International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July

Ref: C0243

Case studies and comparative analysis of energy efficiency in wheat production in different climatic conditions of Europe

Janusz Gołaszewski, University of Warmia and Mazury in Olsztyn, Poland

Marcel van der Voort, Wageningen UR, the Netherlands

Andreas Meyer-Aurich, Leibniz-Institute for Agricultural Engineering Potsdam-Bornim, Germany

Luis L. Silva, University of Évora, Portugal

Athanasios Balafoutis, Agricultural University of Athens, Greece

Hannu J. Mikkola, University of Helsinki, Finland

Abstract

The paper presents results concerning energy efficiency of wheat production considered in the context of specific energy input variation in different climatic conditions of Europe as well as case studies on implementation of selected energy saving measures in practice. It was shown that the highest wheat yield (6.7-8.7 $t \cdot ha^{-1}$) at the lowest specific energy input (2.08-2.56 $GJ \cdot t^{-1}$) is unique for temperate climate conditions. The yield in continental and Mediterranean climatic conditions is on average lower by 1.3 $t \cdot ha^{-1}$ and 2.7 $t \cdot ha^{-1}$ and energy efficiency lower by 14% and 38%, respectively. The case studies have shown that the energy saving activities in wheat production may be universal for the climatic zones or specific for a given geographical location. It was stated that trade-offs between energy, economic and environmental effects, which are associated with implementation of a given energy saving measure or a set of measures to a great extent depend on the current energy efficiency status of the farm and opportunity for investment, which varies substantially across Europe.

Keywords: wheat, energy efficiency, trade-off analysis

1 Introduction

Energy from fossils is an essential input of the modern agricultural production. Even if the sectors of energy and agriculture generate a relatively small part of gross value added (GVA) of national economies (in the EU-27: 3.1% and 1.7%, respectively), they are crucial in fulfilling demands of growing population for energy and agricultural commodities. According to Smil (2008) global cultivated area and energy consumption almost doubled during the 20th century. Further increase of arable land and fossil energy consumption (even if limited) may cause detrimental effects to the environment. That is why improvement in energy efficiency of agricultural production is a way to rationalize the use of environment resources. Reduction of energy input implies specific economic and environmental effects. If the trade-off between those effects is positive it means that energy, economic, and environmental performances are improved simultaneously.

Energy consumption and energy saving potential in a given agricultural production system is differentiated in particular geographical areas. In the EU, the average energy consumption per 1 hectare of utilized agricultural area (UAA) amounts to 5.9 GJ·ha^{-1} with a great variation between countries ranging from 3.9·GJ ha^{-1} in Portugal to 76.6 GJ·ha^{-1} in the Netherlands (Eurostat, 2012). The significant stream of agricultural energy input is associated with production of wheat (*Triticum* spp.). Among cereals, wheat is the crop with the largest cultivated area in the EU-27 which accounts for 26 mil ha and 15% share in the total UAA. The average yield of wheat varies from 2 t ha^{-1} to 9 t·ha^{-1} and to a large extent depends on climatic conditions and other biotic and abiotic factors associated with climate such as soil fertility and water availability or pathogen and weed infestation. According to the Köppen-Geiger climate type map of Europe, the climate zones correspond to continental (*Dfb*), temperate (*Cfb*) and Mediterranean (*Csa*) climates (Peel et al. 2007). Although wheat is grown in the three climate environments, the optimal growing conditions and the highest yields are specific for temperate climate environments (Röder et al. 2014).

The objectives of the study were:

1) to compare energy efficiency of wheat production in Europe with reference to different climatic conditions,
2) to show case studies on implementation of selected energy saving measures and resulting energy, economic and environmental benefits.

2 Materials and methods

The source data (Golaszewski et al. 2012, Meyer-Aurich et al. 2013) from the six EU countries are representing five agricultural regions of continental Europe: Nordic region (FI, Finland); North-Eastern region (PL, Poland); North-Western region (DE, Germany, NL, Netherlands); South-Eastern region (EL, Greece); and South-Western region (PT, Portugal) (Olsen & Bindi 2002). Those five agricultural regions correspond to the three climates: continental (FI, PL), temperate (DE, NL), and Mediterranean (EL, PT) were the base for estimation of energy efficiency in wheat production.

