

# 1 **Specification of Driver Review DR4: Energy and the Food System**

## 2 **Energy and the Food System**

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27

28 **Abstract**

29 Modern agriculture is heavily dependent on fossil resources. Both direct energy use for crop  
30 management and indirect energy use for fertilizers, pesticides and machinery production, have  
31 contributed to the major increases in food production seen since the 1960s. However, the  
32 relationship between energy inputs and yields is not linear. Low energy inputs can lead to lower  
33 yields and perversely to higher energy demands per tonne of harvested product. At the other  
34 extreme, increasing energy inputs can lead to ever smaller yield gains. Although fossil fuels  
35 remain the dominant source of energy for agriculture, the mix of fuels used differs due to the  
36 different fertilization and cultivation requirements of individual crops. Nitrogen fertilizer  
37 production uses large amounts of natural gas and some coal, and can account for more than 50%  
38 of total energy use in commercial agriculture. Oil accounts for between 30 and 75% of energy  
39 inputs of UK agriculture, depending on the cropping system. Whilst agriculture remains dependent  
40 on fossil sources of energy, food prices will couple to fossil energy prices and food production  
41 will remain a significant contributor to anthropogenic greenhouse gas emissions. Technological  
42 developments, changes in crop management, and renewable energy will all play important roles in  
43 increasing the energy efficiency of agriculture and reducing its reliance of fossil resources.

44

45 *Keywords:* Energy in agriculture, fossil energy, agricultural greenhouse gas emissions, land use,  
46 agroforestry, policy

47

48

## 49 **1 Energy Use for food production**

50 The IPCC's 3<sup>rd</sup> Assessment report (IPCC 2001) estimated that by 1995, agriculture accounted for  
51 about 3% (9EJ) of global energy consumption, but more than 20% of global greenhouse gas  
52 emissions. Figure 1 highlights the trend of increasing energy inputs to agriculture since 1971 and  
53 shows the high degree of variability both between regions and over time, for example, the collapse  
54 in energy inputs in the former Soviet Union after the fall of the iron curtain in 1989.

55

56 [INSERT FIGURE 1 HERE]

57

58 Substantial areas of agricultural land also came out of production as these (former USSR) farms  
59 became exposed to global competition with governments unable to continue subsidising  
60 production.

61 The links between, agricultural energy inputs, yields, economic returns, land requirements and  
62 land use change needs further research. However, land use change has major implications for  
63 greenhouse gas (GHG) emissions and carbon stocks, particularly where forest-land is cleared or  
64 where previously arable land is allowed to revert to forest. These issues are discussed briefly in  
65 the 'indirect emissions' section below but are not a major focus in this paper.

66 If energy consumption by agriculture continued to grow at the annual rate outlined by the IPCC  
67 for 1995 (IPCC 2001), total energy inputs into agriculture would have exceeded 10EJ in 2005,  
68 equivalent to a share of about 2% of global primary energy consumption. Therefore, agricultural  
69 demand for fossil energy, whilst growing, represents a relatively insignificant and shrinking share  
70 of the overall fossil energy supply market. On the other hand, as yields and the inputs needed to  
71 support those yields increase, agriculture is becoming more dependent on fossil fuels, either

72 directly for tillage and crop management or through the application of energy intensive inputs e.g.  
73 nitrogen fertilizer and pesticides. Furthermore, the embodied energy in tractors, buildings and  
74 other infrastructure necessary to support agriculture and food supplies is likely to continue to grow  
75 as developing agricultural producers invest in the infrastructure needed to increase yields and  
76 become competitive in the global food commodity markets as outlined in Figure 2.

77 Embodied energy is all the energy used in the creation of a product. In the Life Cycle Assessment  
78 (LCA) analyses described subsequently, it is assumed that the long term phosphorous (P) and  
79 potassium (K) requirements of all crops must be met.

80

81 [INSERT FIGURE 2 HERE]

82

83 Fossil energy inputs into agriculture have generally been outweighed by yield improvements that  
84 deliver positive energy ratios (energy out: energy (fossil) inputs) “i.e. the energy content of the  
85 harvested crop is greater than the fossil energy used to produce the crop,” as highlighted by  
86 Samson et al. (2005), in Figure 3. However, over the full lifecycle of a crop, particularly where  
87 energy-intensive drying and processing are required, in some cases more fossil energy can be used  
88 than is contained in the final product. A detailed assessment of the energy inputs and GHG  
89 emissions from UK agriculture follows. Whilst much of this assessment is specific to the UK, the  
90 heterogeneity in inputs, energy carriers, energy intensities and resulting greenhouse gas emissions  
91 for different crops is considered a conservative representation of commercial agriculture globally.

92

93 [INSERT FIGURE 3 HERE]

94

## 95 **1.1 Contemporary UK agriculture**

96 This section covers the main commodities produced in the UK and is from the perspective of  
97 LCA, which is a standard method for assessing the “cradle to grave” environmental impacts of a  
98 product or process. The detailed breakdown that follows comes from the work of Cranfield  
99 University and is reported in various outputs (Williams et al. 2006; Williams et al. 2009; Audsley  
100 et al. 2010). The work was parameterised for England and Wales, although much applies in other  
101 parts of the UK. The original study included three field crops (bread wheat, oilseed rape and  
102 potatoes), four meats (beef, poultry, pork and lamb), milk and eggs. Tomatoes were included as  
103 the main protected crop. Apples and strawberries were analysed in a later study, together with  
104 overseas production of apples, potatoes, tomatoes, strawberries, lamb, beef and poultry meat.  
105 Primary production up to the farm gate was included in all these studies, although in Williams et  
106 al. (2009), the end point was the regional distribution centre. This section only covers production  
107 to the farm gate.

108 With LCA, all energy use is traced back to resources in the ground, so that overheads of extraction  
109 and distribution are included in reported energy figures. All inputs are considered, so that the  
110 embodied energies in fertiliser, machinery, buildings and pesticides are included along with the  
111 direct energy of diesel and other fuels (also known as energy carriers). Estimates for the energy  
112 inputs into animal production include inputs for the production of all feed crops e.g. UK feed  
113 wheat, UK field beans, American soy and forage (grazed grass and conserved grass or maize) and  
114 for feed processing and distribution. All breeding overheads are also included, so that the final  
115 values represent the totality of energy used per commodity.

116 One of the challenges of these analyses is how to allocate burdens when crops are multi-  
117 functional. Oilseed rape is grown primarily for oil, but a useful meal is also produced as the result  
118 of oil extraction, which can be used as an animal feed. It is common practice with products of

119 disparate properties to allocate burdens by economic value, rather than simply by weight or energy  
120 content and this approach has been used here.

### 121 **1.1.1 Arable crops**

122 Energy inputs to produce the UK's main crops (Table 1) range from 1 to 6 GJ/t. However, each  
123 agricultural product has very different properties and uses, making comparisons using a single  
124 metric problematic. Oilseed rape stands out as being the highest energy consumer per tonne of  
125 product, resulting from relatively low yields and high fertiliser requirements, but the grain is more  
126 energy-rich than cereals or legumes. Bread wheat receives more fertiliser than feed wheat, in  
127 order to obtain the high protein concentrations that are required for bread making and so takes  
128 more energy than feed wheat. Although field beans require no nitrogen (N) fertiliser, they have  
129 much lower yields than wheat and more diesel is used per tonne of beans produced.

130

131 [INSERT TABLE 1 HERE]

132

133 Cereals tend to follow the same pattern, in terms of energy inputs and wheat is used here as a  
134 proxy for cereals in general (Figure 4). UK Wheat also has a similar energy input intensity to US  
135 maize production as shown in Table 1. In non-organic bread wheat production, over half of the  
136 energy used is in fertilisation and about 90% of that energy is in N, typically ammonium nitrate  
137 and urea. Bread wheat is unusual in that urea is applied relatively late in the growth season, as a  
138 foliar feed. Direct field energy is just under a quarter of the input. Post harvest energy inputs are  
139 mainly for grain drying and cooling, which were calculated here on a long term basis: this clearly  
140 varies yearly according to climatic conditions. Pesticide manufacture accounts for less than 10%  
141 of energy input, but a lack of modern data leads to higher degrees of uncertainty about the impacts

142 of pesticide use, with the most recent publically available analysis by Green (1987). In contrast,  
143 organic production uses more diesel per unit production, owing to lower yields and the obligation  
144 to use the plough, coupled with extra cultivations for weed and pest control.

145 Potato cropping is energy intensive compared to cereals and legumes. For example, the energy  
146 used in storage is much larger than other crops: potatoes are kept cool and a proportion is  
147 maintained over the year. This is in contrast to traditional low energy clamping systems, in which  
148 losses were much higher, but the supply season shorter. Early potatoes are generally not stored on  
149 farms, so energy requirements for field operations incur a major fraction of total energy inputs,  
150 which also include irrigation inputs as well as the high energy costs of planting, cultivating and  
151 harvesting. However, because potatoes are high yielding crops, they have low energy input  
152 requirement per tonne harvested. If calculated per tonne of harvested dry matter, because the  
153 harvested biomass is 80% water for potatoes, compared to 15 to 20% for wheat grain, for  
154 example, potatoes would have a higher energy intensity factor.

155 Sugarcane production under Brazilian conditions and management is also high yielding and has a  
156 high water content (70% moisture content) when harvested. The relatively low energy inputs  
157 needed for the production of this semi-perennial crop and lower moisture content compared to  
158 potatoes, means that when accounting for energy intensity on a dry weight basis, sugarcane would  
159 have a lower energy intensity than UK wheat. Even when processed to ethanol and/or crystalline  
160 sugar, because of the use of residual biomass arising from sugar extraction, to provide power and  
161 heat, fossil energy inputs are minimised.

162

163 [INSERT FIGURE 4 HERE]

164

165 The types of energy used vary between crops and production systems (Figure 5), and also  
166 location. In the UK, as with most of Europe, N fertiliser production uses mainly natural gas.  
167 However, according to He (2009) in China, coal currently provides about 80% of the energy  
168 inputs into nitrogen fertiliser production rising from 71% in 2004. Diesel comes from crude oil.  
169 Electricity used either directly (e.g. cooling grain) or indirectly in machinery manufacture, also  
170 uses coal, nuclear and some renewables. The dominant energy carrier in non-organic wheat  
171 production is thus natural gas, but it is crude oil in organic wheat production and in China it would  
172 be coal. The embodied energy in machinery is an overhead of about 40% of the energy used in  
173 diesel, reflecting the high wear environment of cultivating and harvesting, as well as continually  
174 high power demand on engines, compared with road transport.

