The environmental performance of native grassland based livestock production systems

Photo: Giocomo Pirozzi/PANOS

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Executive summary

The research reported here examined the environmental performance of extensive grassland-based livestock production systems with emphasis on native grasslands prevalent in developing countries. The work pays particular attention to various means used to assess the environmental performance of agricultural production systems. It provides a broad assessment of the environmental performance of production from native grassland with respect to global warming. The implications of the results for policy are discussed.

Purpose
The overall purpose of the work was to examine the environmental performance of production based on native grassland. This informs policy on the development of marketing approaches that might refer to the carbon footprint of these products. Such markets address a number of development issues. Native grassland is the only natural resource in many developing regions which is owned by or accessible to the poor. It can only be exploited for food by extensive grazing, particularly in arid and semi-arid situations. Extensive grazing, transhumance and nomadic pastoralism on communally owned land are forms of land management that have evolved over centuries to allow people exploit these natural resources in a sustainable way. The practices and animals used, and the traditional governance of the land, are adapted to the risks posed by this sparse and variable natural resource base. This traditional economic activity provides a large proportion of the cash income and a source of food for some of the world's poorest people[1]. Pastoralism is therefore at the nexus of a number of development challenges: the provision of high quality foods particularly livestock products, the sustainable exploitation of natural resources on land still in its near-wild state, the enhancement of livelihoods of the poor combined with fostering social justice of pastoral peoples and their governance of their natural resource base.

The native grassland resource
The work reviews the global resource in native grasslands and draws on existing and recent literature reviews to outline livestock production in major grasslands in areas where DFID is supporting development. Native grassland is the natural climax vegetation for 4,100-5,600 million hectares or about a third of the ice-free land surface. It is reasonable to estimate that there are about 3,000 million hectares of native grassland remaining. Native grasslands are characterised by periods of drought, either under tropical conditions as in Africa, or in cold climates as in Mongolia. This study examines the grasslands of East Africa, South Africa, Mongolia, India and Central Asia as examples of pastoral based agricultural systems in developing economies.

Production systems are almost self-sufficient requiring little or no inputs of fertiliser and other inputs. With the exception of Central Asia where statistical data may reflect legacies of the Soviet government, analysis of FAO data shows that livestock production on native grassland is characterised by low animal productivity. Production per animal in arid and semi-arid regions is countries one tenth to one fifth that of the UK.

Life-cycle assessment
An account of the use of Life-Cycle Assessment (LCA) to examine the environmental performance of agricultural production systems in these circumstances is provided. A search of the literature reveals no examples of LCA studies applied directly to native grassland based systems. The challenges of using LCA to address the questions raised by pastoral production are outlined. Due to the low animal performance, direct emissions of the potent greenhouse gases methane and nitrous oxide from pastoral based production are high on a unit output basis. However, the full assessment of pastoral production system must balance high direct emissions of these gases per unit output with wider aspects of the environmental performance of these systems, particularly effects arising from the use of native grasslands

[1] Hatfield, R and Davies, J. (2006). Global review of the economics of pastoralism. IUCN Nairobi.

for food production as an alternative to the further expansion of agricultural land from cleared forest. By definition, high wild forest is not an option on these lands. So expansion of agricultural production on native grassland is an alternative to expansion of production on the basis of land-use change – e.g. deforestation. In addition, the extensive sustainable exploitation of native vegetation has biodiversity benefits compared with cropping. These are not easily captured in LCA.

Against this background, attention is drawn to the difference between attributional and consequential LCA. Attributional LCA considers the system as static and attributes emissions from it to the product in question – e.g. meat or milk. Consequential LCA addresses the question of the effect of changes to the system in terms of total emissions. There is some evidence in the literature that the commercialisation of pastoral systems might be associated with increases in animal performance. This would reduce emissions of produce on a per unit output basis and total emissions may be reduced if commercialisation resulted in reductions in stock numbers. A consequential LCA approach may enable such beneficial change to be 'credited' to the resulting products. However, it is highly uncertain that commercialisation would trigger the changes in stocking needed to reduce emissions. Consequential LCA approaches are in their infancy, they require careful interpretation and application, and in this case a positive result would be based on 'crediting' market development with improvement in environmental performance at the animal level, compare with the situation today. The question for an analysis supporting policy is: would the changes brought about by developing markets result in reductions in GHG emissions in total compared with business as usual, even though emissions at the product level remain high? The potential answers to this question have a degree of complexity that will be difficult to translate into clearly understood and reliable marketing claims.

Environmental burdens

Production based on grazed native grasslands contrasts with more intensive livestock production systems (including those based on cultivated grassland) in a number of respects. The system relies on native climax or near-climax vegetation instead of crops and grass grown on land obtained from clearing forest or the degradation of some other high carbon stock use at some point in the past. Production uses very few or practically no synthetic inputs or feed grains.

This study used estimates of emissions arising from UK production as a starting point in a comparative analysis. Carbon dioxide emissions arising from the use of fossil fuels in fertiliser and energy is practically zero for the systems based on native grassland while UK beef and sheep meat production relies on 20 to 30 GJ of primary energy per tonne of carcass meat. This is equal to 500 to 750 kg of mineral oil and causes an emission of 1.4 – 1.8 tonnes of carbon dioxide. However, for intensive UK production, these energy related emissions are only 9 – 15% of total greenhouse has emissions arising from UK production. Emissions as a whole are dominated by methane and nitrous oxide in all systems.

Data on the emissions of methane and nitrous oxide from the pastoral systems are scarce. Data are available for Africa as a whole and these were used because African livestock agriculture is dominated by extensive pastoral systems with relatively little production based on cultivated grass and crops (mostly in South Africa). The analysis indicates that methane and nitrous oxide emissions for African meat and milk are 3 to 10 times greater than the same product from the UK. There are significant uncertainties in the size of emissions, especially from native grassland.

Deforestation is estimated to account for 18% of global greenhouse gas emissions. Examinations of land-use change patterns across the world lead to the conclusion that expanding agriculture drives about 60% of deforestation and other forms of land-use change that emit large quantities of carbon. If this emission is allocated to the global agricultural area, it amounts to a land-use change 'charge' of about one tonne[2] carbon dioxide per hectare of land that was cleared of native vegetation to be used for commercial agriculture. There is great uncertainty in the amount of such land used for beef and sheep/goat meat production world-wide, but it is reasonable to assume that the rate of land use is 20 ha per tonne of carcase meat. With this and the equivalent calculation for milk, a land-use change 'charge' of 20 tonnes carbon dioxide per tonne produce for meat and 2 tonnes carbon dioxide for milk can be applied to production on non-native vegetation. Production from native grassland can be regarded as free of this charge because this land is in its natural state. The evidence available indicates that even when a carbon charge for land-use is applied to animal production from non-native vegetation, the emissions attributable to the products are still lower than those attributable to products from native grassland where these would not apply.

Conclusion and policy implications

Native grasslands yield milk, meat and other animal products while maintaining native vegetation. Conflict with wildlife is less intense than in the case of crop production or ranching. Animal productivity is low. As a result, the direct greenhouse gas emissions from pastoral production are high on a per unit output basis. The best estimate we have at the moment is they are high enough to preclude the marketing of products on the basis of low carbon footprint directly attributable to them. So overall, the analysis of pastoral production using LCA to attribute emissions to products shows that such products cannot be regarded as having a low global warming impact. However, there are great uncertainties in the data, particularly with respect to the extent of nitrous oxide emissions from the excreta of grazing livestock and the consideration of land-use change for other production systems.

Policy is about leading or enabling change. A full environmental assessment of policy on the development of pastoralism would embrace the wider implications. There is evidence that low productivity is due in part to the lack of commercial influences arising from poorly functioning markets. This raises the prospect that the marketing of high value products from specific peoples and places may stimulate local commercialisation leading to improvements in animal performance and the adoption of an ecosystems approach to natural resource management. There would be many benefits, including for the global environment, that could feed through to more holistic assessments of such policy. Measures may be supported by for example the Clean Development Mechanism. A positive outcome depends on reductions in greenhouse emissions due to reductions in livestock numbers compared with business as usual, securing the future of grasslands as a high carbon stock land use, and the exploitation of native vegetation as an alternative to production on deforested land. Such an approach would require the support of holistic (consequential) assessments of environmental and social impacts. Sophistication at all stages in the supply chain would be required from the use of an ecosystems approach to development in primary production through to marketing and informing consumers.

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[2] Research published subsequent to this analysis has estimated this charge to be 1.4 tonnes CO2 per hectare (Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK.

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The environmental performance of extensive native grassland based livestock systems

Introduction

The overall purpose of the work was to examine the environmental performance of production based on native grassland. This informs policy on the development of markets based on the carbon footprint of these products. Such markets address a number of development issues. Native grassland is the only natural resource in many developing regions which is owned by or accessible to the poor. It can only be exploited for food by extensive grazing, particularly in arid and semi-arid situations. Extensive grazing, transhumance and nomadic pastoralism on communally owned land are forms of land management that have evolved over centuries to allow indigenous peoples exploit these natural resources in a sustainable way. The practices and animals used, and the traditional governance of the land, are adapted to the risks posed by this sparse and variable natural resource base. This activity provides a large proportion of the cash income and a source of food for some of the world's poorest people. Pastoralism is therefore at the nexus of a number of development challenges: the provision of high quality foods particularly livestock products, the sustainable exploitation of natural resources preserved in their near-wild state, the enhancement of livelihoods of the poor combined with fostering social justice of pastoral peoples and their governance of their natural resource base.

Changes in global and local food markets bring the need to develop livestock production into sharp focus. The OECD and the FAO predict that the demand for livestock production will double by 2050 and this growth will be largely due to the increased demand in developing economies. As a result there is consensus that the recent increases in the price of crop commodities are a manifestation of a long-term trend. A sustained increase in the value of livestock products combined with increasing concerns about the consequences of expanding agriculture raises the prospect of new or improved opportunities for pastoralists exploiting native grasslands. This study examines these opportunities from the point of view of greenhouse gas emissions and marketing products as beneficial for the global environment.

The work was initiated against a background of three developments:

1. The growing market for products of specific origin produced to high standards of animal and environmental welfare based on an ecosystems approach to natural resource management.

2. Growing concern about the wider implications for global resources of intensive livestock production, particularly grain-fed livestock production and deforestation.

3. The publication of research from New Zealand claiming that grassland based livestock production has a low carbon footprint because of the low inputs of fertilisers and grain based feeds.

The work comprises a review of the native grassland resource and how it is exploited, (particularly in countries where the DFID has a presence), a study of the application of life-cycle assessment to such systems, an outline analysis of the carbon footprint of meat and milk from African production, and a discussion of the policy implications.

Grasslands – the world's foremost agricultural land resource

UNESCO defines grassland as "land covered with herbaceous plants with less than 10 percent tree and shrub cover" and wooded grassland as 10–40 percent tree and shrub cover. The Oxford Dictionary of Plant Sciences[3] defines native grassland as follows:

"Grassland occurs where there is sufficient moisture for grass growth, but where environmental conditions, both climatic and anthropogenic, prevent tree growth. Its occurrence, therefore, correlates with a rainfall intensity between that of desert and forest and is extended by grazing and/or fire to form a plagioclimax in many areas that were previously forested."

It's important to appreciate that this definition does not include 'cultivated grassland' such as grassland of western Europe, which is largely on land cleared from high forested or drained wetland.

This report also includes savannah. Savannah is land whose ground cover is dominated by grass and low vegetation but which also has scattered trees or an open canopy of trees.

The FAO publication 'Grasslands of the World' provides a good overview of the world's grassland, their ecology and exploitation[4]. It is summarised here with the addition of material from other sources, particularly White, Murray and Rohweder (2000).[5]

Estimates of the extent of the world's grassland vary, in part, because of differences in land cover characterizations. The estimates range from approximately 4,100 to 5,600 million hectares[2], or 31 to 43 percent of the earth's surface. Grasslands in the wider sense are among the largest ecosystems in the world (Figure 1); their area is estimated at 5,250 million hectares, or 40.5 percent of the terrestrial area excluding Greenland and Antarctica. FAO statistics record that there are 3,406 million ha of permanent grassland world wide (including non-native grassland). Extensive grasslands are widely distributed across the world's major economies (Table 1). However, when countries are ranked according to the proportion of the area occupied by native grassland, 23 of the top 28 countries are in sub-Saharan Africa with grassland cover exceeding 60% in all cases, and 70% in most (Table 2).

Stable natural grasslands develop as a result of a combination of prolonged dry periods and grazing by wild animals. They develop particularly between the equatorial and desert zones where the dry season prevents formation of tropical forest and where it is not dry enough to result in desert. They also develop in the temperate zone between the desert and temperate forest. Above the temperate forests, tundra is regarded as grassland and has its own form of pastoralism.

