


# OWC 2020 Paper Submission - Science Forum

*Topic 3 - Transition towards organic and sustainable food systems*

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**MODELLING THE GREENHOUSE GAS IMPLICATIONS OF CONVERTING FOOD PRODUCTION IN ENGLAND AND WALES TO ORGANIC METHODS**

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**Abstract:**

Although organic farming can provide numerous benefits from a sustainability perspective, the greenhouse gas impacts of a widespread conversion are still uncertain. An assessment of a 100% shift to organic management within England and Wales was therefore applied, using linear programming and Life Cycle Assessment. The study built on earlier work by including estimates of the emissions associated with additional land requirements, and the offset that could be achieved through soil carbon sequestration in organic systems. The results from the modelling revealed major reductions in productivity under an organic scenario, in particular for wheat, barley, oilseed rape, pork, eggs and poultry meat whereas the production of potatoes, oats, minor cereals and ruminant meat increased. Results from the environmental assessment revealed reduced greenhouse gas emissions under organic management, despite increased emissions per tonne for some products such as carrots, potatoes, poultry meat and eggs. When land use change impacts were included, the greenhouse gas savings that could be achieved through the widespread adoption of organic practices were offset, leading to worse performance overall. Enhanced soil carbon sequestration could offset only a small part of the overseas emissions under the 100% organic scenario.

**Introduction:**

Organic farming systems aim to have a lower greenhouse gas impact than conventional through a lower production intensity, less use of manufactured inputs, and greater soil organic carbon contents. It is suggested that organic practices could contribute significantly to achieving national GHG reduction targets (e.g. Scotland's Organic Action Plan). However, as far as we are aware there have been no rigorous assessments of the validity of this suggestion, covering the main agricultural GHGs: methane ($CH_4$), nitrous oxide ($N_2O$) and carbon dioxide ($CO_2$) from both primary and secondary sources. The study reported here therefore provides a comprehensive assessment of the potential food production and GHG impacts of an up-scaling of organic agriculture to achieve 100% coverage in England and Wales.

**Material and methods:**

A combination of land-use modelling and Life Cycle Assessment were used to assess how total GHG emissions would change under conversion to a 100% organic agriculture in England and Wales. The OLUM (Optimal Land Use Model) model was developed to estimate levels of production under 100% organic management, and is described in detail by Smith et al. (2018). It includes a suite of activities that represent current organic practices within a range of farm types across the entire agricultural land-base in England and Wales to estimate levels of production under organic constraints (e.g. available N and crop rotation requirements).

The environmental impact of the 100% organic production scenario was assessed through an application of the Cranfield Agri-LCA models (Williams et al., 2006). The Agri-LCA models are stand-alone models that were designed to estimate GHG emissions from different agricultural systems in England and Wales, under various assumptions (Williams et al., 2006). Additional overseas land required to compensate for domestic supply shortfalls was also calculated for a range of countries within and outwith Europe. A sensitivity analysis was also undertaken to explore the effect of different assumptions about the requirements for conversion of land from pasture to arable.  Annual topsoil carbon sequestration estimates under organically-managed land were also made following Gattinger et al. (2012) and rates of change in soil C derived from the National Soil Inventory of England and Wales for different land use classes by Kirk and Bellamy (2010).

In addition, there is the opportunity cost of the amount of C that could be sequestered if the additional land required was instead used to maximise its C storage potential, for example by converting it to productive forest. This aspect is considered by Searchinger et al. (2018), who define a 'Carbon Opportunity Cost' (COC) as the amount of C that could be sequestered annually per kg of agricultural commodity if the land were instead used to regenerate forest. We also calculated this.

