The Impact of Biofuels on Food Security

From Global to Local, using Case Studies from Mozambique and Tanzania

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Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

Stephen Thornhill

Abstract

The long-running "food versus fuel" debate has focussed on the impact of biofuels on food security, and, therefore, the justification of government policies to encourage biofuel production. There has been particular criticism of the impact of US and EU biofuel policies on food availability and food prices, with many reports suggesting that rising biofuel production has been largely responsible for reduced global food supplies and higher food prices.

There has been less coverage of the impact of biofuel operations in food-insecure countries, many of which are well suited to producing the highest-yielding biofuel feedstocks and would most benefit from jobs and renewable energy supplies in rural, poverty-stricken areas. Part of the difficulty in assessing the impact of biofuels at the local level is the wide variety of indicators used to measure food security. Whilst many indicators have been developed to measure "status", it is more difficult to measure "impact" and the reasons behind any significant status change.

The objectives of this thesis therefore focus on whether biofuel policies reduce availability and access to food in food insecure countries, how best to measure food security outcomes and whether different types of biofuel operations in developing countries impact on household food security status.

Following an appraisal of existing food security indicators, a novel indicator was developed to measure the nutrient deficiency of households from reported foods consumed, in order to provide a better means of linking status, impact and mitigation. This led to the development of the "household nutrient deficit score", helping to link nutrition outcomes to household decisions on food production and purchases.

Mozambique and Tanzania represent two of the most food-insecure countries with potential for biofuel production. Household surveys were conducted in both countries where biofuel operations had recently been established, from which reliable results were achieved for five operations with different production models and feedstocks. A detailed analysis was also conducted of the global biofuel sector in

order to garner reliable data on biofuel production and feedstock areas over the past decade and to assess the impact of biofuels on staple commodity prices and food and land availability.

The results of the household survey showed that those households with employees of biofuel operations were likely to be significantly more food-secure than other households in the same locality, as reflected in a lower household nutrient deficit score. A regression analysis that controlled for geographical location and other influences on food security, such as household size and crop area, confirmed "biofuel involvement" as a significant factor behind higher food security status. Most "involved" households attributed their improved food security status to better and more stable income from salaried employment.

The macro global biofuel sector analysis found that the harvested area of feedstock attributable to biofuel production was much lower than suggested within the literature, and had barely increased since 2011. Before the introduction of the US and EU biofuel production-enhancing policies around 2005, the global biofuel feedstock area stood at only 6 million hectares: the acreage has increased by 19 million hectares since then, which represents little more than 1 per cent of the global arable and permanent crop acreage.

The macro analysis found little evidence that biofuels had reduced global food availability by diverting land away from food production. The price analysis also found little evidence that US biofuel production had accounted for a large proportion of maize price changes over the past decade. Furthermore, there appeared to be limited transmission between US maize prices, used as a global benchmark, and local maize prices in Mozambique and Tanzania.

One of the main implications of the micro-analysis is that biofuels can, under the right conditions, help improve food security in rural areas of food insecure countries where poverty and hunger is most rife. Hence, policies should be implemented to facilitate the right conditions, and these could include mandatory sustainability certification. In terms of the macro analysis, there appears to be insufficient evidence to justify the claims that biofuel policies in developed countries have led to increased hunger. Indeed, there is an overriding need to better understand the dynamics and impacts of increased food prices on rural households in least developed countries.

1. Introduction

1.1 Background

Climate change is arguably the greatest challenge currently facing humanity. In December 2015, 195 countries finally adopted a legally binding and universal climate agreement at the 21st Conference of Parties (COP21) under the auspices of the UN Framework Convention on Climate Change (UNFCCC). The agreement was made some 24 years after the international community took the first steps to address climate change at the Rio Earth Summit of 1992[1].

Although our global society is only now coming to terms with the need for concerted and substantial action to mitigate global warming, many initiatives have been undertaken since the Rio Summit. One such response has been the rapid expansion of liquid biofuel production over the past decade, encouraged by government policies to partially replace fossil fuels, a major contributor to rising levels of atmospheric greenhouse gases (GHGs).

However, biofuels have courted much controversy. In the early years of the new millennium they were heralded not only as a partial solution to climate change, but also to peak oil[2] and energy insecurity concerns, and rural socio-economic decline. In more recent times biofuels have attracted growing criticism, particularly with regard to their alleged association with;

i) displacement of feedstock, land and other resources from food to biofuel use, raising concerns over food availability

ii) "land-grabbing", and the consequent impacts on the livelihoods of poor rural communities

[1] The Rio Summit took place some 4 years after the international community acknowledged global warming by establishing the Intergovernmental Panel on Climate Change (IPCC) in 1988.
[2] The peak oil issue is now less relevant following research by McGlade and Ekins (2015) that large reserves of fossil fuels need to be left unused in order to keep the global temperature rise below 2 degrees centigrade.

iii) deforestation and other types of land conversion which damage ecosystems and accentuate climate change.

iv) higher, and more volatile, food prices over recent years, particularly affecting the food security of the poorest members of society

v) poor technical efficiency and limited ability to reduce fossil fuel use, and, hence, greenhouse gas emissions.

vi) costly government support to make them commercially viable with competing fuels, and notably fossil fuels

These issues have been particularly voiced within the so-called “food versus fuel” debate, and especially regarding food availability and price impacts.

Proponents, meanwhile, argue that biofuels take many forms, some of which can significantly reduce greenhouse gas emissions, do not involve land-grabbing or environmental damage, do not unduly influence food prices, do not require government support and can help to improve food security by providing employment and income in rural areas.

Despite a plethora of research studies and reports on these and other related issues over recent years, the debate surrounding whether to promote or discourage biofuel production shows no sign of abating and opinion remains divided. The many different types of biofuels and the various conditions under which their feedstocks are sourced create significant dilemmas for policymaking. Yet decisive actions are required by governments to address urgent climate-related problems.

Some of the main concerns regarding biofuels relate to socio-economic impacts. A few months prior to the climate change accord in December 2015, governments agreed the Sustainable Development Goals (United Nations, 2015b). The 17 sustainable development goals (SDGs) set out in the Resolution adopted by the General Assembly of the United Nations (UN), include ending poverty (SDG1), ending hunger (SDG2), ensuring access to affordable, reliable, sustainable and modern energy for all (SDG7), full and productive employment and decent work for all (SDG8) and ensuring sustainable consumption and production patterns (SDG12). A key issue for policymakers will be to ensure that climate change targets agreed in Paris are coherent with the sustainable development goals agreed in New York. Biofuels represent just one example of potential conflicts between environmental and social outcomes.

The food versus fuel debate has remained a contentious issue for more than a decade during which time biofuels have been promoted and then restrained by government policy. The ongoing debate is an indication of the many challenges that are likely to be faced in the implementation of the climate change agreement and sustainable development goals. A particular challenge in this regard will be the measurement of social and environmental outcomes at the micro level with more relevant, accurate and timely indicators than are currently available.

1.2 Justification

1.2.1 Identifying the key policy issues related to biofuels

The key challenges to humanity in the 21st century are perhaps best conceptualised by Kate Raworth's depiction of a *"safe and just space for humanity"*(Raworth, 2012)[3]. Raworth draws on the work of Rockstrom et al[4], who identified nine environmental planetary boundaries, within which they deemed a *"safe operating space"* for humanity to survive (Rockstrom et al., 2009). Raworth then added eleven key social foundations, which represent the *"just"* conditions to meet human rights and needs. The combination of the planetary boundaries and social foundations creates a doughnut-shaped space within which humanity can not only survive but thrive.

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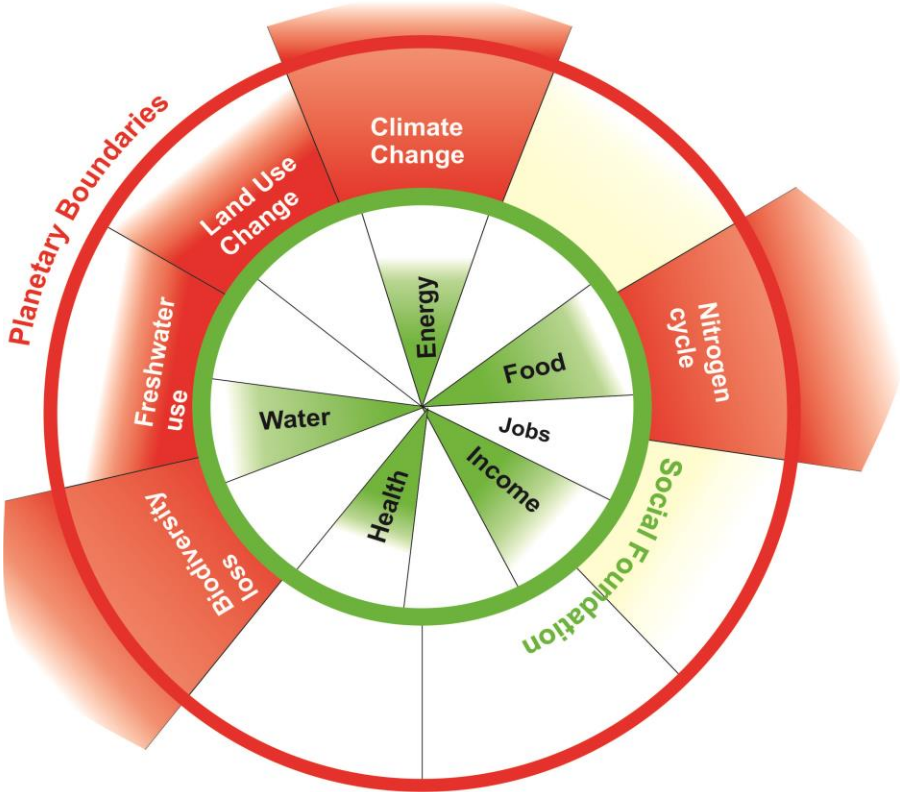
[3] Although developed some years ago this provides a useful framework for identifying the main environmental (including climate change) and human rights problems facing global society, as opposed to alternatives such as the World Economic Forum's annual Global Risks Report, where priority risks identified by world political leaders change from year to year.

[4] The nine planetary boundaries were identified and agreed by 29 leading earth-systems scientists who convened at the Stockholm Resilience Center in 2009.

Figure 1.1 below adapts Raworth and Rockstrom's concepts to show the key environmental and socio-economic issues associated with biofuel production and the current status of each. Thus, for the planetary boundaries, the five environmental issues most directly linked to biofuel production are labelled: climate change, land use change, freshwater use, biodiversity loss and the nitrogen cycle[5]. The red shaded area illustrates the estimated current status of each of these issues compared to their respective planetary boundaries.

Fig 1.1 – Key Environmental and Social Issues Related to Biofuels[6]



Source: Author's adaptation from Raworth (2012) and Rockstrom (2009)

Three of these planetary boundaries have already been exceeded, reflected by the red-shaded area exceeding the circular planetary boundary line. The climate change

[5] Note that Rockstrom et al defined the nitrogen cycle issue in combination with the global phosphorous cycle, but deemed that nitrogen-induced eutrophication of lakes and marine ecosystems posed a much greater risk.

[6] Note that the red-shaded shapes between the green social foundation line and the red planetary boundary line illustrate the key environmental issues related to biofuels. Where the current status of an environmental issue exceeds its planetary boundary, this is illustrated by the red shaded area encroaching outside the red boundary line. The green shaded shapes within the social foundation circle represent the key social issues related to biofuels. The green shaded area depicts the extent to which society meets the social foundation of each of these issues. Note there is no target measure agreed as yet for jobs.

target of 350 parts per million (ppm) of CO_2 atmospheric concentration has already been surpassed, with current levels well over 400ppm (Dlugokenchy and Tans, 2016). Most of the rise in CO_2 concentration is due to the burning of more fossil fuels due to population and economic growth. Alternative energy sources are therefore required in order to help phase out fossil fuel use whilst the population continues to grow, and to maintain economic growth, particularly in developing countries.

It should also be noted that agriculture, forestry and land use (AFOLU) change account for about a quarter of GHG emissions, according to the Intergovernmental Panel on Climate Change (IPCC, 2014), whilst recognising that there is a high degree of uncertainty over these estimates. Over the period 1990 to 2010, the Food and Agriculture Organisation of the United Nations (FAO) estimates that AFOLU net emissions increased by 8 per cent (Tubiello et al., 2014). More recent estimates suggest a decline in AFOLU emissions due to reduced deforestation and increased afforestation.

Nevertheless, the contribution of biofuels to land use change and deforestation, particularly of high carbon-sink tropical peatland, remains an important climate change issue. The IPCC (2014) stated that bioenergy can play a role in mitigation and noted that low emission technologies are already available, including sugar cane bioenergy. But it also raised concerns surrounding the efficiency of some types of bioenergy, as well as impacts on food security and livelihoods.

Biodiversity loss is currently estimated at over 100 species per million (or 0.01%) becoming extinct each year, compared with a target level of 10 per million (Rockstrom et al., 2009). Loss of biodiversity is associated with increased vulnerability in ecosystems to change, including global warming. The growing of monoculture feedstocks for biofuels could have a negative impact in this regard.

In terms of land use, the proposed planetary boundary is 15 per cent crop coverage of global (ice-free) land, compared with a current level of 11.7 per cent, the undershoot difference amounting to just over 400 million hectares. Similarly, freshwater use for human consumption, at 2,600km^3 per annum, is also within the estimated planetary boundary of 4,000km^3 (Rockstrom). The extent to which any expansion in biofuel feedstock production would absorb remaining land and water resources, versus those needed for increased food production, is therefore another important issue.

The main socio-economic issues relevant to biofuels are depicted in figure 1.1 by the green shaded shapes within the social foundation circle. The level of shading corresponds to the approximate degree to which the target for each issue has been met. Thus, for energy, global deprivation in access to electricity, at 20 per cent of the population in 2009, and clean cooking facilities, at 40 per cent of the population, are the two indicators used. This suggests an average deprivation of 30 per cent: hence, only 70 per cent of that target is shaded in figure 1.1.

The example for energy deprivation illustrates the potential dilemma facing policymakers in meeting environmental goals whilst reducing social deprivations. Although climate change goals require a transition away from fossil fuel to other new energy sources, it may take some time before the new sources are sufficiently deployed in order to make electricity or other clean energy accessible to everyone.

This example also highlights the weakness of portraying the major environmental and social problems at the global or planetary level, as this tends to hide significant geographical variances and differences between socio-economic classes. Thus, the overshoot of the climate change planetary boundary reflects excessive fossil fuel consumption levels in the developed world, and particularly the wealthiest actors within those societies, whilst many people in the developing world do not even have access to clean cooking facilities or electricity. Biofuels are already starting to play a role in rebalancing energy access, through the use of ethanol gel and vegetable oil in improved cooking stoves and for electricity generation in remote areas. But the efficiency of such biofuels in comparison to other renewable sources of energy such as solar and wind, also needs to be taken into account.

Recent figures show that just under 11 per cent of the global population remained below the extreme poverty line by 2013 (World Bank, 2016). Hence, the social foundation target for income appears to be closer to being met than many of the other social targets. However, it could be argued that a higher poverty line should be used to measure income rather than the extreme poverty indicator of $1.90 per day.

Linked to income is the other social foundation of “jobs”, reflecting the fact that the unemployed are deprived of the right to decent work. At the time of writing, no targets had been set for this indicator within Raworth’s social foundation. It is, notable, however, that the Sustainable Development Goal 8.5 aims by 2030 to achieve full and productive employment and decent work for all. Biofuels and other bioenergy could play an important role in poverty reduction by providing rural employment and waged incomes, as well as an energy source for other productive activities.

Of the eleven social foundation issues, food security is the one most associated with biofuel production due to “food versus fuel” concerns. The perceived dilemma is that although biofuels may assist in bringing us back within the planetary boundary for climate change, they may also exacerbate food insecurity, damaging one of the key social foundations, the right to food. The two most cited concerns regarding food security are that biofuels;

i) use feedstock, land and other resources (such as water) that would otherwise be used for food production, reducing food availability

ii) encourage higher and more volatile food prices through i) above, reducing food access and stability

These have been the main criticisms of the rapid rise in biofuel production, and associated government policies, over recent years in relation to food security. Much research has been generated to both substantiate and negate these concerns, but the evidence tends to be focussed on specific macro issues using scenarios and econometric models rather than the linkages at the micro or local level.

1.2.2 Justifying the research focus

This brief review of the main environmental and social challenges currently facing our global society, illustrates the potential conflict between environmental boundaries, mainly linked to climate change, and social foundations, mostly linked to human rights. It is therefore important to research those areas where conflict and debate has surfaced: the food versus fuel debate is perhaps one of the most contentious issues in this regard.

Given that biofuels have the potential to help address a number of key environmental and social issues facing humanity in the coming decades, research generating more detailed information on their positive and negative impacts could help guide policymakers.

Food security remains a key concern at the global policy level, with an estimated 800 million people suffering from hunger at the time of writing (FAO, 2015), whilst population projections point to the need for at least a 60 per cent increase in food production by 2050 (Alexandratos and Bruinsma, 2012).

As biofuels often use the same feedstock as food, animal feed and other industrial users, including cereals, vegetable oil and sugar cane, concerns have been raised that biofuels could displace feedstock that would otherwise have been used for food. Those feedstocks also use the same resources, such as land, fertilizer and water, leading to fears that biofuels will absorb scarce resources away from food. In the case of land use it is argued that the growing of biofuel feedstock in one country can lead to indirect land use change (ILUC) in another to offset the reduced food and feed supply. Where land use change occurs on high-carbon sink land or where it leads to deforestation, this can have a marked impact on climate change through increased GHG emissions.

It is also argued that increased competition between food, feed and fuel for the same feedstocks and resources inevitably leads to a rise in food and input prices and land rents. But there are differing views over the extent to which biofuels have displaced feedstock and contributed to rising food prices. Much of the research so far in this field has focused on the adaptation of econometric models at the global and national level. These models have generated widely differing results on the extent to which biofuels influence food price changes, as well as climate change impacts (von Witzke and Noleppa, 2014, Oladosu and Msangi, 2013, Condon et al., 2013).

In response to such research, and adopting the precautionary principle, government support to the biofuel sector has been scaled back in recent years, as in the EU, or restricted, as in the US, with ceilings imposed on “food-based biofuels” (HLPE, 2013). This is despite the fact that the most recent research has cast doubts on the findings of earlier econometric impact studies, particularly as commodity prices have fallen in recent years whilst biofuel production has continued to grow (Tyner, 2013, Oladosu and Msangi, 2013, Baffes and Allen, 2013, von Witzke and Noleppa, 2014).

A notable gap is the lack of research conducted at the micro level on the impact of biofuel operations on household and individual food security, particularly where waged-employment and increased feedstock demand may help to improve rural incomes and thereby food access. Since food insecurity is most prevalent in rural areas of food insecure countries, it is important to elicit the experiences and views of people in such areas who have had direct experience with biofuel operations.

One of the difficulties in assessing impacts on food security at the micro level is the variety of different indicators used to measure food security. Some of the indicators are influenced by non-food factors, such as health, whilst some require time-consuming methodologies employing expensive medical teams. So it is also important to ensure that the indicators used provide relevant and reliable information for assessing food and nutrition security, and that the methodologies employed are sufficiently rigorous whilst also being cost effective.

This study therefore aims to assess the impact of biofuel production on food security by improving knowledge on biofuel and food security linkages, both at the local level using detailed household survey data from field research conducted in Mozambique and Tanzania, and the macro level, using an analysis of global biofuel production and feedstocks used and their relationship with commodity and food prices. It also aims to inform the methodologies and indicators used in assessing food security impact outcomes at both macro and micro level.

1.3 Objectives and Research Questions

The overall aim of this study is to assess the impact of biofuels on food security in developing countries. The main objectives of the study are to assess the ways in, and extent to, which the biofuel industry has influenced food security in food insecure countries, both from a macro and micro perspective and to develop ways of measuring its impact, particularly at the local level.

The research questions are:

1) Does household involvement in biofuel operations in developing countries have a significant impact on their food security status?

2) Does biofuel production have a significant impact on food security in developing countries through reduced food availability, due to the diversion of feedstock and land toward biofuels?

3) Does biofuel production have a significant impact on food security in developing countries through reduced food access, due to higher commodity and food prices caused by biofuels?

4) How do different models of biofuel production influence food security outcomes?

5) What are the best ways to measure the impact of biofuel production on food security in food insecure countries?

1.4 Layout

Following this introduction, chapter 2 contains a literature review on the concept and measurement of food security, developments in the biofuel sector and linkages between biofuels and food security. Chapter 3 describes the conceptual framework developed from the literature review, and on which the methodology is based, as described in chapter 4. Chapter 5 presents the findings of the household surveys in

Mozambique and Tanzania on food security outcomes. Chapter 6 presents the findings of the global biofuel production and feedstock usage analysis, as well as an analysis of the relationship between biofuel production and key commodity and food prices. Chapter 7 contains conclusions and chapter 8 recommendations from the study.

1.5 Contribution

Whilst there have been many studies on how biofuels have affected the global food situation, there has been much less evidence on food security impacts at a local level in developing countries. Where evidence does exist, the impact is difficult to assess, often due to inadequacies in the methodologies and indicators of food security used.

It was envisaged that this study would help address the evidence gap at the local level. It was also hoped that the study would inform the measurement of food security impacts, providing guidance to policymakers, private sector operators and households. The study has contributed to the development of guidelines to help biofuel operators in food insecure countries assess the impact of their operations on food security and to ensure they enhance food security through mitigatory measures where necessary (Thornhill et al., 2012).

At the global level, the many studies assessing the impact of biofuels on food availability and prices have produced a wide range of findings making it difficult to draw any firm conclusions. The use of different types of statistical and econometric models, each with their own set of parameters and assumptions, has been a particular problem in reaching any consensus.

Various studies and reviews have called for better information to improve our understanding of the biofuel sector and its impact on food availability and prices. It was hoped that this study, through a detailed analysis of biofuel feedstock production and a mapping and analysis of biofuel developments over the past decade, will contribute toward this.

Through taking a broad view of both the macro and micro issues, it was envisaged that a more holistic assessment could be made of the linkages between biofuels and food security and the way that those linkages can be best measured.

2. Literature Review

The food versus fuel debate has now been running for over a decade. It is therefore important to examine the literature surrounding this debate in order to assess where the main conflicts lie and why it remains so contentious.

But it is also important to understand the two key components of food security and biofuels within that debate. In order to determine how best to assess food security impacts within the study, a review of the literature on the concept of food security and how it is currently measured was conducted at the beginning of the study. This helped in building a framework for the analysis and in evaluating the ability of existing indicators to measure the impact of biofuels on the key dimensions of food security.

Similarly, a review of the literature on biofuel developments was required early on in the project in order to assess what types of biofuels and feedstocks were most implicated in the debate and where and how such biofuels and feedstocks were produced. This was also important in planning the methodology for assessing the local impact of biofuels on food security, as well as the macro methodology.

By dividing the food versus fuel debate into its two separate components, it was envisaged that this would better inform the review of linkages between them. The following literature review is therefore divided into three main sections:

i) Food security, from its concept and definition, to its measurement and indicators.

ii) Biofuels, from the main types and feedstocks used to national biofuel policies and recent market developments.

iii) Linkages between biofuels and food security, from the beginnings of the food versus fuel debate to the impact of biofuels on food availability, food prices and household incomes.

2.1 A Review of Food Security

2.1.1 The food security concept

Food security is a complex concept, encompassing many factors and outcomes. The factors extend from food production to water availability, access to energy, land rights, incomes, sanitation, health, caring practices, education, conflict, government policy, the economy and the environment, all of which have their own myriad of determinants. The outcomes range from household and individual calorie and other macronutrient intake to the many types of micronutrient deficiency, and the impacts these have on health, education, productivity, incomes and overall well-being.

This highlights the difficulty in determining the reasons behind food insecurity and the actions required for long-lasting solutions. For researchers seeking to assess the impact of a given issue on food security, it is difficult to account for all of the other factors that may have contributed to it.

The concept of "food security" gained increasing public attention during the 1960s and 1970s, following a series of famines that led to millions of people dying from starvation (Devereux, 2000). Outside the famine areas, many more were continuing to die of starvation and hunger-related causes every year, despite the adequate availability of food at a global level. Although the prevalence and severity of famines has reduced in recent decades, chronic hunger persists for hundreds of millions of people, despite the many actions and programmes introduced at international, national and local level over the past fifty years.

At the international level, the World Food Conference in 1974 was the first to focus on the concept of food security as a major political issue, but it was not until 1996 that global policy targets were established. The World Food Summit (WFS) of 1996 set a target of halving the number of undernourished people by 2015, from the estimated 845 million people suffering from hunger at that time to some 423 million (FAO, 1996).

Food security again came to the fore in 2000 with the agreement of the Millennium Development Goals (MDGs) at the UN Millennium Summit that year. However, the MDGs scaled back the WFS 2015 hunger target from 423 million hungry people to a halving of the proportion of people undernourished from a 1990 base level. Given the mid-range population projection by 2015, this effectively meant that even if 600 million people were still starving by 2015, the MDG target would have been met. In fact there were significant revisions to the estimates in 2012 that increased the base year estimate for 1990 and effectively scaled back the target even more to around 700 million people. In the event, the world did not even achieve that target according to the FAO estimates at the time of writing, which put the number of hungry people in developing countries at 795 million in 2015 (FAO, 2015).

One of the conclusions that could be reached for the watering down of the global hunger target is that the international community was unwilling to commit the necessary resources to halve the number of hungry people by 2015. Another might be that world leaders and experts did not believe it was possible to reduce the number of hungry people to 423 million or less, and that the MDGs were therefore a more realistic goal. Whatever the reason, the weaker target has reduced the pressure on our global society to realize the human right to food. The failure to significantly reduce the number of food insecure people has not been felt at international levels, but at local level, within households and by individuals.

So why does the global community continue to fail so many people? The following sections review the literature on three key aspects of this question;

i) addressing the obligations of the international community on food security and why those obligations have not been met

ii) defining the concept of food security and its key dimensions

iii) identifying how food security can be best measured with indicators that can be acted upon to make a real impact in reducing the number of people suffering from hunger

2.1.2 The right to food

The concept of food security has played a significant role in development literature since the 1960s and 1970s, as political pressure was placed on nations to meet their commitment to human rights. This followed the signing of the Universal Declaration of Human Rights (UDHR) agreed in 1948, article 25, which contains the following statement;

> *Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services. (UN, 1948)*

The right to food was more clearly defined in the subsequent International Covenant on Economic, Social and Cultural rights in 1966, article 11, which came into force in 1976 and had been ratified or acceded to by 160 countries at the time of writing;

> *1. The States Parties to the present Covenant recognize the right of everyone to an adequate standard of living for himself and his family, including adequate food, clothing and housing, and to the continuous improvement of living conditions. The States Parties will take appropriate steps to ensure the realization of this right, recognizing to this effect the essential importance of international co-operation based on free consent.*
>
> *2. The States Parties to the present Covenant, recognizing the fundamental right of everyone to be free from hunger, shall take, individually and through international co-operation, the measures, including specific programmes, which are needed:*
>
>> *(a) To improve methods of production, conservation and distribution of food by making full use of technical and scientific knowledge, by disseminating knowledge of the principles of nutrition and by developing or reforming agrarian systems in such a way as to achieve the most efficient development and utilization of natural resources;*

> *(b) Taking into account the problems of both food-importing and food-exporting countries, to ensure an equitable distribution of world food supplies in relation to need. (UN, 1966)*

In addition to the two core international treaties related to food, there is the Universal Declaration on the Eradication of Hunger and Malnutrition, which was adopted at the World Food Conference of 1974 and endorsed by the UN General Assembly in the same year. Articles 1 and 2 of the Declaration state that;

> *1. Every man, woman and child has the inalienable right to be free from hunger and malnutrition in order to develop fully and maintain their physical and mental faculties. Society today already possesses sufficient resources, organizational ability and technology and hence the competence to achieve this objective. Accordingly, the eradication of hunger is a common objective of all the countries of the international community, especially of the developed countries and others in a position to help.*
>
> *2. It is a fundamental responsibility of Governments to work together for higher food production and a more equitable and efficient distribution of food between countries and within countries. Governments should initiate immediately a greater concerted attack on chronic malnutrition and deficiency diseases among the vulnerable and lower income groups. In order to ensure adequate nutrition for all, Governments should formulate appropriate food and nutrition policies integrated in overall socio-economic and agricultural development plans based on adequate knowledge of available as well as potential food resources (UN, 1974).*

The UDHR, of which there are now 185 members, and International Covenant (160 countries) placed responsibility on the international community to ensure the realisation of the right to food for everyone, and an equitable distribution of world food supplies, whilst the Declaration on Eradicating Hunger and Malnutrition should have provided a moral compass for all international and government policy, including the integration of food and nutrition policies in agricultural development planning.

Yet progress in reducing and, ultimately, ending hunger has been slow, with only an estimated 100 million less undernourished people than forty years ago[7] (FAO, 2002, FAO, 2015). The UN has argued that the proportion of hungry people to the total world population has almost halved since 1990, from 19 to 11 per cent[8] (United Nations, 2015a), almost meeting the MDG target: but this target is inconsistent with the UDHR, International Covenant and Declaration aims.

So despite the various international treaties and declarations in the 1960s and 1970s that most countries have committed to, there has arguably been little progress in the past 40 years on imposing a duty or obligation on the international community to provide the right to food to everyone. However, the Sustainable Development Goals agreed toward the end of 2015 finally encompassed a coherent policy with the earlier treaties and declarations by including a target to end hunger, albeit by the year 2030 (United Nations, 2015b). The key question is how seriously the international community will commit to this agreement, including the effectiveness of implementation measures adopted?

2.1.3 Defining food security

A key problem in ensuring the right to food through effective implementation, has been how to define food security in a way that captures the myriad of influences determining whether people are food secure or not.

Definitions of food security at the time of the Declaration to End Hunger and Malnutrition in 1974 were largely based on the availability of food: thus, food availability decline was seen as the key cause of famines and long-term food insecurity. The World Food Conference held in 1974 issued the following definition of food security;

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[7] Note that the FAO has revised its estimates over recent years, but has tended to revise back only as far as 1990. Thus the estimated number of undernourished for 1975 of 900 million is taken from its 2002 State of Food Insecurity (SOFI) report.

[8] For developing countries, the proportion of undernourished people has fallen from 23 to 13 per cent.

> *"Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices"*

But it became evident that famines occurred and hunger often persisted at times when food supply was shown to be increasing. Sen's seminal work on "entitlements", was an important factor in bringing the issue of "access" into the definition of food security in the 1980s (Sen, 1981). This explained that people face starvation if their set of entitlements is not sufficient to provide them with enough food to meet their basic needs and that this can happen whether food availability is increasing or not. As Shaw noted in his book on the post-war history of food security;

> *"From a situation of food shortages in the developing countries ….the focus switched to the importance of ensuring access by poor people to the food they needed through increasing employment and purchasing power" (Shaw, 2007)*

By the 1990s it became evident from the literature on nutrition and other issues that availability and access alone were insufficient to fully encapsulate the concept of food security. Thus, a new dimension of nutrition was increasingly used within the broad umbrella of "utilisation". The UN Children's Fund (UNICEF) introduced a framework for malnutrition at this time, which recognized the importance of non-food factors such as health, care practices, social institutions and politics in achieving food security, particularly for children (UNICEF, 1990).

So the definition of food security has changed over time as new factors have been identified, from an *"availability"* or *"supply"* problem, to mainly a problem of *"access"*, and then also a problem of the effective *"utilization"* of food.

The changing concept of food security has been guided by a wealth of academic literature on the subject, particularly after the Ethiopian famine in the mid-1980s. Maxwell and Smith (1992) reviewed some 180 articles on the concept and definition of food security up to 1991, from which they distilled thirty "influential" definitions.

Hoddinot in a later review (1999) found even more definitions, amounting to some two hundred.

Of the various definitions of food security that have been constructed and adapted over time, perhaps the one most commonly used over recent decades is that adopted by the 183 participating nations of the 1996 UN World Food Summit (WFS), known as the Rome Declaration on World Food Security:

> *"Food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"(FAO, 1996).*

This was an adapted version of the 1983 definition by FAO that first introduced the concept of economic access to food;

> *"Ensuring that all people at all times have both physical and economic access to the basic food they need"*

The important additions in 1996 were the replacement of the word *"basic" with "sufficient, safe and nutritious"* in order to reflect the importance of all nutrients, whilst *"needs"* was expanded to *"dietary needs and food preferences for an active and healthy life"*, again reflecting the importance of an adequate diet for a more rewarding quality of life, but also meeting the cultural preferences of people. However, in order to define what constitutes being food secure in a particular locality, it is not possible to account for every individual's preference. Indeed, food preferences, based on cultural, taste and other factors, may sometimes conflict with optimum diets to meet nutritional dietary needs.

The UN Special Rapporteur in 2001 later defined the right to adequate food as;

> *"to have regular, permanent and unrestricted access, either directly or by means of financial purchases, to quantitatively and qualitatively adequate and sufficient food corresponding to the cultural traditions of people to which the consumer belongs, and which ensures a physical and mental, individual*

> *and collective fulfilling, and dignified life free of fear"*(Ziegler, 2001, as cited by de Schutter, 2012).

Thus, the *"preference"* factor could be viewed in terms of the cultural tradition of groups of people in a particular locality; the focus would then be on meeting nutritional needs from the foods traditionally consumed and available in the locality.

The 1996 World Food Summit definition of food security also requires an interpretation of what constitutes *"dietary needs"* for different age groups and gender. There are FAO, World Health Organisation (WHO) and national guidelines on calorie and nutrient requirements, and these are often based on activity levels and bodyweight criteria rather than having an estimated average requirement. For example, FAO and WHO have issued guideline documents on human energy requirements (FAO et al., 2004), protein needs (WHO et al., 2007) and vitamin and mineral requirements (WHO and FAO, 2004) for different sexes, ages, height, weight and activity levels.

Since 1996 there have been a number of different adaptations of the World Food Summit definition, including that of the UN Special Rapporteur in 2001, yet it remains the definition most commonly used internationally. In 2009 the Declaration of the World Summit on Food Security formalised the addition of the word *"social"* into the section describing *"physical and economic access"*, in order to reflect the importance of social dimensions in accessing sufficient food.

There are other aspects of food security that are not specifically stated within the WFS definition and have become important discussion points in the literature. For example, "sustainability" is at the heart of the Sustainable Development Goals. Climate change, loss of biodiversity, soil erosion and water scarcity are examples of issues that are expected to increasingly impact on food security in the future. One option, therefore, might be to add the phrase "on a sustainable basis" to the end of the WFS definition, in order to incorporate future generations.

Also "nutrition security" is often defined differently from food security, in that the former is more focused on nutritional outcomes whereas the latter is generally defined as having broader dimensions. Whilst the 1996 WFS definition includes the need for *"sufficient safe and nutritious food to meet dietary needs… for an active and healthy life",* it does not specifically incorporate the factors that are essential in supporting adequate nutrition.

The UNICEF framework highlighted the importance of health and care services and adequate sanitation facilities in achieving nutrition security. Various definitions were subsequently developed, with the World Bank defining nutrition security as existing *"when food security is combined with a sanitary environment, adequate health services and proper care and feeding practices to ensure a healthy life for all household members"*[9].

Nutritional factors are generally included in the "utilisation" pillar of food security, but in recent years the term "food and nutrition security" has been increasingly used to highlight the many factors affecting adequate nutrition in addition to calorific food security.

This culminated in the Committee on World Food Security (CFS) proposing a new combined definition of food and nutrition security in 2012; *"food and nutrition security exists when all people at all times have physical, social and economic access to food which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life"(Committee on Food Security, 2012).* The new CFS definition is helpful in specifying nutrition, sanitation and health care as vital components of the utilisation pillar of food security.

Whilst the definition of food and nutrition security has been refined over the years in order to improve the implementation of the right to food, it is now more complex in scope posing difficulties for the researcher and analyst in trying to capture all of the

[9] FAO drafted a new definition to highlight that nutrition security is only achieved when individuals consume the food they need even though they may have access to sufficient food; *"nutrition security exists when all people at all times consume food of sufficient quantity and quality in terms of variety, diversity, nutrient content and safety, to meet their dietary needs and food preferences for an active and healthy life, coupled with a sanitary environment, adequate health, education and care" (FAO November 2011)*

dimensions that contribute to a status of food and nutrition security. This study therefore focuses on the four key dimensions first elucidated in the 1996 definition from the World Food Summit, but with the recognition that the dimension of utilisation is particularly complex and therefore might only be partially addressed.

2.1.4 The dimensions of food security

The World Food Summit definition of food security focuses on food consumption outcomes, but also incorporates the different dimensions of food security. Thus, food security is commonly conceptualised as having four different dimensions, as defined by the Food and Agriculture Organisation (FAO) of the United Nations (UN)[10], each of which is derived from sections of the WFS definition, as described in brackets:

1. Food Availability *("physical access")*

2. Food Access *("economic access")*

3. Food Utilisation *("sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life")*

4. Food Stability *("at all times")*

2.1.4.1 Food availability

Food availability mainly reflects the supply side of the food security equation. It is usually interpreted as meaning that food is physically present because it has been grown, marketed, processed, manufactured, stored or imported into the area. For example, food may be available because it can be found in local markets and shops, or in the wild, or it has been produced on local farms and home gardens, or has arrived as part of a food aid shipment.

Food availability can be affected by many factors, including weather-related yields, failed crops, pasture availability for livestock, a switch from food crops to cash

[10] For a description of the basic concepts of food security see (FAO, 2008a).

crops, transport problems, changes in import prices, tariffs and exchange rates and the availability and quality of storage.

2.1.4.2 Food access

Food access reflects the way in which different people obtain or access the available food. This may include purchasing food, bartering, borrowing, sharing, gifts from relatives, and provisions by welfare systems or food aid. Food access therefore largely depends on a household's available income, as well as on the price of food and access to formal and informal safety net systems.