No grassland is entirely natural, and there are many degrees of interference: particularly fire and grazing by livestock. In native grasslands, these human interventions are extension of natural processes – fire and grazing by wild herbivores. In general, grassland is said to be natural if it is not the result of full ploughing and sowing.

Many of the world's great grassland zones have been developed for arable farming, notably in the North American Prairie, the South American Pampas, and the East European Steppe. Grazing in these areas is now often relegated to the more marginal lands where people are

[3] Allaby, M. 1998. *Oxford Dictionary of Plant Sciences*. Oxford, UK: Oxford University Press.
[4] Suttie, J.M., Reynolds, S.G. and Batello, C. (2005) Grasslands of the World. The Food and Agriculture Organisation.
[5] White, R., Murray, S and Rohweder, M (2000). Grassland ecosystems. WRI.

often totally dependent on livestock for its livelihood. In Africa also there is little extensive uncultivated grassland in regions where the rainfall permits the production of crops.

Developing native grasslands for crop production has knock-on effects on the wider pastoral system by obstructing traditional migration routes in zones of transhumance and denying access to surface water. During the development process, grazing becomes increasing relegated to land disadvantaged in economic terms by distance to markets, topography, poor soil or to areas where growth is limited by moisture availability or by temperature. In many situations, grazing is the principal or only practical method of exploiting the resulting natural vegetation. Native grasslands vary greatly from place to place depending on climate (Figure 2) and productivity is highly variable, particularly in the arid zones (Figure 3). The management of the resultant risks is the characteristic common to pastoralism the world over. The nature of the resource and the associated risks puts pastoralism in the nexus of many developmental issues.

More intensive grassland management using improved pasture often coexists with arable crop production on more advantaged situations. These more developed grasslands must be economically competitive with other cultivated land-use forms at the farm-system level. They require inputs on an on-going basis – re-seeding and maintenance, fencing, fertilisation, harvesting etc. World-wide, grazing of such ‘cultivated’ grassland is associated with relatively large holdings under conventional private tenure arrangements. Beyond this, sown fodder however, often irrigated in semi-arid areas, can provide conserved fodder for lean-season use on a wide range of farm types, including for feeding animals otherwise extensively grazed on native grassland. Fodder growing is traditional in some smallholder areas, for example in Kenya. Analogous to the use of livestock to ‘harvest’ land resource not suitable for crop production, livestock are used within commercial cropping systems to utilise crop residues, often for lean-season feed. In Africa, this results in synergy between cropping and stock rearing with herders moving into the desert fringe during the rains and back to the cropping areas after harvest, in the dry season sustained by crop residues.

Savannah

A savannah is a tropical or sub-tropical ecosystem characterised by the trees being sufficiently small or widely spaced so that the canopy does not close. The result is a herbaceous layer consisting primarily of C4 grasses. Savannahs cover almost half the surface of Africa and large areas of Australia, South America, and India. The formation of savannah is determined by climate where the annual rainfall ranges from about 50 to 130 cm per year concentrated in six or eight months of the year. A wider distribution of rainfall leads to tropical forest. Lower rainfall leads to desert. Savannahs are maintained by climatic forces alone, by additional soil factors, or by the intervention of humans, particularly through fire, tree-felling and cultivation. Soils are generally porous and the organic matter enriched layer is thin.

Temperate grassland

Temperate grasslands are characterized by vegetation dominated by grasses and other low growing species. There are distinct summers and winters and the amount of rainfall is less in temperate grasslands than in savannahs. Major temperate grasslands include the veldts of South Africa, the puszta of Hungary, the pampas of Argentina and Uruguay, the steppes of the former Soviet Union, and the plains and prairies of central North America. The amount of annual rainfall influences the height of grassland vegetation, with taller grasses in wetter regions. The soil of the temperate grasslands is deep and characterised by deep organic matter enriched layers. For this reason, temperate grasslands converted to crop production are the basis of many of the world’s great agricultural zones.

Grazing systems

Grazing systems can be roughly divided into two main types - commercial and traditional, with the traditional type often mainly aimed at subsistence. Commercial grazing of natural pasture is usually very large-scale and commonly involves a single species, usually beef cattle or sheep. Some of the largest areas of extensive commercial grazing were developed in the nineteenth century by immigrants on land which had not previously been heavily grazed by ruminants.

Traditional livestock production systems are varied and use a wide range of species for multiple purposes, determined by climate, vegetation and social systems. Stock are usually kept for subsistence purposes and in many cultures the number of livestock rather than productivity is associated with social standing and this has profound implications for animal productivity and environmental impact.

Traditional sedentary systems often combine crop and livestock production with livestock that can utilize crop residues and by-products. This includes the use of various mobile systems based on transhumance to flexibly exploit more extensive grasslands. Transhumance describes pastoral systems where people move with their animals between two distinct seasonal pasture areas. Nomadism is used for pastoral groups that have no fixed base, but follow forage availability as determined by rainfall. Overall, pastoral management systems have evolved over thousands of years to adapt exploitation to variations in the grazing resource in arid or semi-arid situations.

Socio-political aspects

Extensive grazing, particularly mobile systems present complex challenges to policy development. Mobile systems have evolved to meet the challenges presented by a variable dispersed grazing resource. Traditional laws, land ownership arrangements and land use practices evolved to address variation in water availability in particular. In such systems, the land has been under various form of communal ownership.[6] Political and economic changes over the past 150 years have had a marked effect on the distribution, condition and use of grasslands.[7] Settlement, ranching and cropping have transferred land from communities to individual owners or the state. Independence in former colonies has often been followed by adoption of western models of land ownership leading to the breakdown of traditional authorities and grazing rights. Political change, particularly in the last twenty years, has resulted in profound change in land access rights in many areas previously dominated by extensive grazing on open rangeland governed by traditional laws and customs.

Major pastoral areas – a closer look

East Africa

East Africa comprises Sudan, Eritria, Ethopia, Somalia, Kenya, Uganda, Ruwanda, Burundi and Tanzania. 75 percent of eastern Africa is dominated by grasslands, usually savannah covering a very wide range of altitudes. Extensive grasslands are mostly in arid and semi-arid zones. The area is subject to droughts and a high variability in primary productivity (Figure 2). The savannahs have been grazed by livestock and game for millennia, particularly using transhumance.

East African grasslands are generally either under government control and have open access, are private lands, or are communal property resources controlled by specific communities. Traditional grazing practice involves various forms of transhumance which in turn relies on access to communally managed land.[8] Cattle, camels, sheep, goats and

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[6] Appell, G. N. 1993 Hardin's Myth of the Commons: The Tragedy of Conceptual Confusions. With Appendix: Diagrams of Forms of Co-ownership. Working Paper 8. Phillips, ME: Social Transformation and Adaptation Research Institute.

[7] Abel, N.O.J. and Blaikie, P.M. (1989): Land degradation, stocking rates and conservation policies in the communal rangelands of Botswana and Zimbabwe. *Land Degradation and Rehabilitation* 1, 101-123.

[8] Reid, R.S., Serneels, S., Nyabenge, M., and Hansen, J. (2005). The changing face of pastoral systems in grass-dominated ecosystems of eastern Africa. Chapter 2. Grasslands of the world. FAO

donkeys are the main livestock for subsistence. Stocking rates vary greatly and are high in some places considering the arid or semi-arid conditions (Figure 4). In line with the development of sophisticated ways to manage the risks presented by the natural resource base, most herds are mixed. Indigenous breeds dominate, although exotic (e.g. European) cattle are kept for dairying in high altitude zones. Wildlife, which is important for tourism, is widespread in the grazing lands. Land owned or controlled by individuals serves flexible agro-pastoral systems that integrate traditional extensive grazing with crop and fodder production (Figure 5). Grasslands are increasingly being integrated into settled farming as pastoral systems evolve, and this is linked to sedentarisation.

Key production data are presented in Tables 3 to 5. These data have been extracted from FAOSTAT. For convenience and reference, corresponding data for New Zealand the UK are also provided.

The key feature of these data is the low productivity per animal. While it must be kept in mind that the production data for many counties are very uncertain, it can be concluded that the productivity of cattle is typically one fifth to one tenth that of British and New Zealand cattle while the productivity of sheep and goats is one quarter to one half. Broadly speaking, the lowest productivities are in countries where traditional pastoral practice and arid and semi-arid land predominate.

South Africa
Palmer and Ainslie provide an excellent overview[9] summarised as follows. The South African climate is subtropical, with altitude leading to a range of semi- to arid grasslands. Grassland is mainly in the central, high regions with sour veldt occurring under high-rainfall on acid soils, and sweet veldt on fertile soils in semi-arid zones. Savannah occurs in the north and east. Arid savannah extends westwards to the Kalahari. A vast area of steppe in the centre and west is grazed by sheep and goats.

Compared with other southern African countries, agriculture in South Africa is characterised by commercially managed freehold land (70%). 14% is communally managed for subsistence and reserves or freehold industrial and urban land cover 16% of the area. Overall, natural pasture is the main feed source for grazing livestock. Subsistence farming is based on pastoralism and agropastoralism and is labour intensive. In agropastoralism, cropland is allocated to households while grazing areas are shared by a community. Commercial management of freehold land involves fenced areas in ranches further subdivided into paddocks to enable rotational grazing.

Traditional breeds predominate in subsistence farming systems while exotic and locally-created improved breeds prevail in commercial systems. Sheep are associated with commercial systems and goats are used for farming subsistence. Cattle predominate in the east, and sheep in the drier west and southeast. Goats are widely distributed.

The region is home to large numbers of grazing and other wildlife. They are common on large-scale ranches and are increasing in importance as a managed resource. Low profits from domestic stock have led to an increase in game farming and ecotourism. Much of the better-watered grassland has been converted to crops. In communal areas this gives a patchwork with thicket. Sown pasture is not important, except on dairy farms.

South African cattle are more productive than those in East Africa. Meat production is about 52 kg per head over about 14 million cattle. The meat productivity of sheep and goats is similar to other African countries.

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[9] Palmer, A.R. & A. Ainslie. (2005). Grasslands of South Africa. Chapter 3 in Suttie, J.M., Reynolds, S.G & C. Batello (eds). Grasslands of the World. Rome: FAO. Pp.77-120.

Mongolia
Suttie (2005) provides an overview of the grass based economy and grassland management in Mongolia.[10] Mongolia is a highly pastoral country with about 80% of its large area covered by native grassland, mostly steppe. Approximately 30% of the country's 2.9 million people are nomadic or semi-nomadic. Its climate is arid to semi-arid and cold with approximately 100 frost free days on the steppe restricting grass growth. A wide range of species are kept: cattle, yaks, camels, horses, sheep and goats.

Traditional pasture management prevails despite dramatic political change over the last 100 years affecting land ownership. The period from 1950 to 1990 was characterised by collectivisation of herds which remained mobile maintaining the transhumance approach to management. Following democratic elections in the early 1990s, livestock were returned to private ownership but grazing land and rights remain under public control. Stock numbers have risen as a result but the grassland and grassland infrastructure has not been improved resulting in localised over-grazing. There is also under-grazing in other areas because of lack of infrastructure such as water supplies. The lack of land reform is hindering progress in pasture management and especially the provision of winter fodder.

Mongolian beef and sheep produce on average 26 kg and 5 kg of carcase meat per head per year. This means the stock are more productive than most African herds, but the productivity remains low and typical of extensively managed pastoral systems.

India
Misri[11] provides an overview of pasture based agriculture in India. India has the largest cattle herd of any country: about 283 million cattle and buffalo. Animal husbandry is mainly sedentary and based on a combination of grazing, the feeding of crop residues and fodder production. Irrigated land is used for intensive fodder production for stall-fed animals.

Pastures are mostly the result of the degradation of forest. True natural pasture, e.g. savannah, is only found as sub-alpine and alpine pastures in the higher altitudes of the Himalayas.

The transhumance system is prevalent in the Himalayan region and in some areas of the plains. Otherwise, settled rural communities managed stock using a combination of community grazing lands supplemented with green fodder cultivated in the farmer's fields. During lean periods, tree leaf fodder is also used. These monsoon grasslands are only productive during the rainy season, and the dry season is long and severe; their feeding quality, like that of all grasslands with marked wet and dry seasons, is mediocre when they are young and poor thereafter.

Emphasis is on milk production and milk yields are higher than most African countries at 1,089 kg per cow. India has overtaken the USA as the world's largest milk producer.