175

176 [INSERT FIGURE 5 HERE]

177

178 Although fertiliser manufacture is energy-intensive, reducing fertiliser use has mixed effects.  
179 Energy input per ha is reduced, but so is yield, thus increasing the relative input of cultivation  
180 energy per t. Reducing yield also implies a need to displace production elsewhere in order to  
181 maintain supply. This could be in areas that are less suitable and / or lead to land use change, e.g.  
182 conversion of grassland to arable, with the consequent loss of soil carbon (C). It does appear,  
183 however, that some reduction in N supply can reduce energy use per t bread wheat (Figure 6).  
184 However, a very large reduction in N application can cause sufficient yield loss that cultivation  
185 becomes the dominant energy demand and energy use per tonne increases again.

186

187 [INSERT FIGURE 6 HERE]

188



189 **1.1.2 Animal production**

190 The energies used per tonne of the main outputs of animal production are all substantially higher  
191 than crops (Table 2). This results from the concentration effect as animals are fed on crops and  
192 concentrate these into high quality protein and other nutrients. Feed is the dominant term in  
193 energy use (average of about 75%), whether as concentrates, conserved forage or grazed grass.  
194 Direct energy use includes managing extensive stock, space heating for young birds and piglets  
195 and ventilation for pigs and poultry. Housing makes up a relatively small fraction of total energy  
196 inputs, and is even lower for more extensive systems, like free-range hens. For egg production,  
197 the energy demand of manure management is more than offset by the value of chicken manure as  
198 a fertilizer, hence the negative value.

199

200 [INSERT TABLE 2 HERE]

201

202 The energy carriers used in animal production vary less than crops (Table 3). About one third is  
203 from crude oil and another third from natural gas. However, because animal feed production and  
204 supply requires 70 to 90% of the total energy inputs for livestock production, animal husbandry  
205 may be more vulnerable to high and volatile energy costs compared to the direct supply of arable  
206 crops. This could lead to increased pressure on extensive grazing, reversing the trends over the  
207 recent decades of decreasing land area requirements per kg livestock production.

208

209 [INSERT TABLE 3 HERE]

210

## 211 **2 Current Greenhouse Gas Emissions**

212 Agriculture occupies more than 50% of the world's vegetated land (Foley et al. 2005) and  
213 accounts for between 10 to 20% of all anthropogenic GHG emissions, depending on where the  
214 boundaries are drawn between agriculture and the other sectors (IPCC 2006; International  
215 Fertilizer Industry Association 2009). However, its contribution to methane and nitrous oxide  
216 production is disproportionately large. On a global scale, agricultural processes are estimated to  
217 account for 50% of anthropogenic methane production and 80% of anthropogenic nitrous oxide  
218 production (Crutzen et al. 2008; Olesen et al. 2006). As in industry, at all production stages fossil  
219 fuel combustion for heat and energy represents a direct and major source of agricultural  
220 greenhouse gas emissions. In addition, anaerobic fermentation and microbial processes in soil and  
221 manure lead to releases of methane and nitrous oxide in both livestock and arable systems.  
222 Nitrogen fertiliser production alone consumes about 5% of the global natural gas supplies and  
223 significant amounts of nitrous oxide are emitted during the production of nitrate (Jenssen and  
224 Kongshaug 2003; Kindred et al. 2008; International Fertilizer Industry Association 2009).  
225 Furthermore, emissions as a result of land use change (mainly as carbon dioxide) can form a  
226 significant part of the agricultural impact on the atmosphere.

### 227 **2.1 Arable Sources**

228 The period between 1965 and 2000 saw a doubling of global agricultural production (Tilman  
229 1999). The total area under cultivation has remained relatively static and this huge increase in  
230 output is primarily the result of massive increases in fertilisation and irrigation (Figure 2), as well  
231 as improved crop genetics. Global nitrogen fertiliser applications have increased more than six-  
232 fold over the past 40 years (Tilman 1999), although there has been considerable regional variation.  
233 The production of mineral and synthetic fertilisers, especially nitrogen using the Haber–Bosch

234 Process, uses large amounts of fossil energy, mainly natural gas, releasing around 465 Tg carbon  
235 dioxide into the atmosphere each year (International Fertilizer Industry Association 2009). It has  
236 been estimated that 30% of the total fossil energy used in maize production is accounted for by  
237 nitrogen fertiliser production (Tilman 1999) and that fertiliser production is responsible for up to  
238 1.2% of all anthropogenic greenhouse gas emissions (Wood and Cowie 2004).

239 Fertiliser application can also lead to further emissions. Nitrification and de-nitrification of  
240 mineral and organic nitrogen fertilisers leads to the release of large amounts of nitrous oxide from  
241 soils (Snyder et al. 2009). The IPCC (2006) Tier 1 estimate is that 1% of all applied nitrogen is  
242 emitted in the form of nitrous oxide, although there is considerable uncertainty over this figure.  
243 Loss of nitrous oxide from arable soils accounts for around 1.5% of total anthropogenic  
244 greenhouse gas emissions (International Fertilizer Industry Association 2009). Modern techniques  
245 that reduce soil compaction, such as GPS-guided controlled traffic farming, can reduce nitrous  
246 oxide emissions by between 20 and 50% (Vermeulen and Mosquera 2009).

247 Emissions vary according to cultivation technique and crop type. Anaerobic turnover in rice  
248 paddies is a major source of methane (Olesen et al. 2006), although the anoxic conditions when  
249 paddies are flooded, minimise carbon dioxide release. Ploughing soils encourages microbial  
250 digestion of soil organic matter, leading to greater net carbon dioxide emissions. Energy use at all  
251 stages of arable production represents another significant source of carbon dioxide. However,  
252 differences in farming techniques, levels of mechanisation, scales of production, and soil and  
253 weather conditions in different regions make it difficult to quantify total fossil energy use and to  
254 extrapolate data from one agricultural system to another.

## 255 **2.2 Livestock Sources**

256 Meat, egg and milk production are estimated to account for half of all the greenhouse gas  
257 emissions associated with food production and represent about 18% of global anthropogenic  
258 emissions (Garnett 2009). In the UK, livestock farming generates 57.5 Tg carbon dioxide  
259 equivalent, which is around 8% of total UK emissions (Garnett 2009). Global demand for meat  
260 and dairy products is predicted to increase over the next 50 years due to human population growth  
261 and increased wealth. An important source of greenhouse gases in livestock farming is enteric  
262 fermentation in ruminants, such as sheep and cattle, which produces significant quantities of  
263 methane (Olesen et al. 2006).

264 Growth of crops to feed livestock is another major source of greenhouse gas emissions. Around  
265 37% of global cereal production and 34% of arable land is used to provide animal feed (FAO  
266 2006) and so meat, egg and milk production also contributes to the release of nitrous oxide and  
267 other gases as described above. A further consideration is the efficiency with which animal feed is  
268 converted to meat. A large proportion of animal feed is respired or accumulates in non-edible parts  
269 of the animal. In the case of cattle, up to 10kg of cereal may be required per kg of meat produced  
270 and so cattle farming can represent a significant demand for land and resources (Garnett 2009).

271 Substantial differences exist between the different forms of livestock production in terms of net  
272 energy and protein feed requirements per kg meat produced. Increasing and volatile fossil fuel  
273 prices, unless mitigated, could drive both reductions in meat demand due to increased prices, but  
274 also switching to lower energy intensity, higher efficiency, forms of meat production, possibly  
275 favouring mono-gastric rather than ruminant supply chains.

## 276 **2.3 Indirect Emissions**

277 On a global scale, 75% of anthropogenic greenhouse gas emissions are the result of fossil fuel  
278 combustion. The remaining 25% are primarily the result of land use change (Snyder et al. 2009;  
279 Le Quéré. 2009). However, land also continues to be a net sink for carbon, absorbing about 29%  
280 of total emissions, with the oceans taking up a further 26%. The balance, about 45%, accrues to  
281 the atmosphere (Le Quéré. 2009).

282 Deforestation involves the removal of large aboveground biomass stocks, which represented an  
283 important carbon sink during the 20th century (Bondeau et al. 2007). Belowground biomass is lost  
284 as woody root systems are replaced by the smaller, finer roots of grasses and crop plants.

285 Disturbance during cultivation breaks down soil organic matter and accelerates decomposition,  
286 leading to further losses of soil carbon and, consequently, carbon dioxide emissions (IPCC 2006).

287 The soil organic carbon content of temperate arable, grassland, and woodland soils are of the order  
288 of 80, 100, and 130 t C ha<sup>-1</sup> respectively (Bradley et al. 2005). It is thought that between 50 and  
289 100 years are required for soil carbon content to reach a new equilibrium following land use  
290 change (Falloon et al. 2004; King et al. 2005) and so this form of disturbance leads to a long-term  
291 source of carbon dioxide. It is generally assumed that there is little difference in soil carbon  
292 between annual and perennial food crops, including fruit orchards and plantation crops (IPCC  
293 2006). However, detailed information is lacking and further research is needed to determine the  
294 real effects of perennial crops on emissions from soils.

295 Deforestation in the Brazilian Amazon basin to provide land for cattle ranching and soybean  
296 cultivation for animal feed accounts for a loss of 19,400 km<sup>2</sup> of rainforest each year. This alone  
297 accounts for 2% of global anthropogenic greenhouse gas emissions. Whilst complex interlinkages  
298 and causality chains exist as drivers for deforestation, much of the soybean grown in Brazil is  
299 exported for use as animal feed in Europe, Asia, the USA and Russia. Soybean expansion is more

300 closely associated with Amazonian deforestation than the expansion of other crops (Volpi 2010).  
301 Overall, 7% of anthropogenic emissions, totalling 2.4Pg of carbon dioxide per year, are estimated  
302 to be the result of livestock-induced land use change (Garnett 2009). Consequently, livestock  
303 farming is a major cause of land use change. Use of former forest land for cattle ranching  
304 represents a direct land use change; use of the land to grow feed for livestock overseas represents a  
305 major indirect land use change. Each process results in further greenhouse gas emissions.

306

### 307 **3 Has agricultural productivity been affected by changes in** 308 **energy prices?**

309 Fossil energy prices directly affect the costs of tillage and fertilisers and indirectly affect almost all  
310 aspects of agricultural production, through to the prices of food seen by the end consumer. The  
311 previous sections of this paper have outlined the different energy inputs and greenhouse gas  
312 emissions (energy and non-energy related) of a range of agricultural production pathways for the  
313 major food commodities. The results strongly suggest that the production costs of some  
314 agricultural commodities will be more sensitive to changing fossil fuel prices than others and that  
315 the options for mitigating the risks of fossil energy prices will also differ between those chains.  
316 This section assesses the trends in the price of oil, natural gas and coal over the last four decades  
317 and uses differences between projections for future oil prices to 2030 as a proxy for overall fossil  
318 fuel price volatility in this period.