The LCA-like approach has been chosen to analyze the data excluding of pre-farm gate activities. The level of physical energy inputs were determined using statistical data or in the cases where the data were not available the expert estimates were applied. Energy equivalents, which were applied to convert physical energy inputs into primary energy inputs (PEC), originated mainly from the BioGrace database (2011) (Table 1).

Table 1: The primary energy equivalents for direct and indirect primary energy inputs (PEC) in wheat production.

Energy input	Unit	PEC	References
Direct:			
electricity	MJ kWh^{-1}	9.70	BioGrace 2011
diesel	MJ kg^{-1}	50.00	BioGrace 2011
Indirect			
Seeds	MJ kg^{-1}	2.61	BioGrace 2011
Synthetic fertilizers:			
nitrogen (N)	MJ kg^{-1}	48.99	BioGrace 2011
phosphorus (P_2O_5)	MJ kg^{-1}	15.23	BioGrace 2011
potassium (K_2O)	MJ kg^{-1}	9.68	BioGrace 2011
calcium (CaO)	MJ kg^{-1}	1.97	BioGrace 2011
magnesium (MgO)	MJ kg^{-1}	6.70	Mihov & Tringovska 2010
sulphur (S)	MJ kg^{-1}	2.10	www.stewarshipindex.org
Organic fertilizer	MJ kg^{-1}	0.30	Erdal et al. 2007
Water	MJ (m^3)$^{-1}$	0.63	Mihov & Tringovska 2010
Pesticides	MJ kg a.i.$^{-1}$	268.4	BioGrace 2011

Three scenarios corresponding to wheat production systems with low (L), average (A) and high (H) energy consumption were considered in the countries covered by the study, except the Netherlands, where only a single scenario of average energy input was taken into account (Table 2).

Table 2. Scenarios of energy inputs in wheat production systems by country.

Country	**Energy input scenario**		
	Low	**Average**	**High**
Finland	Direct drilling, low nitrogen input and minimum plant protection	Reduced tillage, conventional nitrogen input and plant protection	Conventional tillage, high nitrogen input and intensive plant protection
Germany	Reduced tillage, low yield, low drying input	Standard values	Conventional tillage, high yields, high drying input
Greece	Low fertilization, no irrigation	Conventional fertilization	Conventional fertilization, irrigation
Netherlands	Wheat production systems do not differ much across the country		
Poland	Low scale production, low yield	Standard values	Intensive production, high yield, high drying energy input, relatively large farms
Portugal	No tillage	Conventional	Conventional with irrigation

The primary energy consumption (PEC) measures of direct energy input, E_D; indirect energy input, E_I; total energy input, $E_T=E_D+E_I$ ($GJ \cdot ha^{-1}$); and specific energy input in GJs per hectare and tonne of grains were estimated. The total energy input was decomposed into main energy input streams and it was regressed to yield. In order to compare energy efficiency of wheat production across the geographical areas the Data Envelopment Analysis (DEA) was applied (Charnes et al. 1978).

The case studies on energy efficiency in wheat production cover various energy saving measures including the specific ones for wheat production as well as those covering the entire farm-crop-production-system (Table 3).

Table 3. Case studies – energy saving measures by climate and country.

Country	**Energy saving measures**
Germany	two grain drying systems, precision agriculture, reduced fertilizer inputs
Netherlands	precision farming, use of compost and less inorganic fertilizer
Finland	energy saving in grain drying and field operations, optimized use of N-fertilizer, biological N-fixing
Poland	change in plant rotation, ploughing of straw and application of multi-compound inorganic fertilizer, and application of effective microorganisms
Greece	reduced tillage system – minimum tillage considered in production of main crops: cotton and wheat, reduced tillage in wheat, reduced fertilizers and pesticides in cotton through precision farming
Portugal	conventional tillage (reference), no tillage, reduction P_2O_5, and irrigation

The energy-economic-environmental analysis of case studies was based on a cradle-to-farm-gate LCA model. The GHG emissions were assessed according to the standard ISO 14040 (ISO 2006). The cost calculations were based on the economic settings in the study countries, while for the energy use and GHG estimates, whenever possible, common methodologies were used.

3 Results

Among cereals, wheat is the crop with the largest cultivated area in Europe but the area varies greatly in the study-covered countries from 88.3 thousand ha in Portugal to 3213.5 thousand ha in Germany (Eurostat 2008). During the last years, wheat yield fluctuated in a quite stable way across the studied countries although the productivity was distinctly different in the climatic zones: temperate (*Cfb*), continental (*Dfb*) and Mediterranean (*Csa*) (Figure 1).