Central Asia
The Central Asian Region comprises is a vast low-altitude plain covering Kazakhstan, Kyrgyzstan, Turkmenistan and Uzbekistan. Much of the area forms the catchment of the Aral sea. Having all been part of the USSR, these countries share a common recent history and so can be group together. These arid to semi-arid plains have traditionally been exploited using mobile herding with crop production confined concentrated in oases and river valleys.

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[10] Suttie, J.M. (2005). Grazing management in Mongolia. Chapter 7 in Suttie, J.M., Reynolds, S.G & C. Batello (eds). Grasslands of the World. Rome: FAO. Pp.265-304.
[11] Misri, B. (1999). India. Country pasture/forage resource profile. FAO.

Traditional herd were collectivised after the Russian revolution and state owned farms characteristic of the USSR emerged. Following independence in the early 1990s, these collective systems collapsed resulting in general decline in herds (especially sheep) and their productivity, including a decline in soil protection practices. FAO data indicate that animals are productive compared with Africa but this is uncertain given the destocking that is taking place because of the low reliability of production statistics.

Assessing the environmental burdens arising from grassland products – life-cycle assessment (LCA)

The primary purpose of this study is to assess the potential for producing livestock products of high environmental performance in developing economies from traditional native grasslands. The potential for high environmental performance arises from the low use of external inputs in production systems that are based on native or near-native vegetation. Low external inputs mean low inputs of fossil energy and potentially harmful substances such as fertilisers, pesticides and drugs. In addition, the maintenance of vegetation in the native or near-native form has biodiversity benefits and can also contribute to the protection of soil and water resources.

The serious marketing of products on the basis of superior environmental performance requires assessment of this performance. Life-cycle assessment is now widely used to support decision making on the part of producers, consumers and policy-makers. LCA analyses production or service systems systematically in relation to a defined useful output or 'functional unit', for example 1 kg of meat. The system used to produce the functional unit is defined, and the assessment is based on an inventory of all inputs and outputs moving across the system boundary. It goes back to the source of inputs such as the extraction and use of fossil fuels used to manufacture fertilisers and pesticides, the extraction of ores giving the popular term 'cradle-to-grave' analysis. Crucially in agriculture and food, it includes pollution gas emissions from biological processes. In many situations, the analysis includes resources uses and burdens arising from disposal, re-use or recycling – for example the handling of packaging for milk or the end-of-life management of building materials. The inventory of resource use and emissions is aggregated and analysed to deliver an assessment of impacts on the environment according to categories of impacts such as Global Warming Potential (GWP), Eutropication Potential (EP), Acidification Potential (AP), Abiotic Resource Use (ARU), Primary Energy Use and Land use

The use of LCA to assess agricultural systems and products in the developed world is now well established. Pioneering work done at Silsoe and Cranfield the UK [12] has applied LCA to quantify emissions from the production of 11 food commodities in the UK. This built on earlier work led by Audsley at Silsoe[13] and followed established LCA methodology, for example such as that set out by Sleewijk et al (1996)[14]. Research applying LCA to agriculture has expanded rapidly since the work at Cranfield was initiated and an international conference in Zurich in September 2008 provided a good overview of current activity. http://www.art.admin.ch/themen/00617/01078/index.html?lang=en .

[12] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

[13] Audsley, E., Alber, S., Clift, R., Cowell, S., Crettaz, P., Gaillard, G., Hausheer, J., Jolliet, O., Kleijn, R., Mortensen, B., Pearce, D., Roger, E., Teulon, H., Weidema, B and van Zeijts H. 1997. Harmonisation of life cycle assessment for agriculture. Final report, Concerted Action AIR3-CT94-2028. European Commission DG VI Agriculture, Silsoe, UK.

[14] Sleeswijk, A.W., R. Kleijn, H. van Zeijts, J.A.W.A. Reus, M.J.G. van Onna, H. Leneman and H.H.W.J.M. Sengers. 1996. Application of LCA to Agricultural Products. Centre of Environmental Science, Leiden University, Leiden, The Netherlands.

The life-cycle assessment of agricultural systems and products has a number of special challenges. These include identifying the true long-term level of inputs and outputs where inputs or production conditions have long-term effects (e.g. soil fertility) or where the full effects of changing from one system to another can take years or even centuries to be realised (e.g. responses of soil carbon to management changes). The estimation of diffuse emissions, particularly biogenic emissions is difficult and often relies on indirect estimates and modelling. The predominant greenhouse gases arising from agriculture are methane (from ruminant digestive systems and animal manure) and nitrous oxide from soils and there remains uncertainty in estimates. Production systems are not just complex themselves, they are usually part of a larger complex with resources flowing between crops, between crops and animals, and between types of animals.

No one analytical tool can cover all aspects of a system. As normally conducted, life-cycle assessment does not consider a number of effects, particularly wider second order effects arising as a consequence of change. This limitation is particularly relevant to agricultural systems. LCA normally assumes systems are in steady-state, i.e. that the production system is stable with the relationship between inputs, outputs and emissions remaining constant as long as the system is not changed. Therefore, analyses do not account for benefits such as carbon sequestration that occurs when a system causes soil organic matter to increase. LCA also does not easily accommodate the effect of production linked to wider system changes. This is particularly relevant to the effects Land Use, and Land Use Change which accounts for 17.3% of global greenhouse gas emissions[15] (Figure 7). Land-use (LU) emissions are net emissions or sequestration of carbon from existing agricultural soils. LCA normally assumes that soil organic matter levels remain constant at the long-term steady-state level for the system used. However, many agricultural soils, even old agricultural soils, are in a state of change determined by their current use in relation to previous uses. So for example, a soil used for wheat production which was previously grassland will lose considerable quantities of organic matter over the decades following the switch from grass to arable until a new and lower steady-state soil organic matter level is reached. Similarly, a soil which has depleted levels of organic matter will go through period of building up carbon levels following a change in practice until a new steady state is reached. This can take decades. The process can be reversed which is the principal reason for the difficulty in including this in analyses. LCA does not accommodate these gains and losses easily.

Land Use Change (LUC) emissions include for example carbon dioxide emissions arising from change in the use of natural or semi-natural high carbon stock land (e.g. deforestation). LCA does not normally accommodate such emissions. Even though deforestation accounts for very significant proportion of global greenhouse gas and most deforested land eventually ends up used for agriculture, LUC emissions are not usually attributed to agricultural products in life-cycle assessments.

Effects of land management on biodiversity are also not easily considered by LCA. The term can extend to rigorous consideration of ecosystem function to the almost aesthetic or focus on emblematic species. While land occupied by production is an indication of ecosystem impacts, the ecosystem function of the land occupied as affected by production practice is difficult to consider in LCA.

Attributional and consequential LCA

The description of LCA provided above is particularly relevant to attributional LCA. As is set out below, the data on the production of meat and milk from native grasslands and the information available on associated levels of methane emissions point towards high greenhouse gas emissions attributable to the resultant products. In these circumstances,

[15] IPCC (2007). Climate Change 2007: Synthesis Report.

'Environmental' marketing cannot be undertaken on the basis of conventional 'attributional' LCA. However, the purpose of this study is to inform policy on the development of ruminant livestock production based on native grasslands in developing countries. Policy in this context is about leading or facilitating change in the production and marketing of livestock. The question then is what are or could be the wider environmental consequences of that change. Could increased production result in improvements for the environment as a whole? Such improvements could arise from avoidance of production expansion elsewhere or by linking the resulting commercialisation of production to reductions in the herd size.

Brander et al (2008)[16] provide a guide for policy makers using LCA in such circumstances. This is summarised here. Attributional LCA (ALCA) provides information about the impacts of the processes used to produce (and consume and dispose of) a product, but does not consider indirect effects arising from changes in the output of a product. Consequential LCA (CLCA) provides information about the consequences of changes in the level of output (and consumption and disposal) of a product, including effects both inside and outside the life cycle of the product. CLCA models the causal relationships originating from the decision to change the output or consumption of the product, and therefore seeks to inform policy makers on the broader impacts of consumption and production policies.

Whereas ALCAs are generally based on stoichiometric relationships between inputs and outputs, and the results may be produced with known levels of accuracy and precision, CLCAs are highly dependent upon economic models representing relationships between demand for inputs, prices elasticities, supply, and markets effects of co-products. Such models rarely provide known levels of accuracy or precision and should therefore be interpreted with caution.

The global environmental impacts of grassland based livestock production

Steinfeld et al[17] provide an overview of the global environmental impacts of grassland based livestock production. Grazing livestock occupy 26% of the ice-free land area, and livestock consume 670 million tonnes of cereals and the meal from about 200 million tonnes of soybeans. These two feed ingredients alone account for a total of 300 million hectares of arable agricultural land (out of a global total of 1500 million ha). Steinfeld et al report that 20% of the grazed area is degraded and this is particularly a problem in the arid and semi-arid rangelands. They attribute 18% of greenhouse gas emissions to the livestock sector as a whole and these emissions are dominated by methane and nitrous oxide which have increased in the same way carbon dioxide emissions have increased (Figure 8). The profile of greenhouse gas emissions as affected by the stage of economic development is characterised by increased role for methane, nitrous oxide and carbon dioxide from land-use change in developing countries (Figure 6).

The range of greenhouse gases emitted in agriculture has special implications for this study. The results of the estimation of emissions from beef, sheep and milk production in the UK provided by Williams et al (2006)[18] serve as a good starting point for discussion (Table 6). Primary energy use and greenhouse gas emissions are key parameters to the assessment of global impacts of products. The burdens of global or transnational importance arising directly

[16] Brander, M., Tipper, R., Hutchison, C., and Davis, G. (2008). Technical Paper. Consequential and attributional approaches to LCA: a guide to policy makers with specific reference to greenhouse gas LCA of biofuels.
[17] Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).
[18] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

or indirectly from grassland based agriculture are principally methane, nitrous oxide, carbon dioxide, ammonia, and phosphorus.

Phosphorus is pollutant of water and a major problem in water bodies affected by intensive livestock production – including production based on grazing. It is generally not a problem associated with extensive grazing of native grasslands and is not considered further here.

Methane

Methane is the product of anaerobic processes, the major source world-wide is ruminant digestive systems. It is also emitted by wet soils and rotting vegetation, from mining, landfill, and from biomass burning. Methane is a potent greenhouse gas with a GHG effect that is 25 times that of carbon dioxide over a 100 year timeframe. Even though methane is relatively short-lived in the atmosphere (about 8 years), the global atmospheric concentration of methane has increased from a pre-industrial value of about 715ppb to 1732ppb in the early 1990s, and was 1774ppb in 2005 (Figure 6). It is responsible for 14% of all greenhouse gas emissions (Figure 7). Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. The greenhouse gas effect of all methane emissions equals about one third of net greenhouse gas emissions making methane the second most important emission driving in anthropogenic climate change.[19] About half of these emissions are man-made, and of these 36% come from livestock.[20] About 80% of this livestock emission comes from ruminant digestion processes – the enteric emissions. The enteric emissions arise largely from the processes in cattle and sheep used to digest grass, forage etc.

Broadly speaking, the lower the digestibility of the forage, the greater the emission per unit nutrient digested. Annex 3 of the FAO's Livestock's Long Shadow[21] presents data on methane emissions across the world. These are presented here in Table 8. Combined with data in Table 7 from the same source, and data in Table 6 setting out life-cycle emissions from UK produced ruminant livestock products, we can make an estimate the methane emissions from livestock from extensively grazed natural grasslands in relation to production.

Tier 2 assessments, i.e. assessments based on feeding practice rather than just animal numbers indicate that developed country dairy cows emit twice as much methane as dairy cows from sub-saharan Africa. Other cattle in OECD countries emit about 13% more methane per head per year. No data relating emissions directly to products that could enable a comparison of products were identified. However, the combination of data available does provide some pointers. The milk yield of cows in sub-Saharan Africa is about 300 l per annum (Table 5). The associated emission of 63 kg methane (Table 8 and 9) means that the emission per tonne milk produced is estimated to be 210 kg or the equivalent of 5250 kg CO_2. This is ten fold the emission of methane estimated from UK production (Table 6).

Turning to beef production, Herrero et al. (2008)[22] provide estimates of emissions from all cattle in Africa on a regional basis. These estimates are based on models that draw estimates of feed intake, as affected by region and vegetation. The average emission is 31 kg per animal giving a total emission of 6.54 million tonnes from the African bovine herd. Data presented by Steinfeld et al (Table 8 and 9) estimate that African dairy cattle produce 3.44 million tonnes of methane. They also estimate that 'other' cattle produce 9.04 million tonnes of methane. Takes these sources together, the emission of methane from African

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[19] IPCC (2007). Climate Change 2007. A report of the Intergovernmental Panel on Climate Change.
[20] Baumert, K.A., Herzog, T. and Pershing, J. (2005). Navigating the numbers. World Resources Institute.
[21] Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).
[22] Herrero, M., Thornton, P.K., Kruska, R. and Reid, R.S. (2008). Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. Agriculture, ecosystems and environment 126: 122-137.

cattle ranges from 6.5 million tonnes to 11.6 million tonnes, with dairy cattle accounting for about one quarter. So for further analysis, it is assumed that the emission from dairy production ranges from 1.6 million tonnes to 3.4 million tonnes and emissions from 'other' cattle range 4.9 to 9.0 million tonnes.