### 319 **3.1 Historic changes in fossil energy prices**

320 Historic trends in the spot prices of oil, natural gas and coal show that throughout the 1980s and  
321 most of the 1990s, spot prices remained below US\$4 per GJ, with coal staying below US\$ 2/GJ  
322 until the turn of the millennium (Figure 7). In fact, until 1995 fossil fuel prices were converging  
323 around US\$2/GJ, making electricity production in particular, more attractive from natural gas than  
324 from coal because of the greater flexibility, decreased capital costs and modularity of natural-gas-  
325 fired power stations. Since 1995, prices have increased, first for oil, then for gas and finally  
326 followed by coal. By 2007, prices for oil and natural gas had more than quadrupled whilst for coal  
327 they had nearly trebled. Since then, as a result of recession and also from increased investment in  
328 new supply and refining capacity, prices have fallen sharply but more recently, since the  
329 beginning of 2009, have started increasing again, particularly for oil, although not yet to the levels  
330 seen in 2007 (US EIA 2009; BP 2009; IEA 2009).

331

332 [INSERT FIGURE 7 HERE]

333

334 In part, increasing supplies are a result of the deployment of new technologies, allowing hitherto  
335 inaccessible fossil fuel resources such as oil shale, tar sands or ‘tight’ gas reserves to be exploited.  
336 It is also a result of conventional supplies becoming constrained and the resulting increase in  
337 prices making previously too expensive reserves possible to access profitably. As shown in  
338 Figure 5, all agricultural commodities in the UK simultaneously use all forms of fossil-derived  
339 energy and some renewables too. A major question remains, as to whether increasing overall  
340 prices and increasing volatility in those prices will drive further diversity in energy supply  
341 resources, or reductions in overall energy intensity or even in the total supply of agricultural  
342 products.

## 343 3.2 Projected fossil energy prices

344 As a result of real and perceived constraints to conventional fossil fuel supplies, in particular oil  
345 and natural gas, robust predictions for prices more than a few years forward are not available and  
346 the uncertainties associated with projections to 2030 are so great that the US Energy Information  
347 Administration currently uses three scenarios for oil price projections that range from US\$50 to  
348 US\$200 per barrel (Figure 8).

349

350 [INSERT FIGURE 8 HERE]

351

352 For natural gas, the dominant energy feedstock for nitrogen fertiliser production, the recent  
353 development of new drilling techniques has released very substantial quantities of so-called ‘tight’  
354 or ‘shale’ gas, reducing the price of natural gas in the US from around US\$13 per MBTU in 2008  
355 to less than US\$5 per MBTU in early 2010 (The Economist, 2010) or from US\$12.7 to US\$ 4.3  
356 per GJ. If tight gas is found elsewhere in substantial volumes, as seems possible, then the historic  
357 link between oil and gas prices will be broken, with oil prices likely to increase significantly and  
358 gas remaining competitive with coal.

359 If bioenergy, particularly biodiesel and biogas, becomes cheaper than the direct fossil fuel inputs  
360 into agriculture, primarily diesel, then a rapid switch to on-farm bioenergy is likely to occur where  
361 rotary power, transport and thermal processing are required. Whilst the complexity of the  
362 interactions between conventional agricultural feedstocks for food and their use for energy, when  
363 coupled to global oil markets makes this price threshold difficult to estimate, it is likely to be  
364 around US\$ 70 to 100 per barrel oil equivalent but may be lower for large scale commercial  
365 production facilities.



366 Whether this switch to bioenergy production is competitive or synergistic with food production  
367 will mainly depend on: the strength of the linkage between energy and food prices, the rate of  
368 increase of demand for bioenergy feedstocks as commodity crops, the impact from increased  
369 investment from bioenergy and the resultant increase in yields of both conventional crops (food  
370 and fuel) and advanced lignocellulosic crops, and, the availability of new land or recovered  
371 degraded or abandoned land.

372

#### 373 **4 Policies to reduce GHG emissions from the food sector**

374 The impact of climate change on agricultural production is still uncertain. However, reports of the  
375 potential outcomes for agriculture are well documented (AEA 2007). Farmers in general face the  
376 looming spectre of climate change at two levels; firstly, by having to adapt existing practices to  
377 cope with the outcomes of climate change (i.e. changing weather patterns; water availability;  
378 changing patterns of pests, disease and thermal stress in livestock) and secondly, by addressing  
379 those farming activities which are contributing factors to increased GHG emissions.

380 Whilst it is likely that farmers will readily adopt measures which will benefit their productivity  
381 and financial outcomes, adopting practices at cost to farming businesses is more likely to require  
382 policy intervention. Developing mechanisms to improve GHG abatement in the agricultural sector is  
383 complex, not least because policy mechanisms are often devised through different departmental  
384 policy-making regimes.

385 Within the EU Climate and Energy Package (2008), the agricultural industry is not part of one of  
386 the main components, the European Emissions Trading Scheme (EU ETS 2009). Agriculture, as a  
387 non-EU ETS sector is charged with reducing emissions to 10% below 2005 levels by 2020, and it

388 is anticipated that this will be through binding national targets. In the policy context, the farming  
389 industry faces many challenges before carbon trading as an economic strategy becomes a reality.

390 The UK Government published its low carbon transition plan in 2009

391 (<http://www.theccc.org.uk/carbon-budgets>). The Plan's main points for *agriculture* are:

- 392 • Encourage English farmers to take action themselves to reduce emissions to at least 6%  
393 lower than currently predicted by 2020, through more efficient use of fertiliser, and better  
394 management of livestock and manure.
- 395 • Review voluntary progress in 2012, to decide whether further Government intervention is  
396 necessary. The Government will publish options for such intervention in Spring 2010.
- 397 • Ensure comprehensive advice programmes are available to support farmers in achieving  
398 this aim, to reduce their emissions from energy use, and to save money in the process.
- 399 • Research better ways of measuring, reporting and verifying agricultural emissions.
- 400 • Encourage private funding for woodland creation to increase forest carbon uptake.
- 401 • Provide support for anaerobic digestion, a technology that turns waste and manure into  
402 renewable energy via biogas.
- 403 • Reduce the amount of waste sent to landfills, and better capture of landfill emissions.

404 Some policy instruments which aim to deliver greenhouse gas mitigation within the sector have  
405 been identified in a report commissioned by the UK's Department for Food and Rural Affairs  
406 (ADAS 2009). The report shows the mitigation potential by 2022 (Table 4), making comparisons  
407 to an earlier Scottish Agricultural College report (SAC 2008). The study does not include  
408 mitigation potential from biomass production, soil carbon sequestration or options for anaerobic  
409 digestion of farmyard waste and does not expand on further economic or market-based policy

410 mechanisms (e.g. carbon trading extending to farming activities). The policy instruments  
411 identified are as follows:

- 412 • Regulatory - Cross Compliance and Nitrate Pollution Prevention Regulations (Nitrogen  
413 Vulnerable Zone (NVZ) regulations)
- 414 • Economic (voluntary participation) - Environmental Stewardship
- 415 • Voluntary - Extend Catchment Sensitive Farming (CSF), Farm Assurance Public  
416 Procurement, Voluntary Agreements and Targeted Communications.  
417

418

419 [INSERT TABLE 4 HERE]

420

#### 421 **4.1 Indirect policy implications for agricultural emissions**

422 Policies to reduce emissions from the fossil energy sector may impact on agriculture in two  
423 different ways. Firstly, by promoting crops which can be used as feedstocks for biofuel or  
424 bioenergy; different growing regimes and more efficient energy inputs may be adopted. Secondly,  
425 greenhouse gas emission reporting requirements which are being developed for biofuels may  
426 affect farming practices, particularly if benefits for improved emissions are transferred down the  
427 supply chain to the feedstock producers. Policies in the UK which aim to impact fossil fuel energy  
428 use and which may in-turn impact on agriculture are the Renewable Transport Fuels Obligation  
429 (RTFO), (DfT 2007) and the Renewables Obligation (RO), (DTI, 2006).

430 In the EU, the Climate and Energy Package (2008) committed the 27 member states to reduce  
431 CO<sub>2</sub> emissions by 20%, and to target a 20% share of energy supply from renewable energy, by  
432 2020 i.e. the so-called “20-20 in 2020”. Policy instruments in the Package, which may then

433 indirectly impact on agriculture, are the Fuels Quality Directive (EU FQD 2009) and the  
434 Renewable Energy Directive (EU RED 2009). The FQD aims to reduce harmful atmospheric  
435 emissions, including greenhouse gases and includes mandatory monitoring of life cycle  
436 greenhouse gas emissions. The RED, aims to promote renewable energies biofuels and has a  
437 component which addresses sustainability of biofuels and the land used to grow biofuel  
438 feedstocks.

439 In the United States, the California Environmental Protection Agency Air Resources Board  
440 (CARB) has been at the forefront of developing policy to reduce emissions from fossil energy and  
441 has developed the Low Carbon Fuels Standard (LCFS 2007). This standard is under review by a  
442 number of individual states in the US, which are also looking to adopt an emissions approach to  
443 the inclusion of biofuels in transport fuels. Nationwide in the U.S., the Environmental Protection  
444 Agency (EPA) has developed, under the Energy Independence and Security Act of 2007, a  
445 Renewable Fuel Standard Program (RFS2, 2009) which aims to increase the volume of renewable  
446 fuel in gasoline from 9 billion gallons (34 billion litres) in 2008 to 36 billion gallons (144 billion  
447 litres) by 2022.

448 In many ways, these policies are leading the development of methodologies which will improve  
449 energy efficiency and reduce GHG emissions across supply chains. Improving emissions and  
450 ensuring the sustainability of biofuels has led to the development of variety of policy-specific  
451 methodologies. They have also encouraged the formation of global stakeholder interactions,  
452 which address environmental, economic and social issues e.g. Roundtable on Sustainable Biofuel  
453 (RSB); Global Bioenergy Partnership (GBEP) and crop specific initiatives e. g. Roundtable on  
454 Sustainable Palm Oil (RSPO); Round Table on Responsible Soy (RTRS) and the Better Sugar  
455 Cane Initiative (BSI).

456 The UK's RTFO has been devised with GHG emissions monitoring and reduction as a key  
457 component and it has been necessary to stipulate methodology and processes to report GHG

458 emissions from the individual biofuel supply chains used by obligated parties in law (RFA, 2009).  
459 The RTFO's Carbon and Sustainability methodologies cover biofuel supply chains from feedstock  
460 source, by country and by on-farm production inputs and outputs. In a biofuel supply chain, this  
461 may encourage farmers to improve management practices, providing that a share of the value or  
462 benefits feedback to farmers. Currently, Carbon and Sustainability reporting is not mandatory  
463 under the RTFO and better practices leading to improved carbon and sustainability profiles, are  
464 not rewarded. Many farmers in the UK have been encouraged by the idea of reducing on-farm  
465 diesel costs by producing their own biodiesel from oilseed rape. However, the market value of  
466 vegetable oil and costs for processing oils into biodiesel will always be calculated against fossil  
467 diesel costs for farm use (Lewis, 2009). Furthermore, farm vehicles will generally be under  
468 warranty from the vehicle manufacturer and it is unlikely that farmers would risk using out-of-  
469 spec fuel, to the detriment of these costly machines.

