive increase from a baseline of just over 0.1 percent N (a marker for organic carbon) at the start of the experiment in 1843 to more than double at 0.28 percent in 2000; whereas those in the unfertilized or chemical-fertilized plots had hardly changed in the same period. There was also more than double the microbial biomass in the manure-fertilized soil compared with the chemical-fertilized soils.

It is estimated that up to 4 t CO_2 could be sequestered per hectare of organic soils each year [40]. On this basis, a fully organic UK could save 68 Mt of CO_2 or 10.35 percent of its greenhouse emission each year. Similarly, if the US were to convert all its 65 million hectares of crop lands to organic, it would save 260 Mt CO_2 a year [41]. Globally, with 1.5335 billion hectares of crop land [42] fully organic, an estimated 6.134 Gt of CO_2 could be sequestered each year, equivalent to more than 11 percent of the global emissions, or the entire share directly attributed to agriculture.

As Pimentel stated [17]: "..high level of soil organic matter in organic systems is directly related to the high energy efficiencies observed in organic farming systems; organic matter improves water infiltration and thus reduces soil erosion from surface runoff, and it also diversifies soil-food webs and helps cycle more nitrogen from biological sources within the soil."

Another way to increase carbon sequestration is to convert croplands, especially marginal croplands into permanent pastures. As mentioned earlier, grasslands have many times more carbon sequestered in the soil than above ground.

Yet a further option is to convert annual crops into permanent perennial crops. Researchers at the Land Institute, Kansas, in the United States are involved in a comprehensive breeding programme to do just that [43] (Ending 10 000 Years of Conflict between Agriculture and Nature, *SiS* 39). The root systems of perennial crops are more than ten times larger and go much deeper than those of annuals, which is why they are more effective in binding soil, retaining and purifying water, recycling nutrients, as well as increasing the carbon stock below ground, as in temperate grasslands.

Reducing energy and greenhouse emission in localised sustainable food systems

The usual accounting for energy use and greenhouse emission in agriculture such as that in Figure 1 [2] leaves out large amounts expended in getting food from the field to plate. Agriculture in the US is responsible for 7.4 percent of national emission just from on-farm accounting [44]; the same is true for the UK [45]. But when emissions from the transport, distribution, storage, and processing of food are added, UK's agriculture and food system is responsible for at least 18.4 percent of the national greenhouse emission, not counting buildings and infrastructure for food distribution, nor wastes and waste treatments.

A lifecycle estimate of the greenhouse emission from farm to plate to waste, based on data supplied by Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique for France [46] put the figure at 30.4 percent of national emission [6]. That is still an underestimate, because it left out emission from the fertilizers imported, from pesticides, and from transport associated with the import/export of food. Also, the emission of electricity from *established* nuclear power stations in France is one-fifth of typical non-nuclear sources.

These figures suggest that the estimated 34 percent of national emission presented in Table 1 for a complete accounting of the agriculture and food system is not too far off the mark.

A study in Iowa in the United States found that local food transport uses one-tenth to a quarter of the fuel consumed by typical large-scale centralized food distribution [47]. Savings on transport would be accompanied by corresponding savings on storage, packaging, infrastructure, and wastes.

Localising food systems could save considerably on greenhouse emission and energy use.

Mitigating potential of organic, sustainable, localised food systems with no further deforestation

The preliminary estimates of the potential of organic agriculture and localised food systems to mitigate climate change based on work reviewed so far are presented in Box 1.

Box 1

Global potential of organic sustainable food systems for mitigating climate change

Greenhouse emission	
Carbon sequestration in organic soil	11.0 %
No deforestation	9.0 %
Localising food systems	
Reduced transport	3.0 %
Reduced building & infrastructure	1.0 %
Reduced processing & packaging	1.5%
Reduced wastes	0.5 %
Reduced livestock by half	1.6 %
Phasing out N fertilizers	

Reduced nitrous oxide emissions	3.8 %
No fossil fuels used in manufacture	0.7 %
Total	**32.1 %**
Energy	
No deforestation	5.0 %
Localising food system	
Reduced transport	5.0 %
Reduced building & infrastructure	1.0 %
Reduced processing & packaging	3.5 %
Reduced wastes & waste treatment	0.5 %
Reduced livestock by half	1.0 %
Phasing out N fertilizers	
Reduced wastes & waste treatment	0.5 %
No fossil fuels used	2.3 %
Total	**17.3 %**

The total mitigating potential of organic, sustainable, and localised food systems is 32.1 percent of global greenhouse emission and 17.3 percent of energy use; the largest contributions coming from carbon sequestration in organic soils of arable land and reduced transport from localising food systems. A stop to deforestation makes just as large a contribution to reducing greenhouse emission and energy use.

These figures update those presented previously [5, 6], and serve as a rough guide to what can be achieved.

Localising both food and energy systems in Dream Farm 2

A still greater potential for mitigating climate change arises if we localise both food and energy systems simultaneously. One way that could be achieved is through the widespread implementation of an integrated food and energy 'zero-waste' 'Dream Farm 2' based on turning wastes and greenhouse emissions into food and energy resources [48]. The core technology is an anaerobic digester that generates methane from livestock manure and other organic wastes such as food, crop residues, paper, etc that can be used for fuel and combined heat and power generation, just like natural gas.