These data indicate that non-dairy cattle produce 4.6 million tonnes of meat and that the methane emission per tonne is between 1065 and 1957 kg (equivalent to 25 – 45 tonnes of CO_2/tonne). The equivalent range for the 25.1 million tonnes of cows milk produced is 63 to 136 kg methane per tonne of milk (equivalent to 1.5 to 3.1 tonnes of CO2 per tonne of milk). These emission estimates compare with 239 kg methane from UK beef production and 22 kg methane from UK milk production (Table 6). Such a level of methane emission alone would make the carbon footprint of African beef more than two-three times that of UK beef. The equivalent for milk is 1.5 to 3 times the UK emission.

The same approach can be used to provide estimates for sheep and goat meat. Herrero et al. [23] estimate that African sheep and goats emit 1.24 million tonnes of methane. Steinfeld et al estimate 3.15 million tonnes. These animals produce 2.1 million tonnes of meat and 4.9 million tonnes of milk. Applying the relationships between meat and milk emissions in cattle, it is estimated here that 86% of the methane emission from sheep and goats can be allocated to meat. This means that the emission per tonne of meat ranges from 509 to 1290 kg per tonne. The equivalent for milk is 35 to 90 kg methane per tonne. For sheep meat, these emissions compare with 310 kg from UK production.

Nitrous oxide

Nitrogen is an essential element for life. It is a major component of protein. Its use as a fertiliser relates to its role in chlorophyll and crop canopies more generally. Nitrogen determines the growth of canopies and how they intercept sunlight and so is a major determinant of the primary productivity of ecosystems. Through increasing crop canopies, the industrial fixation of nitrogen and the increased biological nitrogen fixation in legume crops such as soy has driven the increase in global crop yield potential. Nearly all agricultural activity involves raising nitrogen fixation and/or the availability of reactive nitrogen (e.g. nitrate) above the level found in natural ecosystems. Reactive nitrogen entering the system is taken up by plants and passes through to animals consuming these. There are extensive losses and even the most efficient animal production systems recover only a small proportion of the nitrogen entering them in the product.[24]

Nitrogen is the major 'GHG nutrient' (Williams et al., 2006). Nitrous oxide (N_2O), a trace gas and a very potent GHG, is a product of the nitrogen cycle and is responsible for 8% of greenhouse gas emissions (Figure 7). The intensity of the nitrogen cycle is raised in agro-ecosystems by nitrogen fixation: the manufacture of artificial nitrogen fertilisers and biological fixation by legume crops such as peas and soy. N_2O concentrations in the atmosphere have increased from a pre-industrial level of 270 ppbv to a current level of 319 ppbv (Figure 8). In the case of manufactured fertilisers, manufacture also releases carbon dioxide through the use of fossil fuels. European nitrogen fertiliser manufacture, which is relatively efficient, results in the emission of the equivalent of 7.5 kg CO_2 per kg N (ca 2 kg C). Overall, Kongshaug (1998) estimates that fertiliser production consumes approximately 1.2% of the world's energy and is responsible for approximately 1.2% of the total GHG emissions. The direct N_2O emission from soil arising from all forms of nitrogen fertilisation is equivalent to 1 kg carbon per kg N introduced into the system. Overall, when emissions from other ecosystems enriched by losses to the air and water from agricultural soils are taken into

[23] Herrero, M., Thornton, P.K., Kruska, R. and Reid, R.S. (2008). Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. Agriculture, ecosystems and environment 126: 122-137.

[24] Braun, E. 2007. Reactive nitrogen in the environment. UNEP.

consideration, the equivalent of more than 2.7 t carbon is emitted as N_2O for every tonne N introduced into agri-ecosystems by man, including from nitrogen fixed biologically by legumes. Reducing man's intervention in the nitrogen cycle through raising the efficiency of nitrogen use in agriculture is central to the mitigation of greenhouse gas emissions from primary food production.

Humans have already doubled the amount of reactive nitrogen entering the global nitrogen cycle. Emissions arise in the form of ammonia, nitrate and nitrous oxide. Regardless of whether nitrogen in soils is from manure, fertiliser or legumes, nitrous oxide is emitted from soil processes, particularly denitrification when nitrate is converted to N_2 gas and the trace gas nitrous oxide. Emissions of ammonia from soils and especially from the urine component of manure result in enrichment of ecosystems and indirect elevated nitrous oxide emissions from these enriched ecosystems.

Nitrogen retention by livestock is low – ranging from about 5% for extensively fed ruminants used for meat to about 34% for efficient poultry systems. A huge amount of N is released to the environment in excretion. Considering the situation in native grasslands, it can be assumed that the grasslands themselves do not significantly increase the nitrogen inputs into the global environment. Fertiliser use is low, and the use of fixation of nitrogen by legumes is not substantially higher than the background level. However, the grazing activity raises nitrogen turn-over above that found in wild ecosystems. This mean there are emissions of nitrous oxide which, unlike most agricultural systems, are not traced to fertiliser use or additional legume production.

Steinfeld et al[25] provide estimates of nitrous oxide emissions from animal excreta. The estimates for African livestock are as follows: dairy cattle, 80,000 tonnes; other cattle, 240,000 tonnes; sheep and goats 220,000 tonnes. These result in the following estimates of nitrous oxide emissions per tonne of product: cows milk 3.18 kg; cattle meat 52 kg; sheep and goat meat 90kg; and sheep and goat milk 6.4 kg.

It is reasonable to assume that these systems do not have significant other nitrous oxide emissions so these emissions from excreta can be compared directly with all nitrous oxide emissions calculated for UK production using LCA. Considering data for UK production (Table 6), these levels of emissions are 3 to 6 times higher than those arising from UK production.

Direct carbon dioxide from energy use
The carbon dioxide emitted by animals in respiration is balanced by the carbon dioxide absorbed by the plants they eat so this is not a factor in calculations. Carbon dioxide emissions arise directly largely from the use of fossil energy in manufacturing inputs, fossil energy use and fuels for farm machinery etc.

In modern farming systems, fossil energy use in fertiliser production and fossil fuels used the cause of about 10% of the greenhouse gas emissions attributed to agriculture directly. The corresponding emissions are trivial in systems based on extensive grazing of natural grassland because of the low level of fertiliser and fuel inputs so not considered further here.

Carbon dioxide emissions from land-use change
An estimated 18% of global GHG emissions arises from land use change and forestry (Figure 7). World-wide, the total net emission is estimated to be 7,619 million tonnes CO_2 in 2000. The data are uncertain and emissions could range from 2,900 million tonnes of carbon

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[25] Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

dioxide to 8,600 million tonnes (20% of carbon dioxide emissions). It is estimated that 60% of deforestation can be attributed to the expansion of agriculture.

Life-cycle assessments of agricultural products normally do not consider land-use change or land use. Production systems are based on land that was converted to agriculture many years ago. However, conversion of forest and other high carbon stock land to other uses continues. All forms of land use on land that was previously forested and which is connected to global trade can be seen as contributing to the forces driving continued conversion. Therefore, we can assume that greenhouse gas emissions from land-use change caused by agriculture may be similar in magnitude to greenhouse gas emissions arising directly from agriculture.

Any form of non-forest land use on land that was previously forested or contained some other high carbon stock (e.g. peatland) may be regarded as contributing to LUC emissions. Very little research has been done to allocate LUC emissions to products arising from the use of converted land. A group including the author is doing such a study for the UK food system[26]. The earliest results indicate that land use for commercial agriculture is linked to deforestation equal to 1 t carbon dioxide per ha per year. World-wide, land use per tonne of beef or sheepmeat is in the region of 20 ha per tonne. This means that beef and sheepmeat from commercial agricultural land that was at some stage deforested or whose natural climax vegetation is forest or some other high carbon stock use is linked to deforestation equal to 20 t carbon dioxide per tonne. To understand this fully, it is necessary to understand how this may be calculated using the 'top-down' method.

The top-down method of calculating land-use change emissions arising from agricultural production

This approach involves estimating total observed LUC emissions caused by commercial food production, and allocates that total "pool" of emissions to different food-types based on their land-area requirements per unit of production. It should be noted that this approach does not divide emissions into direct and indirect categories. The method is detailed in Table 11.

Basically, the method calculates global land-use change emissions attributed to agriculture. It then calculates the total amount of agricultural land connected to world trade and the associated production of crops and animal commodities. The land used is allocated to the commodities to give a land use per tonne of each commodity. The land-use change emission per hectare of commercial agricultural land is calculated by dividing the land-use change emission by the total area of agricultural land connected to trade.

The advantage of this approach is it calculates both direct and indirect emissions. The emissions allocated to different food-types will not sum to a figure which is greater than actual observed LUC. This is important to maintain the integrity of a consumption-based emissions accounting approach (i.e. total emissions allocated should not exceed total emissions, also known as the "100% rule"). Food-types which have high land-use requirements (e.g. beef, coffee etc) are allocated higher LUC emissions, and switching to food-types with lower land-use requirements will show a reduction in LUC emissions. In addition, measures such as a reduction in total food consumption will show a reduction in LUC emissions. The division of LUC into direct and indirect categories can be a distraction from the fact that all demand for agricultural land contributes to LUC pressures (either directly or indirectly). Due to the global interaction of world commodity markets it is not possible to draw a boundary around specific products (interactions in the whole system need to be considered). Treating LUC emissions as a single "pool" recognises this.

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[26] Audsley, E, Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., Williams A. 2009. Reducing GHG emissions from the UK food system: how low can we go? A study for WWF UK.

The disadvantage of this method is the method does not pick out the possible differences between food-types which happen to have the same land-area requirements per unit of output. For example, if palm oil and rape seed oil had similar land-area requirements per unit of output then they would be allocated the same LUC emissions per unit of output (although the actual total (direct and indirect) LUC impacts may be different – e.g. palm oil may cause higher total emissions that RSO).

Comparing production from native grassland with production in the UK
Native grasslands yield milk, meat and other animal products while maintaining native vegetation. Conflict with wildlife is less intense than in the case of crop production or ranching. In some cases, wildlife may benefit.[27] However, farm animal productivity is low. As a result, the direct greenhouse gas emissions from pastoral production are high on a per unit output basis (Table 12). The best estimate we have at the moment is they are high enough to preclude the marketing of products on the basis of low carbon footprint directly attributable to them. So overall, the analysis of pastoral production using LCA to attribute emissions to products shows that such products cannot be regarded as having a low global warming impact. However, there are great uncertainties in the data, particularly with respect to the extent of nitrous oxide emissions from the excreta of grazing livestock.

Policy is about leading or enabling change. A fuller environmental assessment of policy on the development of pastoralism would embrace the wider implications. There is evidence that low productivity is due in part to the lack of commercial influences arising from poorly functioning markets. This raises the prospect that the marketing of high value products from specific peoples and places may stimulate local commercialisation leading to improvements in animal performance and the adoption of an ecosystems approach to natural resource management. There would be many benefits, including for the global environment, that would feed through to environmental assessments. Measures may be supported by for example the Clean Development Mechanism. A positive outcome depends on reductions in greenhouse emissions due to reductions in livestock numbers compared with business as usual, securing the future of grasslands as a high carbon stock land use, and the exploitation of native vegetation as an alternative to production on deforested land. Such an approach would require the support of extended tailored assessments of environmental and social impacts. The analysis presented in Table 12 shows that the allocation of a charge of 1 tonne CO_2 for on-going deforestation to existing commercial agricultural land may result in the conclusion that expansion of production based on native grassland is beneficial and that the resultant products are ‘low carbon’. It must be emphasised that there are huge uncertainties in the data and in assumptions. However, it is not unreasonable to speculate that methane and nitrous oxide emissions from native grassland production could be halved and that the CO_2 charge of 1 tonne per hectare of commercial agriculture is reasonable. The key thing is the overall outcome and linking that to well founded product specific claims.

Sophistication at all stages in the supply chain would be required from the use of an ecosystems approach to development in primary production through to marketing and informing consumers.

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[27] Hatfield, R. and Davies, J. 2006. Global review of the economics of pastoralism. IUCN.