Food access can be influenced by shocks such as the loss of livelihood assets and income-earning options, unemployment, food price spikes and the collapse of safety-net institutions that may have once protected people on low incomes. It is also affected by unequal distribution of food within households and socio-cultural factors within communities.

2.1.4.3 Food utilization

Food utilisation is usually interpreted as the way in which people use food to achieve their dietary, nutritional and cultural needs. It is dependent upon a number of inter-related factors, including the diversity and quality of the food and its method of storage, processing, preparation and cooking, as well as the health and educational status of the individual consuming the food and the sanitation facilities of the household.

Food utilization is often reduced (ie in terms of its nutritive value) by factors such as illness, disease, poor sanitation and lack of nutritional knowledge. Food utilization may also be adversely affected if people have limited income for buying the more expensive non-staple foods with higher micronutrients, or limited resources for preparing food, due, for example, to a lack of fuel or adequate cooking utensils or safe water.

2.1.4.4. Food stability

In order to be food secure, a population, household or individual must have access to adequate food at all times. They should not be vulnerable to losing access to food as a consequence of sudden shocks or cyclical events, such as seasonal food production or price fluctuations.

Food security is also measured in terms of the duration of food insecurity, with "chronic" food insecurity tending to be more persistent or occurring over a sustained period of time, "transitory" food security occurring on a short-term or temporary basis due to shocks, whilst "seasonal" food security is often regarded as being both chronic and transitory, occurring persistently on a temporary basis each year.

The first three of the FAO pillars are hierarchical since availability of food is *"necessary but not sufficient to ensure access, which is, in turn, necessary but not sufficient for effective utilization"*(Barret, 2010). Stability cuts across the other three pillars as various shocks affect the availability and access to, and utilization of, food. Households may have a large choice of available food in their locality, but can only access what they can produce, collect, barter and afford. Within the households individuals will then utilise a share of the household's accessed food according to cultural and health factors. Shocks can occur at any of the stages to affect the stability of available, accessible and utilisable food.

The four dimensions provide a useful framework for analysing food security to ensure that key factors and issues are covered. They also provide a useful way of linking back to the literature and to the historical development of definitions, from availability through to access and utilisation.

2.1.5 Measuring food security

Having defined the key dimensions as a framework, a review of how food security is measured is required in order to decide on the methodology to be employed for the study.

Maxwell and Smith (1992) noted that, despite the legal commitments emanating from the human rights agreements on food security, little effort had been made in elaborating *"the content and the duties corresponding to these provisions".* The same point could be made today some twenty years later, and nearly 40 years since the Declaration on Eradicating Hunger and Malnutrition.

Much of the reason for the slow progress in developing effective policies to end hunger (with clear content and duties) can be attributed to the lack of consistent measures and indicators of food security through which international and national progress can be evaluated. Indeed, to quote Barret in his paper on measuring food security, *"measurement drives diagnosis and response",* so it is vital that standardized indicators and methodologies are developed (Barret, 2010).

As part of his review on Household Food Security, Frankenberger (1992) reviewed the development of food security measures, from the early focus on food supply and nutritional surveillance (with relatively little connection between the two), to the increasing focus on food access and entitlements following the African famine of the mid-1980s and the introduction of new socio-economic variables, such as vulnerability and coping strategies.

Despite the advances in understanding the complexity of the food security concept, the development of multi-dimensional measures and indicators that incorporate supply, access and nutritional indicators, has been relatively limited. Instead work has tended to be undertaken within the separate dimensions of food security, as noted by Frankenberger's observation that nutritional surveillance tended to be entrapped in the health sector.

FAO held a symposium on the Measurement and Assessment of Food Deprivation and Undernutrition in 2002, some ten years after Maxwell and Frankenberger's study. This symposium focused on five main methodologies for measuring food security at the time;

i) FAO undernourishment numbers, based on national food availability estimates

ii) Household income and expenditure surveys

iii) Dietary intake surveys

iv) Anthropometric measures to assess outcomes

v) Qualitative, perception-based measures

The symposium highlighted the disparate nature of food security measurement, with experts providing papers according to their sector of work, with health professionals tending to focus on nutrition and anthropometric measures, socio-economists on income and expenditure surveys and perception-based measures, whilst agricultural and development economists tended to focus on food availability.

The 2002 symposium also noted the early work undertaken to assess the relationships between different indicators of food security. For example, Nube revealed very low correlations between estimated food energy deficiency and anthropometric measures, such as underweight children and adults, for 39 developing countries (Nube, 2002). Other studies since have also highlighted discrepancies, including a study for the UK Foresight project, which found that individual dietary intake in the UK and Mexico, as measured by detailed nutrition surveys, was substantially lower than that estimated to be available at a national level from supply and demand balances (Waage et al., 2011). More recently, a comparison of the more popular food security indicators, as used in household surveys in Tigray, Ethiopia, found that different indicators measured different aspects of food security, and that some suggested a high prevalence of food insecurity whilst others did not (Maxwell et al., 2013).

FAO convened another conference on measuring food security at the start of 2012, some 10 years later. In concluding the 2002 symposium, Hartwig de Haen, the then Assistant Director General of the Economic and Social Department, noted that there was *"no perfect single measure that captures all the aspects of food security"* and that a *"suite of indicators"* should be identified that are reliable, timely and cost effective (de Haen, 2002). He also noted the importance of incorporating information on food access and nutrition, and the potential to use qualitative measures. Ten years later, the 2012 FAO symposium was addressing the same issues in trying to identify a core set of indicators.

Researchers are therefore left with the problem of reviewing the various measures being used for food security and choosing the most suitable indicators and methodologies for their particular research area, or indeed, developing new ones. An early task for this study was therefore to identify which indicators were required to best measure the key issues identified within the dimensions of food security most likely to be influenced by biofuels, and indeed, which were achievable within the resources available.

2.1.6 Food security indicators and methods

The OECD Directorate of Development defines an indicator as;

> *"A quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor"(OECD, 2002).*

One could add other roles to this definition of indicators, including the measurement of shocks and other phenomena, but the OECD definition provides a useful starting point in deciding how best to measure the dimensions of food security in a *"simple and reliable"* way.

Given that food security is such a broad and complex concept, however, it is difficult to identify a set of core indicators that accurately measure its various dimensions. Proxy, or indirect, indicators are often used to measure food security in the absence of more reliable but less accessible and less affordable indicators. However, proxy measures often have the disadvantage of not being able to directly attribute changes in food security to specific phenomena.

Hoddinot reviewed the use of food security indicators in 1999, ranging from the 25 broadly defined process and outcome indicators listed by Frankenberger (each of which potentially contained many other indicators) to the 450 individual indicators identified by Chung et al in 1997 (cited in Hoddinott, 1999).

It could be argued that because food security is such a broad concept, the use of many different indicators is unavoidable, and that different situations require different indicators to be used. However, this then complicates any comparisons, making it difficult to gain an accurate assessment of the number of food insecure people, as well as monitoring the impact of different policies.

The following sections reviewing the main food security indicators are categorised by the five main methods used to capture the information, as defined by the 2002 FAO symposium.

2.1.6.1 Global and national indicators

Food availability remains the most common means of measuring food security at the global and national levels. FAO calculates the number of people undernourished in each country from food balance sheets, comprising broad estimates of supply and demand of the major food items. The food availability estimates for a country are converted to calorie-equivalents and then compared with a calorie requirement profile for the national population in question, from a model based on household survey profiles. FAO applies an estimated distribution of calorie availability within the population in order to calculate the number of people below a cut-off point representing the minimum calorie level required (FAO, 2003).

In other words the FAO's estimated numbers of food-insecure people that are so widely used and quoted, are based on food availability rather than actual consumption, ignoring the hierarchical nature of food security. The main criticism of the FAO methodology is the assumption that because food is available it will be accessed. Also, the food balances are very broad estimates, often derived from under-resourced national statistical agencies, and, hence, many components of the supply and demand balance may not be recorded accurately (or even at all). Even where there is a relatively accurate picture of the supply and demand of different foodstuffs, this has then to be converted into different nutrient values using standard composition tables that may not account for varietal or food preparation differences. Nor does the FAO methodology account for seasonal variations in food security, which is the main characteristic of hunger for many in the developing world.

Svedberg (2002) criticises the FAO methodology given the questionable reliability of the food availability data, but also for using a single threshold level for the dietary energy requirement in each country. Headey (2011) notes that the FAO number is very sensitive to the cut-off line chosen and also the minimum calorie requirement, which can vary significantly with physical labour.

De Haen et al (2011) also highlighted problems with the three main components of the FAO indicator, the average national calorie availability per capita, the distribution of access to those calories and the minimum calorie requirement by the population, and found very high elasticities for the global number of undernourished associated with relatively minor changes in these estimated components.

Headey notes that the US Department of Agriculture (USDA) hunger indicator uses a more sophisticated partial equilibrium model of world food production and trade, based on calorie-income elasticities. But the USDA measure only focuses on low-income countries, whereas an increasing proportion of the world's poor are located in middle-income nations (Sumner, 2011). USDA also uses a global calorie cut-off line of 2,100kcal per day per adult equivalent as opposed to the calculations made by FAO for each country depending on the population structure. The use of average elasticities in the USDA model (as in most modelling exercises) is also an area of contention, as different households and income groups will respond differently to income and price changes, depending on their livelihood circumstances.

FAO applied the percentage annual changes recorded in USDA analyses to its own model in order to determine the impact of the food price hikes during 2008 to 2012.

Otherwise FAO would not have been able to provide a timely assessment of the price shocks as its model relies on food balance data that is about three to four years behind the prevailing year. Given that the USDA analysis only includes low-income countries and has a different definition of the cut-off point for undernourishment to that of FAO, the validity of the initial FAO estimates of the number of people suffering from hunger after the 2008 price shock were questioned by many, including William Easterly in his "Aidwatchers" blog on *"made-up world hunger numbers"* (2010).

More recently the Global Hunger Index (GHI) has been developed to provide national level measures of food poverty. Conceived by Wiessman (2002) this index uses the FAO undernourishment figures as part of the calculation, together with child mortality and child underweight prevalence. The resulting score is used to rank countries, which are then grouped into categories describing the level of food insecurity, from "moderate" to "serious", "alarming" and "extremely alarming" (von Grebmer et al., 2011).

The GHI could be regarded as a slightly more useful food security indicator than the FAO measure, since it is a multi-dimensional indicator, incorporating food availability and nutritional outcomes. However child mortality is affected by more than just nutritional intake, as is the prevalence of underweight children. Also, Masset observes that the use of an average score from the three variables reduces the impact of the under-five mortality rate, which is usually a smaller figure than the underweight and undernourishment percentages, whilst the cut-off points for the classification of countries into group headings describing the food security situation as "serious", "alarming" or "extremely alarming" tends to be somewhat arbitrary (Masset, 2011).

The GHI has been refined slightly in recent years, whilst the Economist Intelligence Unit has been producing its annual multi-dimensional Global Food Security Index (GFSI) since 2012, which ranks countries according to their vulnerability to food insecurity (Economist Intelligence Unit, 2016). These are useful indicators for tracking progress each year at national and global level, but their lack of detail in relation to the dimensions of food security raises concerns regarding the accuracy of the numbers generated. There is a clear need for more detailed food consumption information at local level in order to improve the national and global estimates. In other words, the national and global estimates should be calculated from the bottom up rather than top-down.

2.1.6.2 Household surveys of income, expenditure and consumption

It is commonly acknowledged that lack of access rather than availability accounts for most food insecurity (Sen, 1999). This has led to increased focus in recent years on household surveys, such as national income and expenditure and specialist surveys. However, such surveys can be extremely time-consuming and costly, and are often conducted only every few years or, in the case of specialist surveys, on a one-off basis.

The World Bank initiated Living Standard Measurement Surveys (LSMS) in 1979 and during the 1980s when it became apparent that few developing countries had reliable income distribution data for poverty analyses. LSMS use detailed questionnaires, usually involving 2,000 to 5,000 representative households at 3 to 5 year intervals. Many of these national household surveys tend to only include household expenditure data on broad categories, which makes it difficult to use them for any in-depth food security analyses.

However, more and more countries are now expanding their household surveys to incorporate agricultural and food consumption issues (Scott, 2011). For example the Tanzanian Bureau of Statistics conducted its first National Panel Survey from October 2008 to October 2009, incorporating agricultural production, rural development and a wide range of other socio-economic information. This was conducted as part of the LSMS Integrated Surveys on Agriculture initiative (LSMS-ISA) by the World Bank (NBS, 2009). Also, new shorter LSMS-linked surveys have been developed to monitor progress on specific issues in between the more detailed surveys[11].

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[11] For example, the Core Welfare Indicators Questionnaire (CWIQ) involving a core set of living standards indicators, which only takes half an hour to complete.

As well as national government surveys, many household surveys are conducted for smaller research projects, often by NGOs and universities, and often at a more local level. Specialist surveys can be specifically designed for food security research, providing measurements of detailed food consumption from purchases, barter, aid and gifts and from own production or collection, as well as livelihood and other information related to food security, such as access to improved sanitation, health facilities and schools. For example, ICRISAT, IFPRI and Save the Children have all established household panel surveys, visiting the same households over regular periods (Devereux et al., 2004). Such surveys reflect the move since the 1990s toward sustainable livelihood approaches to food security, using methodologies like the Household Economy Approach (HEA) developed by Save the Children UK (2005).

Household surveys have advantages over the macro-level availability-based estimates, as they can more accurately measure actual consumption. The different foods consumed can provide an approximate estimate of nutritional intake, broken down into calories, protein, fat and key micronutrients. These can then be compared with reference food requirements for the individuals and households to assess whether there are any significant deficiencies in particular socio-economic groups or regions.

However, this requires detailed survey instruments in order to capture the required food consumption data and a detailed analysis of all the foods consumed, which can pose a particular problem for analysing the food consumption of communities with varied diets including processed foodstuffs with complex ingredients. Such surveys are also relatively costly and time-consuming.

Recall bias can also be a problem for such surveys, with householders asked to recount their food consumption over the past week, month or even year. However, many households in food-insecure regions have regular food purchasing and consumption patterns, with relatively few meal ingredients, making it easier to recall food usage. In a recent World Bank study of the reliability of recall in agricultural data, it was concluded that the majority of agriculture based data, including production, sale and consumption patterns, did not suffer from “large recall delay” (Beegle et al., 2011).

Household surveys also suffer from failing to identify different intakes within households due to social and cultural factors. However, individual food intake surveys, such as the gold standard 24-hour dietary recall approach, would be even more costly to undertake at the scale required for a nationally representative picture.

One of the biggest problems for both the household surveys and national food availability estimates is in the conversion of the recorded food use to nutritional equivalents, such as calories, protein, fat and micronutrients. Food composition tables are available for many countries, but the level of nutrients derived from different food items largely depends on the type or variety of the food item in question and how that food is prepared, cooked and eaten. Thus composition tables may provide average nutrient tables for wheat, but may not always give details of different varieties of wheat or different types of bread consumed.

Nevertheless, food composition analysis has improved over the years and a number of detailed tables have been released for African countries in recent years, including the West African Food Composition tables by FAO/INFOODS, Biodiversity International and the West African Health Organisation in 2012, as well as for The Gambia in 2011, Mozambique in 2011 (Korkalo et al., 2011), Uganda in 2012 and Tanzania in 2008 (Lukmanji et al., 2008).

Also there is a clearer picture emerging of dietary needs for active and healthy lifestyles, with many national governments providing dietary guidelines, whilst WHO and FAO have released recommended guidelines for energy (FAO et al., 2004), protein (WHO et al., 2007) and various micronutrient (WHO and FAO, 2004) requirements for different age groups and human activity levels. It should also be noted that there are a number of useful guides to inform household survey research in developing countries, including the comprehensive guide by the United Nations (United Nations, 2005).

2.1.6.3 Anthropometric measures

Anthropometry is probably the most common technique used to measure malnutrition in individuals. It involves the measurement of body parameters to indicate nutritional status. This has the advantage of providing outcomes at the individual rather than household or national/global level.

The most common anthropometric indicators used are for child stunting, wasting and underweight. Weight for height of children under 5 years of age is a common indicator of acute malnutrition or wasting in a particular community, whilst height for age is used to assess stunting of young children, with the results being compared to standard values for a reference population. Weight for age is an indicator of underweight through both acute and chronic malnutrition. For adults the Body Mass Index (BMI) is a more common measure, which is also used at times for children. Mid-upper arm circumference (MUAC) is also used in adults and children to measure nutritional status.

However, anthropometric indicators for nutrition also require significant resources in order to capture the data at field level, unless data is already available from a recent survey in the locality. Moreover, they do not provide information on the reasons for poor food access, only the outcome. Some of the anthropometric measures also miss certain types of malnutrition such as oedema and certain micronutrient deficiencies, which are identified by different observation and blood tests. Thus, the anthropometric data may be useful to identify whether food insecurity exists in a certain locality, but if it does, further information is usually required to assess how and why it exists.

More importantly, anthropometric outcomes may not always be associated with food intake, but more with illness and disease, making such measures a less reliable indicator of food security. Also they usually focus on children, but it is known that parents often reduce their own consumption in times of shortage, so the measures may fail to identify hunger amongst adults and adolescents (Hauenstein-Swan et al., 2009). The measures used in anthropometry have also been increasingly questioned in recent years, particularly with regard to the underweight indicator, as more children may be classified as having sufficient weight due to high sugar and fat diets and yet be suffering from malnutrition, whilst the use of a single global growth reference has also come under increasing scrutiny due to genetic differences across geographic regions (de Haen et al., 2011).

2.1.6.4 Perception-based measures

More recently the Household Food Insecurity Access Scale (HFIAS) was developed by the Food and Nutrition Technical Assistance Project (FANTA) in the US to measure food insecurity. The HFIAS is based on the "perception-based" method of asking a series of questions to householders as to whether they perceive their food consumption and dietary variety to be adequate or not[12]. From this the Household Hunger Scale (HHS) has been developed to measure the most severe food insecurity experiences in developing countries[13] (Ballard et al., 2011).

The Gallup World Poll has also a provided subjective information on household food security over recent years due to the inclusion of questions asking respondents whether, at any time in the past year, they did not have enough money to buy the food that they or their family needed or had experienced episodes of hunger (Headey, 2013). In 2014 the Gallup Poll extended its range of questions to incorporate the Food Insecurity Experience Scale (FIES) developed by FAO, which has eight questions regarding food insecurity during the past year (FAO, 2016b).

Perception-based measures have the advantage of gauging well-being within individuals. However, people may not always be able to judge whether they are eating sufficient amounts of each nutrient and recall may be a problem when reporting food security over the past month or more.

[12] This approach was developed in the 1990s by the US Department of Agriculture for the routine measurement of household food insecurity in the US using the Household Food Security Supplemental Module (HFSSM).

[13] Note that the HHS uses those questions in the HFIAS that have been analysed as being cross-culturally comparable, as the other questions in the HFIAS produced varying responses by different cultures.

2.1.6.5 Food intake and dietary diversity indicators

Food intake surveys can take a variety of forms and are often included within household surveys, but may also be one-off exercises. The Household Dietary Diversity Score (HDDS) has become a common measure to assess the ability of a household to access a sufficient nutritional intake, reflected by the variety of their diet. This is generally measured by a 24-hour recall, which has limitations in terms of assessing diets over an extended period unless it is repeated in each of the main seasons. The HDDS also requires each survey be adapted to the local foods and conditions making it more difficult to compare between regions (Kennedy et al., 2011). Perhaps the main concern regarding dietary diversity scores is the lack of quantitative data captured, which could seriously underestimate food security status.

The Food Consumption Score (FCS) used by the World Food Programme is another common method for capturing dietary diversity (WFP, 2008). This measures the frequency of consumption of nine different food groups by a household during the seven days before the survey. Each food group is assigned a weighted value and the overall score is calculated by multiplying the frequency of consumption of each food group by its weighted value, then summing the values for all food groups. Scores over 35 are generally regarded to be acceptable, but below this level households are generally considered to be food insecure.

2.1.6.6 Comparisons of indicators

This brief review of indicators highlights the variety of methods for measuring food security. One of the main problems is that there is often little correlation between the measures. For example, Smith et al (2006) found that household expenditure survey data from 12 Sub-Saharan countries suggested that nearly 60 per cent of the population were undernourished in calorific terms, compared to the FAO estimate for the same countries of less than 40 per cent. Meanwhile Klasen (2007) found a significant difference in the relationship between child undernutrition and overall undernourishment rates in different regions, with the share of underweight children in South Asia, for example, at a much higher level than the share of undernourished people in the total population. The analysis also highlighted a lack of correlation between child underweight and under-5 mortality rates, particularly in South Asia where mortality rates are low but underweight prevalence is high.

In more recent reviews of food security indicators, Masset (2011) found that stunting accounted for twice as many people undernourished in developing countries than the FAO calculation in 2008/9. Also a Gallup World Poll used by Headey in an analysis of the 2008 global food crisis, showed that self-reported hunger actually fell during 2007-2008, whereas FAO initially estimated that the number of undernourished people rose to over 1 billion in 2009 (Headey, 2011). Another fundamental weakness of the FAO numbers is that they do not account for the large number of people suffering from "hidden hunger", due to micronutrient deficiencies.

The FAO indicator of undernourished people was used as the main indicator of the MDG goal to eradicate hunger, as well as forming an important part of the Global Hunger Index and Action Aid Hunger Scorecard. It is therefore not surprising that Masset finds a good correlation between the FAO, GHI and Action Aid measures (Masset, 2011). The weaknesses of the FAO measure, however, and its often poor relationship with anthropometric measures (which themselves may not always provide a true picture of food security), raise concerns over the GHI and other similar multi-dimensional global food security indicators, as well as the way in which progress toward meeting the MDG food security goals was measured and the way in which progress on the SDGs might be measured.

Perception-based measures of food security are a more recent development. The difficulty in creating a globally acceptable questionnaire format for such surveys is illustrated by the development of the Household Hunger Score, which adapted the 9-question Household Food Insecurity Access Score used in the US, down to 3 basic questions, as these were considered to be the only three that would be answered in the same way across all cultures (Deitchler et al., 2010). Also, the Gallup Poll questions on food security could be subject to different meanings of hunger between cultures.˙ Nevertheless, such measures could provide a quick and useful way of capturing subjective food security information, particularly using new technologies such as mobile phone applications. The recent addition of the FIES questions to the Gallup Poll should also provide more informative subjective data.

The dietary diversity and food consumption score indicators provide a useful way of capturing information on micronutrient intakes for a healthy diet, but they do not necessarily capture quantities consumed so well. A recent systematic review of the dietary diversity score found little association with body mass index and recommended that normal or usual levels of food intake be recorded, as well as a longer time period than the 24 hour recalls often used, and more food categories (Salehi-Abargouei et al., 2015).

As with the anthropometric indicators, the HFIAS, HDDS and FCS tend to only provide measures of whether the household or individual is likely to be food insecure or not, as well as the level and frequency of their food insecurity. Given the importance of capturing information on actual food consumption and livelihoods in order to understand the factors behind food security outcomes and in order to measure micronutrient as well as calorie intake, household food consumption and livelihood surveys appear to offer the best single approach for measuring food security. This reflects one of the key recommendations of the 2012 FAO symposium to include more food and nutrition information in large-scale surveys (FAO, 2012).

There also appears to be a general consensus by experts that a suite of indicators should be used in such surveys, assuming sufficient resources are available (de Haen, 2002, de Haen et al., 2011, Devereux et al., 2004, Fan, 2012, FAO, 2012, Wiesmann et al., 2006). Through combining different indicators in the survey, assessments can be made on the accuracy of cheaper and quicker methods, such as perception-based measures for future use. More importantly, the various indicators could be used to measure different dimensions of food security.

Multi-dimensional measures have been developed at the national and global level to incorporate a range of indicators into a single food security score, including the GHI and GFSI at national level. But there has been relatively little progress in developing multidimensional measures at the local level for food security. Sabina Alkire and James Foster developed the Multidimensional Poverty Index (MPI) in 2007 under the Oxford Poverty and Human Development Initiative (OPHI, 2015). This is based around indicators of deprivation at the individual, household or community level that are then weighted to provide an overall score to determine poverty status. The prevalence and intensity of poverty as a percentage of the total population is then calculated in order to scale up to national level. A similar, bottom-up multi-dimensional index for food security could provide a more reliable measure of food security than current top-down approaches.

On the other hand it could be argued that the use of a suite of indicators has been the prevailing situation for many years and that this may have stifled the development of a simpler and more reliable and more consistent means to measure food insecurity. In order to measure progress in a consistent way, it might be better to develop a single approach that can be used by all. The problem with using a suite of indicators is that one is still left with the problem of deciding whether there has been any overall progress in reducing food insecurity if one indicator shows an improvement whilst another suggests a worsening of the situation. This problem could be resolved by allocating weightings to the various indicators in order to reflect the importance of different dimensions of food insecurity, but such weightings could be difficult to agree. Furthermore, the suite of indicators approach could be resource-intensive, requiring different types of information to be captured using different methodologies.

A recent review of food security indicators by Lele and Kinabo (2015) as part of the Technical Working Group on Measuring Food and Nutrition Security for the Food Security Information Network (FSIN), proposed three principles for improving measurement:

i) measure more than calories to capture the various dimensions of food insecurity
ii) cover the whole life cycle and specific needs of each age group
iii) produce new data and present it in ways that mobilize action and catalyze policy.

A subsequent report by the same Technical Working Group added a fourth principle (Lele et al., 2016):

iv) monitor the whole food system, recognizing the interdependence of agriculture, the environment, food and social inclusion, nutrition and health.

These principles build on the call by the International Food Policy Research Institute for *"more and better data"* in its Global Nutrition Report (IFPRI, 2014).

The literature on food security therefore highlights the need for improved ways of measuring food security as the concept and definition of food security has evolved. The main indicators in current use each have their own strengths and weaknesses, to the extent that experts recommend multiple measures be used to ensure a comprehensive food security assessment. But these may be difficult to combine within an overall assessment and the process can be resource-intensive. So it may be better to develop more specific low-cost indicators that are better suited to the issue at hand, together with guidelines on which to use when, and how to compare results from each.

2.2 A Background Review of Biofuels

Biofuels have attracted much public attention over the past decade, particularly following the sharp rise in US and EU production during the first decade of the new millennium. Before reviewing the extensive literature linking biofuels and food security, this section briefly defines and reviews the different types of biofuels and their relative efficiency in terms of energy balances, the development of biofuel production around the world and government policies pertaining to biofuels.

2.2.1 Types of biofuels, feedstocks and co-products

The term "biofuels" encompasses a wide array of biofuel types, feedstocks, co-products, technologies and models of production. This makes it difficult to generalize about biofuels and their varying relationships with key issues such as climate change and food security. Despite this, the term is often used in a general sense, and often without qualifying the diverse properties and impacts of different types of biofuels.

In this study, biofuels are defined as liquid and gel-based fuels, mainly produced from renewable biomass and waste products, and mainly used in transport fuels and for power generation. This definition therefore distinguishes liquid-based biofuels, which are the focus of this study, from solid biomass energy such as wood and charcoal, which remain the most important energy sources for many households in developing countries and account for some 75-80 per cent of total biomass use for energy (Chum et al., 2011).

The literature also refers to first and second (and sometimes third or next) generation biofuels, or "conventional" and "advanced". This terminology is mainly based around the type of feedstock and processing technology employed. First generation or conventional biofuels are those that are already commercially available using starch and oil-based crops, such as cereals, sugar cane, root crops and oil-bearing crops and products, and/or those using conventional technologies such as fermentation and distillation, in the case of ethanol, and trans-esterification in the case of biodiesel, which involves the chosen vegetable oil undergoing a chemical reaction with methanol or ethanol to create either fatty acid methyl esters (FAME) or ethyl esters.

Advanced or second-generation biofuels are those that use relatively new technologies and/or non-conventional feedstocks such as cellulosic raw materials, algae and waste products (Hamje et al., 2014, IEA, 2011a). Hydro-treated vegetable oil (HVO) produces a more energy-dense advanced biodiesel, with lower emissions and a very low freezing point enabling it to be used in cold climates and as aviation fuel.

The two main categories of liquid biofuels covered in this study are:

i) Bioethanol and other similar alcohol-based fuels, which are mainly produced from starch and sugar-based feedstocks such as cereal, root crops and sugar cane, but also from co-products, such as molasses derived from sugar processing and biodegradable waste. Second-generation (2G) technologies use ligno-cellulosic materials, such as energy grasses and short-rotation coppice, as well as straw residues.

ii) Biodiesel (FAME) or straight vegetable oil (SVO), produced mainly from oil-based feedstocks such as oilseed crops, but also waste oil and animal fats such as tallow. 2G technology can produce advanced biodiesel from a wider range of materials, including algae and waste products, such as hydro-treated vegetable oil (HVO).

Ethanol is mainly used as a petrol replacement and can be blended up to 10 per cent (or E10) without affecting conventional engines and 15 per cent (E15) for modern petrol engines. Engine modification can allow higher blends, such as E85 and E100 in Brazil where most cars are now manufactured to be able to use both petrol blends and/or ethanol. Ethanol only has about two-thirds the energy content of petrol but is said to improve vehicle performance through a higher octane rating. This can help to replace dangerous anti-knocking agents used in normal petrol fuels, such as lead and MTBE (methyl tertiary-butyl ether). Ethanol can also be used in gel form for improved cooking stoves and is also produced for a variety of food, drink and industrial uses.

Biodiesel is mainly used as a diesel fuel replacement and can be blended to any proportion with relatively little engine modification, although common blends are 5 to 20 per cent (B5 to B20). Its energy content is about 90 per cent that of diesel and it is said to improve engine performance due to its increased lubricity. The use of straight vegetable oil usually requires engine modification due to its high viscosity, especially at cooler temperatures, although some tropical oils, such as coconut oil, can be more readily blended with diesel for use in conventional engines.

Liquid biofuels have a long history with the first combustion engines using ethanol and turpentine in the early 1800s. The first spark-ignition engine used ethanol in the late 1800s, as did the Ford Model T car in the early 1900s, whilst Rudolf Diesel used peanut oil in his compression-ignition engines in the 1890s (Mastny, 2007). Although oil started to become plentiful in supply and cheap in the early 1900s, ethanol powered engines were still preferred by some because they had less wear and tear, were quieter and produced less exhaust fumes (Reijnders and Huijbregts, 2009).

Liquid biofuels are currently the main alternative energy source to fossil-fuel based transportation fuels, and are now commonly blended in many standard petrol and diesel vehicle blends around the world, helping to reduce the demand for crude oil. Whilst electric-powered vehicles have the potential to consume an increasing share of the road transport fleet, there is currently no real alternative to liquid biofuels for air and sea transport, and airline companies in particular have invested heavily in research to identify the best biofuel-based replacements for existing fossil fuel based fuels.

One of the defining features of biofuels is the wide variety of raw materials from which they can be made and the co-products produced in the biofuel manufacturing process. Bioethanol can be produced by fermenting the sugars extracted from sugar cane and other similar sugar-based crops, or starchy plants, such as cereals and root crops, which involve an extra saccharification step to convert the starches into sugars. But new technology is allowing second-generation feedstocks to be increasingly used and to become commercially viable, including cellulosic feedstocks, such as cereal straw and high-yielding grasses and trees. For example, maize stover (the straw stalks left after the maize has been harvested) is now being used to produce ethanol in the US and China. Municipal solid waste (MSW) is one of the latest ethanol feedstocks to be used in plants in Canada and the EU, with more planned around the world and potential for future expansion (European Biofuels Technology Platform, 2016).

More and more waste and residue feedstocks are being used to produce biofuels, particularly used cooking oil (UCO) and animal fats (eg tallow) in the production of biodiesel and waste products from palm oil processing in hydro-treated vegetable oil. But conventional oilseed crops such as soyabean, rapeseed, sunflowerseed and palm are currently the main raw materials used for biodiesel production. Other technologies have been slower to develop, including algae-based biodiesel, once heralded as the solution to the land and food security constraints of first generation feedstocks.

One of the main issues that is often overlooked in the debate surrounding biofuels is the output of co-products from the different feedstocks used. Most US maize-based ethanol production uses a dry milling process that converts the starch component of the grain into sugars which are then fermented to produce an alcohol beer which is then distilled. Other nutrients, such as protein, and fibre are left behind in the form of a stillage from which an animal feed known as distillers dried grains with solubles (DDGS) is produced. Similar protein feeds are produced using other types of cereal such as wheat. In the case of sugar cane ethanol, most of the co-product is in the form of bagasse, which is usually used as an energy source. But ethanol is also produced from the molasses co-product of sugar production, both from cane and beets.

Substantial quantities of animal protein feeds are also produced in the crushing of oilseeds for biodiesel production. In the case of soyabeans, only 15-20 per cent of the bean produces the oil from which biodiesel is produced, the rest produces a high protein animal feed known as soyameal, which is used as animal feed all over the world. Indeed the main revenue driver for soyabeans is from the meal rather than the oil. Similarly rapeseed yields about 40 per cent vegetable oil to 60 per cent meal, whilst oil palm seeds can yield 50 per cent oil or more. Palm oil fruits are from large fruit bunches and contain a kernel which is also crushed to produce a high quality oil and animal feed, whilst the empty fruit bunches are used as an energy source. The biodiesel production process also produces glycerine, which is often used in the food and drink, personal care and pharmaceutical sectors[14].

The co-products from the various feedstocks are an important component of the revenue generated from each crop. The development of techniques to convert the cellulosic parts of crops, such as cereal and oilseed straw, sugar bagasse, palm fronds and old trees, will add another revenue stream once commercially viable.

[14] Every 10 units of biodiesel produce about 1 unit of glycerol. The biodiesel industry supplies about two-thirds of the global supply of glycerine. The abundant supply of glycerine in past years led to a fall in prices, but in recent years prices have been supported by the development of new uses.

2.2.2 Biofuel energy balances and greenhouse gas reduction

Although the greenhouse gas emission implications of biofuel production are somewhat outside the scope of this study, part of the research related to the climate change impact of biofuels has focussed on land use changes that are inextricably linked to food security.

One of the main reasons why biofuels were initially supported by governments, particularly in the EU and US, was the assumption that feedstocks reduced greenhouse gas emissions by sequestering carbon during growth, offsetting vehicle emissions from the burning of biofuels. Once this assumption is made, then emissions can be calculated through a life-cycle analysis (LCA) of the biofuel production process, capturing all emissions in the production of both the feedstock and biofuel, including transportation to consumers. As long as the biofuel production process emissions are significantly less than those from using fossil fuels, such as petrol and diesel fuels, then the biofuel can be regarded as reducing GHGs and thus helping to curb global warming.

The literature shows a wide range of GHG reduction estimates for each feedstock, partly due to different means of production, but also due to methodological differences. Early estimates of maize ethanol GHG reductions were close to zero or even negative, but recent calculations show the current maize ethanol energy balance at over double the fossil fuel energy input (Gallagher et al., 2016). Energy balances for most feedstocks now suggest significant GHG reductions for most of the major feedstocks, and particularly sugar cane for ethanol and UCO for biodiesel.

But the seminal work by Searchinger et al (2008) calculated that greenhouse gas emissions from biofuel production were much greater once the emissions created from bringing new cropland into production to replace that used for biofuel feedstocks, were factored into the equation. Using a global econometric model, Searchinger et al estimated that maize ethanol production in the US would lead to a doubling of greenhouse gas emissions when GHGs were released from carbon sinks in other countries, as farmers around the world responded to higher prices by converting pasture and forests to cropland.

This concept of indirect land use change[15] (ILUC) has created much controversy, with various studies showing a wide range of impacts, and most later studies suggesting that the Searchinger estimates were exaggerated (eg Khanna et al., 2011, Zilberman, 2016). Despite the surrounding controversy and uncertainty, the concern that policies to encourage biofuel production might lead to increased GHG emissions led to both the US and EU introducing ILUC standards within their respective policies.

Policymakers have tended to base rules and regulations for biofuel production on the findings of complex econometric models. Partial equilibrium (PE) and computable general equilibrium (CGE) models provide a simplified framework of the economic sector (as in the case of the former) or economy (as in the latter), in order to assess how policies could affect market interactions, and how these, in turn, would affect land use changes and GHG emissions.

Existing models that have been established over many years by specialist teams, often in academic institutions, are usually adapted to the specific issue in question in order to assess different policy outcomes. These include the PE models developed by the Food, Agriculture and Policy Research Institute (FAPRI) at the University of Missouri and the Aglink/Cosimo model managed by the OECD and FAO, as well as CGE models such as the Global Trade Analysis Project (GTAP) model at Purdue University, the MIRAGE model used by IFPRI and CEPII[16] and the Common Agricultural Policy Regionalised Impact (CAPRI) model coordinated at Bonn university.

The models are based on theoretical economic concepts that are often contested, not least of which is the idealised view of competitive markets with perfect information flows (eg Taylor and von Arnim, 2006). Many assumptions also have to be made to fit the models to the real world. Hence, different models and different ways of applying such models to the issue at hand often produce very different results.

[15] The literature distinguishes direct land use change (DLUC), where land use may change from pasture or from another crop, to biofuel feedstock on the same farm or locality or country, as opposed to indirect land use change (ILUC), where increased areas of biofuel feedstock lead to land use changes elsewhere due to higher prices for the crops that the biofuel feedstocks have replaced.
[16] Centre d’Etudes Prospectives et d’Informations Internationales

Nevertheless they remain an important means of evaluating market developments and policy choices in the absence of other information.

The ILUC models are linked to food security in that they incorporate assumptions about how the increased demand for feedstocks for biofuel production affects the overall demand for that feedstock, including any food use, as well as any supply response, which may incorporate land use changes as well as productivity improvements.