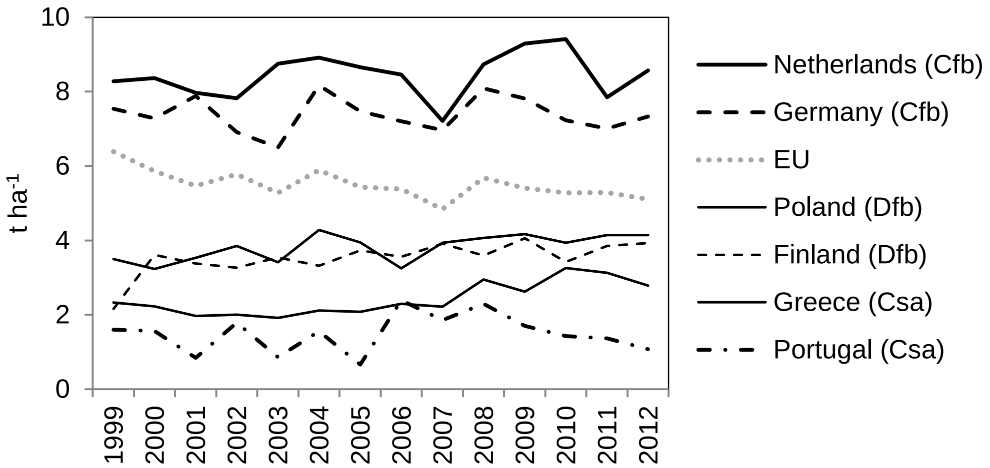

Figure 1. Wheat yield in the studied countries (climate zone), 1999-2012.

Table 4: The energy input (PEC) in wheat production, by country and scenario of energy consumption

Country (area x1000 ha)	Energy input scenario	Yield	E_D	E_I	E_T	E_S
		t ha^{-1}	GJ·ha^{-1}	GJ·ha^{-1}	GJ·ha^{-1}	GJ·t^{-1}
Temperate climate countries						
Germany (3213.5)	Low	6.7	4.1	12.1	16.2	2.43
	Average	7.7	6.3	12.3	18.5	2.42
	High	8.3	8.9	12.4	21.3	2.56
Netherlands (156.5)	Average	8.7	6.6	11.6	18.1	2.08
Continental climate countries						
Finland (219.6)	Low	3.5	3.0	5.6	8.7	2.48
	Average	4.5	3.9	8.0	12.0	2.66
	High	6.0	5.7	9.9	15.7	2.61
Poland (2278.0)	Low	4.8	3.9	9.6	13.5	2.81
	Average	5.8	4.1	10.9	15.1	2.60
	High	7.5	7.9	15.5	23.5	3.13
Mediterranean climate countries						
Greece (657.1)	Low	2.5	5.3	6.5	11.8	4.70
	Average	5.0	10.0	9.9	19.9	3.99
	High	6.0	12.8	9.9	22.7	3.78
Portugal (88.3)	Low	3.0	1.6	7.4	9.0	3.01
	Average	3.0	5.7	7.2	12.9	4.29
	High	5.0	6.3	10.7	17.0	3.39

In terms of wheat production systems with low, average and high energy input the highest yield has been recorded for the temperate climate countries: the Netherlands (8.7 t·ha^{-1}) and

Germany (6.7-8.3 t·ha^{-1}), the medium yield level for the continental climate countries: Finland (3.5-6.0 t·ha^{-1}) and Poland (4.8-7.5 t·ha^{-1}), and the lowest yields were recorded for the Mediterranean climate countries: Greece (2.5-6.0 t·ha^{-1}) and Portugal (3.0-5.0 t·ha^{-1}) (Table 4). The average energy input per hectare of wheat production was highly differentiated in the three climatic zones. In the temperate climate zone the total energy input across the production systems ranged from 16.2 GJ·ha^{-1} to 21.3 GJ·ha^{-1}, in continental climatic zone from 8.7 GJ·ha^{-1} to 23.5 GJ·ha^{-1}, and in the Mediterranean climate region from 2.3 GJ·ha^{-1} to 6.0 MJ·ha^{-1}. For the three climatic conditions the specific energy input varied in the ranges of 2.08-2.56 GJ·t^{-1}, 2.48-3.13 GJ·t^{-1}, and 3.01-4.70 GJ·t^{-1}, respectively.