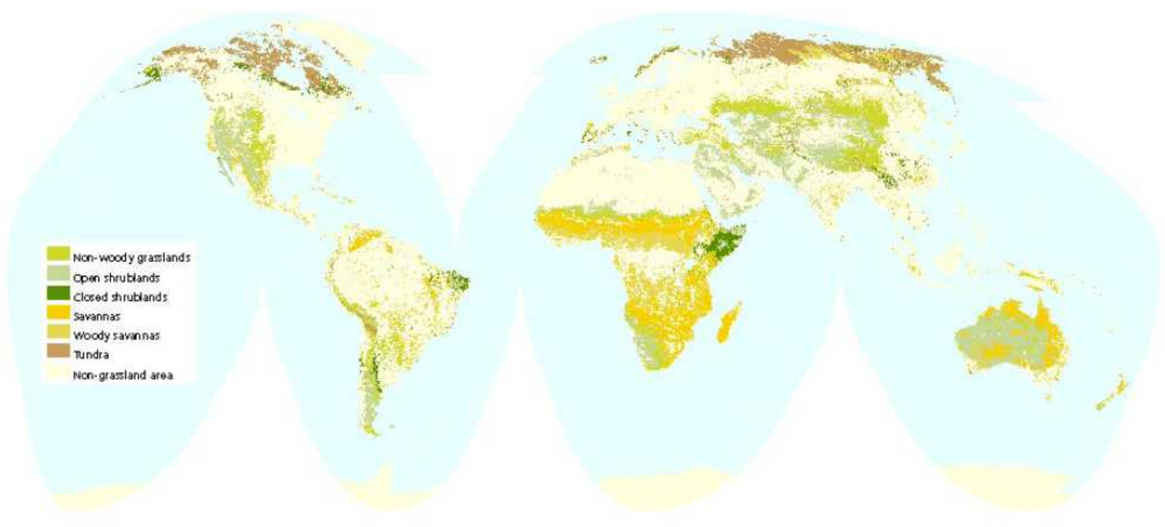

Figure 1

The extent of the world's native grasslands[28,29]

[28] GLCCD. 1998. Global Land Cover Characteristics Database, Version 1.2. Data available online at: http://edc2.usgs.gov/glcc/gifs.php.
[29] Olson, J.S. 1994a. *Global Ecosystem Framework-Definitions*. USGS EROS Data Center Internal Report. Sioux Falls: USGS EROS Data Center. 37pp

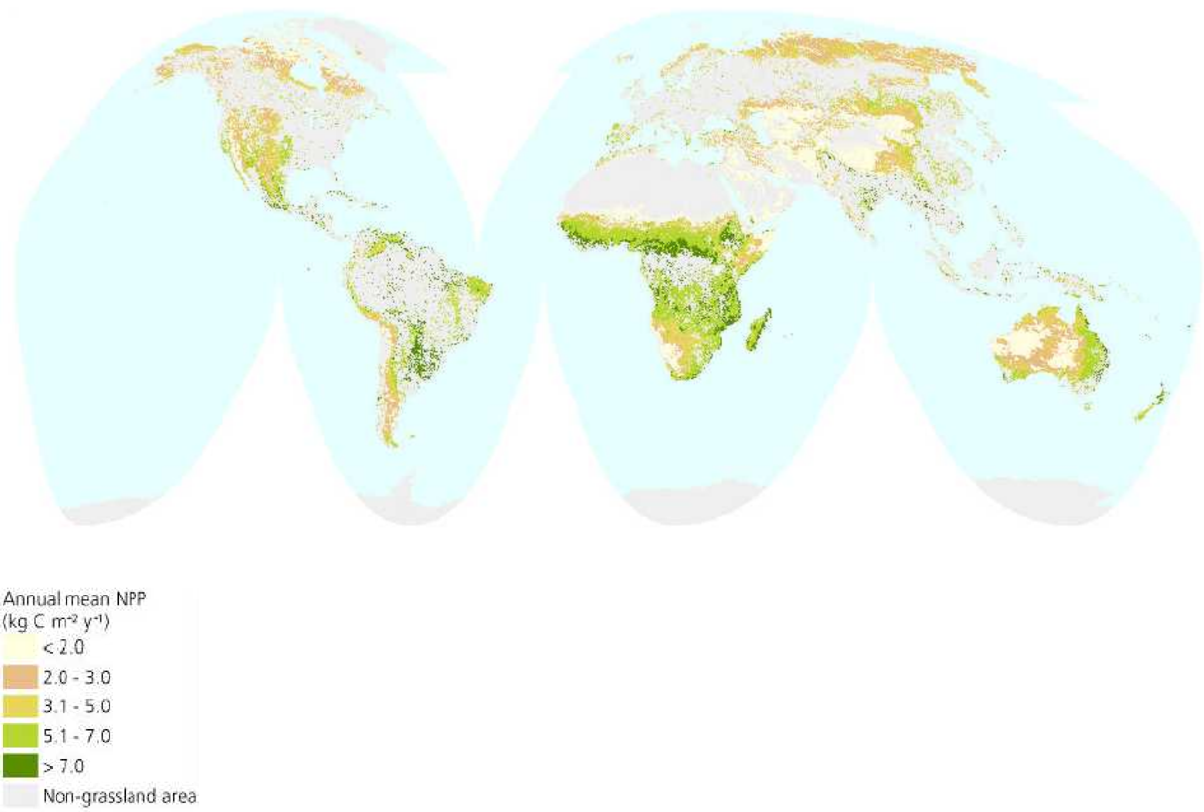

Figure 2. Primary productivity of grasslands.. Net primary productivity, 1982 - 1993[30,31,32]

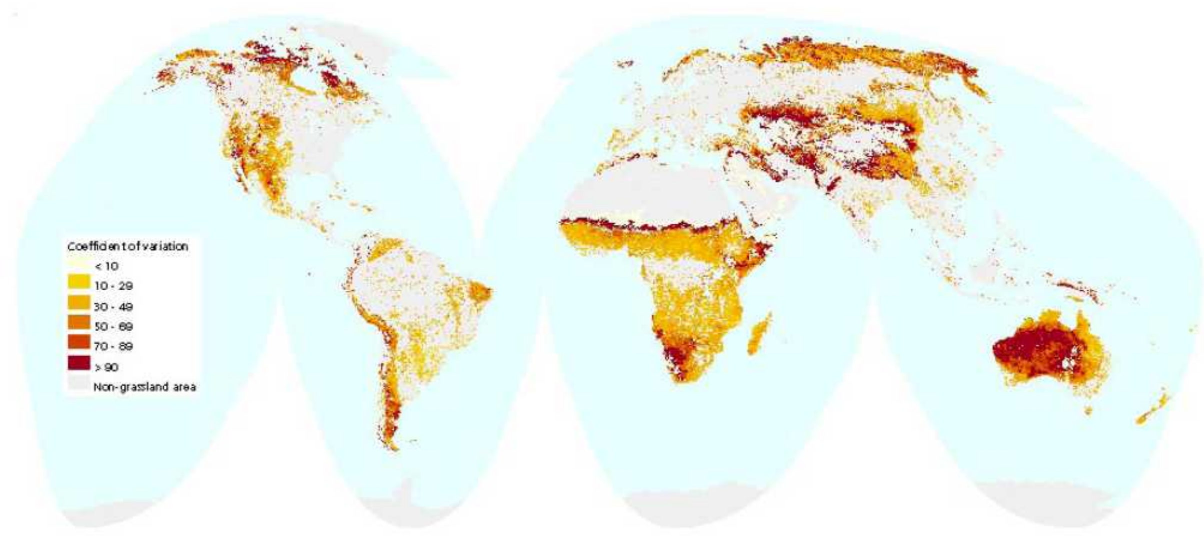

Figure 3. Variation in primary productivity of grasslands

[30] GLCCD. 1998. Global Land Cover Characteristics Database, Version 1.2. Data available online at: http://edc2.usgs.gov/glcc/gifs.php.

[31] Goetz, S.J., S.D. Prince, S.N. Goward, M.M. Thawley, and J. Small. 1999. Satellite remote sensing of primary production: an improved production efficiency modeling approach. *Ecological Modeling* 122:239–255.

[32] Prince, S.D., and S.N. Goward. 1995. Global primary production: a remote sensing approach. *Journal of Biogeography* 22: 815–835.

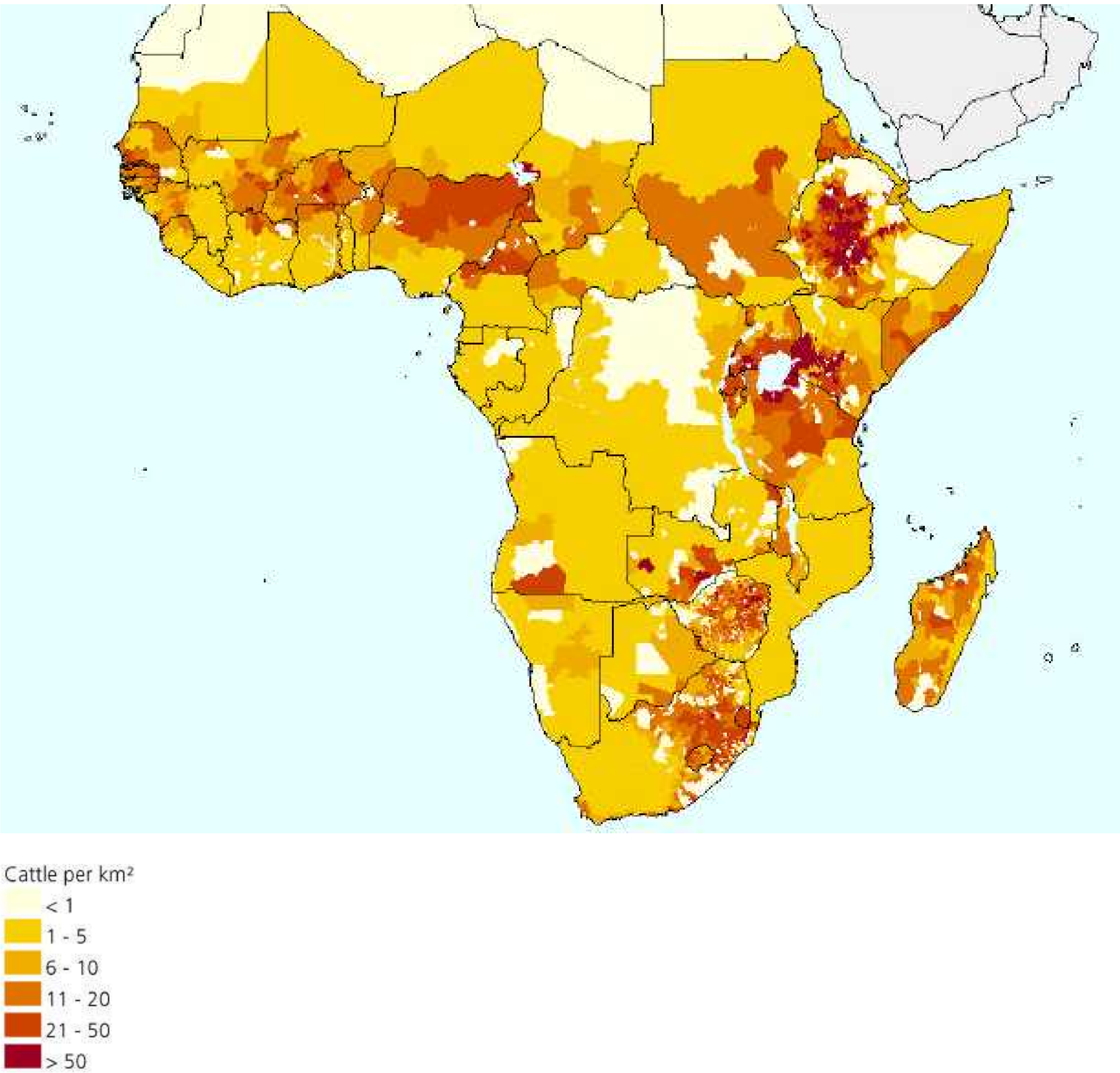

Figure 4. Cattle density in Africa (Source: World Resources Institute - PAGE, 2000)[33] [34]

This map plots the density of cattle in Africa and has been compiled by the International Livestock Research Institute (ILRI). This map shows the highest densities (between 20 and more than 50 cattle per km²) across an east-west band of northern grassland, and along a northeast-southeast band of eastern grassland.

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33 Sources: Environmental Systems Research Institute. 1993, *Digital Chart of the World CD-ROM*. Kruska, R.L., B.D. Perry, and R.S. Reid.

34 Kruska, R.L., B.D. Perry, and R.S. Reid. 1995. Recent progress in the development of decision support systems for improved animal health.. In *Integrated Geographic Information Systems Useful for a Sustainable Management of Natural Resources in Africa*, Proceedings of the Africa GIS '95 meeting. March 6-9, 1995. Abidjan, Ivory Coast.Updated in October, 1998.