Malins et al (2014) identified five key factors that determine the amount of ILUC resulting from the net effect of changes in food demand, productivity improvement and land use changes;

i) price elasticity of food demand

ii) price elasticity of crop yield

iii) price elasticity of area

iv) overall crop mix

v) co-product utilisation

Many of the differences between ILUC models are attributed to different assumptions made with regard to these factors, and the fact that some models do not take all or some into account. Thus, for example, some models incorporate higher price elasticities of supply (yield and area) than others, whilst some do not account for, or have much lower values of, the price elasticity of food demand (Malins et al., 2014)

There are many issues involved in estimating each of these factors. For example, past evidence within the literature suggests little responsiveness of crop yields to prices, particularly in developed regions where optimum inputs of fertiliser and other inputs may already have been reached leaving little scope for further increases. High input prices and environmental policies may also restrict the elasticity of yield to prices.

For co-product adjustments there are a number of ways this could be approached, such as the relative mass volume, the revenue generated or the assumed crop areas displaced on a feed-value basis, whilst some of the earlier models did not account for co-products at all.

Changes in the proportion of crops grown can also have a significant impact on overall productivity. For example, maize plantings in the US have tended to increase over recent decades at the expense of lower-yielding cereals such as wheat, barley and oats. The higher proportion of maize in the overall crop mix has thereby raised the total productivity of the overall cereal area.

Another issue regarding land use that is not accounted for by some of the models is that of double-cropping and other non-yield productivity improvements. Over the past decade it has become apparent that much of the global supply response to increased biofuel demand has been through the more efficient use of land rather than expansion of area (Babcock and Iqbal, 2014). This suggests a low price elasticity of area, which is commensurate with limited additional land availability in countries such as India and China, but also many developed countries, as well as the high cost of accessing and developing new land for crop production. Yet many of the models employ a relatively large elasticity of area response to price.

It is hardly surprising then that the models result in a wide variance of outcomes for greenhouse gas emissions from indirect land use change. For example, one study of eight such models found a significant variation in net CO_2 emissions from biofuels as a percentage of CO_2 emissions of fuel replaced, with ranges of between -5 and -90 per cent for sugar cane (negative values indicate lower emissions than the replaced fuel), +20 to -40 for maize and +35 to -35 for rapeseed (Croezen et al., 2010). Added to this are the assumptions then made on GHG emissions from the different types of land use change, particularly with regard to the extent to which the models incorporate areas with high carbon sinks relative to low carbon sink land. (Ahlgren and Di Lucia, 2014).

Another area of contention in the ILUC debate is that comparisons with fossil fuels are often made without reference to the changing nature and rising external costs related to fossil fuels. Calculations for energy efficiency and climate change impact are standardised in oil-equivalent. But crude oil quality has been decreasing in quality over time and particularly in recent years as oil is extracted from increasingly expensive resources such as tar sands. A recent IEA Bioenergy report estimated that in the US the average energy consumption per unit of crude oil processed increased by more than 50 per cent between 2001 and 2011 (Karatzos et al., 2014). From a climate change perspective, greenhouse gas emissions from oil tar sands extraction and refining are reported to be more than double that of standard crude oil which is used as the benchmark in most analyses (Gerdes and Skone, 2009). Given that it is now evident that a significant proportion of our fossil fuel reserves need to remain in the ground in order to maintain global warming below the agreed maximum 2 degree centigrade increase, this should also be factored into the ILUC equation for biofuels.

2.2.3 Biofuel production around the world

Most of the recent expansion in global biofuel output has occurred in food secure countries such as the US and EU, where the main feedstocks are food-based crops such as maize and vegetable oils. Brazil continues to expand its sugar cane-based ethanol output, whilst other relatively food-secure countries in South America and South Asia have embarked on policies to encourage the production, use and export of biofuels and feedstocks.

There are many sources of biofuel production estimates, the most up-to-date publicly available source being the annual data for the top biofuel producing countries reported in the Renewables Global Status Report compiled by the REN21 Secretariat of the UN Environmental Programme (UNEP). Its 2016 report estimates that global bioethanol production rose to 98.3 billion litres in 2015, compared to its first estimate for 2005 of 33 billion, with production in the US rising from 15 billion in 2005 to 56 billion in 2015 and that for Brazil doubling from 15 to 30 billion. Global biodiesel and HVO production is estimated at 35 billion litres in 2015 versus 3.9 billion in 2005, with EU production rising from 3.6 to 14 billion litres (REN21, 2016).

Apart from Brazil's sugar-cane ethanol sector, biofuel production in Latin America was virtually non-existent in 2005. But in recent years biodiesel production has risen sharply in Brazil, Argentina and Colombia, with an ethanol industry also now being established in the latter two countries. In Asia, China's ethanol production has risen from 1 billion to 2.8 billion litres over the past decade and Thailand produced nearly 1.3 billion litres in 2015. A thriving biodiesel sector has also been established in South East Asia with Indonesia producing 1.7 billion litres, Thailand 1.2 billion litres and Malaysia 0.7 billion, whilst a new HVO plant in Singapore was reported to be producing near to its capacity of 1.2 billion litres[17].

There has been much less biofuel activity in Africa, despite it having the greatest potential of all continents for high-yielding feedstock production, the highest prevalence of food insecurity and the most pressing need for rural development (Maltsoglou et al., 2013, Mitchell, 2011, Wiggins et al., 2013). Indeed, there have been a very limited number of new biofuel operations that have successfully established themselves in Africa over the past decade, after the flurry of start-ups from about 2005 onwards, and fewer still that have actually planted feedstock (Locke and Henley, 2013).

Many reasons can be put forward for the high rate of failure of biofuel projects in Africa, as they are little different from other cash crop operations. Indeed, many biofuel feedstock projects replaced cash crops on former estates, such as cotton and tobacco. One major difference has been the planting of jatropha in many new biofuel projects, which, although traditionally used as a hedge fence in some parts of Africa, remains unproven on a commercial scale and has generally underperformed in terms of oil yield expectations and disease resistance (Pohl, 2010, Kant and Wu, 2011). This accentuated the many risks involved in establishing biofuel feedstock operations in areas with weak agricultural sectors, poorly functioning markets and inadequate infrastructure, in addition to the mounting financial risks as the global recession started to take hold in 2008.

[17] The REN21 report for 2016 includes an additional 1 billion litres of conventional biodiesel produced in Singapore in 2015, but this could not be verified at the time of writing.

Nor has the changing policy environment been conducive to establishing biofuel operations in Africa. The EU Biofuel Policy Directive of 2009 initially raised hopes of a substantial export market for feedstocks and biofuels for least-developed countries under preferential trade arrangements with the EU. It was believed that biofuel feedstock sector expansion in countries with good potential for biomass production, such as Mozambique and Tanzania, could provide additional economic growth and *"crowd in"* much-needed investments that would also bring benefits to the agriculture and downstream sectors (Arndt et al., 2010).

But as the EU Biofuel Policy Directive came under pressure to cap the amount of biofuels made from "food-based feedstocks", investors became increasingly concerned about future demand, particularly since African governments have generally been slow to introduce policies to support their own smaller domestic markets. This has made it difficult for companies to secure sufficient investment for establishing and maintaining biofuel operations in Africa. Some experts also believe that a viable biofuel sector largely depends on the existence of a relatively strong and thriving agribusiness environment, which is missing in most least-developed countries, particularly in Africa (Msangi and Evans, 2013, Maltsoglou et al., 2013).

Hence, many of the biofuel start-ups in countries such as Mozambique and Tanzania, have ceased operating, largely due to the uncertain policy environment, the drying-up of capital funding, the poor viability of jatropha and other feedstocks and the lack of a prevailing agribusiness sector with well-functioning markets and infrastructure (Atanassov, 2013, Locher and Sulle, 2014).

Thus, most global biofuel production is mainly in food-secure countries, and mostly using domestically-grown feedstock. But there is relatively little comprehensive, reliable, consistent and timely data on feedstock use in biofuel production from which to assess its impact on food security.

2.2.4 Biofuel policies

The sharp rise in global biofuel production over recent years has been mainly driven by US and EU policies, aimed at blending specific amounts of biofuels into petrol and diesel transport fuels. This followed the path taken by Brazil some 30 years earlier in the 1970s to support the development of their long-established sugar-cane based biofuel industry.

The main reasons for the adoption of polices to support the establishment of a biofuel industry can be categorised under four main headings;

1. Energy security, as the price of oil and other fossil fuels rose sharply due to rising consumption in major countries and restrictions in supply, including disruptions from the major oil and gas producing areas such as the Middle East and Former Soviet Union.

2. Rural development, as the establishment of a new demand for feedstock provides new markets for farmers and the prospect of higher prices for feedstocks that have previously suffered from a long-term decline in real prices, as well as new rural jobs, both directly in the biofuel sector and indirectly.

3. Climate change, as the consensus view from the scientific community warns that fossil fuel use needs to be drastically reduced and eventually phased out in order to prevent irreversible and catastrophic global warming. The Paris Agreement at the end of 2015 places even more emphasis on replacing fossil fuels with renewable alternatives.

4. Environmental reasons, such as reducing fuel emissions through more oxygenated fuels, and replacing harmful additives to fuel, such as lead-based engine anti-knocking agents.

Different countries have different policy priorities, with Brazil focussing on energy security and rural development, the US also initially prioritising the same issues, but in the 1990s focussing more on environmental factors and more recently on climate change, whilst the EU has mainly focussed on climate change and rural development in developing its biofuel policies.

Government policies to support biofuel production have also differed between the main producing regions. Brazil adopted highly interventionist and supportive policies during the latter part of the twentieth century, not only in terms of establishing a strong biofuel sector but also in terms of fuel standards and the flexibility of its vehicle fleet and, hence, has achieved the highest biofuel blending rates in the world. US biofuel policies only included blending mandates from 2005, with limited policies to improve the flexibility of its vehicle fleet. The EU Commission first introduced indicative targets for the overall use of renewable fuels in 2003 followed by mandatory targets in 2005, but it left member states to decide to what extent they would or could contribute to the overall target, and, hence, progress toward meeting policy targets has been slow.

Mandated blending has also been the preferred option of the more recent policies adopted by new biofuel producers such as Argentina, Thailand, Indonesia and Malaysia, all of which have also tended to be more export-focussed. Worldwide there were some 64 countries with biofuel mandates (including all 27 EU members states) at the beginning of 2016, 13 in the Americas, 12 in Asia-Pacific and 11 in Africa and the Indian ocean area (Lane, 2016). Blending mandates range from Brazil's 27 per cent ethanol rate to Canada's 2 per cent renewable biodiesel rate for a number of Provinces.

There has been widespread criticism of the subsidies provided to biofuel operators by governments, including the biofuel mandates (eg Action Aid, 2015, Jung et al., 2010). The International Energy Agency estimated global biofuel subsidies at some $22 billion in 2010 based on tax reductions and differences between the prices of biofuels and fossil fuels on an energy basis, including the estimated support provided by blending mandates and borne mainly by consumers. Within this total the US accounted for just over $8 billion, the EU just under $8 billion and Brazil $2.7 billion. In comparison fossil fuel subsidies were estimated at $45-75 billion in OECD countries and $409 billion in non-OECD countries in 2010 (IEA, 2011b).

But the argument that large reserves of fossil fuels need to be left in the ground to avoid runaway global warming, suggest that the real cost of fossil fuels in terms of climate change impact is vastly understated (McGlade and Ekins, 2015). Indeed the relative cost of fossil fuels would be many more multiples of the estimated biofuel subsidies if the additional "external" costs of fossil fuels were incorporated into the subsidy calculations.

For example, a recent study found that the risks to global biodiversity from fossil fuel production are greater than those from equivalent biofuel production, due to petroleum exploration activities covering a larger area and located in fragile ecosystems that would otherwise remain undisturbed, whereas most biomass production is in areas already impacted by human activity (Dale et al., 2014).

It is also difficult to evaluate the potential benefits of biofuel subsidies. A favourable outcome of biofuel policies for those countries importing large amounts of oil would be reduced import bills. This argument was put forward by a number of proponents of biofuels before the first food price spike in 2008, including the Worldwatch Institute which noted that 38 of the 47 poorest countries in the world were net importers of oil (Worldwatch Institute, 2006). Oil prices rose sharply in subsequent years, which, together with rising demand, had an increasingly negative impact on the trade balance of such countries, putting pressure on budgets for public health, education and infrastructure services.

With a biofuel sector creating additional demand for certain commodities and theoretically supporting prices of exported commodities, this could help to offset the impact of rising oil prices on the trade balance of net food exporters, as well as reducing the volume of fossil fuel imports[18]. This would have a particularly significant impact on government budgets in food-insecure countries, helping to maximise the revenue available for health, education and infrastructure, which are key factors in improving food security through better access to, and utilisation of, food.

Supporting biofuels can also lead to an effective increase in farm support for agricultural feedstocks such as cereals, sugar crops and oilseeds. Since most of the biofuels are currently being produced in the US, Brazil and EU from domestic

[18] It should be noted here, however, that only one-third (19 out of 53) of African countries earned enough export revenue from agriculture to pay for their food imports in 2007 (Rakotoarisoa et al., 2011).

feedstocks, it is the farmers in these countries that have benefitted most from any crop price increases caused by biofuel policies. In the case of the US, higher maize prices would tend to reduce any direct payments made to farmers under the counter-cyclical payment support system. But in the EU where farm payments are decoupled from price, increased crop prices caused by biofuel mandates would lead to additional income (Bourgeon and Treguer, 2010). Developing countries cannot afford to subsidise their farmers to anywhere near the same extent as those in the US and EU. So a world in which all farmers received more remunerative prices, would help to level the playing field for developing country producers to some extent.

A growing policy concern over recent times has been the sustainability of agricultural and energy production. These concerns have been given greater attention in the formulation of biofuel policies than in agricultural and other energy policies. For example, in the EU biofuel producers are the only end users of crops and other feedstocks that have to comply with approved sustainability certification criteria, including GHG reduction requirements, set by government policy. This is aimed to ensure that all feedstocks used for biofuels qualifying for the renewable energy directive targets are sustainably produced, including imported feedstocks such as palm oil. However, the voluntary certification schemes approved by the EU Commission have come under criticism from NGOs for not being comprehensive enough and for failing to prevent unsustainable practices by feedstock suppliers, such as land-grabbing from local communities and deforestation (German and Schoneveld, 2012, Schlamann et al., 2013).

The following sections review the biofuel policies of the three largest biofuel producers: the US, Brazil and EU.

2.2.4.1 Brazil's biofuel policy

The first large-scale development of biofuels began in Brazil in 1975 under the ProAlcool programme designed to replace imported oil with domestically produced ethanol from sugar cane, whilst boosting rural employment. It was started at a time of high oil prices, following the embargo of oil exports by the Organisation of Arab Oil Exporting Countries (OAPEC) in 1973, and low sugar prices. The Brazilian government set mandatory blending rates in fuel, starting at 11 per cent in 1976, and also encouraged the development of pure ethanol engine cars in the late 1970s. It also set production quotas and price caps for sugar and ethanol, encouraged investment in processing facilities and controlled distribution through the government energy agency Petrobras. The ethanol industry stagnated from the mid-1980s as oil prices fell and sugar prices rose. But since the turn of the century there has been a resurgence of the sector, supported by new credit programmes aimed at expanding capacity. Nowadays, nearly half Brazil’s vehicle fleet is flex-fuel and able to use any combination of petrol and ethanol. The current mandated blend rate for petrol has risen to 27 per cent, with production of ethanol reaching some 30 billion litres, of which 27 billion is used for fuel (Valdes, 2011, Lane, 2016).

A key advantage for the Brazilian fuel ethanol industry is its use of sugar cane, which generally produces 8-10 times more energy than energy inputs. Furthermore, ethanol productivity from sugar cane has been growing at 3.5 per cent per annum over the past 30 years (Horta Nogueira et al., 2013). The cane to ethanol process also provides an energy source for the processing plant and national grid in the form of the bagasse co-product. And many of Brazil’s ethanol plants can switch between sugar and ethanol, depending on the relative profitability of each, with the molasses co-product of the sugar production process also used as an ethanol feedstock.

Brazil also started a National Biodiesel Production Programme in 2004 to promote domestic production and generate employment in the poorer northern areas, including soyabean-growing family farms. The government set its first blending mandate at 2 per cent in 2008 and this had risen to 7 per cent at the time of writing, using some 4 billion litres, with soybean oil as the main feedstock but with a significant proportion of animal fat waste also being used (Valdes, 2011).

The Brazilian biofuel sector is estimated to employ some 820,000 people, almost half the 1.7 million estimated global employment in biofuels and over 10 per cent of the total jobs in renewable energy around the world (IRENA, 2016).

2.2.4.2 US biofuel policy

US biofuels policies also started in the 1970s at the time of the oil embargoes, but failed to have as significant an impact as in Brazil due to the lack of blending mandates. Tax credits were first introduced for ethanol in 1978, but ethanol remained uncompetitive against petrol until the early 1990s when the Clean Air Act was amended to improve the oxygenate content of fuels and reduce carbon monoxide and ozone pollution. At the time methyl tertiary butyl ether (MTBL) was the main oxygenate used, acting as an anti-knocking agent in engines. But ethanol was provided with tax credits under the Energy Policy Act of 1992 to help it compete against MTBL, the credits applying to blends requiring 5.7 and 7.7 per cent ethanol. By the late 1990s MTBL had been classified as a carcinogen and a major contaminant of groundwater, and some states banned its use in favour of ethanol, whereafter US ethanol output started to grow more steeply (USDA, 2015).

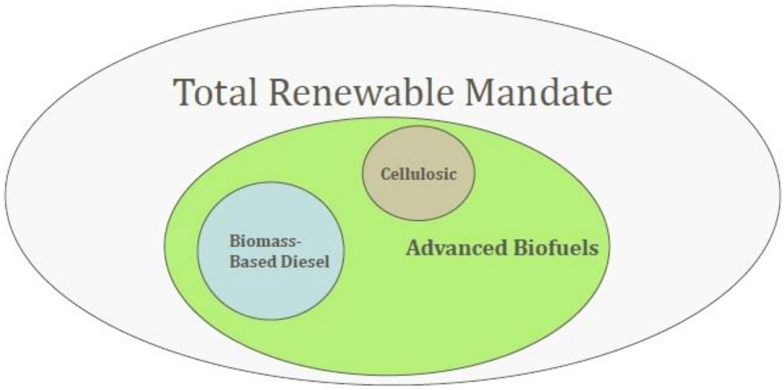
But the real boost for the US ethanol sector came in 2004 and 2005, starting with the Jobs Creation Act of 2004, which introduced the Volumetric Ethanol Excise Tax Credit (VEETC), which allowed oil companies to blend up to 10 per cent ethanol. In 2005, the Energy Policy Act banned MTBL and introduced a Renewable Fuel Standard (RFS) requiring a minimum amount of renewable fuel to be blended by petrol producers each year, starting at 4 billion gallons (some 15 billion litres) in 2006 rising to 7.5 billion gallons (28 billion litres) in 2012. As MTBE was quickly phased out, a 10 per cent ethanol blend (E10) became the main type of petrol sold in the US. The RFS also provided for some petrol suppliers to use less renewable fuel than required under the RFS, by purchasing credits, known as Renewable Identification Numbers (RINs), from those using more ethanol than needed (USDA, 2015).

By 2007 oil prices had risen sharply and there were growing concerns over the US reliance on imported oil. By the end of that year the Energy Independence and Security Act had introduced RFS2, with much more aggressive mandatory blending targets, rising to 36 billion gallons (136 billion litres) by 2022. That total was divided into four nested categories of biofuels according to the estimated greenhouse gas reduction impact compared with fossil fuel equivalents (fig 2.1).

Table 2.1 – US Biofuel Volume Requirements under Renewable Fuel Standards

Biofuel Category & Revisions	**Required Volume**	**Year**	**Min GHG Reduction**	**Feedstocks**
Total Renewable	Billion litres	Applied	vs Fossil Fuel	Main types
RFS1 2005 Start	15.1	2006		All
RFS1 2005 End	28.4	2012		
RFS2 2007 Start	34.1	2008		
RFS2 2007 End	136.3	2022		
Final 2010	*49.0*	*2010*		
Final 2011	*52.8*	*2011*		
Final 2012	*57.5*	*2012*		
Final 2013	*62.6*	*2013*		
Final 2014	*61.6*	*2014*		
Final 2015	*64.1*	*2015*		
Conventional Renewable (D6)	Billion litres	Applied	vs Fossil Fuel	Main types
RFS2 2007 Start	39.7	2009	20%	Maize ethanol
RFS2 2007 End	56.8	2015		
Revised 2010	*41.0*	*2010*		
Final 2010	*44.6*	*2010*		
Final 2011	*46.2*	*2011*		
Final 2012	*47.4*	*2012*		
Final 2013	*52.2*	*2013*		
Final 2014	*51.5*	*2014*		
Final 2015	*53.2*	*2015*		
Biomass-based diesel (D4)	Billion litres	Applied	vs Fossil Fuel	Main types
RFS2 2007 Start	1.9	2009	50%	Soybean oil
RFS2 2007 End	3.8	2012		Rapeseed/canola oil
Final 2010	*4.4*	*2010*		HVO diesel
Final 2011	*3.0*	*2011*		Used cooking oil
Final 2012	*3.8*	*2012*		Animal fats
Final 2013	*4.8*	*2013*		
Final 2014	*6.2*	*2014*		
Final 2015	*6.5*	*2015*		
Advanced (D5)	Billion litres	Applied	vs Fossil Fuel	Main types
RFS2 2007 Start	2.3	2009	50%	Sugar cane ethanol
RFS2 2007 End	79.5	2022		Biobutanol
Final 2010	*3.6*	*2010*		
Final 2011	*5.1*	*2011*		
Final 2012	*7.6*	*2012*		
Final 2013	*10.4*	*2013*		
Final 2014	*10.1*	*2014*		
Final 2015	*10.9*	*2015*		
Cellulosic (D3)	Billion litres	Applied	vs Fossil Fuel	Main types
RFS2 2007 Start	0.38	2010	60%	Corn stover
RFS2 2007 End	60.6	2022		Bagasse
Final 2010	*0.025*	*2010*		Wood chips
Final 2011	*0.023*	*2011*		
Final 2012	*0.00*	*2012*		
Final 2013	*0.003*	*2013*		
Final 2014	*0.12*	*2014*		
Final 2015	*0.47*	*2015*		
Source: (US EPA, 2016)				

Fig 2.1 – US Renewable Fuel Standard Categories



Source – US EPA (2016)

The overall renewable fuel category requires a GHG reduction of at least 20 per cent, whilst the advanced biofuel category requires at least a 50 per cent reduction, as does the biodiesel category, with the cellulosic category required to reduce GHGs by at least 60 per cent. Although there is no specific category for conventional biofuels such as maize-based ethanol, the volume targets for such biofuels are derived from the total targets minus the advanced targets (US EPA, 2016).

Biofuel blending has been encouraged through an excise tax credit of 45 cents per gallon of ethanol blended into petrol and $1 per gallon for biodiesel blending, which was temporarily removed in 2009 leading to a drop in production but was then reinstated. The RFS is based on targets for the usage of biofuels rather than production. But tariffs on ethanol (54 cents/litre) and, to a lesser extent, biodiesel, have also provided protection to the domestic industry.

Within the total required renewable fuel use, conventional maize-based ethanol production was targeted to reach 15 billion gallons (56.8 billion litres) by 2015 and biodiesel to reach at least 1 billion gallons (3.8 billion litres) by 2012. US conventional maize-based ethanol production surpassed the 50 billion litre mark in 2010, but by that stage it had reached a peak for domestic use as almost all petrol had reached a 10 per cent blend (E10), so expansion since then has been stifled by the so-called "blend wall". Another problem has been the slower than anticipated development of cellulosic biofuels for which annual targets have been revised sharply lower in recent years as anticipated commercial volumes have failed to materialise.

The US ethanol sector is estimated to provide some 86,000 direct jobs and 270,000 indirect employment by its industry association (RFA, 2016), whilst the International Renewable Energy Agency (2016) estimates total US biofuel employment at 277,000, including some 50,000 in the biodiesel sector.

2.2.4.3 EU biofuel policy

Whilst the EU has a longstanding ethyl alcohol support system under the Common Agricultural Policy[19], and introduced a scheme to allow crop production for non-food and feed use on set aside land in the early 1990s, its biofuel programme really began in 2001 when the European Commission (EC) launched its policy to promote biofuels for transport in order to cut greenhouse gas emissions, improve energy security and promote rural diversification (Zarilli, 2006). In 2003, a Biofuels Directive[20] introduced indicative targets of 2 and 5.75 per cent, for biofuel use as a proportion of total fuel use in 2005 and 2010, respectively. Under another Directive in 2003[21] member states were allowed to introduce tax cuts for renewable energy sources, whilst the same year also saw revisions to the Fuel Quality Directive (FQD), authorising the use of certain biofuel blends. The EU then introduced specific payments for energy crops in 2004/5 (Vannini et al., 2006).

The 2005 indicative blending target of 2 per cent was not achieved, and following slow progress toward the 2010 target, the EU decided to introduce mandatory targets in 2009 under the Renewable Energy Directive[22] (RED) which was part of the EU Energy and Climate Change Package (CCP), repealing the 2003 Biofuel Directive. The so-called 20:20:20 provisions of the CCP require by 2020, and for the EU as a whole, a;

- 20 per cent cut in GHG emissions compared to 1990

[19] This was mainly to support the distillation of surplus wine into ethyl alcohol (ethanol), but in 2008 the CAP wine regime was changed and this option is no longer eligible under the revised support arrangements.
[20] 2003/30/EC
[21] 2003/96/EC
[22] 2009/28/EC

- 20 per cent improvement in energy efficiency

- 20 per cent share of renewable energy in total energy, including at least a 10 per cent target for renewable energy in transport.

Not only biofuels, but also electric cars or greater renewable electricity use in overall transport, such as rail, can be used to achieve the 10 per cent target for renewable transport energy by 2020. Whilst the 20 per cent overall energy target under the CCP applies at the EU level, the 10 per cent target for renewable energy in transport is obligatory for all member states. Each member state has submitted a National Renewable Energy Action Plan (NREAP) under the RED.

The Fuel Quality Directive was also amended in 2009[23], requiring that all fuel suppliers reduce greenhouse gas emissions by at least 6 per cent on average by 2020. The FQD also restricts the palm oil and soyabean oil content of biodiesel and the blending of ethanol in transport fuels to no more than 10 per cent when it is used as an oxygenate.

The RED also introduced sustainability criteria, excluding biofuels not meeting these criteria from national mandatory targets and eligibility for support. The two main enforcement measures in place are:

i) a minimum 35 per cent GHG emission savings, rising to 50 per cent in 2017 and 60 per cent for new plants from 2018.

ii) sustainable certification from an approved scheme

Default values are used for the GHG emission savings, as defined by the European Commission. The values comprise all life cycle GHG emissions and are generally based on worst-case scenarios[24]. Additional emissions from land use change and any

[23] 2009/30/EC

[24] For example the soyabean biodiesel default value is based on a theoretical pathway using soyabeans shipped from Brazil, resulting in a 31 per cent GHG saving, below the 35 per cent threshold. The same calculation for US biodiesel shipped to the EU results in a 40 per cent saving, but US biodiesel would still be subject to the 31 per cent default value and cannot therefore be used to meet the renewable fuel targets

savings from improved agricultural practices or co-generation of electricity or carbon capture and storage are also taken into account where relevant.

The RED also contains environmental sustainability criteria, excluding all biofuels produced from feedstocks on land with high biodiversity value or high carbon stock, such as rainforests and peatlands. There are also other environmental provisions related to air, soil and water quality and some broad social provisions pertaining to food prices and labour standards.

The approved sustainability certification schemes incorporate these broad minimum provisions in different ways. At the time of writing 19 voluntary schemes had been approved by the EU. In 2013 the World Wildlife Fund analysed the RED and the 13 schemes that had been approved at that time. It found that social issues, such as food security and compliance with International Labour Organisation standards, were not mandatory under RED and not covered within many of the voluntary schemes. Of particular note was that only one of the schemes, that of the Roundtable on Sustainable Biofuels, incorporated adequate provisions for food security (Schlamann et al., 2013).

At the end of 2015 a directive[25] was introduced covering ILUC and amending RED and the FQD. The key revision was to cap the contribution of food crop based biofuels at 7 per cent (on an energy basis) of the 10 per cent target for renewable energy in transport by 2020. Current blending rates for food-based biofuels are estimated to average 5 per cent for the EU as a whole. The Directive also introduced measures to encourage the production of advanced biofuels in the form of double counting of their energy contribution toward the 10 per cent target and a 0.5 per cent non-binding blending target for advanced fuels in each member state by 2020[26].

2.2.4.4 Biofuel policies in other countries

As the US and EU embarked on policies to encourage biofuel production, other countries started to investigate their commercial viability, particularly in terms of

[25] EU Directive 2015/1513

[26] This appears to be a somewhat unambitious target given that current advanced HVO use is estimated to account for over 0.5 per cent of EU transport energy

reducing the cost of increasingly expensive fossil fuel energy imports and for potential exports. Many other countries have now established blending targets and mandates for renewable sources in transport fuels.

In South America, for example, Argentina recently increased its ethanol blending mandate to 12 per cent (E12), whilst its biodiesel rate was 10 per cent (B10) at the time of writing. Colombia had E8 and B8-10 rates depending on the region, whilst Chile had E5 and B5 rates in place. Ecuador was looking to increase its B5 mandate to B10 and was also targeting an E10 rate by 2018. Paraguay was planning to match Brazil, from its slightly lower mandate at E25, whilst Peru had E7.8 and B5 mandates.

Of the other major countries, Canada has E5 and B2 rates, nine Chinese provinces require E10 blends and a national E10 rate is targeted for the whole country by 2020, New South Wales in Australia has E7 and B2 blends, India recently announced an E10 blend[27], Indonesia has an E3 and B15 mandate, with the intention of moving to B20, whilst Malaysia will increase its rate from B7 to B10, with a planned B15 by 2020 and Thailand is planning to increase its B7 rate and has a target of 3.3 billion litres of ethanol use by 2020 but is only using 1.3 billion currently (equivalent to an E12.5 rate).

Governments have set ambitious targets for biofuel production in South East Asia for both domestic use and export. Some of these may be difficult to achieve in the face of rising food demand, particularly given land and environmental constraints in the region (Zhou and Thomson, 2009). There seems to be more scope for expansion in South America, Canada, and Eurasian countries, such as Russia and Kazakhstan, where land resources are more abundant.

There also seems to be considerable scope for some least-developed countries to develop biofuels sectors, particularly in parts of Africa. The Energy Sector Management Assistance Programme (ESMAP) of the World Bank produced a report as early as 2006 outlining the potential for transport biofuels in developing countries

[27] India has an E10 and B5 target for 2022 but has found it difficult in recent years to secure sufficient volumes of ethanol and vegetable oil to support an expansion of fuel blending toward these targets.

and illustrating the potential for replicating the Brazilian biofuel success (Kojima and Johnson). But a decade later this has yet to materialise, partly due to concerns over food security impacts.

2.2.4.5 Summary of biofuel policies

Biofuel policies have been instrumental in the recent expansion of global biofuel production. Policies such as blending targets and mandates, and subsidies and tax credits to processors, have been used by the major producing countries to encourage increased production.

One of the key features of the national volume and blending targets is the relatively small share of overall petrol and diesel fuels envisaged by governments. Biofuels are not seen as full replacements for fossil fuels but more as partial replacements, with the blended fuels benefitting from technical characteristics in biofuels such as ethanol's octane-boosting properties. The relatively low blending rates are partly due to technical limitations regarding potential engine damage from high biofuel blends in older vehicles, but also concerns over feedstock availability and resource use.

It is clear that biofuels have been accepted as a way of reducing fossil fuel use by many countries throughout the world, in order to cut expensive imports, reduce GHG emissions and as a means of supporting rural development. They have been the most practical means of curbing fossil fuel use in transport over the past decade and remain the only viable alternative to liquid fuels at the time of writing. The more developed countries have the advantages of a well-established agribusiness industry and sufficient financing from which to establish their biofuel sectors, whilst those in least-developed nations have struggled to facilitate biofuel operations and establish biofuel sectors.

2.2.5 Biofuels in Africa

Despite the opportunity for many African countries to reduce their dependence on fossil fuel energy supplies, particularly where these are imported, there has been relatively limited development of biofuels in this region. Ethiopia, Malawi, Swaziland and Zimbabwe all have longstanding ethanol production facilities linked to their sugar industries, but relatively little of this was used for fuel purposes until recently.

The African biofuel experience over the past decade can be summarised as an initial flurry of activity from 2005 to 2010 as companies started to acquire land and governments tried to quickly develop national policies and regulation, followed by a period from 2010 to 2015 when many of the projects folded and governments started to introduce clearer policies including blending mandates in some countries, but with relatively little development of biofuel production.

Malawi is the only country that has implemented a long-running and consistent biofuel policy, facilitating ethanol-blending rates of between 10 and 24 per cent since 1982 (currently at E10). The ethanol is produced from two molasses-using plants capable of producing 36 million litres; Ethco at Dwangwa in the central lake-district of Nkhotakota established in 1982, and Press Cane at Nchalo in the southern district of Chikwawa, which started production in 2004. Both are owned by the Press Corporation, a Malawi-based company. Due to a shortage of molasses from the local sugar sector, combined production is running at about half capacity, about half of which is blended with petrol on the local market, supplied to BP, Mobil, Total and Caltex, and the rest mainly exported to DR Congo, Botswana and East African countries as industrial alcohol. The ethanol plants are located next to the two Illovo-owned sugar factories in the country and supplied with the molasses by-product. An expanded sugar sector would help to boost ethanol output and could also bring socio-economic benefits to small farmers and estate workers based on assessments by the existing industry (eg Johnson and Jumbe, 2012).

Malawi has also supported biodiesel production in recent years in order to reduce diesel imports. BioEnergy Resources Ltd (BERL) was established in 2006 and has worked with some 25,000 smallholders to plant jatropha as a feedstock source for its biodiesel manufacturing plant in Lilongwe. Original plans were for 15 million trees to be planted to produce 20 million litres for blending and straight vegetable oil. According to BERL, some 6.6 million trees were planted by 2012 and in 2015 a licence was approved for blending jatropha oil with diesel, with initial plans for 2 million litres to be blended. BERL has diversified into sunflower in recent years, after some disappointing results with jatropha. However, some assessments show significant socio-economic benefits for jatropha growers (eg Dyer et al., 2012).

Zimbabwe also has a long history of ethanol production with the Triangle plant in the Lowveld starting ethanol production from molasses in 1980, with a capacity of 120,000 litres per day. This allowed for an 8-13 per cent national ethanol blending rate to be established during the 1980s with government support in the form of reduced taxes. However, in 1992 the Triangle refinery closed the ethanol plant due to a severe drought which cut supplies of cane sugar and therefore molasses. The company then decided in 1994 to stop ethanol production for fuel blending and to focus on higher value rectified spirits for industrial use, most of which is exported to the EU.

The government supported the original development of the Triangle plant and the blending mandates with tax breaks, but the lack of government support in the mid-1990s followed by another severe drought in the country in 2002, led to the closure of the ethanol facility. In 2005 the Zimbabwean government approached Anglo-American with a proposal to revive the plant in the wake of severe fuel shortages, in return for the reallocation of some land within the land redistribution programme. This was taken up by the company with a new $3 million dehydration facility established and ethanol production resuming in 2008.

Triangle is owned by the Tongaat-Hulett sugar group (owned by the Anglo-American Group), which manages the two sugar mills in the country in the south east; Triangle and Hippo Valley. The plant was producing some 25-35 million litres of ethanol per annum in recent years, including a small amount of dehydrated ethanol for E10 and E15 blends, but with most exported as industrial alcohol.

A new ethanol plant, built by the company Green Fuel at Chisumbanje, started producing fuel grade ethanol from both cane juice and molasses for the domestic market in late 2011. The plant was then closed for a year whilst the company waited for officials to establish a mandatory blending rate that finally came into place in early 2013 at 5 per cent. The blending rate has since been increased to E10 and more recently to E15, requiring some 6 million litres of ethanol per month. The plant was reported to be running at 8 million litres per month in 2015, with stocks being rebuilt whilst the company pressed for a further increase in the national blending rate.

The Zimbabwean government also supported a jatropha biodiesel project, with a view to achieving a B10 blend by 2017, requiring over 100 million litres of biodiesel. It helped a private company to establish a 35 million litre capacity biodiesel plant, which started producing small volumes at the start of 2008, mainly from cottonseed until jatropha seed could be sourced. The company Finealt Engineering recently reported they had 30,000 litres of biodiesel awaiting blending authorisation from the government, as well as limited stocks of some 130 tonnes of jatropha seed.

The National Oil Company of Zimbabwe (NOCZIM) initiated the jatropha programme, with a target of supplying some 50 million jatropha plant seedlings to farmers covering some 120,000 hectares, as a future source of supply for the biodiesel plant. Only farms with more than 5 hectares could participate in the new scheme, organised by the Jatropha Growers and Biofuels Association, and only degraded land could be used so as not to impair food output. However the NOCZIM project was halted in 2010 due to a lack of funding and poor uptake by farmers.

In Angola the government has supported the production of ethanol from sugar cane under its biofuel law of 2010. The government stipulated that the best land would be retained for food production and that they would only allocate more marginal land to biofuel projects. Under the law companies must sell part of their output to the state owned oil company Sonangol to meet domestic blending needs, and must also provide social supports in their locality, including access to water and health facilities. The main project owned by Biocom (60% Angolan owned and 40% Brazilian) has been delayed and only started to produce sugar, ethanol and electricity last year from its 37,000 hectares of cane. It is expected to produce about 6 million litres of ethanol in its first year of production with a capacity of 30 million litres per annum helping to meet its E10 mandate. Other Angolan biofuel projects announced over the past decade, like so many others throughout Africa, have failed to materialise.