**Results:**

Conversion to 100% organic management caused a considerable drop in crop production compared to the 2010 conventional baseline, in particular for wheat, barley and oilseed rape. There was a substantial increase in legume and potato production under the organic scenario - a result of an increase in the cultivated area, as required by the rotational constraints in the OLUM. Grazing livestock numbers increased under the organic scenario, although total carcass outputs did not increase by the same percentage, as a result of lower carcass weights and longer finishing periods under organic livestock management. Monogastric livestock numbers and associated meat volumes fell sharply under the organic scenario, as a result of lower concentrate feed availability and upper stocking rate limits. Overall food production, expressed as metabolisable energy, fell to 64% of a conventional baseline.

Lower greenhouse gas emissions were found for many organic crops largely as a result of the replacement of N fertiliser with biological N fixation in leys, resulting in less $CO_2$ and $N_2O$ from fertiliser manufacture and less $N_2O$ per unit of production.  Organic pig production resulted in lower GHG emissions per unit of production because outdoor organic systems use less fossil energy in housing although $N_2O$ emissions increased as a result of greater leaching and denitrification from organic manures. In common with previous studies, we found that poultry meat and egg production generates greater emissions under organic management due to poorer feed conversion ratios, longer rearing times, higher mortality rates and greater leaching losses compared to conventional systems. Organic dairy, beef and sheep production results in lower total GHG emissions per unit of production, as a result of the increased efficiency of forage production under organic management.

National emissions associated with 100% organic crop and livestock production were smaller for organic farming compared with conventional: by 20% for crops, 4% for livestock and 6% overall. However, the picture is very different when we allow for the additional $CO_2$ emissions from Land Use Change (LUC) overseas to make up for shortfalls in home production and enhanced soil C sequestration under organic methods. The results show that the net effects are sensitive to both the LUC scenario and the degree of soil C sequestration. If all the LUC is by conversion of grassland with no C sequestration, net emissions increase by 56% over the conventional baseline. Whereas, if only 25% of the LUC is from grassland, with a high rate of C sequestration, net emissions are comparable to those in the conventional baseline. With 50% LUC from grassland, and a moderate rate of C sequestration, the net increase is 21%. However, if the COC is added in, the net GHG costs of organic production are much worse. For the Medium LUC and C sequestration scenario, adding in the COC gives a net increase in emissions over the conventional baseline of 1.7 times.

**Discussion:**

Whilst substantial gains in the efficiency of non-renewable resource use could be obtained through a large-scale conversion to organic production methods, a major increase in the area of overseas agricultural production would be required, to compensate for production shortfalls if diets were to remain the same. If only 50% of the additional overseas land area were to be converted from pasture, then the GHG savings obtained by the use of low-input methods commonly applied on organic farms would be entirely offset. At lower rates of grassland conversion, and when soil carbon sequestration rates associated with organic management are factored in, fully organic production could slightly reduce net GHG emissions from England and Wales agriculture. However, fundamental questions remain, i.e. can the additional overseas land required to make up for production shortfalls be found at all, and if it can be found, can this be obtained solely from the existing base of tilled land? With the demands placed on the existing arable land base continuing to increase as a result of growing populations, a shift to lower-yielding forms of agriculture, such as organic farming, could be considered infeasible without a fundamental change in consumption habits, food waste and/or current organic production systems. Lower yields and higher land use requirements could be partly addressed by the increased research towards low-input systems likely under a 100% organic scenario.  Reduced meat consumption and increased direct marketing would also help to reduce land-use requirements by reducing animal feed production and food waste, whilst potentially improving farm incomes. Although many organic consumers may help to encourage moves in this direction, it is important to bear in mind that today's organic consumers are a self-selecting group and not typical of the nation(s). Whether a different national diet and/or routes to market could be provided by the same land area under all organic production is a different study. In summary although there are undoubted benefits to organic farming practices, including soil C storage, reduced exposure to pesticides and improved on-farm biodiversity, these potential benefits need to be set against the requirement for greater production elsewhere.

**References:**

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**Disclosure of Interest**: None Declared

**Keywords**: conventional farming, food security, modeling, organic farming, organic livestock

Table 1: Global Warming Potentials expressed in kg of $CO_2$ / $CO_2$ equivalent per tonne for major crops and livestock products in England and Wales produced under conventional and organic management. Crop impact includes all inputs, fieldwork and crop storage for crops destined for human consumption. Emissions associated with animal feed production are allocated to the livestock product(s). DCW = Dead Carcass Weights.