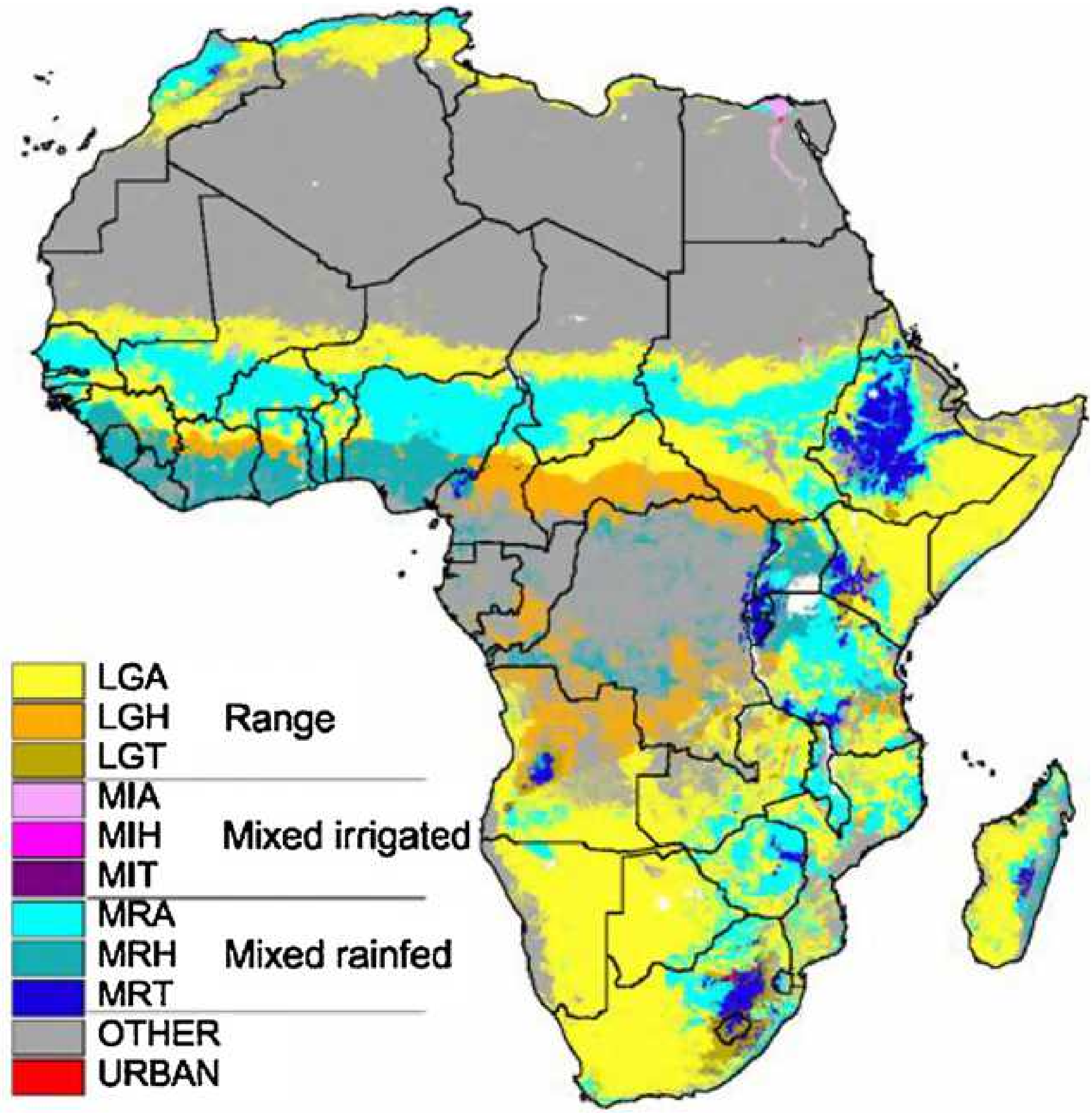

Figure 5. The spatial distribution of livestock systems in Africa—2000 (Kruska et al., 2003). LGA, LGH, LGT = livestock grazing arid, humid and temperate systems, respectively. MIA, MIH, MIT = mixed irrigated arid, humid and temperate systems, respectively. MRA, MRH, MRT = mixed rainfed arid, humid and temperate systems, respectively.

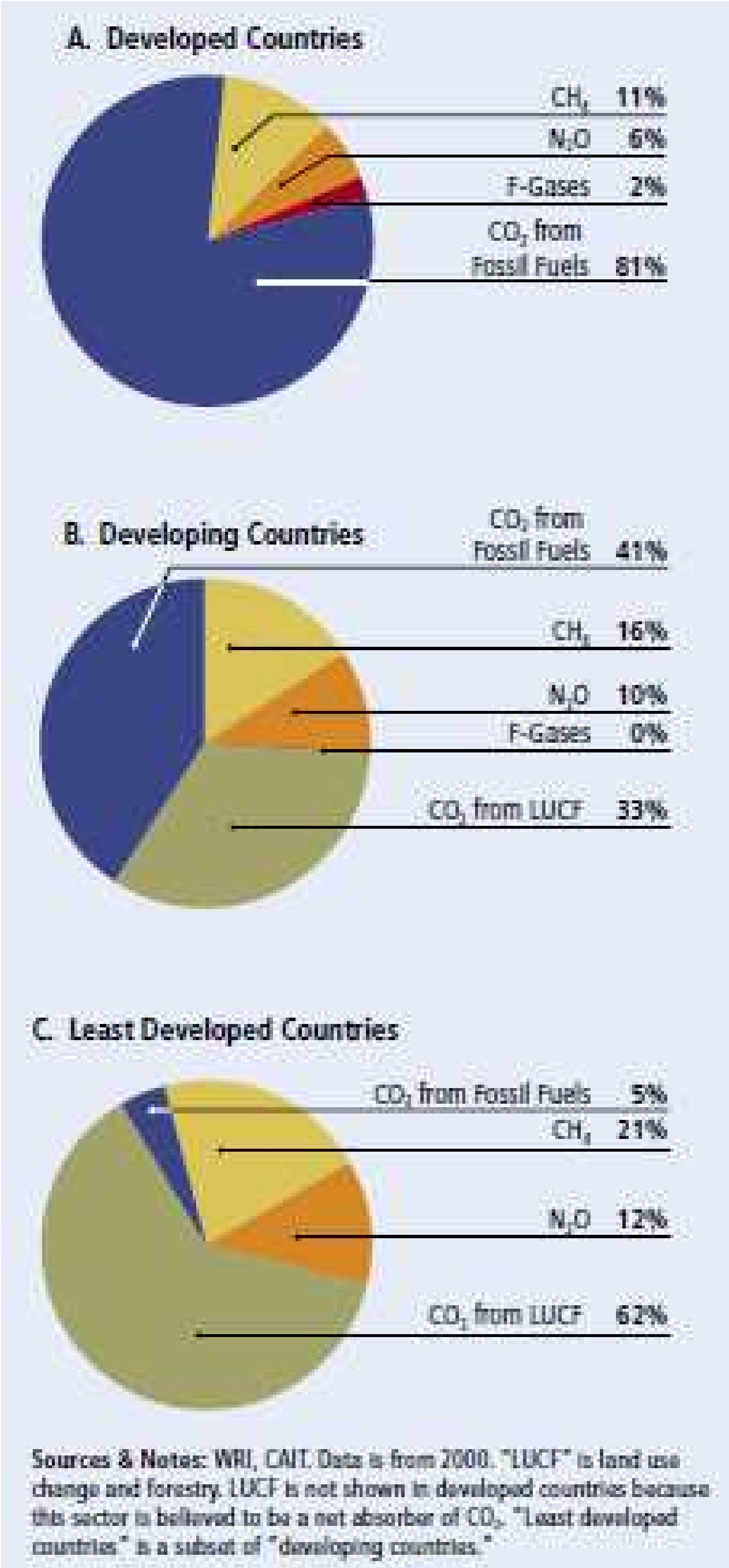

Figure 6. Profile of greenhouse gas emissions as affected by economic development.