Ethiopia embarked on a policy to transform itself into a sugar exporter rather than importer as part of its Growth and Transformation Plan of 2010. The three existing sugar plants of Wonji-Shoa, Methara and Fincha produce some 300,000 tonnes of sugar. Fincha was the only ethanol producer up to 2010, producing some 8 million litres per annum from molasses, until recently when capacity was increased to 20 million. The Wonji-Shoa factory added a 10 million litre ethanol facility in 2013, whilst the Metehara factory added its 12.5 million litre capacity ethanol plant in 2011.

The new Tendaho factory started sugar and ethanol production in 2013 and is gradually increasing its output with a target of 600,000 tonnes of sugar per annum and 63 million litres of ethanol. The Kessem factory also started production last year, including 12.5 million litres of ethanol, rising to 30 million at full capacity and 260,000 tonnes of sugar. Other sugar factories are in development with a potential total production as high as 1.6 million tonnes of sugar and 130 million litres of ethanol. However, the expansion has not happened quickly enough for Ethiopia to reach its E20 target and the national blend remains at E10. In the longer-term, the target is for 2 million tonnes of sugar production and 180 million litres of ethanol.

The Ethiopian government is also reported to be pressing ahead with a joint project with the Norwegian government to produce 450 million litres of biodiesel per annum from jatropha oil, involving an estimated 14 million farmers, but there is uncertainty as to how much progress has been made toward this target.

Sudan was one of the first African countries to diversify into ethanol production following the biofuel expansion in the US and EU, with the Kenana Sugar Company (KSC) establishing a 66 million litre capacity plant in 2009 during the expansion of the sugar industry. Some 40 million litres of ethanol were exported to the EU in 2015, the rest used domestically, including some for fuel blending. The government recently increased the blending rate for ethanol from E5 to E10 and KSC plan to increase ethanol capacity to 200 million litres in the near future.

In west Africa, Addax Bioenergy recently established an 85 million litre capacity ethanol plant in Sierra Leone, supplied by a 10,000 hectare sugar cane estate. Electricity generation to the national grid is another output of the plant, which employs some 2,000 people.

Other African countries have developed policies for biofuel production and fuel blending, but have failed to attract investment in biofuel plants. For example, South Africa launched its National Biofuel Strategy in 2007, with an overall blend target of 2 per cent or some 400 million litres of biofuels. But it failed to provide sufficiently supportive policies to attract investors over the following years. The government then authorised the blending of biofuels in 2013, requiring mandatory blending of up to 5 per cent for biodiesel and 10 per cent for bioethanol starting at the end of 2015. A number of planned ethanol plants are now in the pipeline but it remains to be seen whether these will come to fruition.

The Mozambique government has been more proactive toward biofuel investors, but despite a large number of planned projects, at the time of writing there was only a limited production of ethanol and biodiesel for blending into fuel. Land is the property of the state in Mozambique, where formal requests must be made to lease land for feedstock production, including evidence that an adequate community consultation process has taken place. By the end of 2008 the Mozambique government had officially received proposals from 17 biofuel projects, five of which were for bioethanol feedstock production and 12 for biodiesel crops. The total area of land requested was some 245,000 hectares, a small fraction of the 7 million hectares the government had identified as available for investors in 2008 as part of an agro-ecological zoning exercise (Schut et al., 2010).

By 2009 the Mozambique government had established a national biofuel strategy, including approved feedstocks and national blending targets, with the aim of establishing E10 and B3 blending rates by 2015, rising to E15 and B7.5 per cent by 2020. By the end of 2010 it was reported that 48 projects had registered with the government, of which 23 had planted crops. But by early 2013 a report by the Overseas Development Institute (ODI) noted that only 18 projects were still operating, with a total area amounting to 209,000 hectares, of which only 6,000 hectares had actually been planted (Atanassov, 2013). This reflects the closure of a number of projects during the 2010-2013 period whilst other companies lost their land use rights due to insufficient progress (Locke and Henley, 2013).

In Tanzania, Sulle and Nelson reported official government figures showing that some 20 companies had requested land for commercial biofuel production by early 2009, but also cited earlier reports by Songela and Kamanga that 37 companies had requested land rights amounting to over 4 million hectares, of which 640,000 hectares had been allocated and 100,000 hectares had been granted formal rights of occupancy (Kamanga, 2008, Songela and MacLean, 2008, Sulle and Nelson, 2009). By the end of 2009, the Ministry of Agriculture, Food Security and Cooperatives in Tanzania reported to Action Aid that there were 44 active biofuel companies in the country, of which the Tanzania Investment Centre (TIC) had formally approved only eight projects (ActionAid Tanzania, 2010). By this time the government had suspended all further land transfers to biofuel operations due to concerns over land conflicts and food security.

By 2013 the number of projects approved by the TIC had reached 11, covering some 66,000 hectares, but only another 14 companies were still seeking land for biofuel feedstock production at that stage. Moreover, only four of the approved projects had planted feedstock on a total area of just 1,600 hectares (Locke and Henley, 2013). As in Mozambique, this reflected the closure of a number of projects following the government's suspension of land transfers, but also due to financing difficulties as investors became more concerned about land grab issues and food versus fuel concerns (Markensten and Mouk, 2012).

This brief review of biofuel developments in selected African countries highlights the difficulties faced by both governments and operators in establishing a viable biofuel industry. At the time of writing the production of biofuel on the Continent remained limited to small volumes in a few countries. Production of ethanol is set to increase significantly over the coming years in some of these countries.

2.3 A Review of the Literature Linking Biofuels and Food Security

Africa has the highest prevalence of food insecurity of the world's continents, at 20 per cent of the population, with Eastern and Middle Africa recording rates of over 30 and 40 per cent, respectively (FAO, 2015). Sub-Saharan Africa also has more than half the global population without access to electricity, with less than a third of inhabitants having access in 2012 (IEA, 2014). Given that some 80 per cent of those lacking access are in rural areas, this suggests that the Sub-Saharan region also has the most need and potential for developing a modern bioenergy sector. Yet after a decade that has seen global biofuel output rise sharply, largely as a result of enhancing policies in mainly food-secure countries, Africa and other developing countries have been left behind. This section reviews the literature linking biofuels and food security, to help explain why this may have happened, with particular reference to the concerns surrounding the impact of biofuel production on food availability and prices.

2.3.1 The beginnings of the "food versus fuel" debate

The modern food versus fuel debate began in relation to the Brazilian biofuel policies of the 1970s and 1980s, with Rosillo-Calle and Hall using the phrase *"food versus fuel"* in a Biomass journal article (1987).

One of the first people to elucidate the concept that the emerging support for biofuels in the early years of the new millennium could bring food and fuel into conflict was George Monbiot in his Guardian article *"Feeding Cars Not People"* (2004). Monbiot calculated that for the UK to meet the EU Commission's proposal of 20 per cent of fuel transportation demand from renewable fuels by 2020, it would have to use all of the UK's cropland. Meanwhile in the US, Lester Brown of the Earth Policy Institute used the analogy that biofuels would bring the 800 million people who own cars and want to maintain their mobility in direct competition (for grain) with the 2 billion poorest people in the world who are simply trying to survive (Brown, 2006).

In 2007 Jean Ziegler, the UN Special Rapporteur on the Right to Food, called for a five year moratorium on biofuel production in his 2007 report to the UN General Assembly (Ziegler, 2007a). Ziegler later said *"It is a crime against humanity to convert agricultural productive soil into soil which produces food stuff that will be burned into biofuel"(Ziegler, 2007b).* Within his report Ziegler cited information from an article in the magazine "Foreign Affairs" which estimated that "*to fill one car tank with biofuel (about 50 litres) would require about 200kg of maize – enough to feed one person for one year" (Runge and Senauer, 2007).*

Thus, at the same time as biofuel production was starting to rapidly expand, particularly in the US and EU, much of the reporting of biofuels was markedly critical from a food security perspective. The sharp rise in global commodity prices that began in 2007 and peaked in 2008 fuelled such criticism, as it was believed that biofuel use of feedstocks such as maize and vegetable oil was the main culprit in reducing food availability in relation to rising demand, thereby leading to higher food prices.

The concern surrounding sharply higher food prices and the growing debate around biofuels led to the UN Food and Agriculture Organisation focussing on this issue in its annual State of Food and Agriculture report in 2008. The findings of the report set the tone for policy developments in the EU and US over the coming years. The FAO argued that biofuels would *"offset only a modest share of fossil energy use over the next decade",* but would have *"much bigger impacts on agriculture and food security"*, concluding that there was *"an urgent need to review current policies supporting, subsidising and mandating biofuel production and use"*. At the same time it was argued that *"hasty decisions to restrict biofuels (could) limit opportunities for sustainable agricultural growth that could benefit the poor"*. FAO therefore called for in-depth studies in the context of food security and sustainable development needs (FAO, 2008b).

Whilst the initial focus was on the global consequences of biofuel production taking place in the developed world, there were also reports on the potential for biofuel production in developing countries (Kojima and Johnson, 2006, Worldwatch Institute, 2006, Leturque and Wiggins, 2009, Raswant et al., 2008, von Braun and Pachauri, 2006). These reports highlighted the potential for economic growth in rural areas of developing countries, particularly through the production of feedstock to meet growing biofuel demand. The most energy efficient conventional biofuel feedstocks are tropical crops such as sugar cane for bioethanol and oil palm for biodiesel, and most of the land suitable and available for producing such feedstock is in developing countries. It was argued that many developing countries could build their own biofuel industry in order to replace fossil fuels, both from a climate change and financial perspective, as oil imports create a huge burden for many nations.

Increased employment and incomes in rural areas of developing countries would also help to improve food access and security. Greater investment in health and education from savings made through reduced fossil fuel imports, would particularly improve the utilisation dimension of food security.

Also at this time Pingali et al explained that the focus on adverse impacts of higher food prices on consumers missed the point that there could be a positive supply response, helping to revitalize rural sectors in developing countries, with positive implications for poverty reduction and food security. Arguing that agriculture has been the major engine of economic growth and poverty reduction for many of the countries that have transitioned from least to middle-income status, they argued that many of the remaining least-developed countries are well placed to capitalise on biofuel opportunities, particularly where land is abundant. However, they also noted that such countries face many other constraints that may continue to stifle development (Pingali et al., 2008).

Hence, by the time of the global food price crisis of 2008, the general biofuel debate had fallen into two main camps:

i) Critics - those opposing the expansion of most types of large-scale commercial biofuel production and government support to such, on the basis of reduced food and resource availability and higher food prices, environmental pollution, soil erosion, land rights and climate change concerns

ii) Proponents - those encouraging most types of biofuel production on the basis of better food access through improved rural employment and growth, replacement of fossil fuels and reduced greenhouse gas emissions and as a vital energy resource for developing countries, and particularly rural areas.

There were some proponents who focussed on ways of avoiding food conflicts, such as through using non-food feedstocks (eg Tilman et al., 2009), and some critics that highlighted both challenges and promises (eg von Braun and Pachauri, 2006), but in general the debate fell into the two distinct camps.

This was reflected in the book "Food versus Fuel"[28] published in 2010, which contained two chapters entitled *"Why we should not be using biofuels"* and *"Why biofuels are important"*, each written by a number of experts (Cortez et al., 2010, Pimental et al., 2010, Rosillo-Calle and Johnson, 2010).

The proponents concluded "*biofuels can play an important role in reducing GHGs and in contributing to social, economic and technical development"*. They noted that a continued dependence on fossil fuels would be much less environmentally friendly, would threaten energy security and exacerbate the impact of energy poverty in hindering rural development (Cortez et al., 2010).

The critics focussed on the need to conserve resources for food, rather than fuel, production, as *"there is simply not enough land, water and energy to produce biofuels"*, noting that using food grains to produce biofuels had already caused shortages for the world's poor. They also claimed that most conversions of biomass into ethanol and biodiesel result in a negative energy return (Pimental et al., 2010). The critics also cited Brown's assessment that using food and feed crops to produce ethanol had resulted in a 10-20 per cent increase in key food prices by 2008, including bread, meat and milk (Brown, 2008).

These divergent views over biofuels were reflected in widespread media coverage, with a particularly large number of NGO reports criticising biofuels, and most of the supportive reports emanating from industry associations. In 2011 an article in the Royal Society's Interface Focus journal noted, *"the societal debate on biofuels has become increasingly chaotic"*. The article contained a meta-assessment of secondary literature in the early years of the biofuel debate, between 2006 and 2010, using a People-Planet-Profit framework. Within the "People" category, the impact of biofuels on food prices was the most frequently considered, and most central, issue,

[28] The BBC4 radio Programme "Costing the Earth" was perhaps the first to use the term "food versus fuel", with regard to the current debate, in its broadcast in late 2007 (Eyre, 2007). In the US, Food versus Fuel was the title of a 2008 article in Environmental Health Perspectives (Tenenbaum) and then Rosillo-Calle and Johnson (2010) used the term for the title of their book.

and the majority of stakeholders regarded the impact of biofuels on food security as clearly negative, although some referred to it as neutral/unclear. However, the "Profit" category was consistently regarded to be favourable, particularly for rural employment opportunities, whilst the "Planet" category was consistently negative for first generation biofuels. There was also a clear difference between stakeholders, with NGOs focussing on "Planet" aspects and industry on "Profits". The study also noted that few of the publications reviewed cited scientific or primary data (Michalopoulos et al., 2011).

2.3.2 The ethics of biofuels

Given the mainly negative press over biofuels at the time, more and more attention turned to the ethics of the biofuel policies that had been adopted by the EU and US. It was argued that if biofuel policies were causing more hunger throughout the world they would be unethical. In 2011 the BBC news reported that a Nuffield Study had indeed found that biofuel targets were unethical. The Nuffield Council on Bioethics report concluded that UK and European biofuel policies encouraged unethical practices and recommended changes, including comprehensive ethical standards enforced through certification schemes (Nuffield Council on Bioethics, 2011).

The Nuffield report used three case studies to illustrate some of the problems, noting that;

i) US maize-based ethanol had been blamed for increasing the price of maize and other grains in developing countries

ii) Brazilian ethanol from sugar-cane had contributed to deforestation in rich habitat areas

iii) Malaysian palm-based biodiesel had resulted in land grabs forcing out local indigenous communities, as well as having detrimental impacts on biodiversity through the conversion of forests to palm plantations

It also recommended five principles for ensuring the ethical production of biofuels, stating that biofuels should:

i) not be at the expense of basic human rights, including food, water, health and work

ii) be environmentally sustainable

iii) contribute to reduced GHG emissions

iv) develop in accordance with fair trade principles that provide people with just rewards

v) distribute costs and benefits in a fair and equitable way

But the report also stated that if ethical principles can be adhered to, then there is a sixth principle, which is a duty to develop such biofuels, depending on some key considerations, such as costs and alternative feedstock uses and energy sources.

Few would argue against the six recommendations made by the Nuffield report. But like so many of the reports on biofuels during this period, the recommendations could be applied to any economic activity, not only biofuels. Moreover, the evidence provided to support the view that biofuels were unethical relied on somewhat simplistic assertions and studies.

Gamborg et al provided a more nuanced view of the ethics of biofuels in relation to food security, making the point that the biofuel debate is complex and actually involves many debates that are difficult to unpack, involve empirical uncertainties and involve the *"clarification and relative weighting of potentially conflicting values"* (Gamborg et al., 2011). In relation to food security, they noted that biofuels have been framed as both contributing directly to world hunger and as a means of alleviating rural poverty, thereby reducing hunger. They also made the important point that higher food prices could encourage more investment in agriculture in developing countries over the medium-term.

Thompson (2012) also criticised the *"unsophisticated portrayal"* of the ethical issues involved in the food versus fuel debate, arguing that the idea of a zero-sum food versus fuel trade-off is *"extremely misleading"* taking a more holistic approach in his analysis of the issues. Using a similar argument to the earlier work of Pingali et al, Thompson stated that the idea that higher food prices are disastrous to the world's poor is based on a faulty understanding of the ethics of hunger, as the majority of the poor live in rural areas, many of whom rely on agricultural sales for income. However, again like Pingali et al, he also qualified that theoretical benefits may not be realised by poor households where there is an imbalance of power in the food system.

This recognition of the complexity of food systems contrasts markedly with much of the literature surrounding the biofuel debate, which has been largely couched within a standard neoclassical economic view of the world. Thompson and Scoones (2009) note that the development narrative continues to focus on agricultural productivity as the engine of economic growth, yet this has failed over successive decades to provide sustainable livelihoods for much of the developing world. They are particularly concerned that economic models, such as partial and computable general equilibrium models, are unrealistic and narrow in scope, placing too much emphasis on increasing productivity and value-added and encouraging investment in larger-scale commercial agri-food systems. They emphasise that agri-food systems are embedded in complex, ecological, economic and social processes, and that a more sustainable-focussed approach is required.

A special issue of the Journal of Peasant Studies on biofuels in 2010 contained a series of articles from a political economy perspective. A key theme of many of the papers was the consolidation of corporate power in the agri-food sector, with biofuels providing for profitable investment alliances between agribusiness, energy, motor vehicle and biotechnology companies (McMichael, 2010). This again highlights the difficulty facing many of the rural poor in terms of accessing agri-food markets in order to improve income and the difficulty that many face in negotiating remunerative prices.

White and Dasgupta (2010) in the same journal cite Pingali et al (2008) in reminding us that the use of agricultural feedstocks for non-food purposes is not a new development, but note that the speed of the "biofuels boom[29]" has been more rapid than in the past. Hence, they stress the importance of *"not blaming a crop (or the uses to which a crop is put)"* but analysing the actors involved, their positions of power and the capture of added value within the supply chain.

[29] The term "biofuel boom" is often used to describe the sharp expansion of global biofuel production

2.3.3 Linking biofuels to the dimensions of food security

The various analyses in the literature seem to take as read that biofuels, or at least maize-based ethanol, is associated with rising prices of global food commodities, whether or not this is seen as good or bad from an ethical perspective. There is relatively little discussion of the production of co-products that enter the food chain or the degree to which any supply response may offset increased demand, thereby dampening down any initial price rise.

Indeed there tends to be limited analysis of the many linkages and pathways between biofuels and food security in general. It is important that such pathways are mapped out, not only to identify the various ways in which biofuels may affect food security, but also to assess which are the most influential factors and what might be the best ways to mitigate any negative impacts and enhance any positive influences.

The Food Security Guidelines of the Roundtable on Sustainable Biofuels certification system provides a summary of the hypothesised pathways linking biofuels to the different dimensions of food security (Thornhill et al., 2012). The RSB Guidelines identify the key factors as being the impact of biofuel demand on food availability, through competition for both feedstock and resources, as well as food access, stability and utilisation through the impact on food prices and household incomes.

A subsequent report by the High Level Panel of Experts (HLPE) on Food Security and Nutrition, convened by the UN Committee on Food Security, also identified the key issues linking biofuels and food security as competition for key resources such as land and water in food and feed availability (negative), higher food and feed prices on food access (both negative and positive) and improved incomes on food access (positive) (HLPE, 2013).

These important issues are interlinked. As the HLPE notes in the summary of its review of the impacts of biofuels on food security

> *"When crops are used for biofuels, the first direct impact is to reduce food and feed availability. This induces an increase in prices and a reduction of*

food demand by the poor. It also encourages farmers to produce more. There is also a substitution effect, at consumption level and at production level, which is one of the reasons price increases spread to other crops"(HLPE, 2013).

This encapsulates the links between the food availability and price impacts of biofuels, highlighting how difficult it is to apportion an overall impact because increased biofuel demand encourages increased prices, but also encourages a supply response dampening prices down.

2.3.4 Biofuels and land use

One of the main criticisms aimed at biofuels is that they use feedstock, or grow feedstock on land, that might otherwise be used for food production. Not only that but they also compete for other valuable resources such as water and fertiliser for food and feed production.

A key focus of the food versus fuel debate regarding "availability" has been the "land-grab" issue and its impact on world food supply. Most global biofuel production is from domestically grown feedstock in mainly food-secure countries. However, returning to the ILUC debate outlined in section 2.2.2, it is argued that increased maize production in the US for biofuel use leads to reduced availability for other uses and reduced plantings of other crops, such as soyabeans, leading to land use change elsewhere, including increased plantings of oilseeds in South America to offset any reduction in US soyabean sowings. Since the cultivation of new land for food production from the conversion of forests, pasture and other land use is a major contributor to greenhouse gas emissions, such ILUC effects are particularly important not only in terms of land grabbing, but also regarding climate change.

In the EU, biodiesel use has become more reliant on imports of biodiesel and feedstocks from developing and middle income countries over recent years, as there is limited scope for increased domestic feedstock production. Thus, the expansion of palm oil output in South East Asia and soy oil output in South America has been partly attributed to both EU demand for biodiesel and, more indirectly, US production of bioethanol. The expansion of palm, soyabean and other biofuel feedstocks in less food secure countries has been linked to deforestation, loss of biodiversity, increased greenhouse gas emissions[30] and the loss of land for poor communities, making them more vulnerable to food insecurity (Gerasimchuk and Koh, 2013).

The lack of biofuel activity in Africa over the past decade suggests that the displacement of crops from food to biofuel use has been relatively small, as has the transfer of land, either through outgrowers using more of their land to grow biofuel feedstock at the expense of other cash and food crops, or from negotiated transfers of land from local communities to larger-scale biofuel operators. The experience of biofuels in Africa appears to be at odds with much of the land grab literature that, whilst important in highlighting a potentially serious situation regarding the lack of legal frameworks to protect land rights, appears to have been somewhat exaggerated in terms of numbers and sizes of land grabs.

An appraisal by Cotula (2012) of three systematic reviews of media and research reports on the scale of land grabs, put the range at between 51 and 67 million hectares, with the majority in Africa and one report estimating that biofuels accounted for some 37 per cent of the total area within such deals. Whilst some land may have been originally intended for biofuels, the lack of biofuel production suggests that these figures are significantly overestimated.

Many of the media and research reports appear to have been either exaggerated or speculative and over time the actual areas involved have been scaled back, particularly regarding biofuel investments in Africa. One example was the claim in 2007 that a Chinese company had purchased the rights to 3 million hectares of land in the Congo DR for a palm oil plantation. By 2010 it had become evident that Congo had offered 250 hectares to the company, and since then little has been heard of the project (Brautigam, 2010).

[30] Greenhouse gas emissions can increase with the expansion of cultivated land through the release of carbon stores in the ground, which may be particularly high for certain soil types such as peat lands, as well as reducing the potential for carbon dioxide capture by forests and increasing emissions through the use of fertilisers.

The HLPE report on *Biofuels and Food Security*, noted that the Land Matrix established by the International Land Coalition[31] and partners estimated total land grabs from 2000 to 2011 at some 83 million hectares, of which 56 million were in Africa and between one-third and two-thirds were related to biofuels (HLPE, 2013). In contrast, an analysis of the Land Matrix database by Ecofys found that the maximum global areas that could be designated to biofuels were between 1.4 and 7.6 million hectares, with the most likely amount closer to the lower end of the range (Hamelinck, 2013).

Nevertheless there have been many documented cases of land deals in Africa involving biofuel projects where communities or individual households have lost access to land (for example, see Matondi et al., 2011). Advocacy organisations in particular have highlighted many examples of land transfers failing to follow fair procedures leaving households more vulnerable to food insecurity, particularly when a biofuel operation closes and the land is not returned to previous owners, or equivalent compensation is not made, or the markets for the feedstock disappear (Action Aid, 2012, Friends of the Earth Europe, 2010, GRAIN, 2013). In such cases, any benefits through waged employment or sales of feedstock are lost when the biofuel operation closes. Even if compensation is received the household may become less food secure due to the reduced land area available for food production.

But the land grab argument needs to be placed in the perspective of global food availability, future food needs and actual land use by biofuels. Despite the many reports linking biofuels to land grabbing in food insecure countries, it was not possible to find any showing how much land was actually being used for biofuel production in such countries and the extent to which this could affect food availability in the face of increasing food and fuel demand.

The generally perceived wisdom is that biofuels compete with food for land. This is a logical conclusion if one assumes that land is a limiting factor for food production, so that any biofuel feedstocks using land will inevitably reduce food production. But this assumption is also somewhat at odds with the surplus production and high

[31] Comprises 116 organisations from over 50 countries, including FAO

wastage problems that have beset the major food producing nations over recent decades.

Part of the problem with the food versus biofuel land issue is the lack of clarity and consensus regarding what land is deemed to be available and what might be needed in the future, for food, biofuel and other needs. The following sections therefore review the literature regarding available land for crop production, land used for biofuels and land requirements for future food needs.

2.3.4.1 Availability of land

A review of the literature on global land requirements shows a wide range of opinion on the availability of land for crop production to meet food, feed and other needs such as energy. Much of the variation is due to definitions of the type of land suitable for crop production in different parts of the world, and some of the variance is due to different methodological approaches. Hence, estimates of land availability to meet future needs need to be carefully interpreted.

In order to illustrate some of the main projections and methodologies, the following table (2.2) provides a breakdown from three major analyses of global land availability. The first two columns are taken from the FAO Perspectives to 2050 report published in 2011(FAO, 2011b), whilst the third column is taken from the World Bank 2010 report on Rising Global Interest in Farmland (Deininger et al., 2010).

Bruinsma's chapter of the FAO report uses an estimate of the total area suitable for rainfed agriculture of 4.2 billion (4,200 million) hectares from an earlier Global Agriculture and Ecological Zoning (GAEZ) model. Of this, 1.6 billion hectares is already under cultivation, leaving an additional 2.6 billion. But this includes some forest cover, other protected areas and urban areas, leaving a net balance for agriculture of 1.5 billion hectares, or almost as much again as is currently used (Bruinsma, 2011). Much of this land would require significant investment to make it accessible and sustainably productive, so this broad number can be considered as an extreme maximum.

In the same World Food Perspectives study, Fischer (2011) calculates there are some 1.75 billion hectares of land classified as unprotected grassland and woodland potentially usable for rainfed bioenergy feedstocks, excluding all land currently used for food and feed production as well as forests and other protected areas, human settlements and infrastructure and unproductive land.

Table 2.2 – Estimates of Global Land Availability for Rainfed Crop Production

Figures are in million hectares	**Study by:**		
Land Area Description	**Bruinsma**	**Fischer**	**World Bank**
1.Global Land Area	13,400	13,200	
2.**Suitable Area for Rainfed Agriculture**	**4,190**		
Latin America	*1,066*		
Sub-Sahara Africa	*1,031*		
S&E Asia	*586*		
Near East & N Africa	*99*		
Other	*1,418*		
3.Current Crop Area	1,600	1,600	
4.Forests, Urban & Infrastructure, Water, Non-vegetated		7,000	
5.Unproductive Marginal and Steep		2,850	
6.**Suitable Additional Area for Rainfed Agriculture**	**2,580**		
Latin America	*860*		
Sub-Sahara Africa	*790*		
S&E Asia	*150*		
Near East & N Africa	*10*		
Other	*770*		
7.Suitable Additional Area under Urban	60		
8.Suitable Additional Area Protected	200		
9.Suitable Additional Area under Forest	800		
10.**Net Available Additional Area,** excluding urban, forest, etc	**1,520**	**1,750**	
Latin America		*500*	
Sub-Sahara Africa		*554*	
S&E Asia		*130*	
Near East & N Africa		*12*	
Other		*554*	
11.Pasture Requirements		970	
12.**Net Available Additional Area** excluding Pasture		**780**	
13.**Additional Area with Low-Population Density**			**445**
Latin America			*123*
Sub-Sahara Africa			*202*
S&E Asia			*14*
Near East & N Africa			*3*
Other			*103*
14.**Additional Low-Population Area with Infrastructure Access**			**263**
Latin America			*94*
Sub-Sahara Africa			*95*
S&E Asia			*3*
Near East & N Africa			*3*
Other			*68*
Sources: (FAO, 2011b, Fischer and Shah, 2010, Deininger et al., 2010)			

Much of this 1.75 billion hectares however would be used for livestock grazing, so accounting for pasture needs in each region leaves a net global balance of 780 million hectares.

Fischer's 780 million hectare estimate would also be constrained by urbanisation land requirements and access to adequate infrastructure. These issues were addressed in the World Bank report, in which the potential global supply of additional land suitable for rainfed cultivation, which is non-forested, with a low population density (less than 25 per km^2) and ecologically suitable for one of the five main crops (wheat, sugar cane, palm oil, maize and soyabeans), was estimated at 445 million hectares. Africa accounted for the largest share of this at 202 million, followed by Latin America with 123 million hectares and then the rest of the world, headed by Eastern Europe and Central Asia with 52 million. The World Bank study used data from Fischer and Shah (2010). This also estimated the amount of additional land available within 6 hours of the nearest market city of at least 50,000 people, which reduced the available area to 263 million hectares.

The World Bank study also calculated the output-maximising allocation of crops (of the five selected) for the high and low areas. For the higher 445 million hectare estimate, 157 million would be devoted to maize, 138 to soybean, 88 to wheat, 41 to sugar cane and 22 million to palm. For the lower global area of 263 million hectares, 83 million would produce the best output from maize, 83 million also from soyabean, 71 from wheat, 22 from sugar cane and 4 million from palm. Note that these output-maximising figures do not mean that larger areas would not be suited to specific crops. For example, the potential land suitable for sugar cane from unprotected grass/scrub and woodland (ie unforested) has been estimated by Fischer et al in an earlier study at between 38 (very suitable) and 189 (moderately suitable) million hectares (Fischer et al., 2008).

In an earlier State of Food and Agriculture report in 2008, FAO estimated that there were some 250 to 800 million hectares of additional land available for cropping globally (FAO, 2008b), compared to the current cultivated area of 1.5 to 1.6 billion hectares. The lower figure of 250 million hectares corresponds closely with the World Bank 2010 report lower estimate of 263 million hectares.

In a more recent study, Lambin et al (2013) make the point that there is less additional cropland available than is generally assumed in such large-scale studies, and that the conversion of such land will involve both social and ecological trade-offs. However, in re-calculating the World Bank study area with low population density, at 445 million hectares, using the same constraints but with an updated database (Global Agro-Ecological Zones version 3.0), they estimate a higher additional global area with a low population density of just under 600 million hectares, mostly concentrated in a few regions.

Using a bottom-up approach, they then focus on the potentially available cropland of key regions, such as the Brazilian Cerrado, as well as countries such as Congo DR, Indonesia and Russia, by identifying social and physical constraints. They find that such constraints mean that on average about one-third of the land is suitable, or about 200 million hectares. So even with a much stricter definition of land availability, the more recent study is not far below that of the World Bank's lowest estimate of some 263 million hectares and the earlier FAO lowest estimate of 250 million.

It is of course difficult to know the true extent of global land availability without a detailed land mapping exercise in each country. Some food-insecure countries, such as Mozambique, have conducted such an exercise to ascertain the extent of land for potential food and bioenergy production and have allocated land for investors to lease using this method. But there is insufficient evidence to use such estimates to build a global picture.

A combination of the lowest FAO and World Bank estimates and more recent figure of some 200 million hectares by Lambin et al might provide a useful basis for starting to assess where land is most available and most suitable to meet additional food and other needs, at the minimum cost to greenhouse gas emissions. Better information is required in this regard, so that countries and specific regions could then be targeted for assistance in expanding food and feedstock production, particularly those that are least-developed. Particular attention could be given to restoring degraded and abandoned lands. A recent review of studies put the global degraded land area at between 1 and 6 billion hectares, but some of this would be better suited to forest restoration and some are currently used by communities (Gibbs and Salmon, 2015). An earlier analysis of abandoned agriculture lands found a range of between 385 and 472 million hectares globally (Campbell et al., 2008).

Identifying potential suitable land must also be combined with a detailed analysis of projected food and bioenergy and other land needs into the future, as it may be possible to meet such needs without any significant increased land use, thereby avoiding additional greenhouse gas emissions. For example, if all additional biofuel production were to be restricted to waste products, such as cereal straw, cane bagasse, used cooking oil, animal fats and municipal waste, this would not involve any significant additional land. Similarly if it was deemed that all additional food demand could be met by increased yields, double-cropping and other productivity-enhancing measures, then again little additional land would be required.

One of the main problems is that the models that have been used to assess such needs build in different land availability estimates and, hence, produce very different outcomes (Lotze-Campen et al., 2014). So a detailed land mapping exercise to identify where land is available, and the social and environmental issues associated with each, is the first step required to build a better global picture of land availability.

2.3.4.2 Land usage for biofuel production

Estimating the amount of land required for biofuel needs is beset with uncertainty. There is a lack of clarity within the literature on how much land has been, and is currently, used for biofuel production, particularly in terms of feedstock type and co-product allocation.

For example, a UN Environment Programme (UNEP) report in 2009 estimated that some 36 million hectares were used for biofuel feedstock in 2008 at the start of the biofuel boom, and suggested this was probably a conservative figure given that many biofuel feedstock yields had been overestimated. However, this estimate did not take into account the co-products from biofuel production that fed back into the animal feed market (Bringezu et al., 2009). Langeveld et al (2013), meanwhile, estimated the land devoted to biofuel production in the major producing countries, representing some 95 per cent of global output, at 32 million hectares in 2010, but at only 21 million once animal feed co-products had been accounted for[32]. In a review of the literature on biofuels and food security, von Witzke and Noleppa (2014) reported a range of 45 to 55 million hectares used in the production of bioenergy crops from papers published from 2012 to 2013. A more recent estimate in the open access journal “Scientific Reports” put the total biofuel feedstock area in 2013 at 41.3 million hectares from an assessment of FAOSTAT data (Rulli et al., 2016).

It is also difficult to predict how energy and commodity markets will develop in terms of the competitiveness of biofuels, how policies may change to either encourage or discourage biofuel production, and how technology will develop in terms of improving the competitiveness of more land-neutral second generation feedstocks, as well as alternative forms of energy and transport.

Early estimates of land requirements for different future biofuel scenarios included those from FAO and IEA sources in 2006-2008, suggesting that between 35 and 60 million hectares of land would be required by 2030 (Rosillo-Calle and Johnson, 2010). These estimates were made at the beginning of the biofuel production boom and have been largely overtaken by most projections since.

For example, the Gallagher Review of the indirect impacts of biofuel production for the Renewable Fuels Agency of the UK suggested a range of 56 to 166 million hectares of biofuel feedstock area by 2020 if all countries were to meet their stated policy targets, with the lower figure accounting for the avoided land use benefits of co-products such as animal feed, the introduction of second generation (2G) biofuels and significant improvements in feedstock yields, whereas the higher figure accounts for low yield improvement, no significant contribution from 2G feedstocks and no avoided land use benefits (Gallagher, 2008).

Also the land use projections in a study by Murphy, Woods et al (2011) showed that between 100 and 650 million hectares of land could be required for biofuel

[32] In other words that part of the feedstock used for making biofuels accounted for 21 million hectares, with the remaining 11 million hectares used mainly to produce animal feed products.

feedstocks by 2050, based on various assumptions under two different scenarios by the IEA;

i) a baseline scenario of energy trends with biofuels rising in importance from 5 per cent of total transport fuel demand in 2010 to 10 per cent by 2020, 20 per cent by 2030 and 30 per cent by 2050.

ii) a "blue map" scenario where significant improvements are made in transport fuel efficiency, including a significant increase in electric and hydrogen vehicles from 2030 and with biofuels representing 15 per cent of the total transport fuel demand in 2030 and 25 per cent by 2050.

Different feedstock and biofuel yield assumptions were then made, ranging from pessimistic yields with no growth from 2010 levels to "best-technology" yields at the other end of the spectrum, with two "most likely" minimum and maximum yield assumptions in between the extreme scenarios. Using the blue map scenario, the most likely yield assumptions suggested a biofuel feedstock area of 60 to 100 million hectares by 2020, 120 to 180 million by 2030 and 130 to 200 million by 2050.

Leal et al (2013) also used the IEA scenarios in projecting the land required for a global ethanol output of 200 billion litres in 2020 and 300 billion in 2030, compared to some 85 billion litres at that time. They projected that by 2020 the area for maize and sugar cane based ethanol alone would reach some 55 to 68 million hectares, although this again excluded co-product allocations.

More recently, as part of the Agricultural Model Inter-comparison and Improvement Project (AgMIP), a 2050 target for global bioenergy production, consistent with the two-degree climate change threshold, was used to compare five different economic models incorporating the agri-food sector. This suggested an additional land area requirement ranging from as low as 30 to as high as 340 million hectares, with the other models resulting in 130, 200 and 250 million hectares. It should be noted that the scenario baseline used existing first generation biofuel trends based on prevailing policy targets. The target scenarios then focussed on ligno-cellulosic feedstock expansion to meet the high bioenergy “climate change” target (Lotze-Campen et al., 2014).

This exercise highlighted some of the difficulties in comparing findings, including how much land availability to build into the analysis. The model with the smallest land use change of an additional 30 million hectares simply assumed that less land was available for expanded production, so most of the bioenergy crop expansion was met by a reduction in the pasture and food crop areas, with improved yields expected to offset much of this. The other models incorporated a more elastic land supply resulting in relatively little change to food crop areas and pasture.

Another difficulty in the AgMIP model comparisons was the different assumptions used for the mix of ligno-cellulosic crops by 2050. For example, some of the models excluded crop residues, one only included short-rotation tree plantations and wood-based residues, another excluded short-rotation trees and some excluded energy grasses. Although the range of biofuel land needs in the above examples are somewhat broad, most would absorb a significant proportion of the lower range of global land availability estimates of some 200-250 million hectares, by 2050.

However, it should also be noted that the potential range of area estimates for biofuel feedstocks in the above analyses do not always take into account any substitution effect from the equivalent co-products produced, such as soyameal and distillers dried grains for animal feed (except the low range estimate in the Gallagher Review).