470 As noted by Monbiot (2009), addressing energy needs using on-site, renewable energy options  
471 only reduces dependence on diesel for on-farm use by a quarter. Options for farmers to use  
472 renewable energies, such as biomass or biogas for electricity and heat production are often limited  
473 to on-farm use only, as there are not the facilities or incentives to connect to the electrical grid.  
474 Allowing access to the national grid would give farmers an option to trade renewable energy under  
475 the Renewables Obligation, whereby the mandatory renewable requirement of 15% electricity by  
476 2015, could potentially be met in part by surplus on-farm energy generation, traded as Renewable  
477 Energy Certificates (ROCs). The UK government is also reviewing opportunities for a Renewable  
478 Heat Incentive (RHI), under the Energy Act (DECC 2008), which promotes investment for  
479 biomass boilers and combined heat and power (CHP) facilities.

480

## 481 **5 Options for agriculture to reduce its dependence on energy**

### 482 **5.1 Change tillage / pre-processing**

483 Land preparation has become increasingly mechanised over the years. However, mechanical  
484 tillage systems are energy intensive and expose soil organic matter (SOM) to decomposition,  
485 leading to enhanced greenhouse gas emissions, reduced SOM concentration in soil and potentially,  
486 in short and longer term, to soil erosion and degradation. The potential for reducing the energy  
487 intensity of agricultural production by adopting alternative tillage systems may occur from  
488 decreased fuel use in mechanical operations or as the result of better long-term soil productivity.

489 Alternative methods of land preparation and crop establishment have been devised to reduce  
490 energy requirements and maintain good soil structure. These include, minimum tillage (min-till),  
491 conservation tillage (no tillage or min-till) and direct drilling, resulting in increased surface  
492 organic matter, from previous crops residues (soil coverage of 30%) (Van Den Bosche et al.  
493 2009). Robertson et al. (2000), compared management techniques in a three crop rotation, over  
494 eight years in Michigan. The net changes in soil C ( $\text{g m}^{-2} \text{ year}^{-1}$ ) were for conventional tillage  
495 (plough-based tillage), 0; organic with legume cover, 8.0; low input with legume, 11 and no till,  
496 30.

497 The consequences of reduced tillage on soil carbon are not straight-forward. Baker et al. (2007),  
498 concluded that the widespread view that reduced tillage favours carbon sequestration may be an  
499 artefact of sampling methodology, with reduced tillage resulting in a concentration of soil organic  
500 matter in the upper soil layer rather than a net increase throughout the soil. They did however,  
501 highlight that there were several good reasons for implementing reduced tillage practices. In  
502 contrast to Baker et al. (2007), Dawson and Smith (2007) reviewed the subject area and suggested

503 sequestration rates of 0.2 (0–0.2) and 0.39 (0–0.4) t C ha y<sup>-1</sup> for reduced tillage and no-till farming  
504 respectively.

505 Energy balance calculations resulting from fertiliser application are more difficult to assess, as  
506 interactions with increased soil organic matter become more complex. Studies which focus on  
507 energy inputs, attributed to soil preparation, tend to be regional and crop specific. Energy from  
508 tillage will depend on crop requirements, soil type, cultivation/climatic conditions, equipment  
509 used and engine efficiency.

510 A study which compares conventional and integrated farming in the UK attributed energy savings  
511 in integrated farming almost entirely to the reduction in energy required for mechanical operations  
512 (Bailey et al. 2003). The study also considered the effects on energy of multi-functional crop  
513 rotation; integrated nutrient and crop protection methods and ecological infrastructure  
514 management (i.e. field/farm boundary maintenance to promote biodiversity and reduce pollution),  
515 in integrated systems. A study for wheat grown in Iran provides a more detailed evaluation of five  
516 specific tillage regimes (Tabatabaefar et al. 2009). The study reports the min-till system ('T5' in  
517 Figure 9) as most energy efficient, with energy for tillage accounting for 19% of the total energy  
518 vs. 32.5% for the least energy efficient ('T1'). Yield outcomes are also reported whereby the min-  
519 till system gives the second highest yield of the five systems, but in overall performance T3 is  
520 reported as being the most efficient system when taking both energy input and yield into account.

521

522 [INSERT FIGURE 9 HERE]

523

524 Soil carbon as a component of SOM, is important in carbon turnover within the carbon cycle, and  
525 in maintaining soil fertility, water and nutrient holding capacity, ecosystems functions and  
526 preventing soil degradation. Soil carbon and SOM are important in preserving soil in a productive,

527 quality state for long term crop production (Dawson and Smith 2007). Understanding the  
528 processes of carbon interaction in soils is complex, both at local and national levels. Carbon  
529 losses from the soil organic matter pool, the effect of carbon loss on nutrient availability and crop  
530 productivity, and the subsequent outcomes for agricultural management activities are all important  
531 variables in calculating the overall carbon stocks and productivity of soils (Dawson and Smith  
532 2007). Other farming options, such as residue mulching and the use of cover crops, aim to  
533 conserve and enhance SOM or soil carbon sequestration (Lal 2007).

534 The subsequent effects of nutrient availability on crop productivity vary between cropping  
535 systems (e.g. conventional or organic systems), land types, climatic conditions and time, and  
536 require further research before being fully integrated into farming systems (Kong et al. 2009).  
537 Studies carried out on sites in Belgium have been used to demonstrate nitrogen interactions under  
538 various planting regimes and to demonstrate the action of tillage on organic matter degradation  
539 and the subsequent availability of nitrogen in the nutrient pool over time (Van den Bossche et  
540 al.2009). They report higher soil organic matter, microbial biomass and enzymatic activity for  
541 conservation tillage, which increases with time. The anticipated effect is slower mineralisation or  
542 immobilisation of nitrogen, leading to enhanced soil fertility as the result of long term build up of  
543 nutrient reserves of the soil.

544 Understanding the interaction between soil carbon and nitrogen also adds further complexity to  
545 determining the benefits of increasing soil carbon through changes in tillage systems. Whilst  
546 increasing fertiliser inputs may increase the soil carbon pool, the poorer GHG balance from the  
547 increased use of N fertilisers may negate the sequestration benefit. The reasons for changing  
548 agricultural activities should be clear from the outset. Is the anticipated benefit to reduce energy  
549 inputs, reduce GHG emissions, improve soil carbon sequestration or to maintain the long-term  
550 productivity of soils? Land management choices may then follow, with trade-offs expected and  
551 accepted. For example, planting marginal lands with biomass crops to improve carbon



552 sequestration versus maximising yields on productive lands by increasing fertiliser use, or  
553 adopting min-till systems on land areas where mechanical activities are also degrading soil quality  
554 or causing soil erosion, such as on sloping sites.

555

## 556 **5.2 Energy inputs and impacts of fertiliser use in agriculture**

557 In addition to the direct energy inputs for tillage and harvesting, fertilisers can constitute a  
558 significant share of total energy inputs to agriculture (Figure 4) and food production, particularly  
559 for nitrogen intensive crops such as cereals. Figure 10 shows the different energy requirements  
560 for the main constituents of commercial fertilisers, using European average technologies. The  
561 main nitrogen components of fertilisers, ammonia ( $\text{NH}_3$ ; 32 GJ/t), urea (22 GJ/t) and liquid UAN  
562 (urea ammonium nitrate; 22 GJ/t), are the most energy intensive to produce, whilst the P and K  
563 components all require less than 5 GJ/t to produce.

564

565 [INSERT FIGURE 10 HERE]

566

567 The energy inputs needed to produce and supply fertilisers and pesticides substantially outweigh  
568 the energy required to apply the products in the field. GHG emission factors for production,  
569 supply and use of N, P and K fertilisers, under average UK conditions, are provided in Table 5.  
570 However, for N fertilisers, the GHG emissions arise both as a result of the fossil energy inputs  
571 needed to capture and process atmospheric nitrogen, and also from complex soil-based processes  
572 that result in the production and release to the atmosphere of nitrous oxide ( $\text{N}_2\text{O}$ ) in-field.

573

574 [INSERT TABLE 5 HERE]

575

### 576 **5.2.1 Nitrogen fertilisers**

577 The energy inputs into nitrogen fertiliser production have decreased significantly since the  
578 beginning of the last century as a result of continual technological innovation (Figure 11). GHGs  
579 emitted during its production include carbon dioxide, methane and nitrous oxide as shown in  
580 Table 6. Carbon dioxide emissions account for 98% of the GHG emissions on a mass basis, but  
581 only 33% on a global warming potential (CO<sub>2</sub> equivalent) basis. N<sub>2</sub>O accounts for 0.6% of the  
582 mass of the GHG released but 65% on a CO<sub>2</sub> equivalent global warming potential basis.

583

584 [INSERT TABLE 6 HERE]

585

586 However, whilst ammonia production is the most energy-intensive part of the production of N  
587 fertilisers, nitric acid production causes the release of N<sub>2</sub>O during its production. Nitric acid is  
588 needed to produce ammonium nitrate (AN) through a reaction with ammonia. The N<sub>2</sub>O leaks to  
589 the atmosphere in the nitric acid plants and between 70 and 90% of this N<sub>2</sub>O can be captured and  
590 catalytically destroyed. European plants are now being fitted with this nitrous oxide abatement  
591 technology and as a result overall AN GHG emissions could be reduced, by 40% overall, from  
592 6.93 to 4.16 kg CO<sub>2</sub> eq/kg N.

593

594 [INSERT FIGURE 11 HERE]

595

### 596 **5.3 Farm forestry systems (agro-forestry)**

597 The production of woody biomass on land unsuitable for intensive arable farming or extensive  
598 grazing is widely seen as a low-energy input option, for the production of such biomass for  
599 material or energy usage. Numerous opportunities exist to integrate the production of woody  
600 biomass and agricultural crops or livestock and production and such ‘farm-forestry’ or ‘agro-  
601 forestry’ systems have been widely discussed in the literature and through the work of the  
602 Consultative Group on International Agricultural Research’s (CIGIAR) World Agroforestry  
603 Centre<sup>1</sup>, much of which is focussed on the developing world. A recent geospatial study by Zomer  
604 et al. (2009) has shown agro-forestry to be a significant feature of agriculture in all regions of the  
605 world – see Figure 12.

606

607 [INSERT FIGURE 12 HERE]

608

609 Zomer et al. (2009) provide a cautious estimate that 17% (~ 3.8 Million km<sup>2</sup>) of global agricultural  
610 land involves agroforestry at >30% tree cover and, potentially, this can be as high as 46% or just  
611 over 10 million km<sup>2</sup>, at >10% or more tree coverage rates. Agro-forestry systems are found in  
612 developed as well as less developed regions.