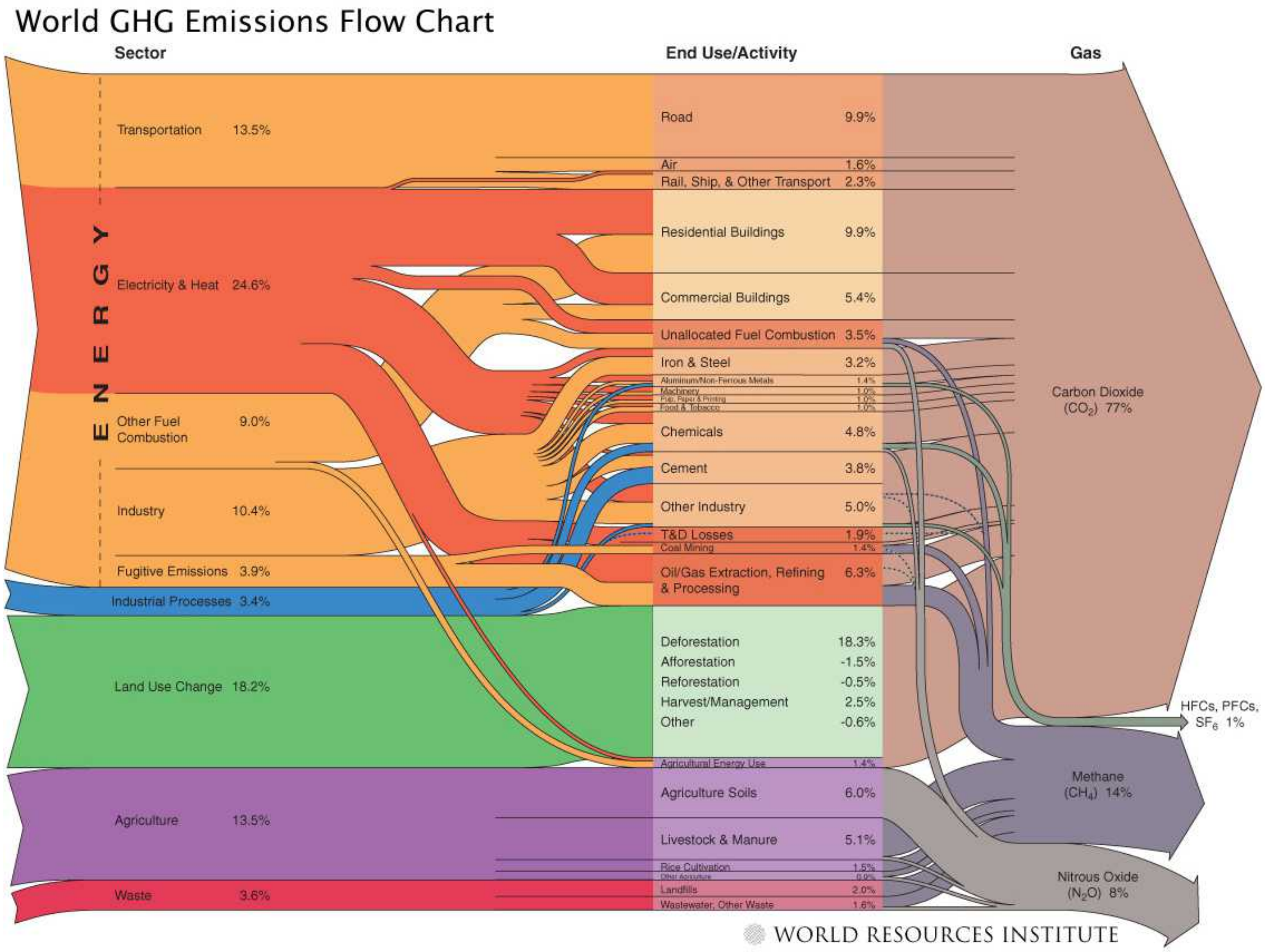

Figure 7. World GHG emissions flow chart

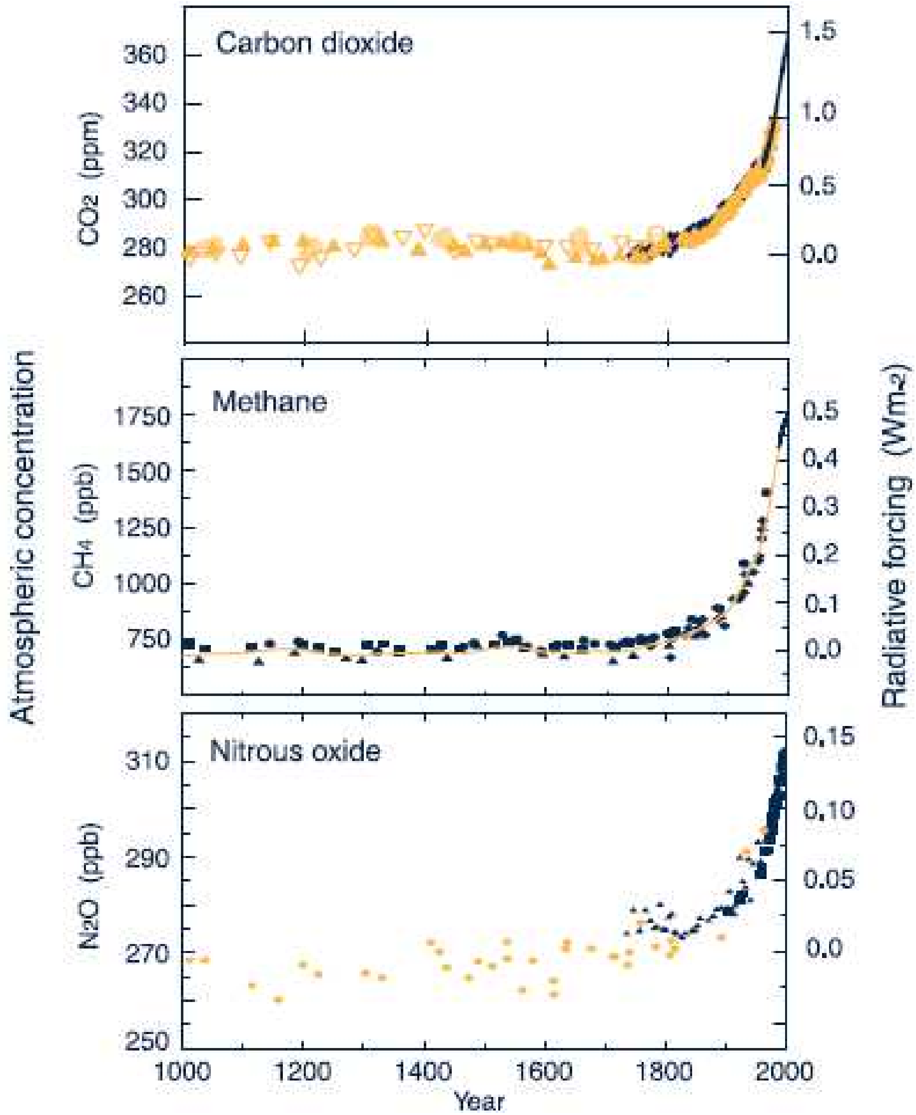

Figure 8
Global atmospheric concentrations of the three leading greenhouse gases.[35]

[35] The Intergovernmental Panel on Climate Change (2001) *Climate Change 2001: The Scientific Basis*.

Table 1. Distribution of grasslands in countries ranked according to total grassland area based on Olsen 1994[36,37] and GLCCD. 1998[38].

Country	Region[b]	Total Land Area (km²)	Total Grassland Area (km²)
Australia	Oceania	7,704,716	6,576,417
Russian Federation	Europe	16,851,600	6,256,518
China	Asia	9,336,856	3,919,452
United States	North America	9,453,224	3,384,086
Canada	North America	9,908,913	3,167,559
Kazakhstan	Asia	2,715,317	1,670,581
Brazil	South America	8,506,268	1,528,305
Argentina	South America	2,781,237	1,462,884
Mongolia	Asia	1,558,853	1,307,746
Sudan	Sub-Saharan Africa	2,490,706	1,292,163
Angola	Sub-Saharan Africa	1,252,365	1,000,087
Mexico	C. America & Carib.	1,962,065	944,751
South Africa	Sub-Saharan Africa	1,223,084	898,712
Ethiopia	Sub-Saharan Africa	1,132,213	824,795
Congo, Dem. Rep.	Sub-Saharan Africa	2,336,888	807,310
Iran	Middle East & N. Africa	1,624,255	748,429
Nigeria	Sub-Saharan Africa	912,351	700,158
Namibia	Sub-Saharan Africa	825,606	665,697
Tanzania, United Republic	Sub-Saharan Africa	945,226	658,563
Mozambique	Sub-Saharan Africa	788,938	643,632
Chad	Sub-Saharan Africa	1,167,685	632,071
Mali	Sub-Saharan Africa	1,256,296	567,140
Central African Republic	Sub-Saharan Africa	621,192	554,103
Somalia	Sub-Saharan Africa	639,004	553,963
India	Asia	3,090,846	535,441
Zambia	Sub-Saharan Africa	754,676	526,843
Botswana	Sub-Saharan Africa	579,948	508,920
Saudi Arabia	Middle East & N. Africa	1,958,974	502,935

[36] Olson, J.S. 1994a. *Global Ecosystem Framework-Definitions*. USGS EROS Data Center Internal Report. Sioux Falls: USGS EROS Data Center. 37pp.
[37] Olson, J.S. 1994b. Global Ecosystem Framework-Translation Strategy: USGS EROS Data Center Internal Report. Sioux Falls: USGS EROS Data Center. 39pp.
[38] GLCCD. 1998. Global Land Cover Characteristics Database, Version 1.2. Data available online at: http://edc2.usgs.gov/glcc/gifs.php.

Table 2. Distribution of grasslands in countries ranked according to proportion of total area. Based on Olsen 1994 [39,40] and GLCCD. 1998[41].

Country	Region[b]	Total Land Area (km^2)	Grassland Area (percent)
Benin	Sub-Saharan Africa	116,689	93.1
Central African Republic	Sub-Saharan Africa	621,192	89.2
Botswana	Sub-Saharan Africa	579,948	87.8
Togo	Sub-Saharan Africa	57,386	87.2
Somalia	Sub-Saharan Africa	639,004	86.7
Australia	Oceania	7,704,716	85.4
Burkina Faso	Sub-Saharan Africa	273,320	84.7
Mongolia	Asia	1,558,853	83.9
Guinea	Sub-Saharan Africa	246,104	83.5
Mozambique	Sub-Saharan Africa	788,938	81.6
Namibia	Sub-Saharan Africa	825,606	80.6
Angola	Sub-Saharan Africa	1,252,365	79.9
Zimbabwe	Sub-Saharan Africa	391,052	76.8
Nigeria	Sub-Saharan Africa	912,351	76.7
Guinea-Bissau	Sub-Saharan Africa	34,117	73.9
Senegal	Sub-Saharan Africa	196,699	73.5
South Africa	Sub-Saharan Africa	1,223,084	73.5
Lesotho	Sub-Saharan Africa	30,533	73.5
Afghanistan	Middle East & N. Africa	642,146	73.4
Ethiopia	Sub-Saharan Africa	1,132,213	72.9
Zambia	Sub-Saharan Africa	754,676	69.8
Tanzania, United Republic	Sub-Saharan Africa	945,226	69.7
Madagascar	Sub-Saharan Africa	594,816	69.4
Kenya	Sub-Saharan Africa	584,453	68.6
Ghana	Sub-Saharan Africa	240,055	64.2
Cote d'Ivoire	Sub-Saharan Africa	322,693	62.3
Turkmenistan	Asia	471,216	62.1
Kazakhstan	Asia	2,715,317	61.5

[39] Olson, J.S. 1994a. *Global Ecosystem Framework-Definitions*. USGS EROS Data Center Internal Report. Sioux Falls: USGS EROS Data Center. 37pp.
[40] Olson, J.S. 1994b. Global Ecosystem Framework-Translation Strategy: USGS EROS Data Center Internal Report. Sioux Falls: USGS EROS Data Center. 39pp.
[41] GLCCD. 1998. Global Land Cover Characteristics Database, Version 1.2. Data available online at: http://edc2.usgs.gov/glcc/gifs.php.

Table 3.
Production of key ruminant meats and milk (tonnes)

Country	Beef and buffalo meat	Cows milk	Sheep and goat meat	Ruminant meat trade kg/ha pasture
Burundi	5,800	16,800	3,900	0.0
Eritrea	16,650	39,200	11,400	0.0
Ethiopia	350,000	1,580,000	124,000	0.0
Kenya	390,000	3,500,000	75,000	0.0
Rwanda	22,000	120,000	5,300	0.1
Sudan	340,000	5,300,000	334,000	0.0
Tanzania	247,000	850,000	40,850	0.0
Uganda	106,000	795,000	34,800	0.1
South Africa	704,950	2,870,870	151,747	0.9
Mongolia	47,000	300,000	102,000	0.0
India	2,833,850	95,619,000	762,000	0.0
Kazakhstan	345,000	4,749,000	117,700	0.0
Kyrgystan	90,850	1,197,660	46,374	0.0
Turkmenistan	100,000	1,400,000	96,500	0.0
Uzbekistan	518,100	5,004,879	736,000	0.0
New Zealand	632,378	15,841,624	574,755	65.9
United Kingdom	850,000	14,450,000	330,000	53.1

Table 4.
Livestock and grassland resources

Country	Number of cattle and buffalos	Number of sheep and goats	Pasture (ha)	Rainfall index (mm)
Burundi	395,741	1,142,933	950,000	1042
Eritrea	1,950,000	3,950,000	6,967,000	323
Ethiopia	40,390,098	37,097,961	20,000,000	1050
Kenya	13,019,000	23,916,500	21,300,000	998
Rwanda	1,004,100	1,734,000	520,000	1115
Sudan	40,468,000	92,323,000	117,180,000	741
Tanzania	17719,091	16,071,000	43,000,000	1116
Uganda	6,770,000	9,400,000	5,112,000	1401
South Africa	13,790,000	31,690,000	83,928,000	640
Mongolia	1,841,600	23,924,400	129,294,000	156
India	279,712,000	187,760,000	11,040,000	1432
Kazakhstan	5,212,900	13,409,100	185,098,000	277
Kyrgystan	1,034,890	3,773,617	9,291,000	419
Turkmenistan	2,024,500	15,089,000	30,700,000	104
Uzbekistan	6,571,400	11,351,900	22,800,000	264
New Zealand	9,510,802	40,034,660	13,863,000	1248
United Kingdom	10,378,000	35,345,048	11,000,000	1129

Table 5. Livestock productivity

Country	Cattle and buffalo meat (kg/animal)	Sheep and goat meat (kg/animal)	Milk yield per cow kg/cow
Burundi	15	3	294
Eritrea	9	3	196
Ethiopia	9	3	200
Kenya	30	3	482
Rwanda	22	4	480
Sudan	8	4	366
Tanzania	14	3	174
Uganda	16	4	350
South Africa	51	5	2,975
Mongolia	26	4	407
India	10	5	1,087
Kazakhstan	66	9	1,975
Kyrgystan	88	12	2,140
Turkmenistan	49	6	1,386
Uzbekistan	79	7	1,576
New Zealand	67	14	3,553
United Kingdom	82	9	7,190

Table 6. Primary energy use and greenhouse gas emissions arising from the production of beef, sheepmeat and milk in the UK (from Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. (From Defra project report IS0205, using data updated in 2009)

Commodity (1 tonne carcase meat or raw milk)	Primary energy use (MJ)	Global warming potential (kg CO_2)	N_2O (kg)	CH4 (kg)	CO_2 (kg)
			Emissions		
Beef	30210	12114	13.50	239	1837
Sheep meat	21834	14605	15.70	310	1381
Milk	2660	1008	0.94	22	169
	Emission in CO_2 equivalent				
Beef	30210	12114	3996 (33%)	5497 (45%)	1837 (15%)
Sheep meat	21834	14605	4647 (32%)	7130 (49%)	1381 (9%)
Milk	2660	1008	278 (28%)	506 (50%)	169 (17%)

Table 7. Data for key productivity parameters for livestock in different world regions (from Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

Region	Chicken meat (kg output/kg biomass/year)[1]		Egg yield (kg/layer/year)		Pig meat (kg output/kg biomass/year)[1]	
	1980	2005	1980	2005	1980	2005
World	1.83	2.47	8.9	10.3	0.31	0.45
Developing countries	1.29	1.98	5.5	8.8	0.14	0.33
Developed countries	2.26	3.55	12.2	15.0	0.82	1.20
Sub-Saharan Africa	1.46	1.63	3.4	3.6	0.53	0.57
West Asia and North Africa	1.73	2.02	7.0	9.4	1.04	1.03
Latin America and the Caribbean	1.67	3.41	8.6	9.8	0.41	0.79
South Asia	0.61	2.69	5.8	8.1	0.72	0.71
East and Southeast Asia	1.03	1.41	4.7	9.5	0.12	0.31
Industrialized countries	2.45	3.72	14.1	16.0	1.03	1.34
Transition countries	1.81	2.75	9.6	13.0	0.57	0.75

Region	Beef (kg output/kg biomass/year)[1]		Small ruminants (kg output/kg biomass/year)[1]		Milk yield (kg/cow/year)	
	1980	2005	1980	2005	1980	2005
World	0.11	0.13	0.16	0.26	1 974	2 192
Developing countries	0.06	0.09	0.14	0.26	708	1 015
Developed countries	0.17	0.21	0.19	0.24	3 165	4 657
Sub-Saharan Africa	0.06	0.06	0.15	0.15	411	397
West Asia and North Africa	0.07	0.10	0.21	0.25	998	1 735
Latin America and the Caribbean	0.08	0.11	0.11	0.13	1 021	1 380
South Asia	0.03	0.04	0.16	0.23	517	904
East and Southeast Asia including China	0.06	0.16	0.05	0.20	1 193	1 966
Industrialized countries	0.17	0.20	0.20	0.25	4 226	6 350
Transition countries	0.18	0.22	0.17	0.23	2 195	2 754

[1] Biomass is calculated as inventory x average liveweight. Output is given as carcass weight.
Source: FAO (2006b).