For example, one study estimated that around 20 million hectares of land was needed to meet the then EU 2020 biofuel target of an average 10 per cent blend in transport fuels. However, it was calculated that the substitution effect of utilizing oilseed meal co-products for animal feed from biodiesel production would save an area equivalent to over 7 million hectares of soyabean cultivation in Brazil (Özdemir et al., 2009). Additional substitution effects would also be seen from distillers dried grains and other ethanol co-products. Indeed, the biofuel industry is already playing a key role in supplying protein feeds to meet the expanding global demand for meat and dairy, particularly in high-growth economies.

The study by Ozdemir et al (2009) concluded that, depending on the feedstocks used and the degree to which the EU would need to import biofuels and feedstocks to meet its needs, the co-products would result in land savings of between 23 and 37 per cent from that required to produce the equivalent animal feed. The calculation was made on the basis of the equivalent digestible protein content from biodiesel co-products related to soyameal production and equivalent metabolizable energy content in the case of maize for ethanol.

These percentages are significantly lower than those calculated in the Gallagher Review which suggests a percentage land saving by co-products of 60 to 66 per cent for EU biofuel blending targets ranging from 5.75 per cent in 2010 to 10 per cent by 2020. This calculation was based on a mass volume change since most EU biofuels are in the form of biodiesel from oilseeds, which generally yield between 60 and 80 per cent protein meal product (Gallagher, 2008).

More recent studies have questioned the assumptions made in earlier models by focusing on land use changes in the early years of the biofuels boom. Babcock and Iqbal (2014) highlighted the fact that models used by policymakers to attribute greenhouse gas emissions to biofuel-induced land expansion, attribute all of the non-yield supply response to land use changes at the extensive margin, sometimes involving forest clearance. However, they argue that land use change also happens at the intensive margin through double cropping (the double-cropped area in Brazil nearly doubled between 2004 and 2014), a reduced amount of un-harvested land (ie a smaller difference between planted and harvested areas), a smaller fallow area and less temporary pasture. They found that outside of Africa, the main response by farmers between 2004 and 2012 was to use land more efficiently at the intensive margin, rather than expanding into new additional land. Given that yield change would also account for a large proportion of any supply response, this suggests that greenhouse gas emissions from indirect land use change attributed to biofuel demand may be much less significant than is currently assumed.

Similarly, Langeveld et al (2013) analysed the biofuel expansion in most of the key producing countries between 2000 and 2010, finding that the net harvested area for food, feed and fibre markets in those countries had increased by 19 million hectares over the period, mainly due to increased multiple cropping.

In particular, whilst the US maize and soyabean harvested area for biofuels expanded by 11 million hectares, they attributed just under 6 million hectares to co-products (on a mass energy basis) so that only just over 5 million hectares was attributed to biofuel use. At the same time the Multiple Cropping Index (MCI)[33] changed from 0.77 to 0.85 releasing an effective 10.9 million hectares. Given that the agricultural area had declined by 3.5 million hectares over the period, this left a 2.3 million hectare increase in the net harvested area in the US[34] (Langeveld et al., 2014).

It is therefore difficult to gauge the extent of biofuel feedstock land needs from the literature given the wide range of baseline estimates and projections based on different scenarios, as well as varying co-product allocations and other assumptions regarding land use. Future land needs will largely depend on food and energy market developments, as well as future policies regarding energy and agriculture. These are impossible to predict with any certainty, but a useful addition to the analysis would be a detailed picture of global land use by biofuel feedstock in each country over the past decade. This would help to ascertain any trends emerging from recent market and policy developments. The extent to which co-products influence land use decisions might also be better represented by their share of revenue streams rather than on a mass or energy or feed-displacement basis.

2.3.4.3 Land required for future food needs

As some of the projections cited above suggest that biofuels could indeed absorb a significant share of the world's additional available land for crop production, this could have a significant impact on future food security, depending on how much land is also required for future food needs. This, in turn, depends on how the supply and demand for food will develop over the coming decades. In the past, Malthusian concerns that food productivity will not keep pace with population growth have

[33] The multiple cropping index (MCI) is defined as the harvested crop area per unit of arable land. Thus, in many tropical areas where double-cropping is practiced the MCI can reach 2, but usually averages about 1.5, whereas in temperate zones the MCI is less than 1, as not all of the arable area is actually harvested

[34] This calculates as 10.9 million - 5.1 million - 3.5 million = 2.3 million hectares.

proved unfounded. Yet the distribution of that food remains unequal, with some 800 million people remaining undernourished in today's world, whilst an estimated 600 million people suffer from obesity (FAO, 2015).

A recent US Department of Agriculture report outlines the key drivers for global food supply and demand up to 2050 (Sands et al., 2014):

i) Change in population

ii) Change in per capita income

iii) Change in agricultural productivity

The extent to which the supply driver of agricultural productivity responds to the two demand drivers of population and income will largely determine how commodity prices will evolve, which, in turn, will influence food prices, and therefore, food security.

Agricultural productivity response depends on two main adjustment factors: yield and area of land, the percentage changes of which should sum to an overall percentage change in production. This assumes that increased double or inter-cropping (where more than one crop is harvested within a growing year or where more than one crop is inter-cropped on the same land), results in increased harvested areas, but not necessarily planted areas. Similarly any increase in cropping intensity where more plants are grown per unit area, would be reflected in increased yields[35], as would a higher share of higher-yielding crops and varieties on a given unit area.

The amount of land required for food needs in the future will therefore largely depend on the increase in demand and changes in yield productivity. If yield productivity is unable to keep pace with rising demand from the growing population and higher incomes per capita, then more land may be required. Many factors can affect both demand and productivity, ranging from reducing food waste, changing diets and climate change related impacts on weather and crop yields.

[35] Assuming that the overall yield from the more intense cropping increases, as too high a cropping intensity could result in lower overall yields as the crops compete for limited soil nutrients.

A number of studies have been conducted over recent years on land requirements for future food needs. They can be categorized into two main approaches: those using statistical extrapolation and those using more complex modelling techniques (Godfray and Robinson, 2015).

Statistical techniques for projecting food demand date back to early Malthusian forecasts, when it was predicted that food production would not keep pace with population growth. Malthusian views persist today, despite the fact that food production has tended to outpace population growth over the two centuries since. Nowadays we have better information at a global level on which to base such analyses following the work of the FAO to build balance sheets of supply and demand for each country, largely based on data from national statistical agencies.

In recent times a number of economic simulation models of the global food sector have been developed, as mentioned in the earlier section on climate change impacts (section 2.2.2). They are generally categorized into two types:

i) Partial equilibrium models, which tend to focus on one economic sector, such as the agri-food sector, allowing for more detail to be incorporated about that sector

ii) Computable equilibrium models, which incorporate a whole economy impact but generally have less detail on the sector in question

These models are market-based in that they solve an economic market equilibrium based on projected supply and demand changes and price impacts. They therefore incorporate various assumptions on the extent to which demand for food responds to changes in prices and income (elasticities of demand) and the extent to which supply responds to changes in prices (elasticities of supply). Differences in such assumptions can result in a wide range of results regarding food projections, as illustrated by recent reviews of models assessing the impact of biofuels on food prices (see section 2.3.5).

As price and income elasticity are fundamental features of economics, there is a considerable literature in this area. Despite this, there are no definitive data for the models to refer to when setting elasticity functions, as many of the elasticity estimates are outdated or refer to a specific country with a given income distribution or a small group of commodities and basic food products rather than the complex food products of today's world. This is a significant problem for econometric models, as supply and demand elasticities in each country and region are constantly evolving in response to the rapidly changing and more globalised agri-food market, as well as per capita income growth and changes in income distribution and tastes. With so many factors affecting supply and demand it is difficult to isolate the extent to which policy, income and prices affect supply and demand responses.

The assumption of perfectly competitive markets in computing market equilibria is also somewhat at odds with the market power that is exerted within global food chains. The same assumption is required in order to derive a supply curve under the ideal of profit maximization by producers. The premise of the rational consumer in standard neo-classical economic theory is also widely critiqued and yet utility maximization remains a key concept in many econometric models. Despite these flaws, and the difficulty in assessing what parameters and assumptions have been used within their complex calculations, such models are increasingly used by governments to project future impacts and guide policy.

The FAO has been using statistical extrapolation models for many years in order to predict likely patterns of food supply and demand into the future. Bruinsma's 2009 paper to the FAO expert meeting on "How to Feed the World in 2050", calculated that an additional 70 million hectares of cropland would be required on a global scale from the base figure of 1.6 billion hectares in 2005 (rising to 1.65 billion in 2030 and 1.67 billion in 2050) (Bruinsma, 2009). Within this net increase, an additional 120 million hectares was calculated for developing countries, including 64 million hectares for Sub-Saharan Africa.

Since then the FAO figures have been updated by Alexandratos and Bruinsma, incorporating a greater increase in the crop area in developing countries, but also a larger decline in the area sown in the developed world, producing the same net 70 million hectare increase globally. These projections present *"a view of how the key food and agricultural variables may evolve over time, not how they should evolve…to solve problems of nutrition and poverty"* (Alexandratos and Bruinsma, 2012). They also incorporate significant average global yield increases for the major food crops on the basis that there is still considerable slack in potential yields (yield gaps) to be exploited in many countries. Thus, 70 per cent of the projected increase in food production in developing countries by 2050 is forecast to be due to yield growth, 20 per cent to expanded land use and 10 per cent due to increased cropping intensity[36].

In contrast, the Gallagher review of indirect land use impacts of biofuels, estimated an approximate range of 100 million to 450 million hectares of land required to meet food and feed needs by 2020 in addition to the 56 to 166 million hectare range for biofuels (Gallagher, 2008).

Other studies suggest that crop yield growth has been declining in recent years, as the average levels in some parts of the world draw closer to the maximum genetically attainable yields (Foresight, 2011). Wirsenius et al (2010) refer to research by Cassman, Pingali and Heisey in 1999 showing that even maintaining current yields may prove to be a challenge due to *"signs of intensification-induced declines of yield potential over time, related to subtle and complex forms of soil degradation"*.

Wirsenius et al suggested land savings could be made due to reduced wastage in the food chain, improved livestock productivity and changes in dietary patterns. They also included calculations for pasture areas, which were not included by Bruinsma and calculated that the overall crop and pasture area could increase by as much as 280 million hectares by 2030, from just under 5.1 billion hectares of all agricultural land currently to 5.35 billion hectares[37]. However, they also pointed to a possible dietary shift from ruminant meat to poultry and pork that could lead to less land being required, as well as improved meat productivity, which would reduce the projected land use for 2030 (of 5.35 billion hectares) by as much as 1 billion hectares, mainly through decreased pasture. Moreover, if food wastage were to be

[36] Cropping intensity is defined as the number of times a crop is harvested per year on a given parcel of land

[37] Comprises 3.62 billion hectares for pasture and 1.73 billion for food and non-food crops

reduced by 15-20 per cent and dietary patterns were to move toward a more vegetarian diet, it is estimated total land use could be as much as 1 billion hectares below the current estimated global crop and pasture area (Wirsenius et al., 2010).

Whilst the various projections are useful in terms of how markets may develop over time and what changes can be made to minimize resource use, they may underestimate how much land is required to end hunger. In terms of assessing whether food security can be reached for the world's population, the French organisations INRA[38] and CIRAD[39] completed their Agrimonde study on scenarios and challenges for feeding the world in 2050. Their approach looked at two scenarios;

> <u>Agrimonde GO</u> - corresponding to a trend-based scenario where the average world Kcal per capita per day level rises to 3,500, with a wide regional variation from over 4,000 in the OECD region to about 3,000 in Sub-Saharan Africa, and crop yields continue to rise according to long-term trends
>
> <u>Agrimonde 1</u> - establishing a sustainable food system where the average calorie intake is 3,000 Kcals per capita per day for all regions (including 500 from meat) and crop yields are based on the conclusions of experts taking into account both regional trends by type of food crop and the potential impact of climate change and intensification.

In the GO scenario the area of cropland, including for non-food uses such as biofuels, increases by some 340 million hectares between 2000 and 2050 and pasture land also gains 244 million hectares in response to continued high meat demand. Meanwhile the Agrimonde 1 scenario increases the cropland area (including biofuel) by 600 million hectares due to the lower projected crop yields and a greater proportion of dietary calories derived from plants rather than pasture-based meat. But this is largely offset by a reduction in pasture land, resulting in the total crop and pasture land rising by only about 100 million hectares from 2000 to 2050 (CIRAD and INRA, 2009).

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[38] INRA is the Institut Nacional de la Recherche Agronomique
[39] CIRAD translates as Agricultural Research for Development

Whether the changes to dietary patterns in the Agrimonde 1 scenario could be achieved by 2050 is open to debate. It would mean significant changes to developed world diets in order to bring the average down to 3,000 kcal per capita per day, although there is growing evidence of benefits for lifespan and potentially large health sector savings through reduced obesity and other health-related problems. Public awareness campaigns and media attention on such health benefits could help to achieve this.

A missing scenario is where dietary patterns continue on trend as in Agrimonde GO, but where yield growth is restricted by climate change and related water restrictions, as well as intensification-related issues and energy-linked increases in input prices and restricted water availability. This could result in a substantial increase in global land use requirements as both pasture and cropland areas rise to counter the slow (or non) growth in yields. Indeed, this would probably absorb most, if not all, of the estimated additional cropland available before 2050.

The Agrimonde scenarios also highlight the major differences between regions within the global figures. Most of the increased land use takes place in Sub-Saharan Africa and Latin America, as this is where most of the additional land is available. Indeed there is limited scope for additional land to come into production in the EU, China and the US, all of whom have biofuel consumption targets above current levels of production.

In a more recent data-driven model, Bajzelj et al (2014) predict that even if yield gaps between developing and developed nations are closed, this will not be sufficient to match increased food demand by 2050, as they use a less optimistic scenario for overall productivity improvements over the coming decades. But they also support the view by the earlier Wirsenius and Agrimonde team studies that changing diets and reducing waste could have a significant impact on land use needs. The difference being that Bajzelj et al find that it is only possible to prevent substantial increases in land use, and associated climate change impacts, through significant changes to diets and particularly meat consumption, whereas the earlier studies suggested less land would be needed if diets changed and waste was reduced.

Econometric equilibrium models have become an increasingly popular means of projecting food supply and demand. In 2010 the agricultural modelling community started a model comparison project known as AgMIP (as noted earlier in this section). This was mainly focussed on assessing the impact of climate change on food availability, particularly crop yields, and prices.

One of the analyses conducted under the project was to compare future food demand using nine different economic models under the same scenario. The scenario used a 50 per cent higher income per capita assumption in 2050 than that used in the FAO 2012 Agriculture Towards 2050 report, and, consequently, all the models predicted a higher global food demand change than the FAO's figure of 54 per cent, ranging from 59 to 98 per cent (Valin et al., 2014). Based on these assumptions the land required for future food production would clearly be higher than the 70 million hectares predicted by FAO, but the extent of the difference depended on how each model attributed supply responses to increased yields and areas.

It should be noted here that the model resulting in the highest food demand under this AgMIP scenario was that developed by the US Department of Agriculture - the Future Agricultural Resources Model (FARM). When a scenario using moderate income growth was used by the FARM team, the model predicted that almost all the change in world crop supply to meet the increased demand by 2050 would come from yield increase with land use for cereals actually lower by 2050 and overall land use unchanged from current levels (Sands et al., 2014). So even if one model predicts a higher food demand than another by 2050, it does not necessarily mean that model would also predict a larger land area, as the yield and area supply elasticities may be very different. This is a key area of contention within the literature. For example, Roberts and Schlenker (2010) calculated supply and demand elasticities for key commodities in terms of calories and concluded that there is little empirical evidence linking yields with prices and therefore assumed all supply responses would be from land use change.

One of the major uncertainties in assessing future land needs for food demand is assessing the impact of climate change on food crop yields and land availability. Not only is there considerable uncertainty regarding the likely evolution of global weather patterns, but the likely impacts on food production are also difficult to predict. There are, however, major concerns regarding the impact of climate change on weather patterns and resulting crop yields, particularly the anticipated impact of reduced water availability on productivity (Ray et al., 2013). The phasing out of fossil fuels may also influence the amount and quality of fertilizers, pesticides and herbicides used, as alternative non fossil-fuel based sources and new cropping practices are phased in. There are some indications that climate change may already have slowed growth in crop yields in recent years (Lobell et al., 2011).

Some models have projected significant increases in land use over the coming decades due to climate change. Another AgMIP study compared nine models using the same economic and climate change scenarios, producing a wide range of results, with land use by 2050 forecast 20 per cent lower to over 40 per cent higher (Nelson et al., 2013). This was attributed mainly again to different supply elasticity parameters used in the models. Some of the models absorbed the induced climate change shocks mostly through greater intensification of crop production, whilst others responded mainly through area expansion. A useful follow-up to the AgMIP study would be to understand why such different elasticities were used, although, as noted previously, it is evident that there are no commonly agreed and empirically proven elasticities to draw upon.

Another study within AgMIP assessed the impact on cropland of four scenarios developed for the IPCC 5th Assessment Report on Climate Change using 10 different economic models (Schmitz et al., 2014). This again highlighted the wide range of results between models for projected land use changes between 2005 and 2050. The findings for scenarios assuming no climate change impact, but with medium pathways for population and economic growth, ranged from nearly 100 million hectares below the current cropland of just over 1.5 billion hectares, to over 400 million above, but with five of the models falling into the range of 150 to 300 million hectares higher and a mean of about 200 million additional hectares.

Under the climate change scenarios, the majority of models fell into the range of just below 200 million hectares higher to just over 400 million hectares more (although the actual range was from 50 to 850 million hectares higher), with a mean of just over 300 million hectares above. The main reasons for the large variation in results in the models were attributed to the different assumptions made on potential available cropland, the cost of converting land into food production and, again, different supply elasticities used within the models.

There also seems to be a lack of attention addressed to urban agriculture in the literature on food projections, with the recognition that more and more food will need to be grown in and around cities. Armar-Klemesu (2000) estimated that urban agriculture accounted for some 15 to 20 per cent of global food production and quoted Mougeot's 1994 estimates that up to 40 per cent of the population in African cities and 50 per cent in Latin America were involved in urban agriculture at that time. It is estimated that urban agriculture is practised by 800 million people worldwide and that garden plots can be up to 15 times more productive than rural holdings (FAO, 2016c). Another recent review puts the number of people involved in urban agriculture in developing countries at 266 million (Hamilton et al., 2013). But reliable market information on urban food production is limited and there has been relatively little research conducted at the global level.

A number of studies have listed the potential of urban agriculture in major cities. For example, Ackermann et al (2014) calculated that the food needs of 100,000 to 160,000 people could be met by using vacant lots in New York. Adding rooftops and hydroponic production in underground and vertical farms could raise these numbers substantially. For example, Despommier of Columbia University calculates that one 30-storey vertical farm alone could feed 50,000 people and that enough of these skyscraper farms, occupying about one-fifth of Central Park, would feed the whole city (Kretschmer and Kollenberg, 2011). The potential for urban food production appears to be sufficiently significant to have a marked impact on future land use needs. Yet few prospective studies or models appear to specifically incorporate this aspect of future food production.

2.3.4.4 Conclusions on biofuel production and land use

A key finding of this brief review of the literature on land availability and future needs, is the lack of consensus surrounding the additional land likely to be needed to meet food and bioenergy demand over the coming decades. Studies on the amount of suitable additional land for rainfed crop production are also wide-ranging, but some of the more conservative estimates converge around an approximate global level of 200 to 250 million hectares, but concentrated within specific regions, mostly in sub-Saharan Africa and South America.

Bringing any new land into crop production will result in greenhouse gas emissions from carbon stored in the soil, though the extent of the emissions varies significantly depending on soil type, vegetation cover and level of degradation. Converting land into food and feedstock production may also have social and ecosystem impacts that are difficult to build into economic analyses. Because of this, it could be argued that all additional land use should be constrained wherever possible and that increased food and feedstock demand should be met wherever possible through increased productivity or food and feedstocks that require little land in their production.

But this could also stifle prospects for alleviating rural poverty and food insecurity in many regions with ample land availability. Restricting the cultivation of new land in food insecure areas due to concerns over greenhouse gas emissions, the majority of which continue to emanate from food secure nations, would be somewhat unethical.

The greatest discrepancies appear to be around the amount of land required to meet food needs, mainly due to the uncertainty surrounding future yield growth and demand changes. On the one hand the availability of food is already more than sufficient to meet everyone’s needs, so a more equal distribution of food combined with the potential to close yield gaps, reduce food waste and change diets in favour of reduced meat consumption in developed nations, as well as more urban food production, might prevent the need for any additional land use. On the other hand, if productivity improvements are not realized due to climate change and other resource-related factors, such as availability of water and fertilizer, then significantly more land could be required.

So it is difficult to assess how much land might be available for biofuel production given such uncertainties. Within the 200 to 250 million hectare potential additional global cropland figure, more than a third would be located in parts of sub-Saharan Africa providing opportunities for rural development and poverty reduction through both food and bioenergy production. A similar potential appears to exist for some parts of South America. Using more land-efficient feedstocks such as sugar cane, palm and second-generation crops, could therefore be a useful way of raising per capita incomes and reducing food insecurity in both regions, particularly where valuable co-products are also produced. But some countries and regions within Africa and South America would be less suitable for bioenergy production where land availability is limited and population density is high. In such areas, and, indeed in other parts of the world, additional biofuel production could be restricted to feedstocks involving minimal land use, such as crop residues, used cooking oil, animal fats and municipal waste.

2.3.5 Biofuels and food prices

It is commonly argued that the expansion in global biofuel production, spurred by government policies and high oil prices, has been a major cause of increased food prices and price volatility around the world, making it more difficult for the poor to access sufficient nutritious food on a regular basis, particularly in developing countries where households spend a greater proportion of their incomes on food.

In particular, the sharp rise in US and EU biofuel production over the past decade is often cited as one of the most important causes of the commodity price spikes in 2008/9 and 2010/11 to 2012/2013 (Mitchell, 2008, FAO, 2009, Tenenbaum, 2008, Wise and Brill, 2012, de Gorter et al., 2013). The increase in commodity prices is estimated to have resulted in an additional 100 to 115 million undernourished people following the 2007/8 price crisis and some 44 million following the 2011 surge (Ivanic and Martin, 2008, FAO, 2009, Ivanic et al., 2011). These numbers have since been questioned, with the FAO revising its long-term estimates in 2012 to show a declining trend in the number of undernourished people over the period 2005 to 2015 (FAO, 2015). Nevertheless, the prevailing public perception, reinforced by media reports, appears to be that biofuels compete with food production and therefore increase food prices and thereby accentuate food insecurity (Kline et al., 2016).

Yet evidence remains inconclusive on the extent to which biofuels influenced the price spikes on the main global commodity exchanges, as there are a wide range of assumptions and results within the various analyses and studies. This makes it difficult to compare analyses and assess biofuel impacts against the many other forces involved in the price formation of different crops used for biofuel production (Tyner, 2013). Indeed, many of the recent analyses suggest that biofuel demand played a relatively minor role in the commodity price increases (Condon et al., 2013, Kretschmer et al., 2012, Oladosu and Msangi, 2013, Zilberman et al., 2012, Baffes and Haniotis, 2010). It is also arguable whether higher global commodity prices necessarily lead to increased food insecurity, due to the potential gains for many rural producers and sellers of foodstuffs.

There are many reasons for the different views adopted on how biofuels affect food security through their impact on food prices. The HLPE report on Biofuels and Food Security commissioned by the UN Committee on Food Security (HLPE, 2013) noted five reasons why it is particularly difficult to analyse the linkages:

i) Because the main biofuel producers are in developed countries, the main channel of food insecurity is the hypothesized transmission of high international prices to local market prices in food insecure countries, hurting net food buying households, but which may also benefit net food seller households.

ii) There are many different types of biofuels and feedstocks making it difficult to extrapolate findings from one type to another.

iii) Impacts may be different in the short and long-term, as a short-term price rise hurting consumers, could lead to a longer-term increase in supply through increased investment and higher rural employment and incomes.

iv) There are many other factors besides biofuels that influence food prices.

v) Food security does not depend on the strength of price increases, as a modest price increase could hide a significant reduction in demand (and hence food consumption) that is mostly offset by increased supply.

An additional point is that commodity price movements on international markets may not translate to increased food prices, as the raw material component of a food product, such as bread, may represent a small proportion of its price.

Another factor more directly related to biofuels is the influence of co-products on commodity prices. For example, the production of DDGS when processing maize into ethanol has created a new animal feed source in the US, reducing the demand for maize in animal feed, and, thereby, creating a dampening effect on maize prices to help offset the bullish effect of increased demand for ethanol production.

Given the numerous difficulties in identifying the extent to which biofuels impact on food prices, a number of studies focus on one of the main biofuel types or one of the main producing countries. Since the US is the largest producer of biofuels, and maize is the main feedstock used, and maize is generally regarded as the foundation price for the global food market, the following section focusses on this aspect of the global biofuel market.

2.3.5.1 The US maize ethanol and food price link

The main biofuel feedstock linked to food prices is US maize, which is mainly used for animal feed, either domestically or via exports. In past decades the US accounted for between 50 and 75 per cent of world maize exports, and US prices tended, therefore, to act as the world market benchmark. In recent years, the US share of world trade has fallen to between 30 and 40 per cent, but the US remains the world's leading maize exporter. Hence, the US maize price often forms the ceiling price for maize markets in importing countries around the world, calculated as the import parity price for US maize shipped to each destination.

Fundamental supply and demand information plays an important role in US maize price formation. The US maize market is relatively transparent in regard to market information, with regular reports from official and industry sources on the supply and demand side of the balance, with the added advantage of a long-established and high volume futures market based in Chicago. Buyers and sellers assess estimated supply against forecast domestic use and exports in order to assess the relative supply "tightness" of the market. If supplies are deemed to fall short of demand then the market will be in tight supply and prices should rise to accommodate this, providing an incentive for increased production.

Hence, a useful indicator of the fundamental market situation is the end-season stock level, as this is the result of the supply and demand balance each year. The importance of the end-season stock level is also influenced by developments in consumption each year. A more useful indicator therefore is the end-season stock-to-use ratio, reflecting stocks as a ratio of domestic and export use[40]. The lower the ratio the tighter the supply and demand balance and prices will tend to rise when the balance is tight and fall when the stock-to-use ratio increases.

The extent of the relationship between stocks and prices is considered to have changed over recent years, with commodity prices appearing to be increasingly responsive to changes in the ratio. This may be partly attributed to the perceived greater risk in commodity markets that supply will fall short of the sharply rising demand seen for maize and other cereals and other foodstuffs in recent years, which, it is argued, have changed the long-term dynamic and trend for grain markets (Piesse and Thirtle, 2009). But this also follows the established literature on commodity price behaviour in relation to stocks, with "normal" markets becoming more fragile as stocks decline in relation to use (Deaton and Laroque, 1992).

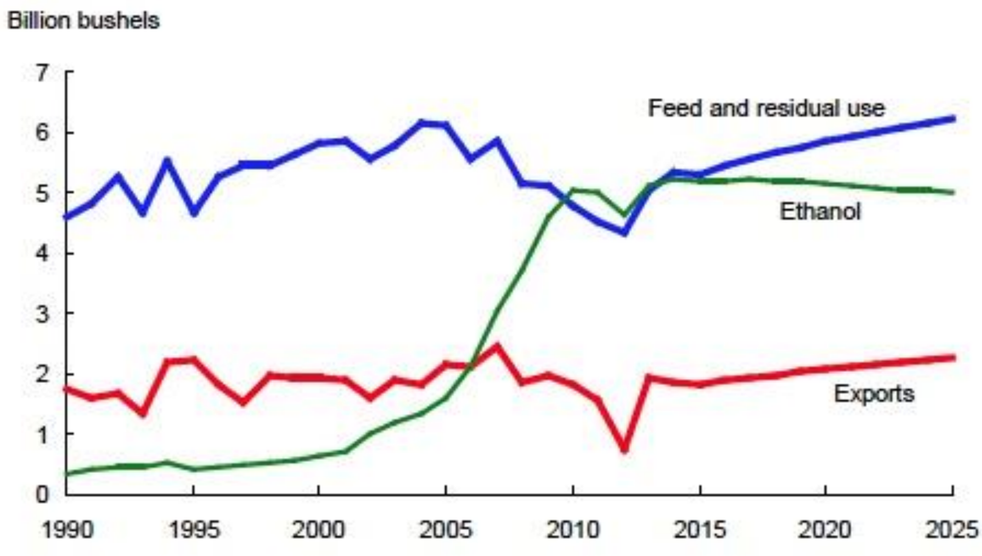
The steep rise in US biofuel production over the past decade has played a major part in the increasing demand for US maize. Indeed, ethanol demand overtook animal feed use from 2010 to 2013 before falling back, with the latest USDA projections at

[40] Some stock-to-use ratios are calculated using domestic use only, some are calculated at global or regional level, or for the major exporting countries or nationally, and some use specific types, varieties and grades of a particular commodity, such as hard high protein wheat as opposed to soft low protein wheat.

the time of writing suggesting feed use and exports will continue to rise whilst ethanol use will stabilize (USDA, 2016c).

Increased maize output managed to keep pace with rising use over the past decade, allowing feed use and exports to remain relatively stable, although a decline is apparent in both from about 2007 to 2011, followed by a steep cut in exports in 2012 due to the drought-affected crop that year. Since then both animal feed use and exports of maize have recovered to levels closer to the pre-biofuel boom trends (fig 2.2).

Fig 2.2 – US Maize Use 1990-2015 and Projections 2016-2025

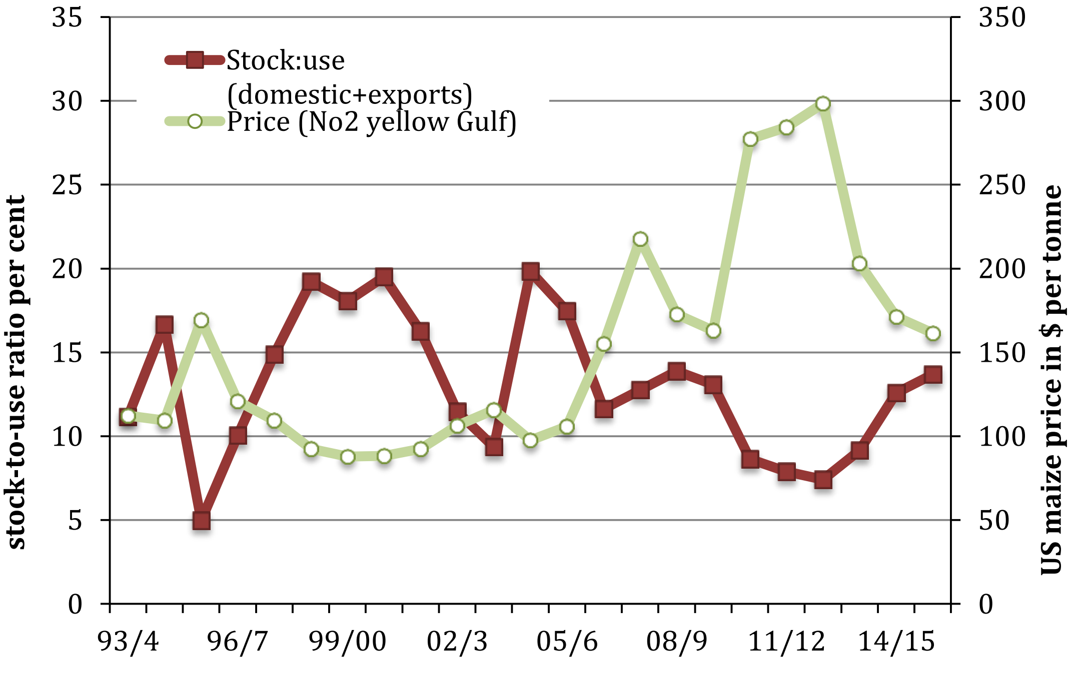


Source: (USDA, 2016c)

Figure 2.3 illustrates how US maize prices tend to mirror the stock-to-use ratio, with average season prices rising when stocks fall and vice versa. Over time the price response to stock-to-use ratio changes appears to have become more volatile and in some years prices do not move as predicted, such as in 2007/8 when US maize prices rose at the same time as the stock-to-use ratio increased. So there are clearly other factors at play in the determination of maize prices. Nevertheless, the relationship is significant enough to allow commentators to use it as a way of predicting prices as new market information comes to light (eg Good and Irwin, 2015) .

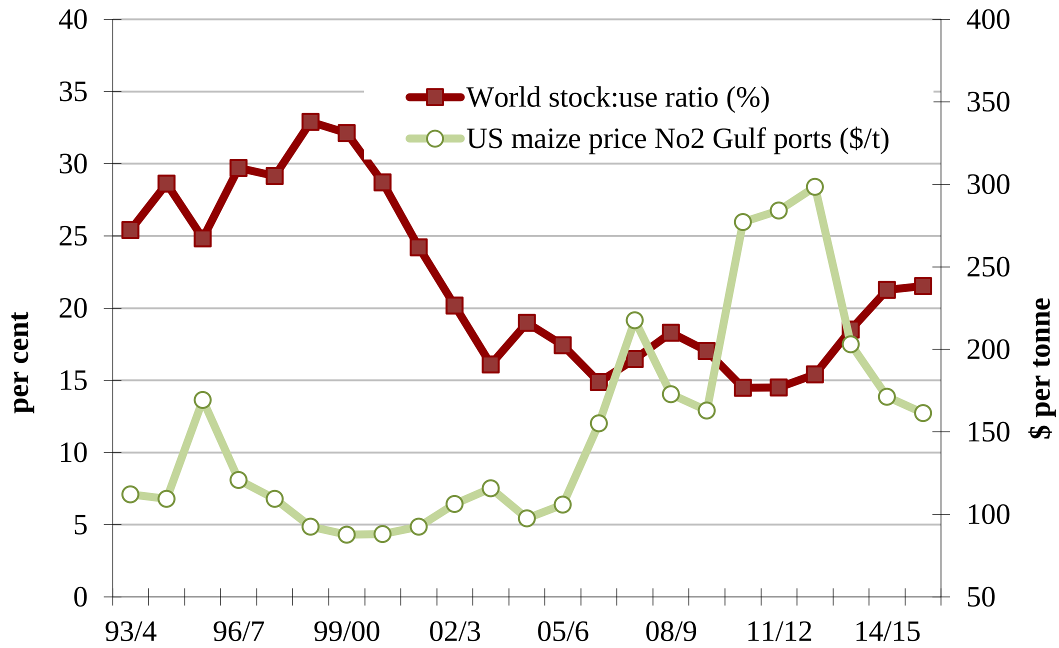
Since the US is the largest maize exporter, it might be expected that US maize prices would also correspond to the supply and demand situation on the world market for maize. Figure 2.4 shows that when world maize supplies are relatively tight in relation to demand, the stock-to-use ratio falls and this usually helps to lift US maize prices higher. So as the world stock-to-use ratio has recovered in recent years, US maize prices have fallen. Similarly when world stocks of maize were much larger in relation to usage in the 1990s, US maize prices were much lower. But the relationship does not appear to be as close as that for the US stock-to-ratio against the US maize price.

Fig 2.3 – US Maize Price versus US Maize Stock-to-Use Ratio



Source: Compiled from data from USDA and NASS

Fig 2.4 – US Maize Price versus World Maize Stock-to-Use Ratio



Source: Data from USDA and NASS

Bobenreith, Wright and Zeng (2013) conducted a study of maize, wheat and rice prices against world stock-to-use ratios from 1961 to 2007, finding correlations of -0.5, -0.4 and -0.17[41], respectively, although when the stock-to-use ratios for each grain were aggregated into a calorie ratio there was a slight improvement in the correlations for maize prices (-0.57) and wheat prices (-0.5) and a significant improvement for rice values (-0.47). Wright (2014) also makes the point that grain prices reflect their substitutability, as in the case of calories and other nutritional values, and storability, enabling stocks from one harvest to be carried over for use in subsequent years. Wright also noted that the sharp increase in biofuel demand from 2005 to 2011 prevented stocks from being able to buffer prices as they had done in previous times, due to the sharp drawdown in stock levels.

So biofuel demand appears to have had an influential impact on US and, hence, world maize values through its influence on the US stock-to-use ratio. But there are clearly other factors that influence the price response to the fundamental situation for maize. Thus, when the US maize stocks-to-use ratio rose in 2007/8, prices did not fall as expected but continued to rise. One explanation is that maize prices that year

[41] Note that the correlations were calculated for de-trended prices rather than actual market values

were pulled higher by the sharp rise in other commodity market values, notably oil and wheat, reflecting the substitutability factor. Similarly, the high maize prices in 2010 and 2011were reported to be one of the key factors supporting world wheat prices at higher levels than the wheat stock-to-use ratio suggested at that time (USDA, 2011).