The main energy input in wheat production was associated with the use of fertilizers (Figure 2). The weighted averages of indirect energy inputs required for the use of fertilizers in the temperate, continental and Mediterranean climate countries accounted for 10.97, 9.46, 7,75 GJ·ha^{-1} and share of 59%, 60%, and 46% of the total energy input, respectively.

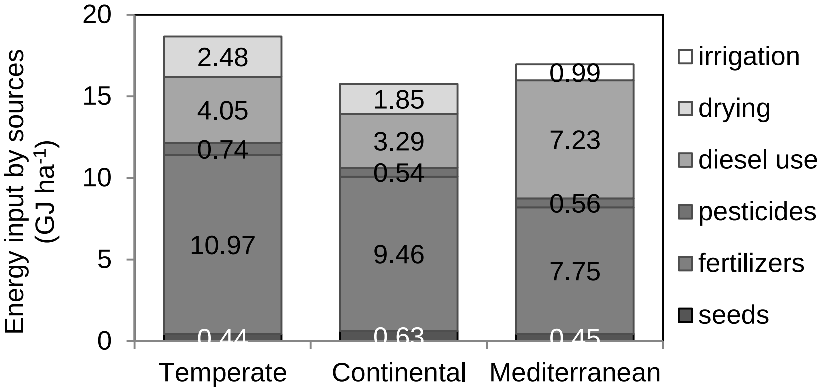

Figure 2. The structure of energy input in wheat production by climatic zones of Europe.

The diesel use for field operations was the second main energy input. The relatively high amount of diesel use was recorded for the Mediterranean climate countries: 7.23 GJ·ha^{-1} and this figure was 1.8 and 2.2 times higher than in the temperate and continental climate countries.

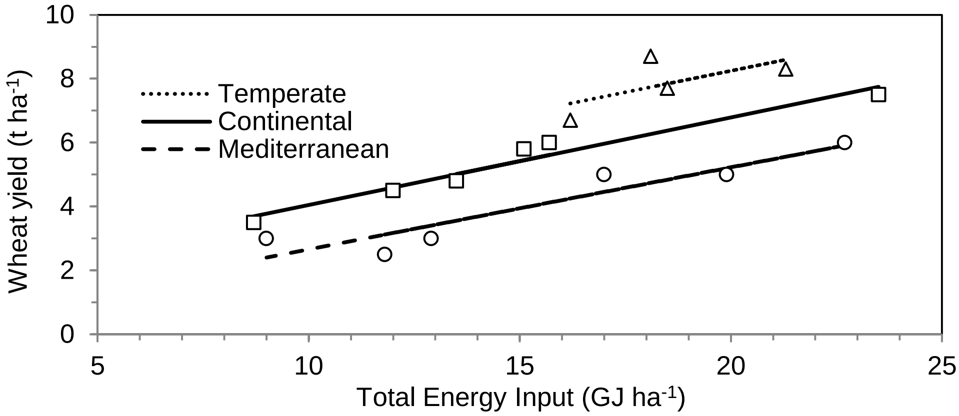

Figure 3. The regression between total energy input and yield by climatic zones of Europe.

The other significant direct and indirect energy inputs have been to a great extent specific for geographical location and climatic zones. In the temperate and continental climate regions the additional energy on wheat production has been associated with drying while in the Mediterranean climate region – with irrigation. There is a general linear tendency for higher energy use to be associated with higher yield (Figure 3, Table 5). The three fitted lines of regression between the total energy input and yield correspond to the three climatic zones of Europe. The parallelism of lines indicates that the average increase in yield per unit increase of energy input was similar across climatic zones and accounted for 0.27 t·GJ^{-1}. The yield difference between the lines is 1.3 t·ha^{-1} between temperate and continental climatic zones and 1.4 t·ha^{-1} between continental and Mediterranean climatic zones. The results of DEA analysis of energy efficiency in wheat production for the three climatic zones of Europe are presented in Table 5.

Table 5: The parameters of regression between total energy input and wheat yield and estimates of relative energy efficiency by climatic zones.