613 The widespread and significant proportion of agricultural land under agro-forestry management  
614 (e.g. in Central and South America) already points to a successful form of integrated land  
615 management for both crop production and woody biomass for energy production. This indicates a  
616 capacity for agricultural land management to accommodate integrated energy production;

---

<sup>1</sup> see <http://www.worldagroforestry.org/af/>

617 currently, in most cases, the woody biomass is used for immediate local needs such as fuelwood  
618 for cooking. However, there is also considerable scope for more widespread introduction of tree or  
619 coppice material to agricultural land specifically to meet on-farm energy needs and, subject to  
620 transportation constraints, as an economic product for off-farm sale. For example, in the UK, a  
621 number of estates are currently using wood produced on the estate for biomass heat schemes  
622 which is encouraged under the UK's Bioenergy Capital Grant Scheme.

623 With combinations of increasing prices for conventional energy inputs to farming and incentives  
624 for low-carbon forms of renewable energy, farmers may be incentivised to allocate a proportion of  
625 their crop land to meet on-farm energy use, for example, for diesel fuel replacement or potentially  
626 for high-value low-carbon certified electricity, either produced on-farm or from farm-derived  
627 woody/residual feedstocks. The ability to co-produce woody biomass for heat and/or power  
628 generation at farm scale, alongside commodity crops provides a potentially attractive route to  
629 mitigating increased or volatile external energy costs (e.g. for drying, livestock management or  
630 domestic use) and potentially as a saleable commodity in its own right (biomass fuel product(s)).

631 Future incentivisation for farmers to minimise agricultural GHG emissions is also likely to favour  
632 greater integration of forestry and/or woody biomass cultivation on farm e.g. short rotation  
633 coppice or perennial grasses such as *Miscanthus* in UK/EU. At the individual farm level,  
634 cultivation of perennial biomass crops on a proportion of the land may provide an attractive route  
635 to 'balance' more GHG intensive cultivation activities with carbon 'credits' from enhanced C-  
636 storage in soils, via avoided emissions from displaced fossil fuel requirements or as a direct  
637 economic benefit from biomass sales at a premium due to renewable heat and power incentive  
638 value trickling down the supply chain. Recent studies by Hillier et al. (2009) have illustrated the  
639 GHG benefits associated with soil carbon storage effects for certain biomass crops and land use  
640 transition scenarios modelled in a LCA context for England and Wales. Attention is also being

641 given to the use of biochar<sup>2</sup> as a potential energy source (during the charring process) and  
642 significantly as a soil-based carbon sequestration and storage approach that can also offer soil  
643 fertility benefits (Sohi et al.2008; Collison et al. 2009). Biomass supply for biochar production can  
644 be drawn from diverse sources, including woody biomass from agro-forestry systems as well as  
645 from existing UK farm biomass, such as hedgerow management (Gathorne- Hardy, pers. comm.  
646 2009).

## 647 **6 CONCLUDING REMARKS**

648 This paper has identified that there are significant risks to future farming and yields due to  
649 increasing and increasingly volatile fossil fuel prices. Whilst it has been difficult to obtain robust  
650 projections for oil, natural gas and coal prices, it is clear that:

- 651 1. Fossil fuel prices, particularly those of oil-derived products, will increase significantly  
652 over the coming decades and will become more volatile.
- 653 2. Prices, on a unit energy basis, between oil, gas and coal are likely to diverge with the  
654 possibility of a break in the traditional linkage between gas and oil prices emerging. Unless  
655 substantive agreements emerge from the UNFCCC's inter-governmental negotiations that  
656 limit access to coal, its large and widely distributed reserves will mean that it is the least  
657 vulnerable of the fossil fuels to price increases; a switch to coal away from oil and natural  
658 gas is likely where that is possible e.g. for processing and nitrogen fertiliser production.

---

<sup>2</sup> Biochar is carbonised biomass or charcoal. When biomass is turned into charcoal and applied to soils it is believed to have a half-life in the soil in order of 1000 years.

659 3. The world's major crops are dependent on different shares of their energy inputs from oil,  
660 gas and coal. Thus relative changes in fossil fuel prices will affect each crop type  
661 differentially.

662 4. Major areas of concern are:

663 a. Increasing oil prices will directly affect the price of diesel used for tillage, transport  
664 of crops from fields and from storage to processing and end use.

665 b. Increasing natural gas prices will have the most immediate effect on nitrogen  
666 fertiliser prices.

667 c. Coal is still used for nitrogen fertiliser production, particularly in China, and is  
668 likely to be least affected by worries about reserve depletion. From a GHG  
669 perspective, a switch away from oil and gas to coal, rather than to renewable,  
670 would be detrimental.

671 d. Increased costs for direct and indirect energy inputs into agriculture may lead to  
672 lower yields for the world's major agriculture commodity crops. In turn, this is  
673 likely to lead to an expansion of land areas under these crops, in turn leading to  
674 increased GHG emissions, as a result of land use change, and increased prices due  
675 to less efficient production. Significant land expansion will also have detrimental  
676 effects on biodiversity and possibly on water resources.

677 5. Reasons for optimism:

678 a. Substantial gains in efficiency of energy use and GHG emissions are possible in all  
679 areas of food and bioenergy supply chains and from both conventional and  
680 advanced supply chains.

681 b. Recent policy developments for bioenergy, and in particular, biofuels, have  
682 demonstrated that the highly complex and heterogeneous systems necessary to

683 account, monitor, reward and penalise good or bad greenhouse gas and wider  
684 sustainability criteria, are amenable to policy. It is possible, and indeed necessary,  
685 that many of the lessons learnt in developing these policies and mechanisms for  
686 biofuels, can be applied to any form of biological production including food.

687 c. New tools, in particular spatial zoning and land management tools, are highlighting  
688 the potential for revised management and crop choices that could allow enhanced  
689 carbon stocking and biodiversity from integrated land management and planning  
690 that couples annual and perennial agriculture.

691 d. The developing of novel drilling technologies that have enabled access to ‘tight’  
692 gas reserves in the US may delay a switch to coal and reduce inflationary pressures  
693 on nitrogen fertiliser prices.

694 Whilst increasing fossil fuel prices could pose a major risk to agriculture, as production costs  
695 increase, and also cause increased volatility in prices between the different major agricultural  
696 commodities, there is substantial scope for technological and management innovations to occur  
697 decreasing the dependence on fossil energy supplies and in creating opportunities for new markets  
698 e.g. in renewable energy. The opportunities and threats will vary substantively between the  
699 different crops and a careful review on a crop-by-crop basis is necessary to understand and  
700 manage these threats and the risks to future production posed by increasing fossil fuel prices.

701

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863 **Table 1 Primary energy used in arable crop production (GJ/t). All values are for England and Wales, except**  
 864 **soy, sugarcane and maize. (based on Williams et al. 2006)**

	Primary Energy used, GJ/t		
	Non-Organic	Organic <sup>a</sup>	National "Basket"
Bread Wheat	2.52	2.15	
Oilseed Rape	5.32	6.00 <sup>b</sup>	
Potatoes (National Commodity Level)			1.39
Potatoes Main Crop	1.46	1.48	
Potatoes 1st Earlies	1.40	1.25	
Potatoes 2nd Earlies	0.79	0.75	
Feed Wheat	2.32	2.08	
Winter Barley	2.43	2.33	
Spring Barley	2.27	2.64	
Field Beans	2.51	2.44	
Soy Beans (US)	3.67	3.23	
Sugarcane (Brazil) <sup>c</sup>	0.21		
Maize (US) <sup>d</sup>	2.41		

865 a. Based on long term yields obtainable from stockless rotations.

866 b. Very little grown currently

867 c. Per tonne of harvested sugarcane delivered to the mill, 2005/2006: sample of 44 mills (100 M t  
 868 cane / season), all in the Centre-South Brazil; data as reported by Macedo (2008).

869 d. Per tonne of harvested maize grain. Derived from Farrell, A. 2006.

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872 **Table 2 Energy used in animal production at the commodity level in England and Wales (derived from**

873 **Cranfield LCA model. Williams et al, 2006)**

Commodity	Poultry	Pig meat	Beef	Lamb meat	Milk	Eggs



Unit	1 t ecw	1 t ecw	1 t ecw	1 t ecw	m <sup>3</sup>	1 t
Primary energy, GJ	17	23	30	22	2.7	12
Feed	71%	69%	88%	88%	71%	89%
Manure & litter	2%	1%	1%	1%	0%	-4%
Housing	1%	4%	0%	0%	3%	3%
Direct energy	25%	26%	11%	11%	26%	12%

'ecw' = edible carcass weight (killing out percentage \* live-weight), but the energy used in slaughter is not included. 1 m<sup>3</sup> milk weighs almost exactly 1 t and 15,900 eggs weigh 1 t.

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877 **Table 3 Energy carriers used in animal production**

	Poultry	Pig meat	Beef	Sheep meat	Milk	Eggs
Crude Oil; %	44%	36%	33%	38%	32%	41%
Natural gas; %	27%	28%	45%	46%	40%	28%
Coal; %	13%	17%	9%	7%	13%	15%
Nuclear; %	12%	15%	9%	7%	13%	12%
Renewable; %	3%	3%	3%	2%	2%	4%

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880 **Table 4: Scale of UK Agricultural Abatement Potential by 2022 by Policy Instrument (ktCO<sub>2</sub>e per year; ADAS**  
 881 **2009)**

Policy	SAC	ADAS
Extend Coverage of NVZs to 100% farmed area	not covered	
Extend area and scope of NVZs	2,531	602
Targeted Communications	351	212
Voluntary Agreements	480	238
Farm Assurance public procurement	10	6
Cross-compliance - additional standards within existing rules	896	896
Cross-compliance – extend scope through negotiations with EU	3,420	1,491
Environmental Stewardship	647	647
Enhance CSF – to 100% farmed area	515	200
Enhance CSF – extend area and scope	648	333

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885 **Table 5: GHG emission factors for fertilisers, seeds and pesticides (Woods et al. 2008)**

Agricultural Input	GHG Emissions (kg CO <sub>2</sub> eq/kg applied)
Nitrogen fertiliser (as N)	6.69
Phosphate fertiliser (as P)	0.71
Potash fertiliser (as K)	0.46
Lime	1.80
Pesticides (as active ingredient)	5.41
Seed material	0.87