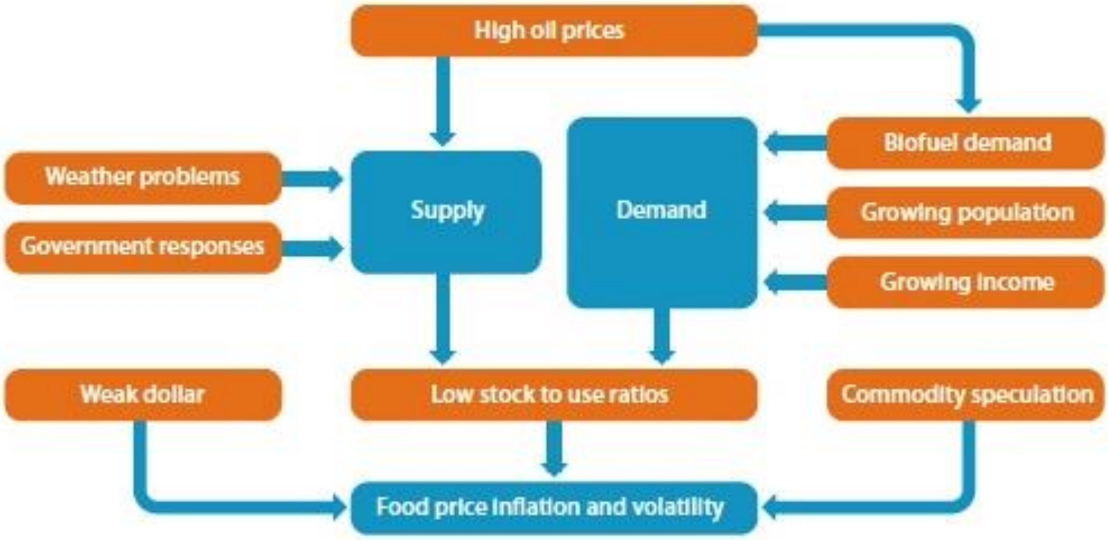
It should also be noted that the prices shown in figures 4 and 5 are nominal values and that if adjusted for inflation, the recent movements would be less pronounced in relation to those of previous years. Indeed, a UK government report in 2010 illustrated how the 2008 food price spikes were much smaller than those witnessed in the 1970s in real terms, even though the real crude oil price spike was much larger (DEFRA, 2009). In a joint review of global food price volatility, the major UN-based organisations, plus OECD and WTO also highlighted the fact that in real terms the food price spike of 2008 was in fact quite small in comparison with previous spikes in the mid-1970s (FAO et al., 2011). But Dorward (2011) argues that a comparison of real prices adjusted by consumer price indices in developed nations is misleading for those most affected by food insecurity, for whom price increase as a proportion of income is a more appropriate measure.

2.3.5.2 Factors contributing to the recent food price spikes

A number of studies have investigated the factors believed to be responsible for the rise in maize and other commodity prices in recent times. The Committee on Climate Change in the UK encapsulated the main factors in its Bioenergy Review of 2011. Figure 2.5 shows how a number of key issues are hypothesized to have combined to influence supply and demand, with the added impact of currency markets and futures market speculation.

Assuming the chart represents cereals as a whole, there would be other forces within the supply and demand balance between different cereals and also between different types of the same cereal. Thus, wheat prices would affect maize and rice prices, according to their cross price elasticities.

Fig 2.5 - Factors Contributing to Food Price Formation



Source: (Collier et al., 2011)

High oil prices have been put forward as the most important influence on food commodity prices by a number of studies, including a recent analysis for the World Bank (Baffes and Allen, 2013). Changes in non-food commodity markets, such as oil, can impact on grain markets through higher input costs on supply, but that linkage is relatively weak historically. It is also argued that the oil and biofuel price link is now an important factor in food commodity price developments. As oil prices rise this should encourage cereal, sugar and oilseed demand as biofuels become more competitive for blending in transport fuels, although increased biofuel use should also help to dampen oil price increases to a certain extent (Harvey and Pilgrim, 2011).

Whilst there has been a relatively close correlation in recent years between oil and maize prices, it is difficult to prove causation, as a close relationship between the two is not always intuitive. Biofuel policies in the major producing countries are based around usage targets and blending mandates, creating an inelastic demand. In the US the annual ethanol blending targets are based on a maximum blend of about 10 per cent ethanol in petrol, known as the blend wall. Thus, as oil prices increase the blend wall would prevent more ethanol being used, and, hence, maize prices from moving higher[42]. Similarly the mandated use targets create an inelastic demand that should prevent maize prices falling in line with any drop in oil prices. However, export demand for ethanol could allow maize prices to follow higher oil prices upwards, as long as there is spare production capacity.

Speculative activity has also been put forward as another major factor in the price spikes of recent years, based on the concept that speculative bubbles were created during the financial and commodity market panics, spurred by the increased participation of hedge and index fund investors (Piesse and Thirtle, 2009, Timmer, 2010). However, a detailed study of index traders in the US found little evidence that such funds have any influence on commodity futures price movements, and the same authors note that this corresponds with most other empirical studies over recent years (Aulerich et al., 2014), whilst Irwin and Good (2009) also find little evidence of a speculative bubble, arguing that fundamental market forces offer a better explanation.

Other influences commonly attributed to the commodity price spikes of recent years include the weakness of the dollar. It is argued that a weaker dollar encourages commodity prices to rise to offset the currency movement. Thus, if the dollar weakened, US export prices of maize would fall when denominated in the currency of the importing country, thereby creating additional demand and lifting dollar-denominated prices higher. One study attributes one-fifth of the 2007/8 cereal price spike to the weakening dollar (Headey and Fan, 2010).

Trade policies were also cited as having particularly influenced wheat and rice prices during the first of the recent price spikes in 2007/8. Export bans on wheat and rice exports at the time were estimated to have accounted for 45 per cent of the rice price rise and 30 per cent of the wheat price spike (Martin and Anderson, 2011). Export bans would affect both the supply and demand side of the market balance, depending on the extent to which the domestic market in question was insulated from the international market. An export ban should increase domestic availability and dampen down prices in a surplus domestic market helping to maintain domestic demand, particularly if the domestic market is protected from international prices via

[42] In fact higher oil prices could reduce ethanol demand as petrol consumption falls, thus reducing the demand for maize also.

import levies or tariffs. However, this would then remove potential supplies from the world market, helping to lift international prices.

The other key factor driving commodity prices is the continued global population growth and rising per capita incomes. This factor is often overlooked as being long-term and gradual, and hence, not as relevant to the recent spikes in commodity prices. Population growth is certainly gradual, but the fact that most of this growth has been in developing countries where a high proportion of income is spent on food, has accentuated that impact over recent decades.

Furthermore the rising per capita incomes recorded for many developing and middle income countries in recent years, have resulted in significant impacts on world food demand, particularly where diets change from mainly staple cereal and root crops to meat and dairy goods that require substantial tonnages of animal feed. In other words, because the high population and income growth since the turn of the millennium has been in countries with a high income elasticity of demand, and because much of that demand has been for resource-intensive foods, this led to a sharp rise in food demand over the past decade. Chakrovarty et al (2015) used a partial equilibrium model to show that food demand effects, including projected changes in diets towards meat and dairy, could account for half of the anticipated food price impacts over the longer-term.

At first, large global stocks of grain and other commodities helped to absorb this rising demand for food. But as stocks dwindled and biofuel demand started to rise steeply, the supply risk increased, leading to a sharp rise in prices. When combined with supply shocks such as the US drought in 2012, the 2010 Russian drought and the successive droughts in Australia during the first decade of the new Millennium, the burgeoning food demand, which has been exacerbated by biofuel demand and other factors, has played a key role in reducing the stock-to-use ratio of staple cereals such as maize, hence, lifting world prices.

2.3.5.3 Analyses of price responses to biofuel production

As with climate change impacts and land use changes, various analyses and models have been developed to investigate the degree to which biofuels caused recent food price spikes and how they may affect food prices in the future. A paper by Mitchell in 2008 brought the food price versus biofuel debate to the forefront of public attention, suggesting that up to 70 per cent of the 2007/8 global cereal price spike could be attributed to biofuels (Mitchell, 2008). His analysis was based around the argument that biofuels accounted for most of the increased consumption of maize between 2004 and 2007 leading to lower stocks and higher prices. This view was supported by a number of other studies, but other analyses suggested a much lower impact, leading to a long-running debate and numerous analyses since.

At its heart the debate is a relatively straightforward comparison of two opposing views. Westhoff (2010), perhaps best describes the two camps in his book *"The Economics of Food"*.

Supporters of biofuels point to the fact that the amount of maize used for US ethanol production represented just over 5 per cent of total global cereal consumption[43]. Accounting for the fact that about half the valuable outputs from maize used in ethanol plants are distillers dried-grains for animal feed, thereby replacing maize and other feedstuffs that would otherwise have been used, then the amount of maize used specifically for biofuels would be just 2.5 per cent of world grain use.

Opponents, meanwhile, argue that much of the increase in world cereal consumption was due to the newly-emerging biofuel demand. For example, global cereal use increased by 270 million tonnes between 2005/6 and 2011/12, of which US maize use for ethanol increased by 86 million, or nearly one-third of the global total. Because US ethanol use was such a large proportion of the steep global rise in cereal demand in such a short space of time, world grain stocks fell in relation to rising needs, forcing prices higher. Thus, opponents argue that the long-term trend in cereal supply and demand was disrupted by the sudden surge in biofuel use, exacerbating

[43] The 2011/12 USDA estimates put US maize use for ethanol production at 5 billion bushels, or 127 million tonnes, compared with global wheat, coarse grain and rice use of 2,300 million tonnes.

the more gradual rising demand for grain and other feedstuffs for meat and dairy sectors in countries experiencing strong population and economic growth.

However, this relatively simple division of the two opposing camps in the early years of the debate, has now been surpassed by a plethora of complex studies that have tried to explain the link between biofuels and prices of maize and other commodities. One systematic review found 121 such studies using original research and quantitative estimates for the period 2000 to 2012 (Persson, 2015), Another found 170 studies related to the impact of maize ethanol on maize prices alone (Thompson et al., 2016). Other reviews have also been conducted in order to try to find some consensus on how biofuel demand influences food prices (eg Kretschmer et al., 2012, von Witzke and Noleppa, 2014). But a common theme that emerges from these reviews is the wide variation in findings, with many suggesting relatively little impact and others agreeing with Mitchell's early analysis. A particular difficulty is comparing "incomparable" studies due to the many different approaches and assumptions adopted.

Given the considerable amount of literature published in this field over the past decade it is more useful, and practical, to consider the reviews. Each has used different ways of categorizing the many studies. For example, the HLPE study (HLPE, 2013), De Gorter, Drabik and Just (2013) and Zilberman et al (2012) all used different groupings in reviewing the literature, but these groupings by and large fell into either the more qualitative review of supply and demand, including the "perfect storm" or "ad -hoc multi-factor" analyses, or the more quantitative, based on either statistical or econometric models. The other main difference was that some of the studies were backward-looking in trying to explain recent food price developments, whereas others were forward-looking in terms of trying to project future prices under different scenarios.

The "perfect storm" analyses were largely backward-looking and followed the argument put forward by Mitchell and many UN and other official organisations at the time of many complex and inter-linked factors that were impossible to disentangle (FAO et al., 2011). Thus, many of these studies reported that it was too difficult to attribute a percentage of food price change to biofuels, let alone any other influence. This was also the view of a number of academic studies at the time, with the various forces comprehensively covered by Westhoff (2010) regarding the 2008 food price crisis and later by Tyner (2013). Meanwhile, from a more quantitative and forward-looking perspective, Baldos and Hertel (2014) ran a model using a reasonable range of different scenarios and parameters, resulting in cereal crop prices of between 70 per cent higher and 40 per cent lower by 2050, highlighting the importance of the assumptions and parameters used.

Recent reviews of the numerous quantitative analyses have attempted to identify the reasons for the wide range of results and to apply a meta-analysis to the findings in order to determine the likely range of biofuel impacts using normalized approaches and assumptions.

One such review found that the significant variation in the estimated impact of biofuels was due to the differences in the modelling approaches, geographical scope and assumptions built into the models (Oladosu and Msangi, 2013). The authors found that many of the studies up to 2008, which suggested that biofuels accounted for most of the rise in commodity prices, have since been revised downwards, but that the role of many of the non-biofuel factors remained unclear.

Zhang et al (2013) also set out to explain the reasons for the wide range of estimates of biofuel impacts on food prices, but from a forward-looking perspective. They attempted to reconcile the differences between projection studies using four partial equilibrium models and five CGE models. Key differences were found between the CGE models in terms of the potential supply of land, the contribution of animal feed co-products and the substitutability between biofuels and petrol and diesel. For the partial equilibrium models the main differences were the way in which agricultural and energy markets were modelled, the design of scenarios and the treatment of trade.

A systematic review of studies that attempted to quantify the average impact of biofuel production and demand on commodity and food prices, also revealed considerable uncertainty surrounding the influence of biofuels (Persson, 2015). Persson normalized the results of 121 studies by dividing the price change in each by the size of the biofuel demand change. This resulted in a narrower range of findings, with the rise in ethanol production between 2000 and 2008 responsible for an estimated 11 to 43 per cent of the world maize price change during that period.

The systematic review also revealed that, on average, US wheat and soyabean prices increased by about half as much as maize due to the rise in US ethanol production from 2000 to 2008, whilst meat price gains averaged about one-fifth of the maize price increase. At the world level, the global rise in fuel ethanol production was calculated as being responsible for an average 23 per cent of world coarse grain price increases between 2000 and 2008, whilst the rise in biodiesel production was found to be responsible for an average 8 and 38 per cent of oilseed and vegetable oil prices, respectively.

But again the most striking feature of this systematic review was the wide variation in price responses to increased biofuel demand. This meant that the averages were calculated from a very wide range of results, questioning their value. Persson attributes most of this variation to differences in supply and demand elasticities used between the studies. Those recording large price effects tended to assume a zero supply elasticity, whilst those with small price changes tended to incorporate a strong supply response through area or yields or both. Most partial equilibrium models assumed a zero yield elasticity, but many models assumed quite large yield elasticities. Most models assumed relatively large area elasticities, but again with a wide variance. It should also be noted here that whilst supply elasticities are more likely to increase over the long run, most of the studies focussed on short-term outcomes.

Persson argues that the price impacts of increased biofuel demand crucially depend on the supply and demand elasticities selected, but that "*there is considerable uncertainty around the value of these parameters*" and that a particular concern is the lack of empirical evidence for supply elasticities, especially for developing countries and in the longer-term. He also notes the need for better information on land transformation within such analyses.

Whilst Persson's analysis helped to produce a narrower range of values from the wide range of findings, a meta-analysis of some 150 projections from 29 studies of the impact of US maize ethanol production on maize prices (or a close proxy for maize values such as average grain prices) produced an even wider range of results (Condon et al., 2015). In order to make the studies more comparable Condon et al converted the various study findings into maize price changes per unit of ethanol production (in both volume and percentage terms). These normalized prices, or elasticity measures, followed the same principle used by Persson, but they showed a wider range of results. Elasticity values (the percentage US maize price change per percentage increase in US ethanol production) ranged from as low as 0.003 to as high as 1.3. These values resulted in percentage changes in maize prices from 2000 to 2008 accounted for by US biofuel production of between 0.01 and 85 per cent.

Thompson, Hoang and Whistance's (2016) review of 170 studies for the Food and Agricultural Policy Research Institute (FAPRI) on the impact of US ethanol demand on US maize prices, also finds a wide range of results, with the price impact being higher for those studies that do not incorporate a supply response. For those that do, well under half the increase in maize demand was estimated to have been met by increased supply. Although some studies suggested that increased production offset all the increase in demand, most did not. The land use estimates also varied markedly from no change to millions more hectares of additional land allocated to maize and other crops in the US and the rest of the world. The FAPRI study was unable to draw any conclusions on trade and co-product impacts.

Given that the supply elasticity assumptions are one of the main sources of discrepancy within the various econometric modelling studies, it is worth noting that there has been a recent revival in studies on estimating agricultural supply elasticity within the extensive agricultural economics literature. This revival has been largely in response to the indirect land use change debate, as policymakers sought better evidence on acreage responses to higher prices, and, consequently, on yield response to prices also.

The traditional view within the economics literature held that all, or nearly all, of any crop supply response to price, came from farmers changing their planted areas. The long-held assumption has been that yields are largely influenced by weather in the short-term and technological change in the long-run, rather than price. But in recent decades, some studies have found that yields also respond to prices through input use and other production measures.

Over more recent years, a number of new studies have found contrasting evidence on yield response. Berry and Schlenker (2011) concluded that most empirical evidence points to yield elasticities for US maize of around zero, arguing that fertiliser use has reached optimum levels and that any yield increase on existing land would be offset by more marginal lower-yielding land coming into production. But Goodwin et al (2012) point to a number of studies over the decades showing a significant yield response and in their own analysis find a long-run elasticity of 0.25 for US maize yield response to prices.

The opposing findings largely reflect the different underlying approaches taken in estimating the supply elasticities. This arises because of the difficulty in isolating price responses of plantings and yield from the many factors that influence both. Furthermore prices themselves are determined by a wide array of supply and demand factors operating in equilibrium and influencing each other. Thus, it is argued that regressions of yield and price, or area and price, may indicate correlation but cannot prove causation.

Thus different econometric approaches have been adopted to estimating supply elasticities. Berry and Schlenker (2011) argue that much of the literature fails to account for the endogenous relationships between variables when measuring price impacts. They argue that an instrumental variables (IV) approach, using only exogenous instruments, should be used in order to prevent an endogeneity problem. Weather has traditionally been used as the exogenous instrument to shift supply and thereby trace out the demand curve. Roberts and Schlenker (2010) also use past weather shocks to shift demand and trace out supply.

But Goodwin et al (2012) find a significant though small intra-seasonal yield response to price changes that could themselves be influenced by weather shocks. The short-term responses are corroborated with focus group evidence confirming that farmers often take actions during the season in response to price changes that would affect yields, including changing their overall crop area allocations (eg to more higher yielding crops in the overall mix) and the timing and level of inputs and other measures (eg falling output prices and increasing input prices may discourage input use at certain times of the year).

Others use different approaches, such as the “difference GMM” or “system GMM methods”, the latter used by Haile et al (2016) in their recent analysis of worldwide acreage and yield response to international price changes[44]. In their comprehensive global analysis of the area and yield elasticity of wheat, maize, rice and soybeans, Haile et al found that yield and area own elasticities were mostly similar in order of magnitude, but that the overall supply elasticities to price were generally small. A weakness of this analysis was the use of a world price for each commodity, which assumed complete price transmission to national markets, an assumption that is widely contested in the literature (see below).

Clearly, the widely different views regarding the impact of biofuels on food prices have been difficult to explain and resolve. However, there does appear to be a growing consensus that the early estimates attributing more than half of the commodity price spikes to sharply rising biofuel demand have been revised downward in recent years. Persson’s normalized range of 11 to 43 per cent of US maize price increases being attributed to increased US maize ethanol output between 2000 and 2008, perhaps provides the most rigorously analysed range of values, although only covering a few of the early years of the biofuel boom before an apparent supply response had managed to catch up with the sharp rise in demand. Recent reviews have also highlighted the inherent weakness of many of the studies that lack a supply response when calculating price impacts, as such studies tend to attribute a larger percentage of price changes to biofuel demand.

There also appears to be some empirical evidence that speculative activity only had a small influence, if any, on the price spikes of recent years. The large percentages of

[44] The system GMM method transforms the instruments in order to make them exogenous to the fixed effects.

price spikes attributed to the impact of trade policies and exchange rates by some studies, also seems difficult to verify in the more recent literature.

Meanwhile the influence of oil prices seems to have become more widely accepted as a key driver of maize and other commodity prices over the past decade. However, both the input and output linkages appear to have underlying theoretical weaknesses in that oil only accounts for a certain proportion of input and distribution costs, whilst biofuel output is often constrained by mandates and blend walls associated with engine performance and policy restrictions, as well as plant capacity.

Overall, the literature suggests that the perfect storm theory seems to fit best, as the evidence appears to point toward a combination of biofuel and other demand changes, high oil prices, exchange rate changes and trade policies, accentuating the strong demand emerging from population and per capita income growth in many developing countries, combined with a series of weather-induced supply shocks over the past decade.

In a recent modelling exercise Baldos and Hertel (2014) argue that in the long-run, crop commodity prices are likely to return to their long-term decline in real terms, and that the recent spikes in food prices were transitory. One of their key arguments is the slowing of population growth compared to previous decades when productivity had to keep pace with both rising population and strong per capita income growth.

2.3.5.4 Transmission of international prices

Increased world grain and oilseed prices can have a marked impact on food insecurity in developing countries, where people commonly spend more than half their income on food. The perceived wisdom is that if biofuel policies are indeed contributing to high world grain prices, then they are also contributing to an increased number of people suffering from hunger. This is based on the assumption that most food-insecure households are net buyers of food, that food expenditure accounts for a large proportion of household income in poor households and that there is a higher elasticity of demand for food in developing countries.

Bryngelsson et al (2012) provide a review of evidence supporting the case that higher food prices lead to increased food insecurity, as well as concluding the same from their own study of four sub-Saharan countries. An earlier study by Ivanic and Martin (2008) of nine countries draws the same conclusions. However, both studies qualify that most of the evidence is based on short-term impacts and that high prices could invoke higher wages and greater productivity over the longer-term.

Other studies show more varied evidence on the degree to which commodity price spikes on the main global exchanges have translated into higher food prices for food insecure households in developing countries. Abbot (2009) argues that many developing countries adopted policies to protect domestic markets from much of the increase in international prices, and that, although global market prices seldom transmitted fully and immediately to domestic markets, there was a wide difference in transmission between countries. A later study of commodity prices in 14 countries also found a variation in transmission rates, with relatively no transmission in China and India, compared to domestic price overshooting in Ethiopia and Nigeria[45] (Baltzer, 2013).

Taking the example of the major biofuel feedstock, maize, the extent to which increased values on the US market translate into higher prices of maize in the local markets of southern Africa, depends on many factors, including whether the country is a net importer of cereals, whether it has good infrastructure and functioning markets, including adequate market information, as well as the policy and supply and demand conditions for all foods in the locality (including any supply shocks) and market power within the local agri-food supply chain[46].

Cereal prices in mainland Africa tend to be particularly volatile, partly due to poor infrastructure and very high transport costs. A report by the Overseas Development Institute (ODI) just after the first global cereal price spike in 2007/8, noted that the very high increases in maize prices recorded in Africa, were, in most cases, not correlated with international prices, but caused more by local market and other

[45] The term “overshooting” here means that domestic price changes were much greater than international commodity price movements

[46] There is also the question of the substitutability of different types of grain, as the Chicago futures market price is based on yellow corn, used mainly as animal feed or to produce high-fructose corn syrup and ethanol, whereas much of the maize used in Africa is of the white variety used mainly for human consumption.

factors, including poorly functioning markets (Keats et al., 2010). Minot (2011) also found that African food price volatility had not increased in recent years and that domestic factors may contribute more influence on local price volatility than international price fluctuations.

Headey (2014) used a relatively simple regression model of domestic food prices in selected developing countries against exchange rates and an international food price index incorporating staple foods weighted by domestic consumption, finding that the international food price index could account for about a third of the domestic price movements on average. This is much lower than the 50 per cent transmission estimated from a study of seven large Asian countries by Dawe (2008), and the 66 per cent transmission estimate used by Ivanic and Martin in their 2008 study of nine developing countries, but higher than the average long-run transmission elasticity of 25 per cent calculated for staple cereals by Baquedano and Liefert (2014) for a larger number of developing countries.

It is also notable that in a later and more comprehensive study of price impacts in 2010, Ivanic and Martin noted large differences in impacts between countries which they attributed mainly to the wide variation in the extent of transmission from global to local prices (Ivanic et al., 2011). Thus in countries with a high price transmission there was a significant increase in poverty rates, which could have implications for trade policy as this implies the more open an economy, the more likely that volatile world prices would exacerbate poverty levels. But it should also be noted that no supply response or wage impacts were included in their analysis, so the potential positive impacts to net sellers and higher wages to workers were excluded.

Minot's (2011) econometric study of sub-Saharan countries also supports the argument that price transmission varies greatly between countries, and that there is generally limited transmission from global to local markets. From some 62 price series over a period of four to eight years, only 13 were found to have long-run price relationships, and of these only 6 had a long-term transmission elasticity that was statistically significant. Thus, whilst Ethiopia, Malawi and Mozambique had the highest transmission rates (although for all three the average rate was less than 40 per cent), Kenya, Uganda and Zambia had no prices showing any long-term relationship.

The findings also varied between staple crops, with almost half the domestic rice prices closely related to world values, which is perhaps not surprising given that many sub-Saharan countries rely on imports of rice. More importantly for the biofuels and food security linkage, only 10 per cent of the domestic maize prices included in the analysis were connected to world prices, or effectively US export values (Minot, 2011). This is corroborated to some extent in a recent study of countries in Latin America, Africa and Asia, which found some statistically significant maize price transmission to local markets in only 4 of 27 countries (Ceballos et al., 2016).

Given that domestic staple cereal prices in most developing countries seem only to have followed international trends to a limited extent, Dawe et al (2015) calculated price indices for rice, wheat and maize in Africa, Asia and Latin America, finding that all three staples recorded weighted average prices in 2013 above the levels prevailing in early 2007 before the first of the recent global commodity price spikes. The rise in domestic prices of just under 20 per cent for wheat and rice and just under 30 per cent for maize, were much less than the international price increases over that period. But again there was a wide variation in results between regions and countries.

Gibson (2013) questions the overall reliability of food price data in developing countries, with few collecting spatially detailed food price information, particularly from rural areas. Indeed, most national consumer price indices use urban centre data. Gibson is particularly critical of statistical agencies failing to collect market price data to match household income and expenditure survey information, and the lack of quality-specific price data, which makes it difficult to assess the impact of higher prices on nutrient intakes. This is particularly important for poorer households who may substitute a food source whose price is rising for another cheaper source with lower calories or other nutrients.

2.3.5.5 Are high food prices good for the poor?

Wright (2014) makes the point that there is very little in the literature on how consumers were affected in practice by the recent commodity price spikes *"beyond simulated changes in the number of people below certain international poverty* *measures"* and that we *"know embarrassingly little about how food consumption and prices have evolved at the individual or household level on a worldwide basis"*.

As noted above, the generally accepted view is that higher food prices increase poverty and hunger, as in the review of studies up to 2010 by Compton et al (2010) and Ivanic and Martin's estimates of the additional millions of people falling into poverty following the 2007/8 and 2010/11 food price increases (Ivanic and Martin, 2008, Ivanic et al., 2011).

However, a recent study of self-reported food insecurity by over 50,000 people in 18 Sub-Saharan African countries over the period 2005-2008, found that there was only a small increase in the overall incidence of food insecurity, despite a sharp rise in food prices, and that perceived food security actually improved in rural households (Verpoorten et al., 2013).

There is also ongoing debate on the extent to which higher commodity prices make rural households less food secure, as many of them derive much of their income from sales of farm produce. Given that three-quarters of all poor[47] people live in rural areas, it is generally believed that the majority of the world's undernourished people live in rural areas and about half are from smallholder farms (UN Millennium Project, 2005, World Bank, 2008).

There is some evidence that farmers in Africa have responded to higher commodity prices in recent years through increased and more diversified production, which could have a positive impact on economic growth and food security (Conceicao et al., 2011, Tyner, 2013). In a review of recent food price developments, Wiggins and Keats note that global cereal prices have fallen back in recent years due to a strong supply response by farmers to higher prices, particularly in the developing world (Wiggins and Keats, 2014). However, this argument is somewhat at odds with the evidence of poor price transmission between international and domestic grain prices for many developing countries.

[47] Living on less than $2 per day

Concern has also been expressed over the mixed messages issued by UN, NGO and other organizations on food prices over the past decade, as many previously advocated that low commodity prices were damaging to developing countries, yet are now campaigning against the impact of higher food prices (Swinnen and Squicciarini, 2013) . In an earlier review, Swinnen notes that up until the 2007/8 global food price spike, the general consensus was that low food prices had a detrimental impact on developing countries, as the sale of foodstuffs was the main source of income for many of the world's rural poor. Following the recent food price spikes, the widely-held view now appears to be that high food prices have a detrimental impact on most people on the developing world, as net consumers of food. This raises the question *"what is the right price of food?"* (Swinnen, 2011).

More recent econometric research points to longer-term benefits of high food prices for poverty-reduction in India (Jacoby, 2013) and Uganda (van Campenhout et al., 2013), which is attributed mainly to the strong linkage between food prices and rural wages. Headey (2014) uses a similar analysis at international level, finding that higher food prices reduce global poverty in the medium (within a year) to long-term, whilst acknowledging that there may be adverse consequences in the short-term, particularly for net food purchasing consumers in urban areas. Indeed, Headey reaches the conclusion that higher food prices from 2005 onwards could have reduced the number of poverty-stricken people by between 87 and 127 million, in stark contrast to Ivanic and Martin's numbers.

Nevertheless, concerns remain over the impact of high food prices on many poor households. Dorward (2012) argues that despite evidence there may be some longer-term benefits, this should not detract from the need for policies and actions to address the very serious impacts that high food prices have for many poor households.

These findings suggest there should be more focus on differentiating between the rural and urban poor in policies aimed at improving food security, as well as between short and long-term impacts. They also suggest that more emphasis could be placed on identifying a satisfactory range of food prices in order to encourage increased food production and investment in the agriculture sector, whilst maintaining the affordability of food for consumers. Prices falling outside this range may then require targeted policy interventions, including safety nets for the most vulnerable households when prices are high and support to vulnerable farmers when prices are low.

2.3.6 Food security impacts of biofuels at the local level

The Overseas Development Institute (ODI) notes that research on the food security impacts of biofuels at local and household level has been limited and the results inconclusive (Locke and Henley, 2014). An earlier review also concluded that *"more evidence on the impacts of biofuels at the local level is desperately needed"* (Hodbod and Tomei, 2013), whilst Tanner's (2013) review of the impact of large-scale land acquisitions on food security finds *"very little direct analysis of food security and malnutrition using scientific means"*.

The Locke and Henley review found just five studies with sufficient information on the food security impacts of biofuel "plantations" in Africa, focusing mainly on the land displacement issue. They concluded that the evidence points to negative impacts associated with the displacement of land or communities, with the exception of one project in Ghana where alternative land was provided by the biofuel operation (Boamah, 2011). In the other four studies some losses of land were reported from food production or foraging locations resulting from a failure by biofuel feedstock companies to follow fair negotiation processes or to provide equivalent compensation.

In terms of income and expenditure, the results were more mixed for the same five plantation-style projects. In an oil palm plantation in Liberia, some households increased their income but for others rising costs and reductions in other revenue streams offset the benefits of employment (Balachandran et al., 2012). A study of a jatropha plantation in northern Ghana found that over two-thirds of employees experienced a positive income benefit and no household with employees felt a negative impact (Schoneveld et al., 2011). Another study of a jatropha estate in Ghana also reported improved incomes and food production (Boamah, 2011).

Nevertheless, the ODI report concluded that the impact of large-scale biofuel plantations had largely been negative in the establishment phase, due to communities losing land, and in some cases this had displaced food production and was not compensated. But none of the studies employed detailed food security methodologies and indicators, so it is not clear what the actual nutritional outcomes were, for example, in cases where improved incomes occurred in tandem with land losses. There is also a danger that some of the studies may have selected case studies where communities had lost land to biofuel operations, ignoring other beneficiaries in the locality.

Other studies of plantation-style biofuel models find some positive income and food security benefits. In a study of over 300 households in the vicinity of a jatropha plantation in Madagascar in 2008, it was found that employment opportunities were limited in that area and the biofuel operation offered income-earning opportunities for the poorest households, resulting in improved food security in the locality (Bunner, 2009, Grass and Zeller, 2011). In a later study of the same plantation in 2010 it was found that the overall poverty situation in the locality had worsened, largely due to adverse weather conditions and poor yields. However, plantation incomes had remained constant and thus contributed to a stabilisation of incomes and food security for those households with employees (Bosch and Zeller, 2013).

There have been more research studies on biofuel feedstock outgrower models, although few of these used randomized samples or investigated the impact on food security indicators. However, one study of a castor seed outgrower project in Ethiopia found that participation in the programme had significant positive impacts on household food security, as measured by calorie intake and the number of food shortage months (Negash and Swinnen, 2013). In terms of land use and income, the ODI review of outgrower projects found that most households could produce biofuel feedstock without negatively affecting food production and consumption, but income generation was limited.

Other studies have highlighted significant benefits for outgrowers of different feedstocks. Recent literature reviews of outgrower schemes and other contract farming arrangements in Africa show higher incomes for participants compared with non-participants (Prowse, 2012, Sahin et al., 2014, Stockbridge, 2007). However, in another review within a recent study of cocoa and oil palm cash crop farming in Ghana, the results surrounding food security were inconclusive. Indeed, in its own detailed survey using multiple indicators the study found an adverse relationship between cash crop production and household food security (Anderman et al., 2014). An earlier review of horticultural supply chains in Africa concluded that the poorest households are more likely to benefit, in terms of improved food security, from employment on large-scale farms and estates than as outgrowers (Maertens and Swinnen, 2009).

It is therefore difficult to draw any conclusions from the literature regarding the local impact of biofuel operations on food security, except that far more research and evidence is needed, particularly concerning food security outcomes.

2.3.7 Other issues linking biofuels and food security

The linkages between biofuels and food security reviewed in this section so far have focussed on the impacts on food prices, land availability and income from sales of feedstock and employment on biofuel operations. A number of books and studies have focussed on the wider range of social, economic and environmental issues concerning biofuels (Clancy, 2013, Gasparatos and Stromberg, 2012, Rosillo-Calle and Johnson, 2010, Rutz and Janssen, 2014). These include other issues linked to food security, such as the provision of local energy in food production, distribution and storage, the use of biofuels for cleaner cooking and the increased investment in rural areas associated with biofuel feedstock production.

2.3.7.1 The energy, food and climate change trilemma

Food and biofuel supply chains rely on significant energy inputs. Indeed, energy has been the major factor driving economic growth and achieving food security in the developed world over the past century, as pre-industrial societies moved from renewable energy sources, such as wind and water power, to fossil fuels during the industrial revolution (Giampietro and Mayumi, 2009).

The world now faces the dilemma of transitioning away from fossil fuel energy resources, and indeed leaving many reserves in the ground, whilst developing countries continue to strive to end poverty through economic growth. Some experts believe that continued global economic growth cannot be guaranteed given the constraints of phasing out fossil fuel use and the limitations of other scarce resources such as land, water and soil (Heinberg, 2011).

Moreover, the adverse climate change impacts of GHG emissions from burning fossil fuels, deforestation, farming and other land-use practices, is now a more pressing concern for the world, threatening to reduce food production and endangering the stability of our climate and, hence, the survival of the human species in the longer-term. The trilemma of food security, energy security and climate change should therefore be the main concern for policymakers around the world (Tilman et al., 2009). The Paris Climate Change Agreement and UN Sustainable Development Goals suggest there is an urgent need to;

1) significantly reduce and phase out fossil fuel use

2) promote renewable and sustainable energy sources which significantly reduce GHG emissions

3) adjust food production systems to improve productivity and production, and adapt to changing climate patterns, whilst at the same time reducing GHG emissions (Pye-Smith, 2011)

The food security of a rapidly growing population in the developing world will largely depend on how well these objectives are achieved. It is clear that improving food production in the least-developed countries may lead to increased GHG emissions. But the impact of these countries on global climate change is relatively small, so the onus on reducing and phasing out fossil fuel use and using more renewable energy sources and developing more sustainable food systems, must be on the developed world, which accounts for the largest GHG emissions per capita.

If biofuels can help to significantly reduce GHG emissions and reduce fossil fuel use, this could help to alleviate the adverse impact of climate change on food production in vulnerable areas. On the other hand biofuels may have to compete with food over limited resource inputs, such as land, and thereby restrict food production.

Most least-developed countries need to increase energy inputs into the food chain in order to improve food security as populations continue to grow. Biofuels may play an important role in introducing energy sources into many food insecure areas that have traditionally relied on human and livestock labour, particularly as fossil fuel supplies dwindle and prices rise.

Energy is not only required in food production for cultivation, crop drying and irrigation pumping, but also in post-harvest storage, marketing, processing and cooking, and indirectly, in the form of fertiliser, pesticides and herbicides. Storage is a particular problem for developing countries where a high proportion of production is lost after harvest due to a lack of energy resources for chilled storage of perishable goods (FAO, 2011a). Lynd et al (2015) argue that there is considerable evidence that bioenergy can help food security and economic development in Africa, citing Brazil as an example of such synergy.

The FAO has noted in the past that the agri-food sector in the developing world has insufficient modern energy and that this hinders food security, with clear evidence that energy inputs affect productivity (FAO, 2000). Indeed, the FAO has a long history of work on integrated food energy systems (IFES), which has seen a resurgence in recent years (Bogdanski et al., 2010). At the turn of the millennium FAO called for an energy transition in rural areas, but energy access was not included as a specific target in the Millennium Development Goals, and, hence, has not been treated as a priority area of action. However, the Sustainable Development Goals have a specific target of affordable, reliable and clean energy for all (SDG 7). Biofuels can play a role alongside other renewable energy sources to help improve food security, particularly in remote rural areas.

2.3.7.2 Investment in rural areas

Productivity of staple food crops has significantly improved in most regions of the world over recent decades, but yields in Sub-Saharan Africa (SSA) have remained relatively flat. According to FAOSTAT data average SSA cereal yields increased by less than 30 per cent between the periods 1961-63 and 2003-05, compared to 144 per cent in Latin America and 177 per cent in the developing countries of Asia. Thus, it is estimated that increased planted areas accounted for 80 per cent of the total rise in SSA cereal production from 1980 to 2009, whilst yield increases accounted for 80 to nearly 100 per cent of production increases in East and South Asia and Latin America over the same period (Staatz, 2011).

The poor performance of the agri-food sector[48] in sub-Saharan Africa and other food insecure areas, has led to a growing consensus in the international aid community that insufficient resources have been directed to SSA agriculture over recent decades, both as aid and by national governments. More and more evidence points toward the importance of increased agricultural productivity in providing income and employment opportunities to pull up other sectors of the economy (eg Anriquez and Stamoulis, 2007, Cervantes-Godoy and Dewbre, 2010, Dethier and Effenberger, 2012, World Bank, 2008).

The new global focus on investing in agriculture as a platform for growth started in 2002 and 2003, with the African Union and aid partners establishing the Comprehensive Africa Agriculture Development Programme (CAADP) and pledging to raise spending on agriculture to 10 per cent of public budgets within five years[49]. The G8 summit in 2005 then agreed to increase aid to $50 billion per annum by 2010, incorporating pledges for a comprehensive set of actions on agriculture and the rural poor. The G8 summit in 2009 then pledged 20 billion euro a year in aid specifically for agriculture to support the CAAPD.