**Crops**

| | Beans | | Carrots | | Potatoes | | Milling wheat | | Oats | | Winter Barley | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conv. | Org. | Conv. | Org. | Conv. | Org. | Conv. | Org. | Conv. | Org. | Conv. | Org. |
| $CO_2$ | 173 | 174 | 36 | 40 | 85 | 103 | 158 | 155 | 147 | 184 | 155 | 168 |
| $CH_4$ | 0 | 0 | 2 | 0 | 4 | 3 | 6 | 0 | 4 | 0 | 5 | 0 |
| $N_2O$ (direct) | 68 | 142 | -4 | -8 | 36 | 17 | 234 | 105 | 183 | 129 | 199 | 106 |
| $N_2O$ (secondary) | 35 | 49 | 2 | 9 | 3 | 11 | 23 | 66 | 16 | 54 | 16 | 35 |
| $N_2O$ | 103 | 191 | -2 | 1 | 39 | 28 | 257 | 172 | 199 | 183 | 216 | 141 |
| **Total** | **276** | **365** | **36** | **41** | **128** | **135** | **420** | **326** | **350** | **367** | **376** | **309** |

**Livestock**

| | Pig meat (DCW) | | Poultry meat (DCW) | | Beef (DCW) | | Sheep meat (DCW) | | Milk ('000 litres) | | Eggs | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Conv. | Org. | Conv. | Org. | Conv. | Org. | Conv. | Org. | Conv. | Org. | Conv. | Org. |
| $CO_2$ | 2,217 | 1,380 | 3,067 | 2,877 | 2,428 | 1,640 | 1,627 | 917 | 210 | 168 | 1,616 | 1,728 |
| $CH_4$ | 808 | 304 | 93 | 89 | 7,403 | 8,454 | 14,068 | 14,564 | 637 | 711 | 777 | 772 |
| $N_2O$ (direct) | 781 | 1,245 | 754 | 1,319 | 3,405 | 3,065 | 3,034 | 2,543 | 185 | 125 | 641 | 743 |
| $N_2O$ (secondary) | 569 | 633 | 605 | 995 | 1,792 | 301 | 1,022 | 854 | 36 | - 49 | - 205 | - 105 |
| $N_2O$ | 1,350 | 1,878 | 1,359 | 2,314 | 5,197 | 3,366 | 4,056 | 3,397 | 221 | 77 | 436 | 638 |
| **Total** | **4,375** | **3,561** | **4,520** | **5,280** | **15,029** | **13,460** | **19,751** | **18,878** | **1,068** | **957** | **2,829** | **3,137** |

Table 2: Total GHG emissions from crop and livestock production under conventional 2010 baseline year and 100% organic production scenarios allowing for High, Medium and Low levels of overseas LUC and soil C sequestration and the Carbon Opportunity Cost' (COC) of Searchinger et al. (2018) – see Material and methods.

| | **Conventional production** | **Organic production only** | **Organic production with high LUC and no CSEQ** | **Organic production with medium LUC and med CSEQ** | **Organic production with low LUC and high CSEQ** | **Organic production with COC - Searchinger et al. (2018) values** |
|---|---|---|---|---|---|---|
| kt $CO_2$ equivalents $yr^{-1}$ by source | | | | | | |
| $CO_2$ | 16,994 | 15,169 | 45,758 | 28,454 | 15,323 | 50,863 |
| $CH_4$ | 17,826 | 18,964 | 18,964 | 18,964 | 18,964 | 18,964 |
| $N_2O$ | 14,499 | 12,344 | 12,344 | 12,344 | 12,344 | 12,344 |
| Total kt $CO_2$ equivalents yr-1 | 49,319 | 46,476 | 77,066 | 59,761 | 46,631 | 82,170 |