Climatic zones of Europe	**Regression analysis parameters:**			**DEA analysis:**
	intercept	**regression coefficient**	R^2	**relative energy efficiency (range)**
Temperate	2.880	0.268	0.412	1.00 (0.81 – 1.00)
Continental	1.307	0.274	0.956	0.86 (0.66 – 0.86)
Mediterranean	0.094	0.266	0.878	0.62 (0.44 – 0.69)

In comparison with the most efficient energy use in temperate region countries (NL, DE), the energy efficiency of wheat production in continental and Mediterranean region countries was on average lower by 14%, and 38%, respectively. It is worth noticing that the ranges of energy efficiencies between climatic zones overlapped each other.

Table 6: Energy efficiency measures and associated reduction effects of cost, energy use and GHG emission by country case studies.

Energy efficiency measure	**Annualized Cost**		**Primary energy use**		**GHG emission**	
	€/ha	**%**	**MJ/ha**	**%**	CO_2**e/ha**	**%**
Germany (per crop basis)						
Dryer I (energy use optimization)	20	2.1	801	4.2	43	2.5
Dryer II (energy use optimization)	13	1.4	440	2.3	23	1.3
Precision farming	31	3.3	640	3.3	61	3.5
Reduced nitrogen use	0	0.0	846	4.4	101	5.9
Netherlands (per crop basis)						
Precision farming	24	0.4	810	2.9	30	1.0
Compost application	-12	-0.2	1837	6.6	136	4.5
Finland (medium energy intensity)[1)]						
Thermal insulation of dryer	5.0	-	164	1.3	20	-
Fuel economic tractor operating (education)	4.5	-	145	1.2	17	-
Poland (per crop basis)						
Change in plant rotation	20	1.8	836	5.5	49	3.1
Straw ploughing plus multi-fertilizer	157	13.8	0	0.0	0	0.0
Effective microorganisms	11	1.0	218	1.4	44	2.8
Greece (per farm or per crop basis)						
Reduced tillage in wheat and cotton	1050	23.4	76531	8.5	5581	7.7
Reduced tillage in wheat	650	14.7	21861	2.4	1594	2.2
Precision farming	18	0.2	59377	6.6	6191	8.5
Portugal (per crop basis)						
No tillage	46	8	3062	45	104	30
Reduced use of phosphorus	6	2	126	3	9	2
Irrigation[2)]	-242	7	-6808	3	-364	15

1) data were reported per t basis and recalculated using average yield 4.5 t/ha (Gołaszewski et al. 2012)
2) negative figures for cost, energy use, and GHG emission are associated with implementation of the irrigation system; the percentages are associated with positive effects due to increased yield.

Different examples of energy saving measures were applied in case studies reported by six countries covered by the study. In general, they enable improvement in energy efficiency of wheat production or show the potential of trade-offs between energy savings, GHG-emissions, and farm economics. The exemplified energy saving measures reflect the activities which may be considered as universal (like precision agriculture, reduced tillage or fertilizer use) or specific (like optimization of drying process or implementation of irrigation system) for a given geographical location.

Indifferent of the climatic zone, all the presented energy efficiency measures targeted the main direct and indirect energy inputs in wheat production. Energy efficiency measures considered in the temperate climate countries (DE, NL) assumed reduction of electricity/fuel use in drying and reduction of mineral fertilization by precision farming (also a potential for reduction of direct energy use), reduced application of nitrogen and organic soil improver. In the continental climate countries (FI, PL) the measures assumed reduction of direct energy use by insulation of dryers, efficient diesel use in field operation and application of multi-fertilizers while reduction of indirect energy use by lower fertilizer use by changes in crop rotation (including presence of leguminous crops), ploughing of straw and application of effective micro-organisms. The implementation of energy saving activities in wheat production may be particularly efficient in Mediterranean climate countries (EL, PT). The reduction of direct energy inputs was associated with no tillage or reduced tillage and implementation of irrigation systems as well as with reduction of indirect energy use by precision agriculture and limited phosphorus use.