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[48] The term agri-food sector" is used in this study to incorporate all activities within the supply chain from farm inputs to processed foods and other goods.

[49] Note that as at the deadline in 2008 only 7 countries had achieved the set target according to NEPAD, although this had risen to 8 in the 2011 NEPAD report.

It is difficult at this stage to assess how successful this investment has been in reducing food insecurity. The recent global food price crises appear not to have increased the number of food insecure people as much as initially estimated: so would the situation have been worse without the increased aid?

One of the criticisms of aid for agriculture in the past has been the apparent lack of return from such investments, particularly in Sub-Saharan Africa. The more successful farm policies of South East Asia comprised trade protection and substantial support for their growing agri-food sectors, including subsidized inputs, as well as the development of a strong institutional framework and investment in infrastructure. A study which tracked economic development between similar pairs of countries in South East Asia and Sub-Saharan Africa, found that a focus on food productivity and supply, together with economic freedom for small farmers and macroeconomic stability, were the main factors behind the faster development trajectory of the Asian countries (Kees van Donge et al., 2012). An earlier study by the OECD also found that those developing countries that had been most successful in achieving poverty reduction over the period from 1985 to 2005 also had the highest rates of agricultural growth during that period (Cervantes-Godoy and Dewbre, 2010).

Biofuel operations in rural areas of developing countries can help to improve local agricultural productivity through spillover impacts. They could also help to improve rural development through the multiplier effect of improved incomes, encouraging the establishment of local retail and other service industries. Some companies also contribute to improved infrastructure through the building of roads and bridges. Many also establish better water access through the establishment of boreholes and pumps, as well as providing or contributing to better education and health facilities.

2.3.7.3 Food utilisation issues

Achieving food security ensures that people have sufficient food for an active and healthy life. Active, healthy and educated people enhance labour productivity and manage resources within the food supply chain more effectively. Indeed, it can be argued that overall economic development and prosperity are largely determined by the quality of human resources, which, in turn, is largely determined by their nutritional status as this affects both health and education. The goal of food security for all people should therefore be the priority of all countries, and particularly those with large proportions of their population currently food insecure, both from a social (health and human rights) prerogative, and from an economic growth perspective.

Empirical evidence linking nutritional health to productivity has been shown by various studies at both macro and micro level, as reviewed by Sahn (2010). In particular, a number of studies have shown a causal effect of iron deficiency on work productivity and earnings (Haas and Brownlie, 2001). Iron deficiency, or anaemia, has also been shown to have a significant impact on educational ability (Hurtado et al., 1999).

Other health-related issues that have received less attention in the food versus fuel debate are the problems of smoke inhalation, deforestation and labour burden from the use of wood, charcoal and other biomass as a cooking fuel. In many least-developed countries, the residential sector is the largest user of energy and wood, charcoal, dung and crop residues are the main fuels for cooking and heating. It is estimated that some 3 billion people currently rely on traditional biomass as their primary fuel source (World Health Organisation, 2016).

Such biomass use often leads to deforestation and environmental damage and is widely regarded as being unsustainable as forest supplies dwindle and populations continue to rise. Women and children are usually the main collectors of wood for fuel, often involving long treks during the day reducing their available time for other work and school.

Women and children are also the main victims of smoke-inhalation exposure during cooking and heating, damaging their health, reducing labour productivity and leading to millions of related deaths. The World Health Organisation (WHO) recently estimated that some 4.3 million premature deaths were linked to exposure to indoor air pollution from cooking with solid fuels in 2012 (World Health Organisation, 2014). More recently the International Energy Agency has estimated that 3.5 million premature deaths occur each year due to indoor smoke created during cooking (IEA, 2016).

Biofuels offer an alternative clean, renewable fuel for cooking and local energy needs, as well as for transport. For example, low cost stoves have been developed to utilise ethanol gel and vegetable oils, whilst generators can run on vegetable oils for rural electrification and power needs, such as irrigation pumps, hand-held ploughs and refrigeration for perishable food storage and medicines (Practical Action Consulting, 2009).

So there are also potential benefits for developing countries from biofuels in providing energy and employment to rural communities, as well as reducing their reliance on biomass for cooking and oil imports for transport needs.

3. Conceptual Framework

Miles and Huberman (1994) define a conceptual framework as one that *"explains, either graphically or in narrative form, the main things to be studied – the key factors, concepts or variables – and the presumed relationships among them".* In order to identify the main factors, relationships and pathways linking biofuels to food security, and the areas of potential conflict between them, a mapping exercise was conducted drawing from the literature review.

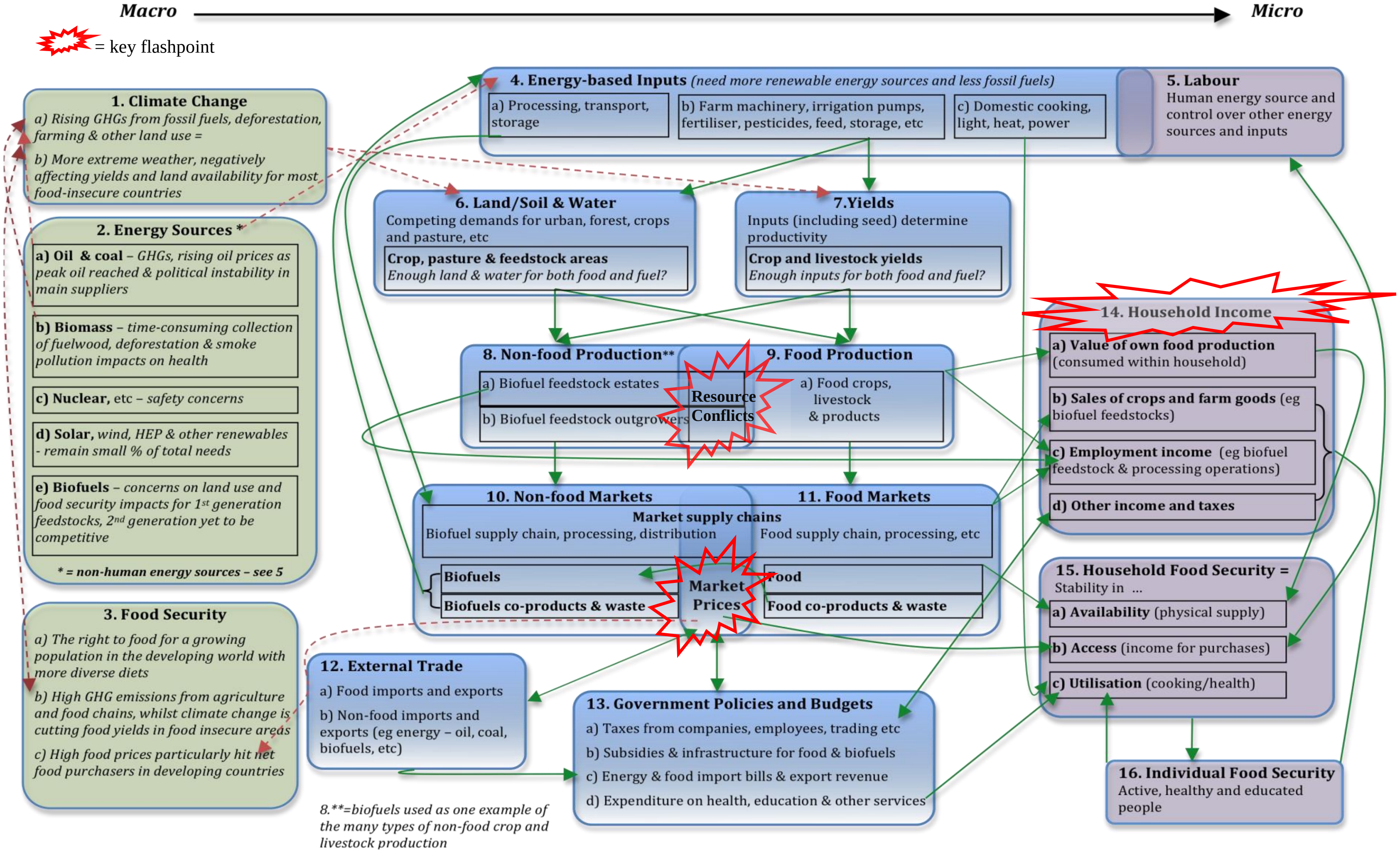
Figure 3.1 is the resulting map of the key factors identified linking biofuels with food security. The factors are mapped from those pertaining to the macro environment on the left to those regarding the household and individual food security, or the micro perspective, on the right. The factors are also mapped according to the agri-food supply chain, with inputs at the top flowing down through production to markets at the bottom.

Each factor box is coloured and numbered with sub-headings to explain its contents. Directional arrows are then used to show the main relationships between the factors, with green arrows showing the linkages between food and biofuel supply chains and household food security and the red dashed arrows linking key policy issues to each other and to points within the supply chain.

The three green boxes on the left of the map designate the key global macro policy issues relating to biofuels and food security, selected from the Raworth and Rockstrom frameworks. These reflect the *"trilemma"* of food, energy and the environment as conceptualised by Tilman et al (2009).

Climate change is clearly the primary issue facing humanity, as listed in box 1. Urgent solutions are needed to reduce and phase out fossil fuel use, including biofuels where relevant. Without climate change mitigation more extreme weather events are expected to negatively affect food production, through lower yields and reduced land availability.

Fig 3.1 – Mapping the Linkages between Biofuels and Food Security from Macro to Micro



The energy crisis is closely related to climate change. In box 2 alternative energy sources are listed to highlight the energy dilemma. Renewable energy sources need to be scaled up rapidly in order to offset the reduction in fossil fuel use required to remain within the Paris COP21 target of a 1.5^{o}C global temperature increase above pre-industrial levels (United Nations Framework Convention on Climate Change, 2015).

But most renewable energy sources are linked to the generation of electricity, so alternative liquid fuels are also required for long-distance transport, including air travel, and for those remote areas not connected to the electricity grid. Indeed in most least-developed countries alternatives are also required to biomass as a source of cooking fuel, which leads to deforestation and respiratory-related deaths.

Food security is listed in box 3 as a key global social issue, with some 800 million people deprived of, and despite their right to, sufficient food. Within this box is the dilemma regarding climate change impacts on food production, yet at the same time the global agri-food system is responsible for as much as half of global GHG emissions (GRAIN, 2016)[50]. Food security requires ample supplies of affordable food for all, so conflicts with biofuels may arise where biofuel operators compete with food producers for feedstock and resources and, in turn, encourage higher food prices.

The blue boxes in the middle of the map represent the macro and meso economy related to biofuel and food production to highlight the fact that feedstocks for food (including animal feed) and fuel compete for the same energy-based inputs (box 4) and other resources, such as labour (box 5), land and water (box 6).

The energy-based inputs are divided into farm-based inputs such as fertilizer, irrigation and farm machinery in 4b, supply chain inputs such as processing and transport in 4a and household energy inputs such as cooking, light, heat and power in 4c. Labour is treated as a separate energy input in box 5. Box 4 therefore links to the box 2 energy alternatives in that most of the energy inputs are currently fossil-fuel based, but these need to change to renewables in order to arrest climate change.

[50] The calculation by the NGO GRAIN takes into account supply chain costs, such as transport, storage, refrigeration and retail costs of food, as well as the agriculture, forestry and land use (AFOLU) estimates used in the IPCC's estimate accounting for about 25 per cent of total emissions.

The farm-based inputs in box 4b combine with land and water resources in box 6 to determine yields of crops and livestock and production of food and non-food biomass and livestock, including co-products.

The first main clash or conflict between food and biofuels is therefore where food and non-food production (boxes 8 and 9) overlap as they compete for resources, and in particular land. Both involve the use of fossil fuel inputs and land cultivation (and sometimes also land conversion, including deforestation), potentially exacerbating climate change. Note also that box 8 only uses biofuels as one example of the many non-food uses and is divided into 8a representing medium to large-scale biofuel feedstock production on large farms and estates, and 8b representing generally smaller scale farms acting as outgrowers of feedstock for biofuel operations, in order to highlight the different production system choices.

Food and non-food production is then either consumed directly on-farm (box 14a) or marketed through food and non-food supply chains (boxes 10 and 11). On-farm food use is an important aspect of food security in food insecure countries, particularly in rural areas where many farms are semi-subsistence.

The second main conflict point occurs within the marketing chain for food and non-food production, both for the feedstocks and for final products such as biofuels within boxes 10 and 11. Within such markets prices are formed by supply and demand conditions, government policy and markets for competing products such as oil in the case of biofuels. High oil prices can therefore raise demand for biofuels, in turn increasing demand for feedstocks such as maize, which then, in theory, increases the price of maize for food consumers. Rising food prices would particularly affect access to food for net food purchasing households in food insecure areas.

Box 12 highlights how external trade in feedstocks and products also influence market prices, as do government policies in box 13. Thus a government mandate to blend a minimum percentage of biofuel in transport fuels could lead to increased import demand for a feedstock from another part of the world, raising prices for that feedstock, and potentially food prices too. But import tariffs and export revenue may also enable increased government expenditure on health and education, which, in turn, can help to improve utilisation of food.

The pink shaded boxes on the right side of the map represent the “micro”, or household and individual level. Household income is a key factor in food security, as poverty and food insecurity are closely related. Box 14 divides household income into four main types:

a) value of own food production

b) income from farms and other own-businesses, such as sales of crops

c) income from employment

d) income from other sources such as remittances and government transfers

Research shows that food insecurity is often highest in rural areas of developing countries, and often in farm-based households, where income can fluctuate from year to year in response to changing weather conditions, environmental events such as flooding and pest and disease outbreaks. So increased income sources, such as through demand for biofuel feedstocks and the creation of rural jobs in biofuel operations, can help to improve food availability and access and stability in such areas.

But the evidence from the literature is that the establishment of biofuel operations in food insecure countries has created conflicts regarding land grabbing and environmental impacts. So, the income impact of biofuels is another point of controversy regarding food security.

This study therefore focuses on three key areas or flashpoints linking biofuels and food security derived from the literature review and mapping process:

i) Food access and stability related to the impact of biofuel production on employment and income in rural areas of food-insecure countries

ii) Food availability related to competition between biofuels and food (and other non-food uses) for feedstocks and resources such as land.

iii) Food access and stability related to the impact of biofuel production on prices of feedstocks and food

Whilst these are the three key issues analysed within the study, other linkages are also acknowledged, such as the potential benefits of biofuels for rural energy needs in food insecure areas.

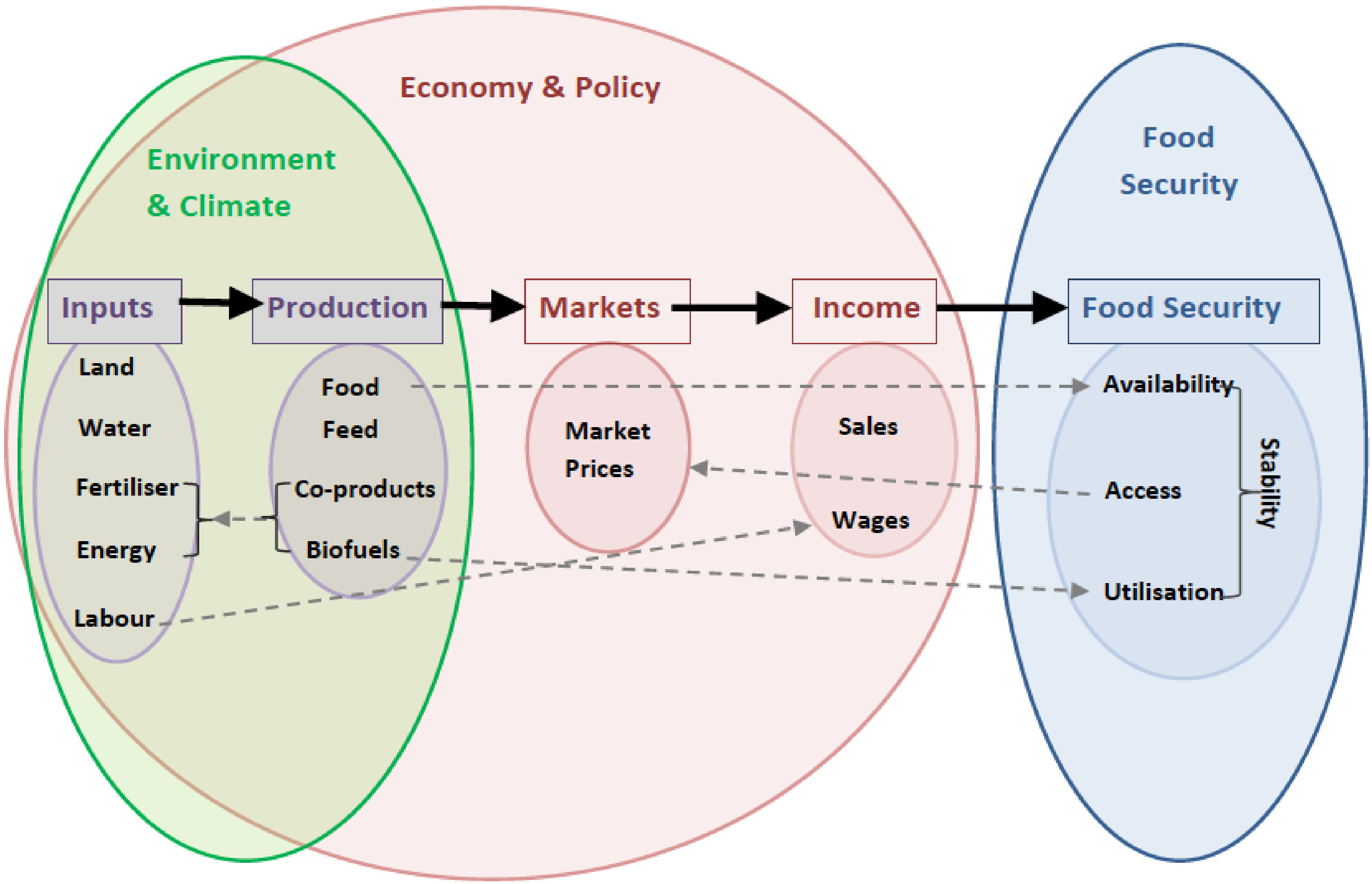
The three key issues are conceptualized in figure 3.2, which provides a simplified framework drawn from the mapping exercise. The central theme of the framework is the flow of resources (inputs) used in food and biofuel production through to household food security, depicted this time as a horizontal flow. Most food and biofuel produced from the resource inputs, flows to markets, where prices respond to economic supply and demand fundamentals and to policy. This creates income from sales of food and biofuel feedstocks, as well as from the wages of those employed in food and biofuel production. Income is then the main link to food security availability, access and stability, although access also depends on the prices of foodstuffs.

The food availability linkage is mainly captured within the input and production boxes, where the same limited resources are used for competing food, feed and biofuel demand. This is situated within both the environment and economy/policy spheres, as not only resource and product prices, but also food subsidies, biofuel mandates and trade barriers, will all influence the supply of feedstock for food and fuel. The food access issue relating to food market prices is largely influenced by the supply and demand of feedstocks that may be used for food or non-food (including biofuel) purposes, but also policy factors. At the micro level, household income is influenced by revenue from own-business sales and also wages from employment including biofuel operations.

These three key issues covering resource availability, food prices and household income, all feed into the food security outcomes in terms of affecting the availability, access and stability dimensions of food security. The utilisation dimension of food security is concerned with the quality and diversity of diets, as well as health and sanitation linkages. These issues are related to food availability and access in terms of the variety of food available and the affordability of food, education and health services.

The conceptual framework therefore provides a focus for the study on the three key areas identified, the major factors affecting each and the linkages to the different dimensions of food security.

Fig 3.2 -A Conceptual Framework of the Flow of Selected Biofuel-Related Impacts on Food Security



4. Methodology

The methodology chosen in researching a particular issue is inevitably influenced by the experiences and views of the individual concerned. This researcher first encountered the subject of this study when organising, and delivering a paper for, a conference on whether biofuels and food security were compatible (Thornhill, 2008). At the time the answer to this question from the conference speakers was a resounding “no”. However, this researcher was struck by the lack of evidence directly linking biofuels to food insecurity, with many of the negative outcomes associated with land grabbing, poor labour conditions, high food prices and other issues that did not appear to be specific to biofuels, as well as limited evidence from food-insecure households in developing countries. This instigated a research proposal to garner information on how biofuels were affecting household food security in food-insecure countries.

The mapping exercise conducted in the development of the conceptual framework illustrates the complex linkages between biofuels and food security moving from the macro to micro level. An individual’s food consumption will be influenced by the amount of food produced and income earned by the household, as well as the health and education status and energy needs of the individual[51]. These factors are influenced by a complex mix of market characteristics and forces, government policies, intra-household factors, cultural and socio-environmental conditions, the impacts of which are difficult to isolate and evaluate.

The methodology for this study therefore focuses on the three key issues distilled from the mapping exercise into the conceptual framework:

i) The effect of biofuel operations within food insecure countries on income and food production and prices at the micro level

ii) The effect of global and national level biofuel production on food availability at the macro and micro level

[51] Whilst time-consuming to measure, the distribution of food within the household has also been cited as an important factor in the level of individual food insecurity

iii) The effect of global and national biofuel production on food prices at the macro and micro level

The methodological approach therefore incorporated both macro and micro analyses in order to capture a more holistic view of impacts. It was also decided to use both quantitative and qualitative methodologies at both levels: ie a concurrent mixed methods approach (eg Creswell, 2009).

A key finding from the literature was the use of speculative, aggregated and proxy data in many of the analyses on biofuels and food security. Whilst it is recognized that the use of such data is sometimes required where information is absent and in order to build simplified models, this may lead to over-generalised findings, particularly where questionable assumptions are incorporated. One such assumption would be that of full employment in many CGE modelling impacts of biofuel operations in least-developed countries where there is both under and unemployment, and where jobs could significantly improve livelihoods and food security. A focus of this study was therefore to capture detailed information, at both the macro and micro level, on what has actually happened over the past decade in terms of biofuel and food security linkages.

It is also evident that the measurement of food security is by no means an exact science, as reflected in the weaknesses of different methodologies and proxy indicators identified within the literature and the calls for innovative approaches (Coates, 2013, de Haen et al., 2011, Headey and Ecker, 2013). It was therefore decided to adopt a novel approach to measuring food security. The main aim was to employ a metric and methodology that was relatively easy to capture information for, and best reflected reported consumption of, the main nutrients from actual foods (rather than food groups or types) and to compare that against calculated nutritional requirements, accounting for any periodic shortfalls.

Food security is best measured at household and individual level (de Haen et al., 2011). A household survey was therefore conducted in food insecure areas where biofuel operations had been established. This, together with focus groups and key interviews, provided the detailed information for the micro-analysis.

For the macro analysis, information was compiled on biofuel policies and production at the national level in order to build a comprehensive database. This enabled land use and potential raw material diversion, and co-product impacts to be assessed for each feedstock type in each country. This was then used to determine the main linkages between biofuels and food security at the macro level, and in particular, the impact of biofuels on land availability. In terms of food prices, it was decided to focus on maize, as the main feedstock used in biofuel production, and particularly on US maize prices, which tend act as the global benchmark.

4.1 Pre-Survey Desk Research, Interviews and Focus Groups

The first component of the methodology comprised desk research for a feasibility study, in order to establish the scope of the fieldwork operations given the available resources.

Of the food-insecure African countries, Mozambique and Tanzania attracted most initial interest from biofuel investors in the post-millennium years, partly due to their suitability for growing favoured feedstocks such as jatropha and sugar cane, but also due to the favourable policy environment in both countries. By 2008 a number of biofuel feedstock companies were operating in both countries employing workers and outgrowers (Schut et al., 2010, Songela and MacLean, 2008). It was therefore decided to undertake the field research in Mozambique and Tanzania in 2009 during the expansion phase of biofuel projects in the region.

The process of identifying biofuel operations in each country began through correspondence with government departments in 2008. In Tanzania the Ministry of Energy and Minerals provided a list of projects underway, whilst in Mozambique, the Centre for Promoting Agriculture (CEPAGRI) provided a list of ongoing and approved operations. Further research was conducted to find out more information about the small number of officially reported companies and to identify other potential biofuel feedstock operations in each country, working with local universities and NGOs. A number of biofuel companies were then contacted to assess their current operations and whether they would be willing to provide information by interview.

Eight projects were eventually selected – four in each country – involving different feedstock supply models (plantation/estate, outgrower and mixed) at different scales (large to community-based) and different feedstocks (jatropha and sugar cane). The sites selected are shown in figure 4.1.

A project plan was then developed for the household surveys in each location and research teams were established, comprising postgraduate researchers from local universities (University of Dar Es Salaam in Tanzania and Eduardo Mondliane University in Mozambique) and two researchers from University College Cork, plus translators and drivers. In Mozambique representatives from FAO and the University of Johannesburg joined the research team. Logistical plans were finalised and the Tanzania research was then conducted over the course of two months from May to June, 2009 and the Mozambique research over a similar period from August to September.

Pre-survey meetings were held with government departments in order to gain permission for the household surveys and to provide information on current policies regarding biofuels and food security. Other experts in the field of food security and biofuels were also interviewed, including embassy staff, NGOs, UN agencies and consultants. Semi-structured interviews were also conducted with biofuel company representatives, village chiefs and local officials in each location prior to the survey.

Two focus groups were held in each location before the household surveys commenced in order to capture essential information for the questionnaire. One group comprised farming households in the area in order to identify the main crops grown and livestock raised, production practices and costs, main crop production problems, storage and losses, marketing channels, units of sale and prices, food consumption issues, other income sources and changes in the locality since the biofuel operation was established. The second group comprised only women from households in the locality in order to assess gender issues and food purchasing and consumption details, such as units and methods of purchase, prices paid, hunting and wild food collection, meal patterns and amounts consumed within the household, shortage months, income issues and changes since the biofuel operation had been established.

The focus groups also helped clarify queries arising from the testing phase of the household survey questionnaire, as well as other qualitative information such as the importance attached to different nutrients when producing and purchasing food.

4.2 Household Survey Methodology

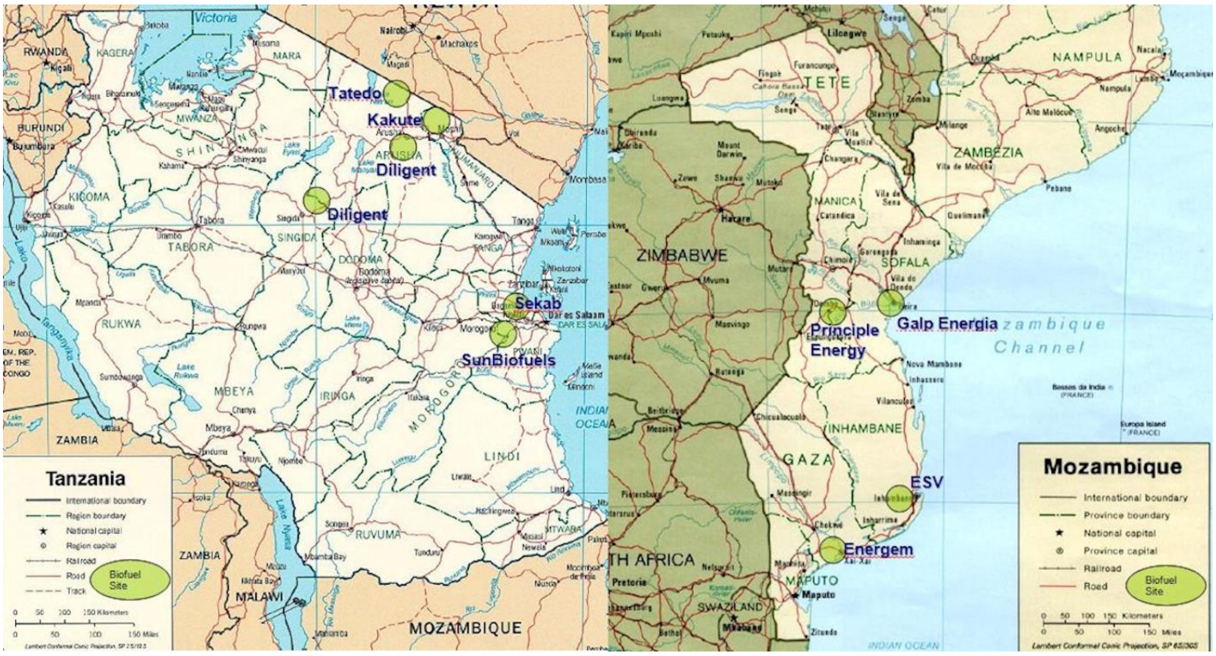
The methods employed for the household survey followed standard guidelines produced by the UN and other organisations. Particular use was made of a number of chapters within the UN guide *Household Sample Surveys in Developing and Transition Countries* (2005). Sample and questionnaire design and measurement error were key factors in the pre-survey preparatory work, particularly in the identification of information required for the indicators.

As the survey was constrained by a tight budget and timeframe, it was decided that the number of study sites would be limited to one randomly selected village or hamlet in the vicinity of a biofuel operation in order to ensure a representative sample, and so that sufficient detail could be obtained from each household within the time available.

4.2.1 Study sites

In Mozambique, four biofuel feedstock sites were identified for research at the end of 2008; two jatropha estates, one sugar cane estate and one mixed jatropha estate and outgrower operation. Both jatropha estates in the southern half of the country, owned at the time by Energem Biofuels in Bilene, Gaza Province and ESV Bio Africa in Inhassune, Inhambane Province, were well established at that stage as significant employers and were in the process of increasing their planted areas. Similarly a sugar cane estate owned by Principle Energy in Dombe, Manica Province, had grown crops on demonstration plots, cleared a sizeable land area, installed pivot irrigations systems and was employing workers for the main planting phase. The Galp Energia outgrower project near Beira had established a small nucleus estate of jatropha at the time of the survey, but an initial scoping study revealed that it was at too early a stage of development to assess food security impacts on outgrower households in the locality.

Fig 4.1 - Biofuel feedstock sites in Tanzania and Mozambique selected for surveys



In Tanzania, the selected biofuel feedstock operations included two well-established jatropha outgrower models in the north of the country, one project operated by Diligent Tanzania in Arusha covering a wide area of outgrowers extending down to Singida Province and another in Arusha run by Kakute Ltd, focusing on community energy projects, including links with the nearby village electrification projects run by TaTEDO (Tanzania Traditional Energy Development Organisation). The other two projects identified were large estates in the process of starting up in the east of the country closer to Dar Es Salaam; a sugar cane project owned by the Swedish company SEKAB and a jatropha estate operated by the UK-registered Sun Biofuels. At that time the two estates were starting to employ local people and both were confident that by early 2009 they would be sufficiently well established to measure the food security impact on local households. However, by the time of the survey in mid-2009, both projects had been delayed to the extent that it was deemed too early to assess their impact, although a household survey was conducted at the Sun Biofuels site, the results from which are not included in this study.

The three sites in Mozambique and two in Tanzania used in this study were all in rural locations at significant distances from the nearest major towns and cities, with low population densities and poor infrastructure. Most households around the sites practised semi-subsistence farming prior to the establishment of the biofuel operations, with little alternative employment available. Average household incomes in per capita adult-equivalent were reported to be just under $1 a day in the two selected sites in Tanzania and just over $1 a day in the three sites in Mozambique. All the sites were in food insecure areas: those surveyed in Mozambique were located in Gaza, Inhambane and Manica provinces where stunting prevalence of under-5s averaged 34, 34 and 48 per cent, respectively, in 2009 (WFP, 2010). The two sites in Tanzania were located in Arusha and Singida regions where the average stunting prevalence in 2010 was recorded as 44 and 39 per cent, respectively (NBS, 2011).

4.2.2 Tanzania research

The three biofuel sites visited during the field research are shown on the map of Tanzania in figure 4.1. The withdrawal of SEKAB from Tanzania just before the field survey meant that the planned visit to the sugar cane site at Bagamoyo had to be abandoned. The majority shares owned by SEKAB have now been bought by the former managers of the project under the Agro Ecoenergy Tanzanian registered company, which is part of the Swedish company EcoEnergy Africa. The original 400,000 hectare project has now been scaled back to a much smaller area of about 20,000 hectares in the near-term in the Bagamoyo district, where it is planned to produce 130,000 tonnes of sugar, enough electricity to power 100,000 rural homes and 10 million litres of ethanol from the molasses co-product of sugar production (Agro EcoEnergy, 2016).

4.2.2.1 Jatropha outgrowers in Singida

Diligent is a Dutch-based company that has been involved in jatropha cultivation and oil production in Tanzania since 2005. It sources its seeds from local outgrower farmers who pick, shell and dry the seeds for sale to Diligent's buying team. At the time of the field survey there were reported to be some 5,000 farmers registered, but actual production was from fewer farms, amounting to some 2,000 tonnes of seed and yielding some 500,000 litres of oil per annum.

Diligent had a small crushing plant in Arusha with a capacity of 70,000 litres per month at the time of the survey, although this subsequently increased to 100,000 litres. Production was expected to increase further under Diligent's plans to expand the area covered by its jatropha outgrowers from 5,000 to 50,000ha, providing at least 10 million litres per annum, with a longer-term target of 40 million. The jatropha oil was used in straight form for local use in modified engine cars, including those owned by a local safari company, in generators for local power needs, including for mobile phone masts, as well as in improved cooking stoves and as a replacement for kerosene in lamps.

Diligent's jatropha oil production was restricted by the limited supply of seed from farmers and outgrowers, partly due to the low prices paid to farmers, at TS100 per kg of seed or about 0.06 euro, and low yields from the outgrower system. The TS100 per kg price was a minimum price, but rising collection and transport costs restricted Diligent's ability to pay a higher price than the minimum. Seed was collected from Arusha, Babati, Handeni, Singida and Monduli regions, often involving long distances and high transport costs.

The Singida collection region was selected for the field research, given its traditional status as one of the least food secure regions of Tanzania. The broad midland area of Tanzania is described by FAO as a semi-arid mixed crop and livestock zone, with a low population density and an estimated 50 per cent of households below the poverty line (Perfect and Majule, 2010). USAID classifies the Singida region within the Tabora-Singida midland maize, sunflower and livestock livelihood zone.

The village randomly selected for the survey was Ikiwu in Singida Rural district. Most households in this area cannot grow enough crops on the land owned and therefore keep livestock and also produce sunflower seed for cash income where possible. As the area was also close to the Ruaha Game Reserve, there is always a danger of wildlife damage to crops.

Fig 4.2 - Jatropha Hedges, Providing Protection for Crops from Livestock Damage in Ikiwu, Singida

Jatropha has been grown as a hedge for many decades in the area, largely to designate field boundaries and protect crops from livestock and wildlife damage. Farmers only realised there was a market for jatropha seeds following the visit of the Diligent seed collectors to the village. However, they reported that yields and prices for the seed, at TS100-150 per kg, were too low to justify large-scale plantings, particularly compared to the better returns from sunflower seed sales to the local processing company. The areas devoted to jatropha hedges ranged between 0.2 and 0.5 acres for most farms and yields were reported to be low at some 400 to 500 kg per acre of hedge, although some of the hedges were newly-established and were expected to yield higher in future years.

4.2.2.2 Jatropha outgrowers in Arusha

Kakute (Kampuni ya Kusamaza Teknoljia) is an Arusha-based company promoting local renewable energy production and providing consultancy in jatropha cultivation. It was selected as an example of a small-scale outgrower operation, organising the collection of seeds for local crushing and the use of the resulting oil in soap-making, improved cooking stoves, lamps and power generation.

Two of the villages in which Kakute operated were randomly selected for the survey; Kingori and Ngurdoto. Key features of the location were reasonably good yields for foodcrops, but on very small areas for each household, with limited employment opportunities, making households vulnerable to food shortages at certain times of the year and in years of unfavourable weather. USAID classifies the area as the Kilimanjaro-Meru maize, coffee and plantains livelihood zone, with a high population density but relatively productive and with good market opportunities from nearly large towns and tourism.

Fig 4.3 - Extracting Oil from Jatropha Seeds in Mseseweni, Ngurudoto, Arusha for Power Generation (Maize Flour Mill)

The villages practised mixed farming, with a greater variety of crops grown than in Singida, but with most households producing from much smaller areas. Jatropha is often intercropped with food and cash crops such as maize and coffee in the villages and also grown as a live hedge, as a wind-break for households and to prevent soil erosion. The extracted jatropha oil was used in a generator to power a maize mill in the village, and some sold to the Tatedo project generating electricity in nearby Leguruki village, whilst some of the seeds were sold to Diligent and used for a local soap-making business. But, as with the Singida survey, producers reported that the seed prices at some TS100-150 per kg were too low to encourage significant expansion. As well as selling the seed, the leaves and seedcake were used as compost fertiliser.

4.2.2.3 Jatropha plantation at Kisaware

Sun Biofuels was a UK-based company with biofuel investments in Tanzania, Mozambique and Ethiopia. The Tanzanian venture was based on an estate production model for jatropha, with some 18,000 hectares targeted, employing up to 5,000 workers and potential for more production from outgrowers.

At the time of selecting the Sun Biofuel site in the Kisaware District of Tanzania, it was about to start employing local villagers. Some months later when the field research was underway, the company was still waiting for official clearance to start production. This meant that most of the households in the surrounding villages had not had sufficient involvement with the biofuel operation in order to assess impact. It was decided to conduct a survey anyway as a baseline for future reference, but not to use the results within the analysis.

4.2.3 Mozambique research

The four biofuel sites visited in the course of 2009 in Mozambique are shown on the map in figure 4.1.

4.2.3.1 Jatropha estate at Bilene

Bilene is located in Gaza Province, just north of Maputo in the south of the country. Bilene district is situated on the lowland plains within the Southern coastal maize, cassava and fishing livelihood zone, where the dry season runs from April to September and the main crops grown are maize, cassava, beans, sweet potatoes and groundnuts. Bilene town has become a popular tourism centre, but the rural areas around it remain relatively poor with many households producing insufficient food to meet their needs. The establishment of a jatropha feedstock operation offering employment and regular wages was therefore welcomed by many in the local community, and Energem Resources took over the operation in 2007.