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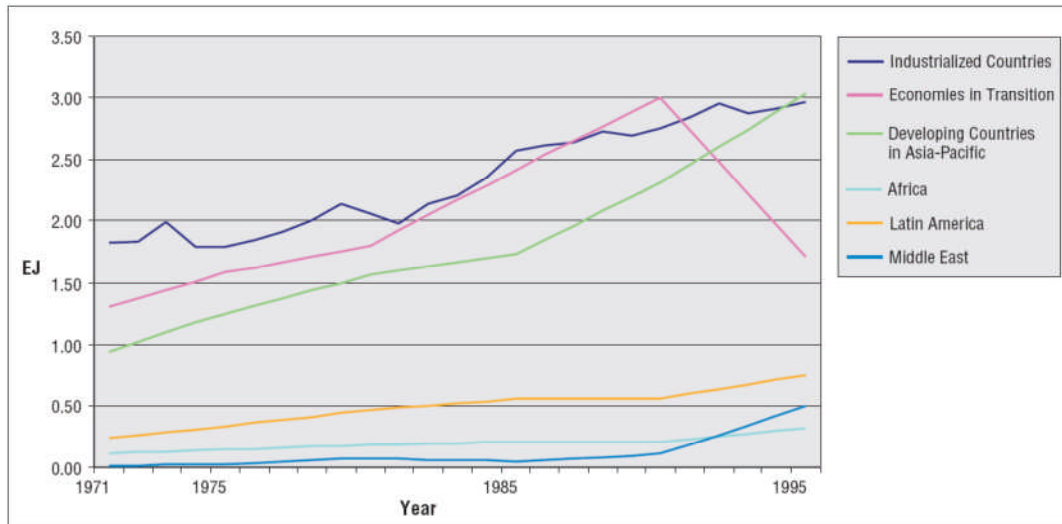
889 **Table 6: Primary Energy Inputs and Greenhouse Gas Emissions Associated with Ammonium Nitrate**

890 **Manufacture in Europe (Elsayed et al. 2007)**

Nitrogen Fertiliser Manufacture	Primary Energy Inputs (MJ/kg N)	Carbon Dioxide Emissions (kg CO <sub>2</sub> /kg N)	Methane Emissions (kg CH <sub>4</sub> /kg N)	Nitrous Oxide Emissions (kg N <sub>2</sub> O/kg N)	Total Greenhouse Gas Emissions (kg/kg N)
Ammonium Nitrate	40.74 ± 5.43	2.30 ± 0.26	0.012 ± 0.001	0.015	2.33
kg CO <sub>2</sub> eq/kg N		2.30	0.28	4.44	6.93 ± 0.26

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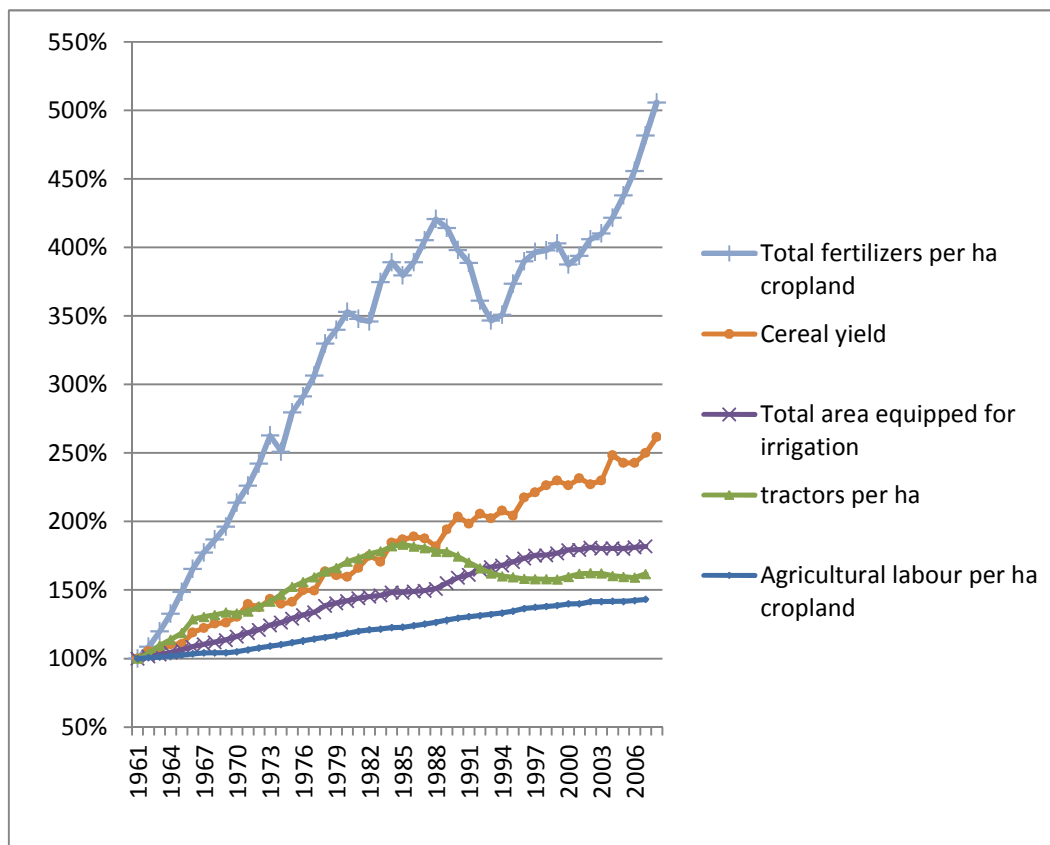
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894 **Figure 1: Primary energy use in agriculture, 1970 to 1995. (IPCC, 2001)**

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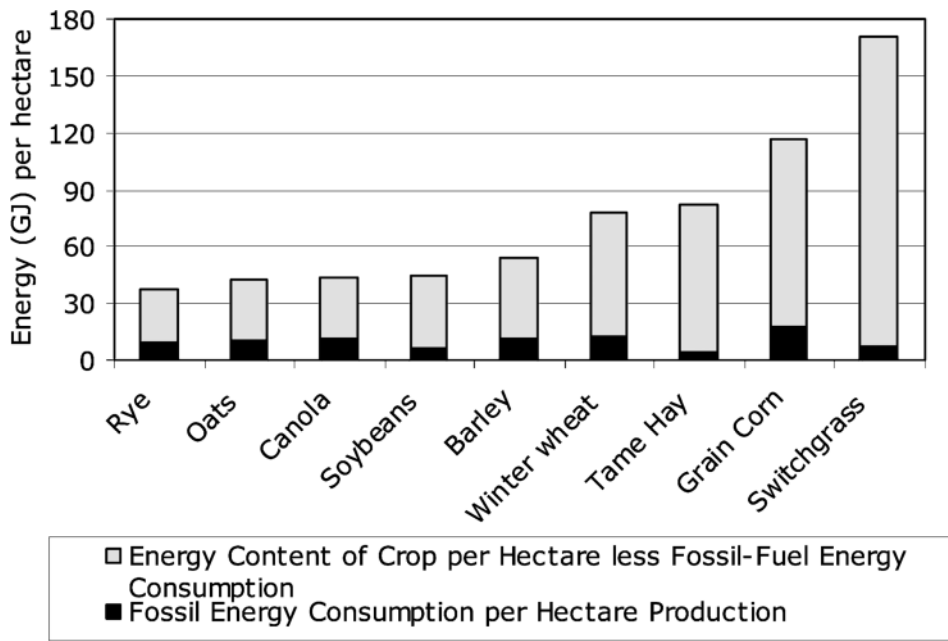


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897 **Figure 2: Global trends in the intensification of crop production (index 1961–2002/2005). Updated from Hazel**  
 898 **& Wood (2008), based on FAOSTAT 2010.**

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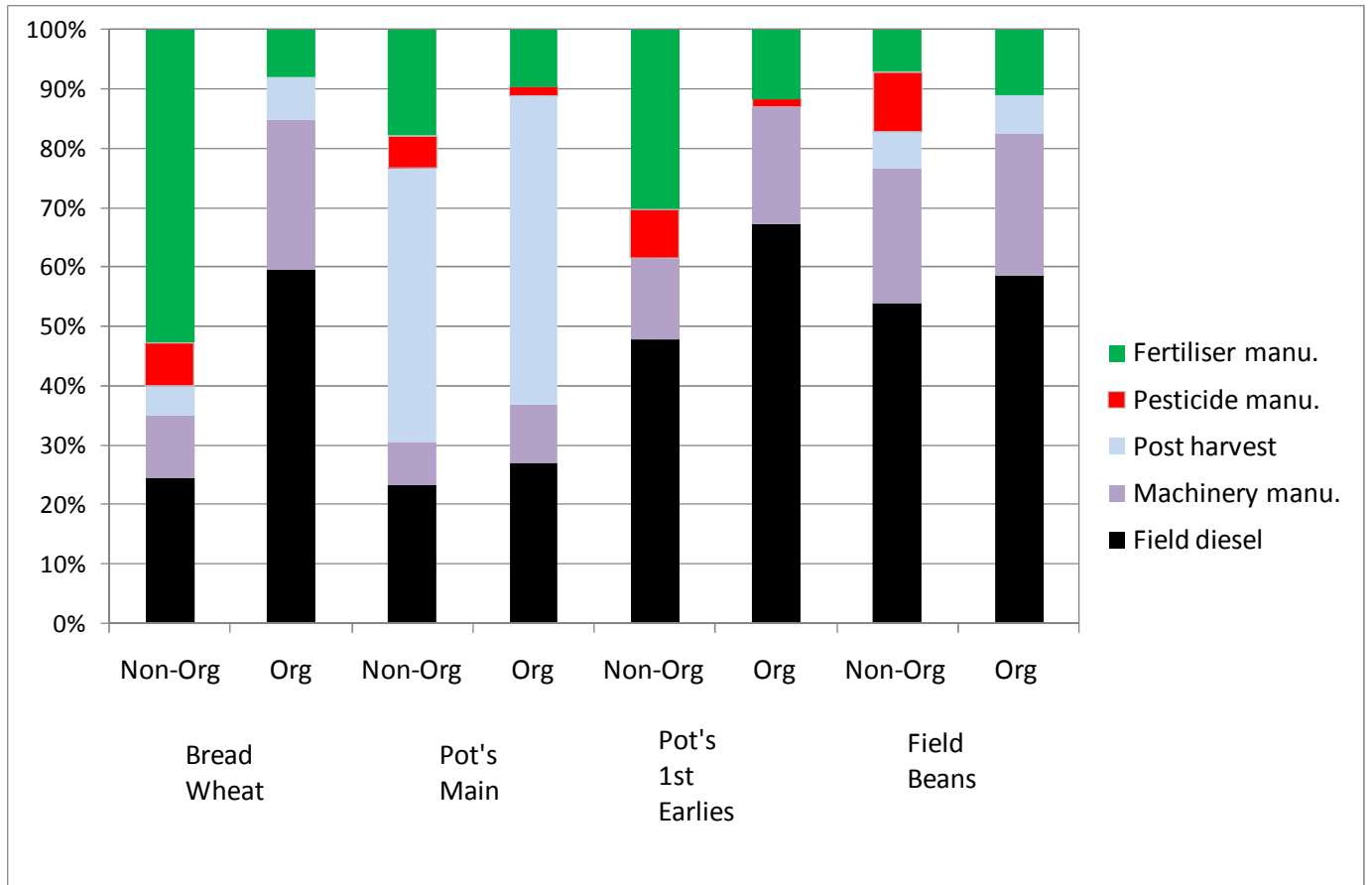


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902 **Figure 3: Solar energy collection in harvested component of crops and fossil fuel energy requirements of**  
903 **Canadian (Ontario) crop production, in Giga-Joules (GJ) per hectare (Samson et al. 2005).**