4 Conclusions

The energy input in wheat production is highly differentiated across the climatic zones of Europe. The highest wheat yields (6.7-8.7 $t \cdot ha^{-1}$) at the lowest specific energy input (2.08-2.56 $GJ \cdot t^{-1}$) are unique for temperate climate conditions. On average, the yield in continental and Mediterranean climatic conditions is lower than in temperate climate conditions by 1.3 $t \cdot ha^{-1}$ and 2.7 $t \cdot ha^{-1}$, respectively. Across the climatic zones there is a similar linear tendency for higher wheat yield to be associated with higher energy input. On average, the wheat yield increases by 0.27 $t \cdot ha^{-1}$ per 1 GJ of energy input. The indirect energy embodied in fertilizers followed by direct energy in fuels is the main energy input in wheat production. In comparison with the most efficient energy use in temperate climate conditions, the energy efficiency in continental and Mediterranean regions is lower by 14%, and 38%, respectively.

The case studies associated with implementation of energy efficiency measures show that there is a potential for energy savings in wheat production and trade-off effects between energy savings, GHG-emissions and farm economics. The exemplified energy saving measures reflect the energy saving activities which may be universal for Europe or specific for a given geographical location. The profitability associated with implementation of a given energy saving measure or a set of measures to depends a great extent on the current status of the farm and opportunity for investment, which varies substantially across Europe.

5 References

BioGrace, 2011: (www.biograce.net)

Charnes A., Cooper W., Rhodes E. 1978. Measuring the efficiency of decision-making units. *European Journal of Operational Research*, 2, 429–444.

Erdal, G., Kemal, G., Esengun, K., Erdal, H., Gunduz, O. 2007. Energy use and economical analysis of sugar beet production in Tokat Province, Turkey. *Energy* 32, 35-41.

Eurostat, 2012.

Golaszewski J., de Visser C., Brodzinski Z., Myhan R., Olba-Ziety E., Stolarski M., Buisonjé F., Ellen H., Stanghellini C., Van der Voort M., Baptista F.J., Silva L.L., Murcho D., Meyer-Aurich A., Ziegler T., Ahokas J., Jokiniemi T., Mikkola H., Rajaniemi M., Balafoutis A., Briassoulis D., Mistriotis A., Panagakis P., Papadakis G. 2012. State of the art on Energy Efficiency in Agriculture. Country data on energy consumption in different agro-production sectors in the European countries. AGREE Project Deliverable 2.1., 69 p. Available in the Internet: http://www.agree.aua.gr/index-4.html

ISO. 2006. Environmental Management – Life Cycle Assessment – Requirements and Guidelines. ISO SS-En ISO 14044

Meyer-Aurich, A., Jubaer, H., Scholz, L., Ziegler, T., Daalgard, T., Yli-Kojola, H. Esala, J., Mikkola, H., Rajaniemi, M., Jokiniemi, T., Ahokas, J., Golaszewski, J., Stolarski, M., Brodzinski, Z., Myhan, R., Olba-Ziety, E., De Visser, C., Van Der Voort, M., Stanghellini, C., Ellen, H., Klop, A., Wemmenhove, H., Baptista, F.J., Murcho, D., Silva, L.L., Silva, J.R., Peça, J.O., Louro, M., Marques, C., Mistriotis, A., Balafoutis, A., Panagakis, P., Briassoulis, D. 2013. Economic and environmental analysis of energy efficiency measures in agriculture. Case Studies and trade offs. AGREE Project Deliverable 3.1., 157 p. Available in the Internet: http://www.agree.aua.gr/index-4.html

Mihov, M., Tringovska, I. 2010. Energy efficiency improvement of greenhouse tomato production by applying new biofertilizers. *Bulgarian Journal of Agricultural Science* 16(4), 454-458.

Olesen J.E., Bindi E. 2002. Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy*, 16, 239-262.

Pelletier, N., Audsley, E., Brodt, S., Garnett, T., Henriksson, P., Kendall, A., Kramer, K., Murphy, D., Nemecek, T. & Troell, M. 2011. Energy intensity of agriculture and food systems. *Annual Review of Environment and Resources*, 36, 233-246.

Peel, M. C, Finlayson, B. L, McMahon, T. A. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11, 1633-1644.

Röder, M., Thornley, P., Campbell, G., Bows-Larkin, A. 2014. Emissions associated with meeting the future global wheat demand: A case study of UK production under climate change constraints. *Environmental Science & Policy*, 39. 13-24.

Smil V. 2008. Energy in nature and society: general energetics of complex systems. The MIT Press, Cambridge, Mass.

Woods J., Williams A., Hughes J.K., Black M. & Murphy, R. 2010. Energy and the food system. *Philosophical Transactions of the Royal Society, B: Biological Sciences* 365 (1554), 2991-3006.