From the amount of organic wastes available in the UK, I have estimated that anaerobic digestion would save 3.2 percent of total energy consumed (or 12.9 percent of transport energy), while mitigating 7.5 percent of total greenhouse emissions [46].

In addition, because energy is used locally, its efficiency can increase by up to 70 percent, and hence reduce energy use accordingly. A modest assumption of 30 percent reduction in energy use due to efficiency gain would bring the total energy saved to 50.5 percent. Similarly, the reduced energy use results in 17 percent savings in greenhouse emissions, and brings the total emissions saved to 56.6 percent (Box 2).

Box 2

Global potential for mitigating climate change by localising food and energy systems in Dream Farm 2

Greenhouse emission	
Organic, localised food & farming	32.1 %
Methane & nitrous oxide & fossil fuel substituted	7.5%
Fossil fuel savings from efficiency gains	17%
Total	**56.6 %**
Energy	
Organic, localised food & farming	5.0 %
Biogas Energy	17.3%
Energy efficiency gain from localised production & use	3.2%
Total	**50.5 %**

Incorporating solar, wind and micro-hydroelectric power would provide more than enough energy, compensate for nearly all, if not all greenhouse emission, and free us entirely from fossil fuels.

References

1. Barker T, Bashmakov I, Alharthi A, Amann M, Cifuentes L, Drexhage J, Duan M. Edenhofer O, Flannery B, Grubb M, Hoogwijk M, Ibitoye F I, Jepma CJ, Pizer WA, Yamaji K. Mitigation from a cross-sectoral perspective. In *Climate Change 2007: Mitigation.Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA. eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.
2. Bellarby J, Foereid B, Hastings S and Smithye P. Cool Farming: Climate impacts of agiculture and mitigation potential, Greenpeace International, Amsterdam, January 2008.
3. Ho MW. Biofuels: biodevasttion, hunger false carbon credits. Science in Society 33, 36-39, 2007.
4. Ho MW and Gala R. Food miles and sustainability. Science in Society 28, 38-39, 2005.
5. Ho MW and Lim LC. Mitigating climate change through organic agriculture and localized food system. Science in Society 37, 47-51, 2008.
6. Ho MW, Burcher S, Lim LC, et al. *Food Futures Now, Organic, Sustainable, Fossil Fuel Free*, ISIS and TWN, London, 2008.
7. Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Choles B, Sirotenko O. Agriculture. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
8. International Assessment of Agricultural Knowledge, Science & Technology (IAASTD) Synthesis Report