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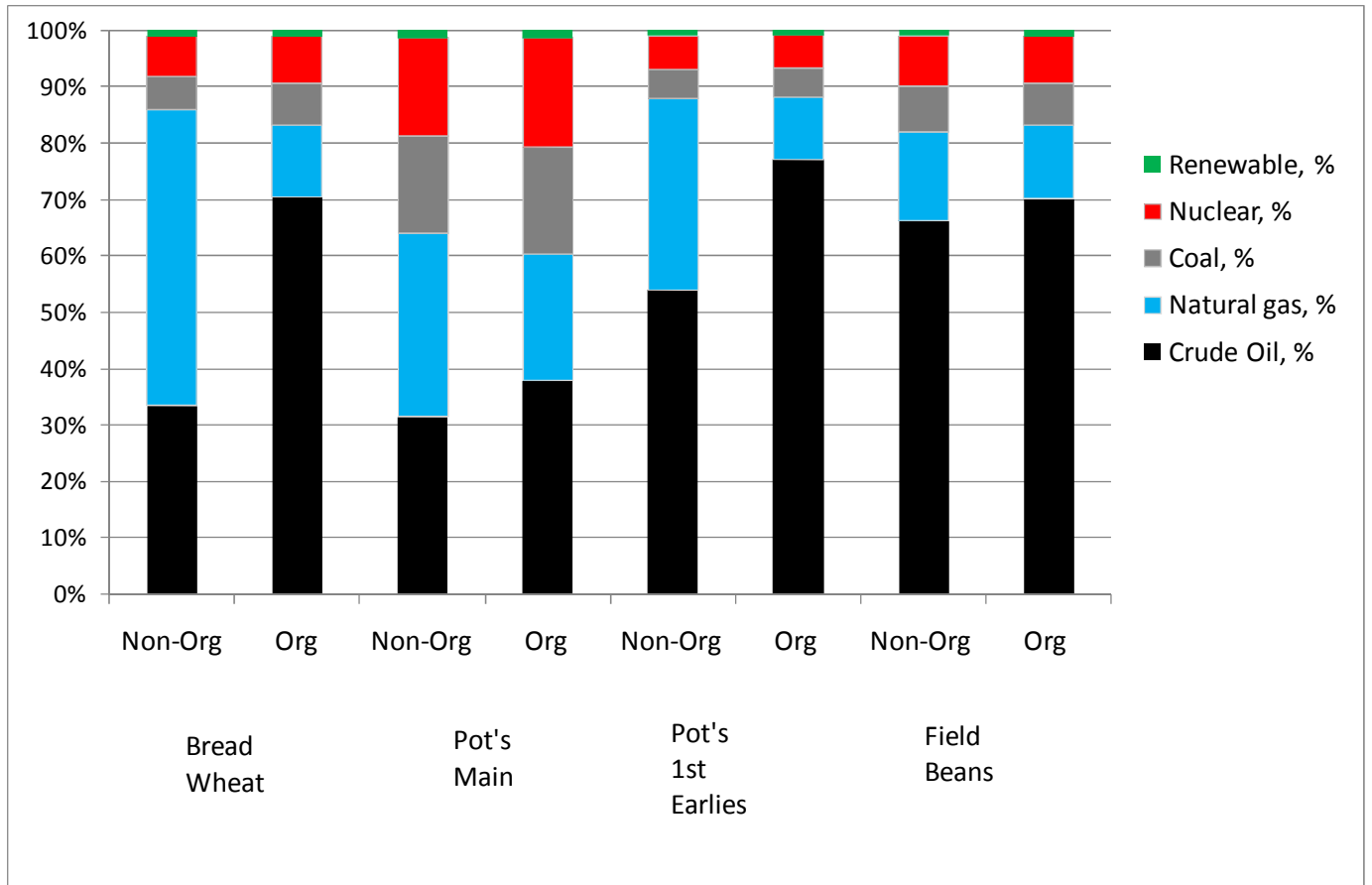


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907 **Figure 4 Breakdown of energy used in major domestic crop production ('Pot's = potatoes; 'manu' =**

908 **manufacture)**

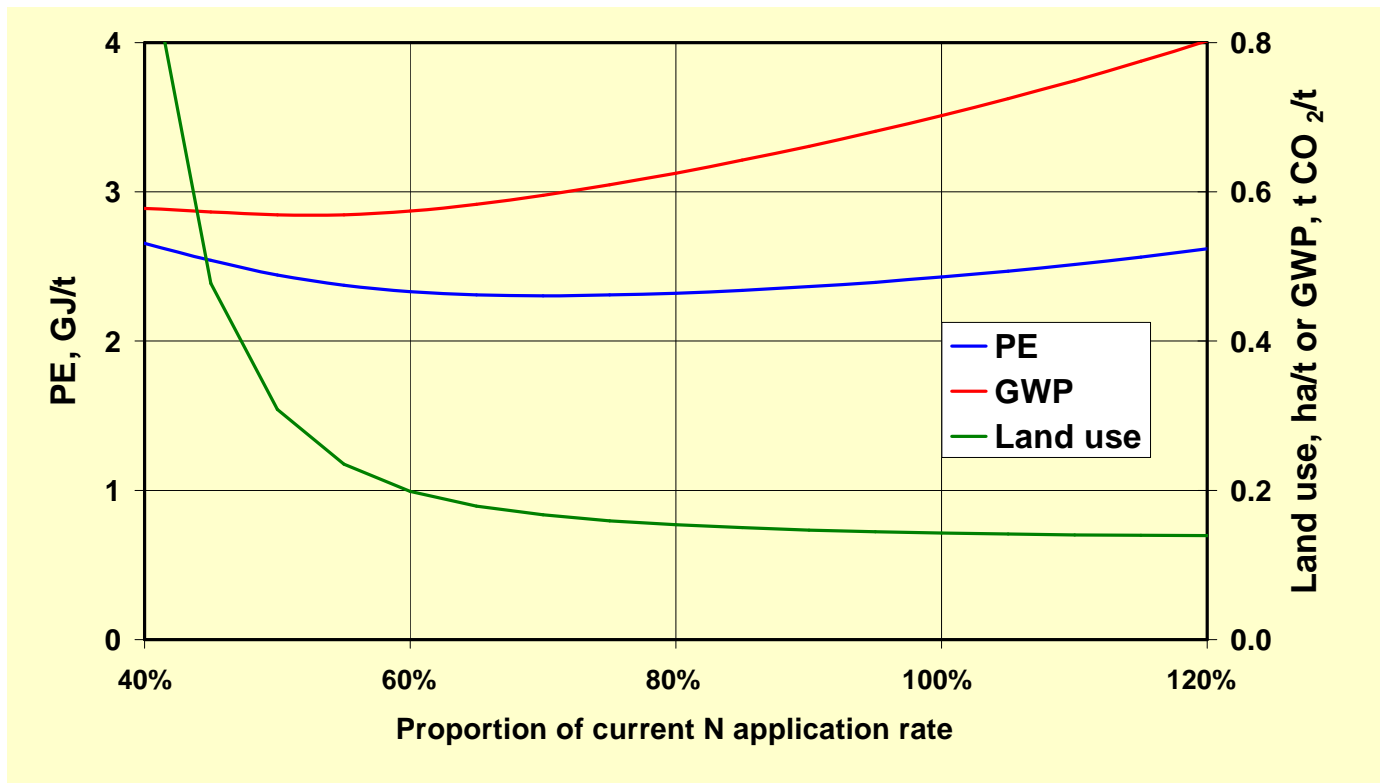
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911 **Figure 5 Distribution of energy carriers used in field crop production**

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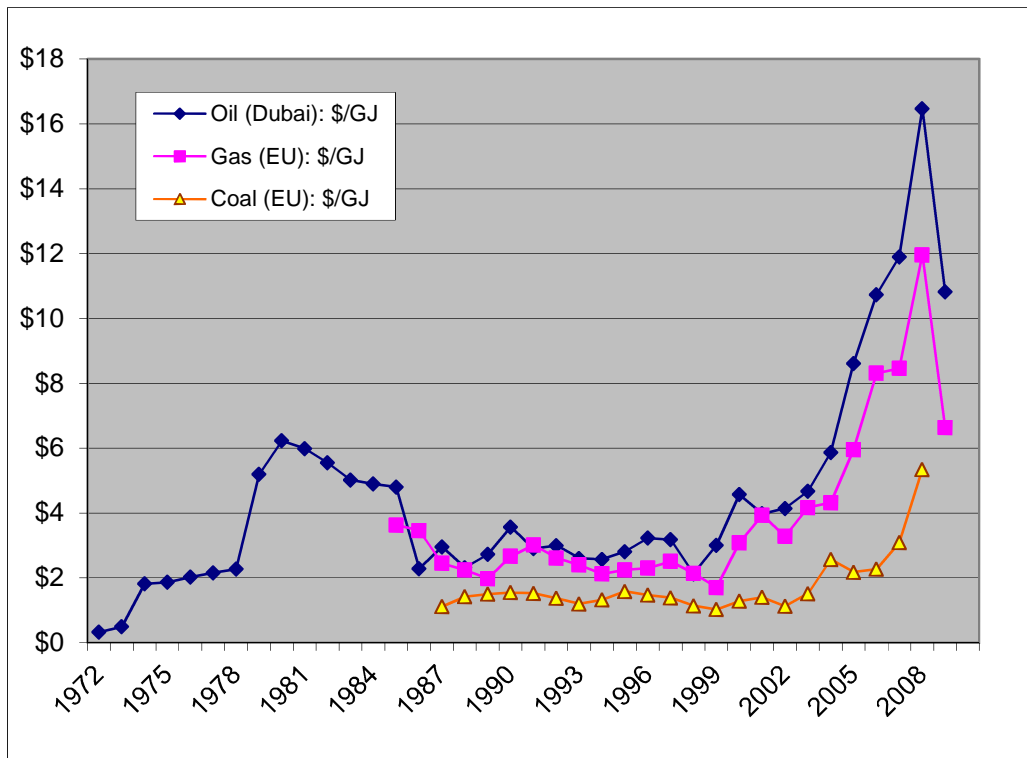


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914 **Figure 6** Effects of changing N supply on bread wheat using the Cranfield model (Williams et al. 2006; PE =  
 915 Primary Energy; GWP = Global Warming Potential)