Table 8. Estimates of enteric methane emission from livestock in different world regions (from Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

Enteric fermentation emission factors (EF) for cattle (kilogram CH_4 per head per year) by production system and world region. Tier 2 based estimates compared to tier 1 emission factors

Region	Dairy cattle				Other cattle				
	Grazing	Mixed	Weighted EF	Tier 1 EF	Grazing	Mixed	Industrial	Weighted EF	Tier 1 EF
Sub-Saharan Africa	79	39	60	36	44	27	-	36	32
Asia excluding China and India	79	53	54	56	66	38	-	38	44
India	70	45	45	46	41	17	-	18	25
China	102	63	84	56	85	38	-	49	44
Central and South America	93	62	78	57	58	33	23	47	49
West Asia and North Africa	91	60	61	36	49	31	-	32	32
North America	115	100	100	118	50	33	26	35	47
OECD excluding North America	102	97	98	100	45	27	26	32	48
Eastern Europe and the CIS	-	59	59	81	-	45	24	41	56
Other developed	96	129	99	36	45	27	28	45	32

Table 9
Estimates of methane emissions from livestock manure management in different world regions (from Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

Manure management methane emission factors (EF) for cattle (kilogram CH_4 per head per year) by production system and world region. Tier 2 based estimates compared to tier 1 emission factors

Region	Dairy cattle		Other cattle		Pigs	
	Weighted EF	Tier 1 EF	Weighted EF	Tier 1 EF	Weighted EF	Tier 1 EF
Sub-Saharan Africa	2.5	1	1.5	1	1.6	2
Asia excluding China and India	18.6	16	0.8	1	7.4	4-7
India	5.3	6	1.5	2	12.4	6
China	12.9	16	1.0	1	7.6	4-7
Central and South America	2.4	2	1.0	1	9.6	2
West Asia and North Africa	3.8	2	2.4	1	1.7	6
North America	51.0	54	9.5	2	22.7	14
OECD excluding North America	41.8	40	10.9	20	11.1	10
Eastern Europe and the CIS	13.7	6	9.1	4	2.8	4
Other developed	12.8	1	1.9	1	21.7	6

Table 10. Estimates of total enteric methane emissions from livestock in different world regions (from Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

Region/country	Emissions (million tonnes CH_4 per year by source)					
	Dairy cattle	Other cattle	Buffaloes	Sheep and goats	Pigs	Total
Sub-Saharan Africa	2.30	7.47	0.00	1.82	0.02	**11.61**
Asia *	0.84	3.83	2.40	0.88	0.07	**8.02**
India	1.70	3.94	5.25	0.91	0.01	**11.82**
China	0.49	5.12	1.25	1.51	0.48	**8.85**
Central and South America	3.36	17.09	0.06	0.58	0.08	**21.17**
West Asia and North Africa	0.98	1.16	0.24	1.20	0.00	**3.58**
North America	1.02	3.85	0.00	0.06	0.11	**5.05**
Western Europe	2.19	2.31	0.01	0.98	0.20	**5.70**
Oceania and Japan	0.71	1.80	0.00	0.73	0.02	**3.26**
Eastern Europe and CIS	1.99	2.96	0.02	0.59	0.10	**5.66**
Other developed	0.11	0.62	0.00	0.18	0.00	**0.91**
Total	**15.69**	**50.16**	**9.23**	**9.44**	**1.11**	**85.63**
Livestock Production System						
Grazing	4.73	21.89	0.00	2.95	0.00	**29.58**
Mixed	10.96	27.53	9.23	6.50	0.80	**55.02**
Industrial	0.00	0.73	0.00	0.00	0.30	**1.04**

* Excludes China and India.

Table 9 Estimates of methane emissions from livestock manure in different world regions (from Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

Region/country	Emissions (million tonnes CH_4 per year by source)						
	Dairy cattle	Other cattle	Buffalo	Sheep and goats	Pigs	Poultry	Total
Sub-Saharan Africa	0.10	0.32	0.00	0.08	0.03	0.04	**0.57**
Asia *	0.31	0.08	0.09	0.03	0.50	0.13	**1.14**
India	0.20	0.34	0.19	0.04	0.17	0.01	**0.95**
China	0.08	0.11	0.05	0.05	3.43	0.14	**3.84**
Central and South America	0.10	0.36	0.00	0.02	0.74	0.19	**1.41**
West Asia and North Africa	0.06	0.09	0.01	0.05	0.00	0.11	**0.32**
North America	0.52	1.05	0.00	0.00	1.65	0.16	**3.39**
Western Europe	1.16	1.29	0.00	0.02	1.52	0.09	**4.08**
Oceania and Japan	0.08	0.11	0.00	0.03	0.10	0.03	**0.35**
Eastern Europe and CIS	0.46	0.65	0.00	0.01	0.19	0.06	**1.38**
Other developed	0.01	0.03	0.00	0.01	0.04	0.02	**0.11**
Global Total	**3.08**	**4.41**	**0.34**	**0.34**	**8.38**	**0.97**	**17.52**
Livestock Production System							
Grazing	0.15	0.50	0.00	0.12	0.00	0.00	**0.77**
Mixed	2.93	3.89	0.34	0.23	4.58	0.31	**12.27**
Industrial	0.00	0.02	0.00	0.00	3.80	0.67	**4.48**

* Excludes China and India.

Table 11 Estimates of nitrous oxide emissions from livestock manure in different world regions (from Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann, Cees. 2006. Livestock's Long Shadow. FAO).

Region/country	N_2O emissions from manure management, after application/deposition on soil and direct emissions						
	Dairy cattle	Other cattle	Buffalo	Sheep and goats	Pigs	Poultry	Total
	(.... million tonnes per year						
Sub-Saharan Africa	0.06	0.21	0.00	0.13	0.01	0.02	**0.43**
Asia excluding China and India	0.02	0.14	0.06	0.05	0.03	0.05	**0.36**
India	0.03	0.15	0.06	0.05	0.01	0.01	**0.32**
China	0.01	0.14	0.03	0.10	0.19	0.10	**0.58**
Central and South America	0.08	0.41	0.00	0.04	0.04	0.05	**0.61**
West Asia and North Africa	0.02	0.03	0.00	0.09	0.00	0.03	**0.17**
North America	0.03	0.20	0.00	0.00	0.04	0.04	**0.30**
Western Europe	0.06	0.14	0.00	0.07	0.07	0.03	**0.36**
Oceania and Japan	0.02	0.08	0.00	0.09	0.01	0.01	**0.21**
Eastern Europe and CIS	0.08	0.10	0.00	0.03	0.04	0.02	**0.28**
Other developed	0.00	0.03	0.00	0.02	0.00	0.00	**0.06**
Total	**0.41**	**1.64**	**0.17**	**0.68**	**0.44**	**0.36**	**3.69**
Livestock Production System							
Grazing	0.11	0.54	0.00	0.25	0.00	0.00	**0.90**
Mixed	0.30	1.02	0.17	0.43	0.33	0.27	**2.52**
Industrial	0.00	0.08	0.00	0.00	0.11	0.09	**0.27**

Table12. Structure of the "Top Down" calculations used to estimate the Land-Use change emissions chargeable to commercial agricultural production based on methodology used by Matthew Brander of Ecometrica, UK.

Step 1. Calculate total LUC emissions per year.

The first step is to calculate total annual LUC emissions. There are a number of methods or data sources for this information, including:

(a) Using data on areas of deforestation and other natural habitat conversion (e.g. FAO 2005) and default emissions factors for land conversion (from IPCC 2000).
(b) Or estimates in the IPCC Fourth Assessment Report (IPCC 2006).

Output from Step 1: a figure (or range of figures) for global LUC emissions in $GtCO_2e/yr$.

Step 2. Estimate the proportion of total LUC emissions attributable to commercial agriculture (including livestock production).

There are a number of causes of LUC, e.g. commercial agriculture, logging, subsistence agriculture, and other anthropogenic causes (urban expansion, infrastructure etc.). It is therefore necessary to estimate the proportion of total LUC emissions attributable to commercial agriculture. There are a number of methods or data sources for this information, including:

(a) FAO (2005), IPCC (2006) and other existing literature provide estimates of the proportion of global deforestation and other LUC caused by agriculture.
(b) Estimates can be made using figures for the area of new agricultural land each year (from FAOstat), and the conservative assumption that all new agricultural land will be from converted natural habitats.

Output from Step 2: a figure (or range of figures) for the proportion of global LUC emissions attributable to commercial agriculture, as a percentage (%) and $GtCO_2e/yr$.

Step 3. Allocation of LUC emissions attributable to commercial agriculture to different food-types/commodities.

The total emissions attributable to commercial agriculture need to be allocated to different food-types/commodities (e.g. grains, vegetables, fruit, meat, etc).
This involves:

(a) Dividing total LUC emissions attributable to commercial agriculture by the total land area used for each food-type/commodity to give emissions per hectare.
(b) Dividing the resulting tCO_2e/hectare figures by the commodity output per hectare for each food-type/commodity

Output from Step 3: figures for the emissions per unit of output for each food-type/commodity ($kgCO_2e/kg$ of commodity).

Step 4. Calculation of UK food LUC emissions (by food-type/commodity).

UK food LUC emissions can be calculated by multiplying the emissions factor for each food-type (from Step 3) by the quantity of each food-type/commodity consumed by the UK.
Output from Step 4: figures for total LUC emissions from UK food consumption by each food-type/commodity consumed (tCO_2e/food-type). This output can then be used in the mitigation scenarios in the main part of the research project (e.g. switching to food-types with lower land-area requirements, or reducing LUC emissions by reducing total food consumption through reducing waste).

Table 12. Primary energy use and greenhouse gas emissions arising from the production of beef, sheepmeat and milk in the UK (from Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. (From Defra project report IS0205, using data updated in 2009)

Commodity (1 tonne carcase meat or raw milk)	Primary energy use (MJ)	Global warming potential (kg CO2)	N2O (kg)	CH4 (kg)	Fossil fuel CO2 (kg)	Land-use change CO2 (kg)
UK livestock emissions without land-use change						
Beef	30210	12114	13.50	239	1837	0
Sheep meat	21834	14605	15.70	310	1381	0
Milk	2660	1008	0.94	22	169	0
UK livestock emissions in CO_2 equivalents						
Beef	30210	12114	3996 (33%)	5497 (45%)	1837 (15%)	0
Sheep meat	21834	14605	4647 (32%)	7130 (49%)	1381 (9%)	0
Milk	2660	1008	278 (28%)	506 (50%)	169 (17%)	0
UK livestock emissions with estimates for land-use change						
Beef	30210	22114	13.50	239	1837	10,000
Sheep meat	21834	24605	15.70	310	1381	10,000
Milk	2660	2008	0.94	22	169	1,000
UK livestock emissions in CO_2 equivalents						
Beef	30210	42114	3996	5497	1837 (5%)	20,000(48%)
Sheep meat	21834	44605	4647	7130	1381 (3%)	20,000 (45%)
Milk	2660	4008	278	506	169 (4%)	2,000 (50%)
Extensive production from natural grassland in Africa						
Beef	0		52	1065-1957	0	0
Sheep/Goat meat	0		90	509-1290	0	0
Cows milk	0		3	210	0	0
UK livestock emissions in CO_2 equivalents						
Beef	0	39887-60403	15392 (25-39%)	24495-45011(61-75%)	0	0
Sheep/Goat meat	0	38347-56310	26640 (47-70%)	11707-29670(30-53%)	0	0
Cows milk	0	5718	888 (15%)	4830 (85%)	0	0