25 November 2007, http://www.agassessment.org/docs/Synthesis_Report_261107_text.pdf

9. Ho MW. GM-free organic agriculture to feed the world. Science in Society 38, 14-15, 2008.
10. Scialabba NE-H and Hattam C (eds) *Organic agriculture, environment and food security*, FAO, Rome, 2002.
11. Norton B. UK direct and indirect energy use, UK energy use Statistics, 2004, BERR, Department for Business Enterprise & Regulatory Reform, http://www.berr.gov.uk/energy/statistics/publications/ecuk/overall/page17954.html
12. Greenhouse gas emissions, down since 1990, National Statistics Online, http://www.statistics.gov.uk/cci/nugget.asp?id=901
13. Hood CF and Kidder G. Fertilizers and energy. University of Florida, Florida Cooperative Extension Service. http://www.p2pays.org/ref%5C08/07671.pdf
14. Energy Consumption in the United Kingdom, dti, http://www.berr.gov.uk/files/file11250.pdf
15. van Leeuwen JWS. Nuclear power=the energy balance. Part A, October 2007, www.stormsith.nl
16. Pimental D, Flesh J, Bonnfield A, Carcia X, Gregory O, Grufferman J, Horan C, Lambert E, rochon E, Schlenker J, Schenider M and Walling E. Environemtnal conservation for the individual (in manuscript), 2006, cited in 17.
17. Pimentel D. Impacts of organic farming on the efficiency of energy use in agriculture. An Organic Center State of Science Review, Organic Center, August 2006, http://organic.insightd.net/reportfiles/ENERGY_SSR.pdf
18. Ho MW. Biofuels for oil addicts. Cure worse than the addiction? Science in Society 30, 29-30, 2006.
19. Badgley C, Moghtader J, Quintero E, Zakem E, Chappell M.H. Aviles-Vazquez K, Salon A and Perfecto I. Organic agriculture and the global food supply. Renewable Agriculture and Food Systems 2007, 22 (2), 86-108.
20. Ho MW. Scientists find organic agriculture can feed the world & more. Science in Society 36, 15-17, 2007.
21. Edwards S. Greening Ethiopia for food security & end to poverty. Science in Society 37, 42-46,2008.
22. Stolze M, Piorr A, Häring A and Dabbert S. 1999. *Environmental and resource use impacts of organic farming in Europe,* Commission of the European Communities, Agriculture and Fisheries (FAIR) specific RTD programme, Fair3-CT96-1794.
23. Kramer SB, Reganold JP, Gloer JD, Bohannan BJM and Mooney HA. Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. *PNAS* 2006, 103, 4522-7.
24. Pachauri RK. Less meat, less heat: impacts of livestock on climate change. Brussels, 20 August 2008, http://www.vegetarisme.be/download/pub/pachauripers/Rachendra%20Pachauri%20-%20less%20meat%20less%20heat.ppt
25. Ho MW. Dream farm 2, a work of art. Science in Society 40 (to appear).
26. Fallon S and Enig MG. Vegetarianism: what the science tells us. Western A Price Foundation, 31 December 2000, http://westonaprice.org/basicnutrition/vegetarianism.html
27. "Cutting methane emissions of flatulent cows", Organic Inform, Elm Farm, 13 July 2007, http://www.organicinform.org/newsitem.aspx?id=217
28. Stern Review on the Economics of Climate Change, HM Treasury, 2007, http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm
29. Saunders PT. The economics of climate change. *Science in Society* 2007, 33, 20-23.
30. Righelato R and Spracklen DV. Carbon mitigation by biofuels or by saving and restoring forests? *Science* 2007, 317, 902
31. Ho MW. Saving and restoring forests saves far more carbon emissions than biofuels. Science in Society 37, 17, 2008.
32. Luyssaert S, Schulze E-D, Bőrner A, Knohl A, Hessenmőller D, Law BE, Ciais P and Grace J. Old-growth forests as global carbon sinks. Nature 2008, 455, 213-5.
33. Ho MW. Multiple uses of forests. Science in Society 26, 18-19, 2005.
34. Orskov B. Sustainable multi-cultures for Asia Europe. Science in Society 26, 20-21, 2005.
35. Ho MW. Organic yields on par with conventional & ahead during drought years. Science in Society 28, 17-18, 2005.
36. Clark MS, *et al.* 1999. 'Crop-yield and economic comparisons of organic, low-input, and conventional farming systems in California's Sacramento Valley', *American Journal of Alternative Agriculture* 14 (3), 109-121; and Clark MS *et al.* 1998. 'Changes in soil chemical properties resulting from organic and low-input farming practices', *Agronomy Journal* 90, 662-671.
37. Petersen C, Drinkwater LE and Wagoner P. *The Rodale Institute Farming Systems Trial: The First 15 Years*, The Rodale Institute, 1999.
38. Huntington T. Available water capacity and soil organic matter. Encyclopedia of Soil Science, 2nd edition, Taylor & Francis, 2006.
39. Rothamsted Research, Guide to the Classical and other Long-term Experiments, Datasets and Sample Archive, Rothamsted Research, Harpenden, 2006. www.rothamsted.ac.uk
40. Hepperly P. Organic farming sequesters atmospheric carbon and nutrients in soils. The Rodale Institute, Pennsylvania, USA, 15 October 2003, http://www.newfarm.org/depts/NFfield_trials/1003/carbonwhitepaper.shtml
41. "New finding: organic farming combats global warming…big time" Laura Sayre, The New Farm, 10 October 2003, http://www.newfarm.org/depts/NFfield_trials/1003/carbonsequest_print.shtml
42. Global land use area change matrix, FAO Corporate Document Repository, 1 January 2008, http://www.fao.org/docrep/010/ag049e/AG049E03.htm
43. Cox S. Ending 10 000 years of conflict between agriculture and nature. Science in Society 39, 12-15, 2008.
44. Executive Summary Inventory of U.S. Greenhouse Gas Emissions and sinks: 1990-2005. April 2007 http://www.epa.gov/climatechange/emissions/downloads06/07ES.pdf
45. Garrett T. Overall UK consumption related GHGs, April 2007, Food Climate Change Research Network, http://www.fcrn.org.uk/frcnresearch/publications/Overall%20food%20GHGs.doc
46. How much greenhouse gases in our plate? Jean-Marc Jancovici. March 2004 http://www.manicore.com/anglais/documentation_a/greenhouse/plate.html
47. Pirog R, van Pelt T, Enshayan K and Cook E. *Food Fuel, and Freeways: an Iowa Perspective on How Far Food Travels, Fuel Usage, and Greenhouse Gas Emissions*, Ames, Iowa: Leopold Center for Sustainable Agriculture, Iowa State University, 2001, cited in Brody S, Chernoh E and Feenstra G. Assessment of energy use and greenhouse gas emissions in the food system, a literature review. Agricultural sustainability Institute, University of California, Davis, November 2007.
48. Ho MW. Dream Farm 2: organic, sustainable, fossil fuel free. In Ho MW, Burcher S, Lim LC, et al. *Food Futures Now, Organic, Sustainable Fossil Fuel Free*, ISIS & TWN, London & Penang, 2008 (in press).

The Institute of Science in Society, PO Box 51885, London NW2 9DH
telephone: **[44 20 8452 2729] [44 20 7272 5636]**

Contact the Institute of Science in Society