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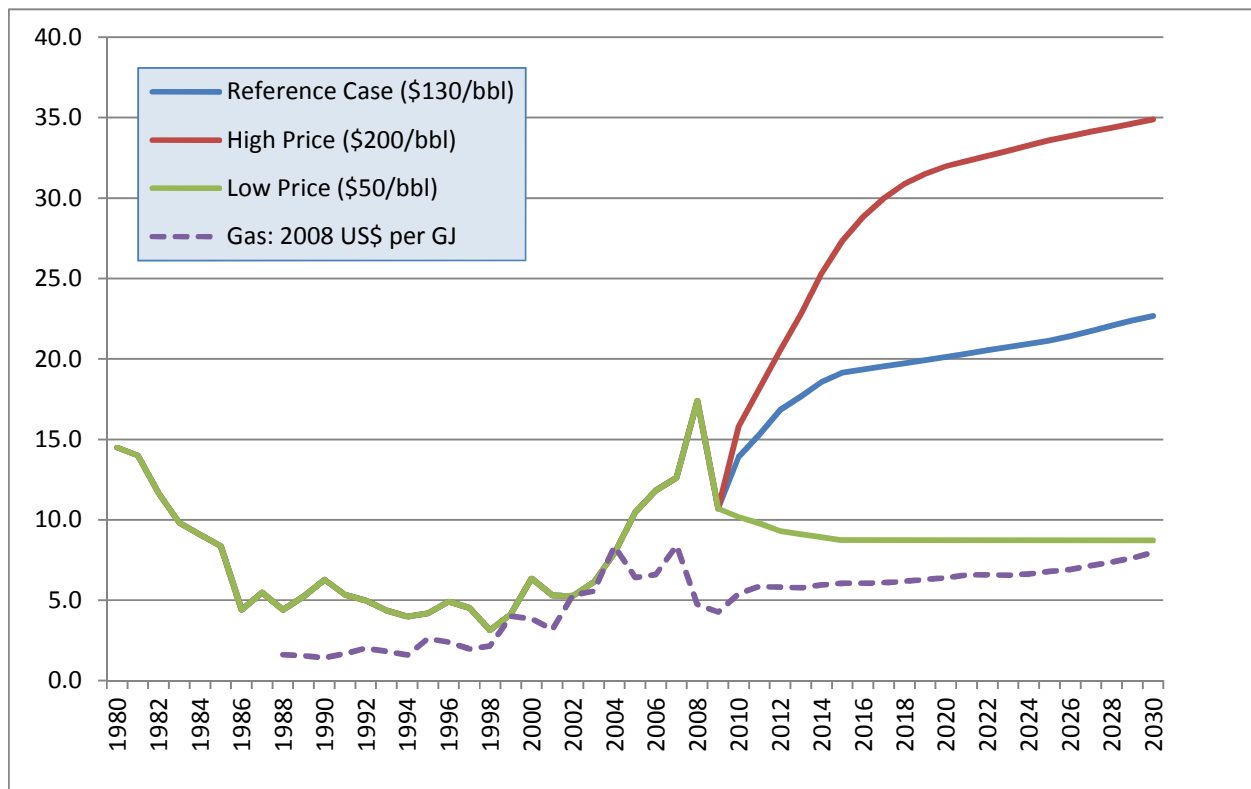




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918 **Figure 7: Trends in Global oil, gas and coal spot-market prices; 1961 to 2009 (US\$/GJ. BP, 2009; IEA, 2009)**

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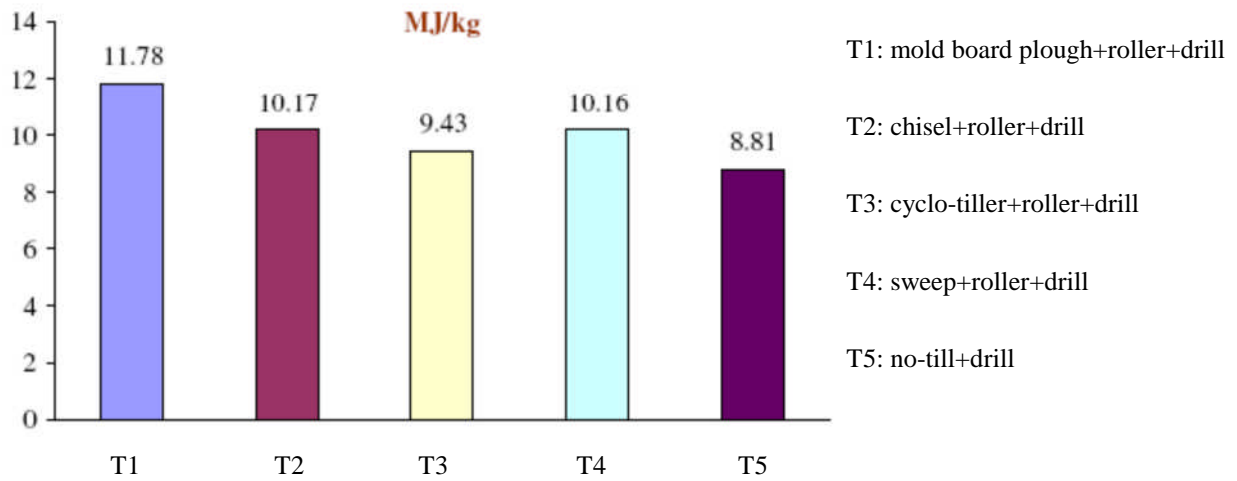


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921 **Figure 8: Projected oil and gas price ranges to 2030; US\$/GJ (US EIA 2009)**

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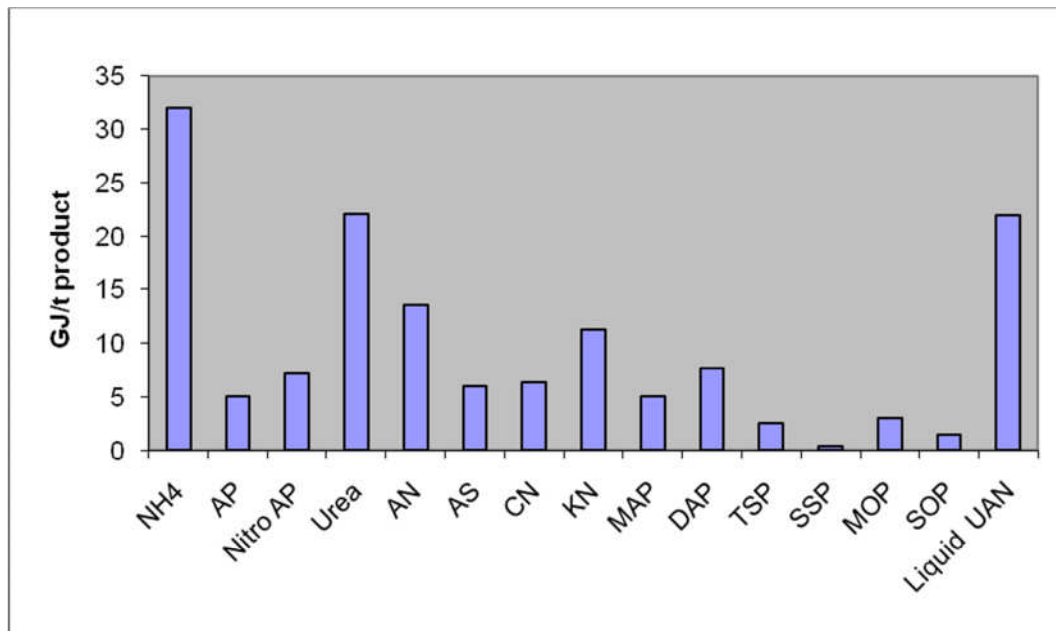
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925 **Figure 9: Energy consumed for 1 Kg wheat production in Maragheh region of Iran (Tabatabaeefer et al. 2009).**

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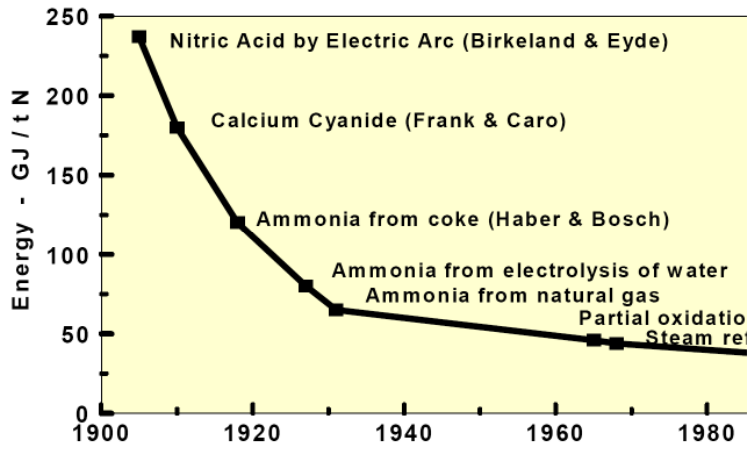
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930 **Figure 10: Energy inputs into the main fertiliser building blocks; European average technology (Jenssen and**

931 **Kongshaug 2003)**

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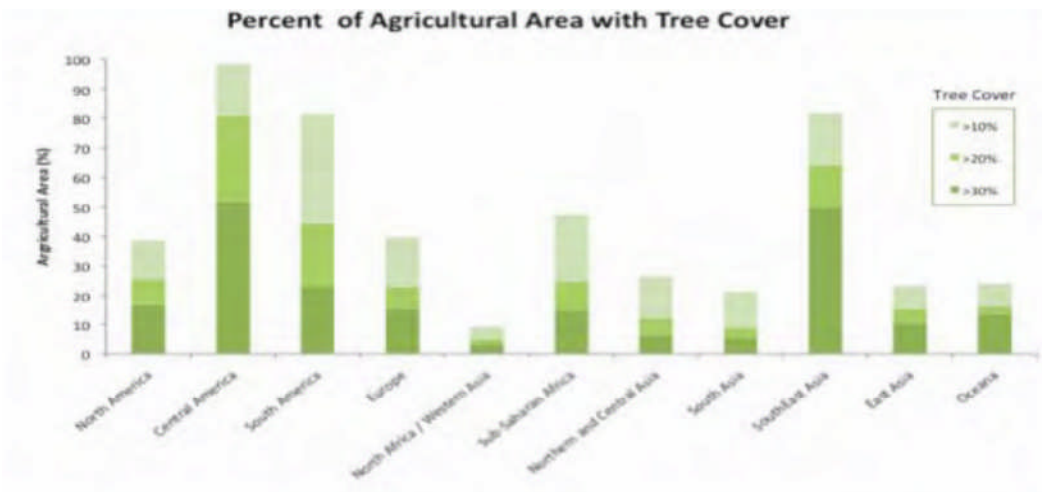


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935 **Figure 11: Historic Development of Energy for N-fixation (Kongshaug 1998)**

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939 **Figure 12: Percentage of world agricultural land that can be regarded as being under agro-forestry systems to**

940 **varying intensities (after Zomer et al. 2009).**

941

# Energy and the food system

Woods, J.

2010-09-01T00:00:00Z

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Jeremy Woods, Adrian Williams, John K. Hughes, Mairi Black and Richard Murphy, Energy and the food system, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 27 September 2010, Volume 365, Number 1554, Pages 2991-3006.

<http://dx.doi.org/10.1098/rstb.2010.0172>

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