Energem Resources was originally a Canadian company listed on the Toronto exchange, with a base in South Africa and involved in a number of renewable energy and mining projects throughout Africa. It was listed on the Alternative Investment Market (AIM) of the London Stock Exchange in order to attract funding but had to delist due to financial difficulties. Various news releases in 2009 and 2010 stated that it was owed some $60 million and had not been able to produce its financial statements as a result. In 2011 it was put into administration as it still had not been able to recover the debts (Mason, 2011).

The financial difficulties hampered progress at Energem's jatropha estate in Bilene. The company had hoped to eventually plant up to 60,000 hectares of jatropha from a secured land base of 20,000. Some 1,000 hectares of jatropha had been planted at the time of the research, but the planned expansion was being restricted by the funding difficulties and some of the local employees had already been temporarily laid off at the time of the survey.

About 500 local people were reported to have been employed by Energem at the Bilene project, with wages ranging from a basic 1,650 metical (MZN) per month (just over $60) to as high as 3,200 MZN for supervisors. At the time of the survey this number had been reduced to 300 due to cashflow problems. In mid-2010 the company paid arrears for two months wages owing to workers and later made redundancy payments to the 300 remaining workers.

Fig 4.4 - Young Jatropha Trees on the Energem Estate in Bilene

Some key features of the project included the fact that communal village land had been transferred to the Energem project in return for employment and land provided in other areas, with promises to develop the community, including water pumps and a school. The company also provided the use of tractors for employees to cultivate their land and provided for flexible working hours allowing employees to continue producing their own food.

Whilst the village welcomed the employment and wages, some staff had been temporarily laid off and the community was still waiting for a school building two years after promises were made, although some water pumps had been installed. Also the land provided as compensation for the lost communal land, following its transfer to the project and amounting to about 200 hectares, was a longer distance from the households. There were also reports that villagers were put under political pressure to transfer their land to Energem (Ribeiro and Matavel, 2009). The project closed down in 2010 with the loss of all the jobs, although redundancy payments were made.

4.2.3.2 Jatropha estate at Inhassune

Inhassune is situated in Panda district in the semi-arid interior zone of southern Mozambique, known as the Southern semi-arid cereals and cattle livelihood zone. Soils are generally poor and sandy with low productivity, so drought tolerant crops such as sorghum and millet are often grown, although maize, cassava and beans remain important subsistence crops, whilst groundnuts also provide a source of income. The rural poor are mainly dependent on their own food production and the collection of wild foods and hunting, and the zone is classified as a high food security risk. The survey was undertaken around the site of a former cotton plantation that some of the households had previously been employed on but had closed down some years earlier. So the establishment of the jatropha biofuel operation by ESV Bio Africa was welcomed by most of the rural villagers

ESV Bio Africa was a UK holding company and part of the ESV Group, which operates mainly in the Ukraine agricultural supply chain, including the supply of oilseeds for the EU market. ESV secured some 11,000 hectares to develop a jatropha estate on the disused cotton plantation at Inhassune, with a view to producing jatropha oil for biodiesel production. Most of the households in the area practised semi-subsistence farming and agricultural labouring following the closure of the former cotton estate. ESV was employing over 1,000 people at the height of its operation (reportedly 1,350 at one point), not just from Inhassune but from other villages. ESV paid wages above the norm, with a basic salary of 2,000 MZN per month for employees and 1,250 MZN for seasonal workers.

As with Energem, it was clear that funding problems were delaying progress. The staff were owed salaries at the time of the field survey and the owner had left the estate to find new buyers. Some of the employees had continued to work on the farm at the request of the government but for little or no pay.

Feedback from the research highlighted the high respect the villagers had for the company, as water pumps had been established, and a new school and health centre built. Furthermore the company had loaned out its tractors to employees for cultivating food crops, as well as providing expertise to improve yields. But when

ESV wages had stopped many had to find alternative employment at lower salaries, including as labourers for local road-building projects. Many of the jatropha plants at the time of the survey had been damaged by pests and had deteriorated so it was difficult to assess the viability of the operation at that stage.

Fig 4.5 - Ploughed and Irrigated Maize Production on Fields Bordering the ESV Jatropha Plantation, Inhassune.

In late 2009 it was reported that the estate had been sold to an Italian joint venture SAB Mozambique, controlled by Api Nova Energia and Seci Energia who were in the process of re-employing staff and paying back wages owed (Hanlon et al., 2011). In 2012 the Seci Api joint venture reported that it had harvested its first crop of 10 tonnes of jatropha oil which was sold to a local processing company (Macauhub, 2012). Of note was the fact that ESV continued to report that money owed to them from SAB Mozambique had still to be repaid by 2014 (ESV Group Plc, 2014).

4.2.3.3 Sugar cane estate at Dombe

Dombe is located in the centre of Mozambique in the Central Manica and Sofala mixed cropping zone, one of the most productive parts of the country where rainfall is high, but flooding is a common problem. The main crops grown are maize, sorghum, cassava, sesame, groundnuts, sweet potatoes, cow-peas and beans, with some livestock also kept. Apart from the flooding problem, food losses are also high due to inadequate storage. The poorer rural households with limited farm sizes tend not to be able to meet all of their food needs and generally work as labourers to meet the remainder of their requirements.

Principle Energy is a UK-based renewable energy company controlled by Principle Capital and established in 2007. Principle Energy focussed on bioethanol projects in Africa, acquiring 23,000 hectares of land in Manica Province near Dombe in 2008 for sugar cane production as a feedstock for bioethanol. A bioethanol factory was planned for the site with much of the ethanol expected to be shipped out of Beira to the EU via the Suez Canal under an offtake agreement with a major oil company. Roads were also built, and it was planned that a bridge would also be built to replace the small ferry over the Lucite river which was prone to flooding.

The project was based on an intensive sugar cane estate model using pivot irrigation booms, each covering over 50 hectares, with plans to extend the range to 65 hectares for future pivots. The project involved clearing the semi-scrub wasteland and degraded woodland before cane plantings were made. At the time of the survey some 100 hectares of cane had been planted under two pivots and a trial plot had previously been developed producing high yields of around 130 tonnes of cane per hectare

The company planned to employ 1,600 people from the prevailing level of 100, as some had been laid off in 2009 due to the global financial downturn and the lack of funds for the next phase of development. Basic wages were at the minimum wage level for the region, which at the time of the survey was some 1,500 MZN per month.

Most of the households in the surrounding area practised semi-subsistence farming before the establishment of the biofuel operation. Feedback from the survey and focus groups suggested that villagers were happy to be earning a wage, but that the wages were quite low in relation to household costs, including food prices and school and health fees. There was also a feeling that not enough locals were being employed in relation to workers migrating from Zimbabwe and other areas.

Fig 4.6 - Pivot Irrigation for Sugar Cane Plantings at Principle Energy's Site near Dombe

4.2.3.4 Jatropha estate and outgrowers at Buzi

Buzi is located in the coastal sugar cane and fishing zone just south of the city of Beira in the centre of the country. The area is quite productive with high rainfall and therefore suitable to water-intensive crops such as sugar cane, rice, maize and vegetables.

Galpbuzi is a joint venture between Galp Energia, a Portuguese energy company and Companhia do Buzi of Mozambique. The project is based on producing jatropha seed using an outgrower model around a nucleus estate. It was planned that most of the oil produced would be shipped to Portugal to help meet the country's renewable energy requirement under the EU Renewable Energy Directive. Galp Energia was also involved in another jatropha venture near Chimoio, known as MozamGalp.

Fig 4.7 – Sorting and Drying Jatropha Seeds at Galpbuzi's Jatropha Estate, Buzi

The Galpbuzi project aimed at securing 25,000 hectares mainly in the area of the old Buzi sugar and cotton estate. At the time of the survey some 150 hectares of jatropha had been planted on trial plots, employing 73 workers at 1500 MZN per month. The company were in the process of scaling up to 320 hectares on the estate and had also started using seed sourced from a small number of outgrowers. However, it was too early to assess the impact on outgrower farmers as only a small number had been contracted and it was at too early a stage to assess impact on their livelihoods and food security status.

4.2.4 Sampling

Each biofuel company provided information on the surrounding villages and hamlets in which most employees or outgrowers were located. A village, or group of hamlets, was then randomly selected by multi-stage sampling. The list of villages was larger for the outgrower-based models, as a wider range of locations supplied feedstock to them. For example, the biofuel company Diligent, based in Arusha, Tanzania, collected jatropha seed not only from sites within the Arusha region but also as far afield as Singida. The more remote and food-insecure Singida region was selected out of the listed supply areas. There were six main villages from which Diligent collected jatropha seed in this area, and the village Ikiwu (in the Kijota rural ward, Singida District Council) was randomly selected by drawing lots at a meeting with the local seed collector.

In each location the local authorities were contacted to obtain permission for the research following approval from the national authorities. For example, in Tanzania the research was approved by the Ministry of Energy and Minerals in Dar Es Salaam, whilst Singida District Council approved the local survey work and provided a profile of Ikiwu village, which comprised 10 hamlets predominantly practising mixed farming. From the 10 hamlets, three were randomly chosen again by drawing lots – Kiwukati, Matundi and Mbura. These hamlets comprised 316 households and the village chief provided a list of the households from which 37 were randomly selected through a process of drawing lots from 1 to 10 for the first household on the list to be selected and then taking each ninth subsequent household. Teams comprising researchers from University College Cork, University of Dar Es Salaam and local translators then interviewed the selected households using the pre-tested questionnaire.

A similar process was conducted when choosing the survey sites for the Kakute biofuel operation. Two villages were randomly selected from the various sites from which jatropha seed was collected; Kingori and Ngurdoto, in Aremeru District. Both villages had five hamlets and one hamlet was randomly selected in each: Madukani in Kingori, comprising 200 households and Mseseweni in Ngurdoto, comprising 136 households. Again approval was gained from the local district council, household lists were provided by the village chief and households were randomly selected from these by drawing a random number from 1-10, and subsequently selecting every ten households: thus, 20 were selected in Madukani and 14 in Mseseweni, representing some 10 per cent of the overall population.

For the plantation or estate models, most of the employees were located in the villages next to the biofuel operation. Thus, the Energem jatropha estate near Bilene, Gaza Province in southern Mozambique mainly employed those from nearby Chilengue and Nzeve villages. Nzeve village was selected for the household survey, which is a more rural location where households were mainly involved in agricultural production or as farm labourers prior to the establishment of the jatropha estate. Most of the 37 households in the village were surveyed (31), from which 19 had at least one member of the household employed by Energem. Teams comprising researchers from University College Cork, Universidade Eduardo Mondlane, FAO and local translators interviewed the households in Mozambique.

The ESV jatropha estate was based in Inhassune village in Panda District, Inhambane Province, on a former cotton plantation that had closed down in 1990. The village had a population of some 2,000 split between two main areas A and B, from which the biofuel operation sourced most of its employees. Area A was randomly selected, comprising 300 households from which 30 were randomly chosen.

The Principle Energy sugar cane project near to Dombe in Sussundenga District, Manica Province, also mainly employed people from the nearest villages, including Chibue, which was chosen randomly from the local villages around the main settlement area of Pambanissa. A meeting with the local village head established that Chibue had 239 households and 32 were randomly selected from these by visiting the site and interviewing households in different parts of the village.

Whilst it is recognised that the household surveys only provided a representative sample of a particular village or hamlet in each biofuel site, each was randomly selected to prevent any bias rather than purposively selecting a location where there were reported to be negative issues. This methodology of focusing on one or two villages or hamlets in the vicinity of a biofuel operation may, however, have missed impacts experienced in other villages nearby.

However, the research project had insufficient resources to carry out a comprehensive survey of all the communities surrounding each biofuel site and wanted to avoid any pre-selection bias. Also, the number of villages influenced by the biofuel operations tended to be relatively limited in most cases. For example, most of the local employees hired in the Mozambique operations were from one or two adjacent villages. Similarly, it was not possible to survey communities outside the influence of the biofuel operation as counterfactual sites given the available resources. It would also have been difficult to account for the many different socio-economic and environmental influences on food security when comparing sites.

Table 4.1 shows the villages and hamlets randomly selected for the household survey in each of the biofuel feedstock sites and the number of household interviews used in the analysis after exclusions[52]. The total useable returns used in the survey analysis was 166, representing 14 per cent of the total household population for the villages surveyed, of which just under half had been involved with a biofuel operation for a year or more, either as outgrowers or as employees.

Table 4.1 - Survey details of households in selected villages close to biofuel operations

Biofuel operation & location	Hamlet(s)/ Village(s) selected	Type of biofuel operation	No house-holds (HH)	No HHs surveyed	No HHs involved in biofuels
Energem Biofuels, Bilene, MZ	Nzeve village	Jatropha estate	37	31	19
ESV BioAfrica, Panda, MZ	Area A of Inhassune village	Jatropha estate	300	30	15
Principle Energy, Dombe, MZ	Chibue village	Sugar cane estate	239	32	12
Diligent Tanzania, Arusha, TZ	Kiwukati, Matundi & Mbura hamlets of Ikiwu village	Jatropha outgrower	316	37	18
Kakute Ltd, Arusha, TZ	Madukani hamlet of Kingori village, Mseseweni hamlet of Ngurdoto village	Jatropha outgrower	336	36	15
Total			1,228	166	79
Note – HH = household, MZ = Mozambique and TZ = Tanzania					

[52] The table excludes unusable returns as well as the households surveyed in Mzenga village, Kisaware, close to the Sun Biofuel operation, as it was deemed too early to assess the impact of the biofuel operation at the time of the survey

4.2.5 Household questionnaire

In order to capture the necessary information from which to assess the impact of the biofuel feedstock operations on local food security, a questionnaire was developed for the household interviews. The questionnaire covered household demographics and social issues, food consumption and expenditure, cooking and fuel use, food production, income sources and biofuel-related issues (see appendix 2).

It was designed in a way that helped triangulate the food consumption, expenditure and production responses so as to arrive at a household food balance, ensuring that consumption did not exceed, or fall considerably short of, own production and purchases. This was then linked with the income data in order to produce a budget for each household. This helped to ensure that incomes were verified when a household reported food expenditures.

The questionnaire contained both quantitative and qualitative elements, enabling quantities of food produced, purchased and consumed to be calculated, as well as perceptions of food security status before and after the biofuel operation had been established. The questionnaire was also designed to capture the information required for the main food security indicator, as described in the following section.

4.2.6 Developing the household nutrient deficit indicator

In choosing the best indicators to use in the study, consideration was given to early findings from the literature review. It was decided that that the definition of food security to base the indicators on should be that from the 1996 World Food Summit; *"when all people, at all times, have access to sufficient, safe nutritious food to maintain a healthy and active life".* It incorporates nutrition as an important component of food security, rather than just a focus on caloric intake, as well as the need for sufficient food for an active and healthy life, as opposed to a minimum basic level.

The review also identified the four key dimensions of food security - availability, access, utilisation and stability – as crucial to measuring outcomes, as these give rise to many issues, such as price and income relationships, seasonal insecurity and non-food influences, such as sanitation and health. Thus, the complexity of the food security concept poses particular problems in terms of the level of detail required to measure it. However, it is important that each of the four key dimensions are represented as far as possible in any food security assessment.

The study also had limited resources for its fieldwork activities, requiring a prudent approach to measures used. For example, the 24 hour dietary recall methodology is often referred to as the gold standard for measuring food and nutrition security, together with anthropometric and biomarker methods. But these methods are expensive to implement, requiring highly qualified staff and repeat surveys to be undertaken[53]. Also, non-food issues, such as illness and disease, may influence anthropometric and biomarker outcomes, making it difficult to assess the extent of food and nutrition security in a particular locality.

At the time of the survey proxy measures, such as the household dietary diversity score (HDDS) were still in their infancy, with FAO Guidelines on the HDDS not being issued until 2011. Perception-based measures whilst used in developed nations, were also not widely used in developing countries.

The literature also noted the difficulty in using such indicators to assess whether a household or individual was malnourished as different indicators could give different results. This had led to calls for innovative methods to improve measurement, including making indicators more nutrition-sensitive.

For this study it was decided to develop a novel metric that would capture nutritional information from reported food consumption into a single score. A key aim of the metric was to ensure that it linked to the availability, access, stability and utility dimensions of food security as far as possible.

[53] There is also an ethical issue over the use of anthropometric and biomarker methods for measuring food security, which are often viewed as over-intrusive, particularly where blood samples are involved.

Most household surveys on food security capture food consumption at one particular point in time, such as over the previous 24 hours or the previous week, which may not reflect dietary patterns over the longer-term. Within the focus groups and interviews conducted before each of the surveys, it was found that diets tended to be relatively stable for most households in most months of the year, apart from well-known periods of shortfalls during the pre-harvest and other specific periods. Households were therefore asked to report their food consumption over the past week where this was typical[54], in terms of both the number of meals and types and quantities of food consumed and purchased, and then to report less frequently consumed foods by month or year. They were also asked if there were any shortage periods during the past year, how long they lasted and how they affected the number of meals or size of portions and types of food eaten[55].

The responses were then used to calculate the estimated amount of calories, protein, iron and vitamin A consumed by each household by month over the year. Food composition tables from Tanzania were used to calculate the nutritional content of the reported food consumption data (Lukmanji et al., 2008). These were then compared with the calculated minimum requirements for each household and percentage gaps were then derived for each of the four nutrients considered. FAO and World Health Organisation dietary requirements for moderately active and average height adults and children for each age group and gender type were used for the dietary requirement calculations (FAO et al., 2004, WHO and FAO, 2004, WHO et al., 2007). This provided a useful measure of the consumption of the main macro and micronutrients by the household each month during the year, identifying any major deficits and surpluses, and allowing such gaps to be traced back to the main foods produced, purchased and consumed.

[54] Where the past week's consumption was deemed to be "untypical", respondents were asked to report a more normal pattern of weekly food consumption and purchases.

[55] Note that the consumption data was reconciled with the household production, sales and food purchase data to create household food balances for each of the main food items, as a way of cross-checking household responses. For most households and most foods the consumption data balanced the survey data on food purchases and net production (ie own production minus sales), with only small positive or negative balances. Where larger balances were evident at the time of the survey, explanations were sought from the respondent and the data was re-checked and corrected where necessary. Some of the larger balances were explained by losses in storage.

Whilst each of the percentage gaps calculated for calories, protein, iron and vitamin A provided a useful guide to household food security for each nutrient, it was felt that a combined measure would be more useful for making an overall assessment of food security for each household. Combining macronutrients and micronutrients into an overall average score poses many issues, not least of which is whether certain nutrients are more important to households and individuals than others. Also, any significant surplus gap in one nutrient could outweigh an important deficit gap in another.

One way of ensuring that any large surplus nutrient gaps do not overwhelm any nutrient deficits in an overall average score is to only use deficit gaps when calculating the nutrient status of a household; hence, any surplus gaps are recorded as zero. But the calculated nutrient gaps can only be considered as an approximate calculation of nutrient intake. Also, some level of surplus nutrient intake would be more ideal than a zero or deficit gap in view of the fact that household requirements are calculated on moderate activity and many rural households would require higher nutrient consumption to match their activity levels or to realize their potential productivity. It was therefore decided to create a household nutrient score with a maximum cap on any individual nutrient surplus of 50 per cent, as anything exceeding this level would not be beneficial to the household in terms of health, expenditure and wastage[56].

It was also decided to weight the individual nutrient gaps when calculating the overall household nutrient deficit score, with a weighting of three for the calorie gap, two for the protein gap and one each for the iron and vitamin A gaps, based on the focus group assessments of their relative importance in local diets (ie that calorie intake was three times more important to households in the survey locations than iron or vitamin A and protein was twice as important)[57]. As the indicator was

[56] If the analysis was aimed at identifying obesity issues in the population then a maximum capping would not be as relevant, although any excessive surpluses would be apparent from the individual nutrient gaps within the total score.

[57] This reflected focus group responses that energy was the most important nutrient for work and health, followed by protein (muscle strength). Only iron and vitamin A were mentioned (in terms of anaemia and eye health) as important micronutrients across the sites surveyed. It also follows the guidance by Maxwell and Smith (1992) that *"food security is a multi-objective phenomenon, where the identification and weighting of objectives can only be decided by the food insecure themselves"*.

developed to reflect the level of food and nutrition insecurity, the overall score was calculated as the average deficit gap, so that the higher the score the greater the deficit.

Each nutrient deficit gap for a household can therefore be described as:

Household Nutrient Deficit Gap = the percentage difference between reported household <u>consumption</u> of each nutrient (calories, protein, iron, vitamin A, etc) and the calculated household <u>requirement</u> of each nutrient.

The overall Household Nutrient Deficit Score (HNDS) then uses the individual household nutrient deficit gaps to create a weighted average deficit score for the macro and micronutrients included in the calculation.

Household Nutrient Deficit Score = (Household calorie deficit gap x 3) + (Household protein deficit gap x 2) + (Household iron deficit gap x 1) + (Household vitamin A deficit gap x 1) divided by 7.

A positive HNDS denotes a weighted average deficit in the main macro and micronutrients, whilst a negative score signals an average surplus of the main nutrients[58]. The scores for each household are then combined to provide mean and median scores for the population in question in a similar way as calorie deficits are commonly used.

In order to assess the impact of biofuel operations on the HNDS the ideal approach would be to conduct a baseline survey of food consumption before the operation was established, with impact surveys after. Since all of the biofuel operations used in this analysis were well established at the time of the survey, measures of change over

However, it is of course recognized that many rural households would not be able to define their specific nutritional priorities.

[58] A more detailed Household Nutrient Deficit Score might incorporate more nutrients and different weightings according to a more detailed assessment of the relative importance of different nutrients in the diet. The simplified methodology used in this analysis captures the important macro and micronutrients in rural areas of Mozambique and Tanzania, where iron and vitamin A deficiency are common problems and households require significant intakes of calories and protein for manual work.

time had to be perception-based. Households were therefore asked whether their food security status had improved, worsened or had not changed since the biofuel operation had started. Householders were also asked to describe how their food security status had changed. Other qualitative information in the questionnaire included how households felt about the establishment of a biofuel operation in their locality.

4.2.7 Quantitative methodology

Descriptive statistics from the survey were calculated using means, standard deviations and frequencies where appropriate. Correlation tests (one-way ANOVA) were also performed to assess the relationship between the HNDS metric and a number of key variables, including biofuel involvement of households.

The household survey results were also analysed using a regression model. Using the HNDS as the dependent variable, and after testing for normality and excluding outliers, regression analyses were undertaken of some key variables likely to affect food security status, and, hence, to help assess the importance of biofuel involvement. There are many factors influencing household food security, including income and food production, but also household characteristics, such as its size and the age and gender of the household head. Some of these variables will be influenced by the biofuel operation, especially income. Others, such as household size, land area farmed and age and gender of household head, are less likely to be affected by the establishment of the biofuel operation. Step-wise multiple regression models were therefore used to assess the extent of the impact of each these independent variables on the dependent HNDS variable.

The first multiple regression analysis compared households involved with biofuel operations versus those not involved. The first step or model compared the mean HNDS between the groups, the second step controlled for the different geographical sites, the third controlled for a group of variables less likely to be influenced by the biofuel operation (household size, size of farm and gender of household head), and the fourth step controlled for household income, which was more likely to be influenced by biofuel involvement.

The second linear regression analysis compared the two different groups of biofuel involved households, those with employees and those acting as outgrowers, with the non-involved households using the same steps as in the first analysis.

A third regression analysis was conducted involving more independent variables but using a proxy for income instead of actual household income, due to the potential endogeneity problem between biofuel involvement and household income within the analysis. Similar to the previous two regression analyses, the third analysis examined four separate models in order to assess the impact on food security of each variable or group of variables. The first model again assessed the impact on the HNDS of household biofuel involvement as outgrowers or employees compared to non-involved households. The second model incorporated the geographical influence of the different village sites and the third model included a slightly larger group of predictor variables less likely to be influenced by the establishment of the biofuel operation in the locality. A final model then incorporated a variable for different income sources, grouped into households deriving most of their income from farming activities, representing 65 per cent of the total and those relying mainly on non-farming sources, such as waged-employment, accounting for 35 per cent.

Linear regressions that were robust to extreme residuals were performed to estimate the difference in food security status, according to the HNDS, between the three different household groups before and after controlling for potential confounders. The robust regression uses iteratively re-weighted least squares. Initially it performs an ordinary least squares regression, calculates Cook's distance, and eliminates the gross outliers for which Cook's distance exceeds one and then performs a weighted regression that gives lower weight to observations with larger residuals (Street et al., 1988).

4.3 The Macro Analysis Methodology

The development of the conceptual framework from the literature review identified that land availability and food price impacts were the two key concerns regarding biofuels and food security at the global or macro level. There have been many studies on these issues, some of which have been referenced within the literature review, and many of which involve the development of econometric models to determine the potential impact of biofuels into the future.

Given the many econometric analyses that have been conducted over recent years, and the very wide range of results regarding land use changes, indirect land use and price impacts from the various studies, it was decided to adopt a different approach to assessing how biofuel production at the global level may have affected land availability and food prices both at the global level and in food insecure countries[59].

As most of the recent increase in global biofuel production has occurred over the past decade, and that much of this was encouraged by policies introduced in the US and EU in the period leading up to 2005, it was decided that sufficient reliable information should be available to analyse how much additional land has been utilised by biofuels over the past decade and the extent to which this has affected food availability within developing countries and could affect future global food security.

Similarly, the main biofuel feedstock price developments over the past decade on the main commodity markets influencing global food prices, can be analysed in order to assess the fundamental, policy and other factors that may have affected them over that period. The influence of biofuel production on the price-forming factors can then be assessed over the same period.

As such the approach adopted is retrospective rather than the more common forward-looking predictions over the longer-term. But through understanding how the biofuel sector has changed in the past decade, this can enable better policies and projections for the future. This approach, although data-driven, also incorporates a significant amount of descriptive review and, is, thereby, as much qualitative in its nature as quantitative. It was felt that through capturing the detail of what had actually

[59] Many of the more detailed econometric model analyses involve large teams of experts in their development, as well as access to the relatively few institutionally owned CGE and PE models for adapting to biofuels.

happened regarding global biofuel production and key feedstock commodity prices over the past decade, this could help inform future analyses.

One of the concerns emanating from the literature review was the reliability of the estimated land areas used for biofuel feedstocks within such analyses, particularly regarding the large range of feedstock types and co-products produced. Many of the referenced reports appear to have significantly overestimated both the current and future projected land use by biofuels. Some of the projections incorporate unrealistic assumptions, such as the complete replacement of all transport fuels with biofuels.

A detailed analysis was therefore undertaken of biofuel feedstock land use by each country over the past decade in order to derive more accurate estimates of how much land is being used by each feedstock in each country for both biofuel and co-product outputs. From this analysis, more realistic assessments of future biofuel land use can then be made. The detailed biofuel land use analysis also provides a comparison with the reviewed studies of global land availability and projected food needs in order to assess potential future conflicts between food and fuel.

The macro methodology on land use therefore focuses on a detailed analysis of global biofuel and co-product production and feedstock use, yields and areas harvested over the past decade in order to identify the key changes over that period. The findings from this analysis were then used to assess the extent to which biofuel demand influenced the fundamental supply and demand situation for the main feedstock used, and in turn, the influence of those changes on commodity and food prices.

4.3.1 Measuring biofuel production and feedstock use

Reliable and consistent statistics on biofuel production are difficult to obtain. Where official data are available, they are often quoted in different metrics, such as tonnes or litres, or oil-equivalent barrels and different measures of energy output. In the case of ethanol, most sources quote total ethanol production rather than that used for fuel purposes, whilst biodiesel figures often exclude hydro-treated and straight vegetable oil for use in fuels. Even in Brazil, where biofuels have been produced on a large-scale since the 1970s, there are no official estimates of ethanol production for fuel use, only total ethanol production for all uses, divided between anhydrous and hydrous ethanol. And trade statistics are difficult to verify due to the different customs codes under which ethanol and biodiesel can be traded, including as blended petrol and diesel.

Global official data also tends to be delayed by a number of years, and there is generally very little up-to-date information on feedstocks used and co-products produced each year. The difficulty in obtaining reliable data is apparent from the literature, with many studies using information from only the major producers, often with extrapolated estimates of feedstocks and co-products using standard biofuel yield coefficients and average feedstock yields applied to all countries, despite large yield differences between countries and from year to year.

Given that biofuels are relatively recent phenomena in most countries, it is not surprising that reliable, timely and consistent information is difficult to obtain. Nevertheless, the use of various estimated and extrapolated numbers could lead to very different outcomes when analysing the impact of biofuels, particularly on the land use of feedstocks.

A key aim of this study was therefore to obtain reliable, up-to-date and detailed information on biofuel production and feedstock use from each country around the world, using official government sources and statistical agencies wherever possible. Where official data was not available or was outdated, or believed to be unreliable, industry associations and company sources were used to build a more recent global picture of the biofuel sector and the feedstocks used in each country. For example, within the EU, the ethanol industry association ePure provides annual statistics of EU fuel ethanol production, whilst the European Biodiesel Board (EBB) provides similar information for EU biodiesel production[60].

The figures were triangulated with other sources wherever possible in order to ensure reliability and consistency. For example, a number of companies, such as FO Licht,

[60] At the time of writing in mid-2016 biofuel production by member state was only available up to 2014 from ePure and 2013 from the EBB.

Oil World and Platts, provide market specialist market intelligence on biofuels, whilst international bodies such as the International Energy Agency, OECD, FAO and the UN Environmental Programme also provide some statistical information. Some of the major energy companies also produce statistics for biofuels, such as BP’s annual statistical review.

A number of key sources were used to build the estimates of ethanol production for fuel use. The US Energy Information Administration provides monthly statistics on US fuel ethanol production in its Monthly Energy Review (US Energy Information Administration, 2016), whilst the US Department of Agriculture releases regular information on maize usage in its monthly Feed Outlook (Capehart and Allen, 2016). For Brazil, data from the Ministry of Agriculture (Ministerio da Agricultura, Pecuaria e Abastecimento or MAPA), the Petroleum, Natural Gas and Biofuels National Agency (ANP) and the Brazilian Sugarcane Industry Association (UNICA), was used to derive the fuel ethanol production estimates and feedstock use. In the EU, official Eurostat and ePure data were used in conjunction with specialist agency estimates such as FO Licht and Strategie Grains. Similar sources were used for the biodiesel estimates, as well as data from specialist vegetable oil and biodiesel providers, such as the European Biodiesel Board (EBB), FEDOIL (the EU vegetable oil and protein meal industry association), the Malaysian Palm Oil Board and Oil World.

There are often significant differences in the production and usage estimates issued by the various sources, some including more categories than others, such as all ethanol[61] rather than just fuel ethanol, straight and hydro-treated vegetable oil rather than just conventional biodiesel, whilst some only include the major-producing countries or feedstocks used, and others only provide combined biofuel totals, rather than dividing between ethanol and biodiesel.

Another factor that can account for differences in the production and feedstock estimates are the different metrics and conversion factors used. For example, there are even significant differences in converting biofuel production to oil-equivalent

[61] For example, the OECD and FAO annual outlooks include total ethanol production, including that for the beverage sector.

figures, with the USDA using a coefficient of one tonne of biodiesel to 0.9 tonnes of oil equivalent, whereas Eurostat uses a coefficient of 0.86. Where such discrepancies existed, other reliable sources were consulted and a judgement was made on which figure to use or whether to use a mean or median value.

This is a particular issue where there are no surveys of feedstocks used in biofuel production (which is the case for most countries), so that biofuel production has to be converted back to feedstock. As reported ethanol yields per tonne of feedstock can vary considerably, this can result in a wide range of feedstock usage, and hence, areas harvested. In converting biofuel feedstock production back to areas planted, average annual yield data was used for each country using national sources, FAOSTAT and US Department of Agriculture data. The average yield data are likely to result in an overestimate of land areas used, as much of the feedstock for biofuel production is likely to have been produced on larger, specialist farms and estates, using specific crop varieties suited to the end-use and achieving higher yields than the national averages.

Whilst, it was decided that it would be more prudent to use consistent data from official databases rather than a variety of reported yields from industry sources, where there were obvious inconsistencies, industry sources were used. For example, wheat accounts for a significant proportion of the ethanol produced in Canada, but the preferred wheat used is the soft variety, which usually yields at least 50 per cent above the main spring varieties. However, some spring varieties that fail the export or domestic breadmaking specifications are also sometimes used. Hence, the Canadian calculations used the average wheat yields officially recorded for Canada raised by 25 per cent, to reflect the proportion of higher yielding varieties usually used versus the smaller amount of failed spring wheat crops.

4.3.2 Accounting for co-products

Most of the feedstocks used to produce biofuels also produce valuable co-products. For some feedstocks, such as soybeans, the co-product (in this case the protein meal) produces more revenue than the oil extracted to produce biodiesel. It would therefore be incorrect to apportion all of the feedstock crop area to biofuels when other co-products also play an important role in determining planted areas and production.

There are various ways of accounting for co-products in different types of analyses. Wang, Huo and Arora (2011) in reviewing life cycle analyses of biofuels, specify five potential methods:

i) mass-based
ii) energy content
iii) market-value
iv) process-purpose
v) displacement

In this analysis the estimated proportion of market-value revenue is used to determine the proportion of area relating to biofuels from each feedstock.

Due to the different nature of the various biofuel feedstocks, it is difficult to compare the results of a basic mass-based method. For example, relatively little of each tonne of sugar cane harvested results in ethanol output compared to each tonne of maize harvested, but sugar cane has a much higher yield per hectare than maize. Energy content is also related to the mass of the various outputs and may not reflect other important attributes such as nutrition in the form of protein content.

The displacement method is often used when dealing with life-cycle analyses of biofuel co-products, as many of the co-products are used as animal feed, displacing other feedstuffs, and therefore, land used in the production of those other feedstuffs. But it is not always obvious what other products have been displaced and what units of measurement should be used to calculate the displacement effect.

In terms of land use decisions, the revenue generated from different co-products would be a more influential factor. For example, most of the revenue from processing soyabeans for biodiesel (about two-thirds) is from the soyameal produced, so soya oil prices (ie the biofuel feedstock) would be less influential in whether to plant soyabeans than soya meal prices. In contrast, only a quarter of the revenue from maize processed for ethanol is from the DDGS protein meal even though the mass of the DDGS output is similar to that of ethanol. In many parts of the world the molasses by-product from the sugar refining process is the main feedstock for ethanol production, but molasses only account for about 5 per cent of the value of co-product outputs in the sugar manufacturing process, and would therefore have a relatively small impact on land use.

A problem with the market-value approach is the fact that relative prices of the co-products fluctuate according to market conditions. However, average values over recent years, omitting extreme levels, can provide a useful and acceptable indication of the relative value of the different co-products. These prices can then be applied to the output of each co-product from the feedstock processed. This methodology provides a more consistent and intuitive apportionment of the areas sown to each feedstock, as using the mass-based or displacement breakdown of co-products would tend to underestimate the importance of biofuel revenue in planting decisions.

An alternative view would be that the nutritional value of the crop components would be a better way of apportioning land use to different co-product. It could be argued, for example, that starch has relatively little nutritional value compared to other macro and micro-nutrients, so the use of the starch component of the maize plant for ethanol production would be of little value relative to the protein-rich co-products, with protein, fat and fibre constituents. Adopting a “nutritional value” focus would therefore attribute a much lower proportion of land to ethanol production from maize than using the co-product market-value methodology. However, it would be difficult to determine definitive values for the numerous nutrients of the many feedstocks used to produce biofuels.

In using the co-product market-value method, it is also important to note that the feedstock is often broken down into many constituents, including low value co-products, such as straw, husks and cobs from cereals, bagasse from sugar cane and fronds and empty fruit bunches from palm. Biotechnology has reached the stage where many of these “low-value” co-products can now be used for a variety of purposes, including for biofuel production, and there is now a market value for many of them.

The co-product market value methodology used in this analysis excludes the low value co-products such as straw and maize cobs from the calculation and, therefore, tends to exaggerate the amount of land attributed to biofuel production. It would be difficult to apportion an average value to such products, as market information may not always be available, and the value of such products may vary between regions. For example, maize cobs may have little value in most areas (or even a negative value), but would be in demand close to the ethanol plant in China that uses maize cobs. In any case the market-value of such co-products would generally be so low as to make little difference to the overall calculation.

In order to avoid double-counting of land use, ethanol produced from co-products such as maize stover and cobs are deemed to have a zero land use, as that land area is already accounted for in the use of the grain component for biofuel production. In fact, this also makes little difference to the overall land use calculation as second generation cellulosic biofuel production is relatively small at present with only a few commercially viable plants in operation.

There are, however, more and more waste products being used for biofuel production which also have zero land use implications. Biodiesel produced from used cooking oil or animal fat is not counted as using land, as the feedstock was originally produced for non-biofuel purposes. In the palm oil production process, a number of waste residues, such as palm fatty acid distillates and spent bleaching oil, are increasingly being used, particularly for hydrogenated vegetable oil production. Spent bleaching oil is often sent to landfill in Indonesia and Malaysia, so it could be argued that the recovery of oil from this waste product for HVO production would result in a net land saving. Moreover, a number of plants have been established in recent years to process municipal solid waste into biofuels, with landfill savings. For the purpose of this methodology, such waste products are treated as having no land use implications rather than having net land savings.

Given that the market-value methodology employed is more likely to overestimate the land use attributable to biofuel than underestimate, mass-based co-product calculations have also been included at times in order to provide a minimum and maximum range.

4.3.3 Price analysis methodology

The fundamental supply and demand issue connecting biofuels and food prices is that when feedstocks and resources, such as land and fertiliser, are used to make biofuel, this restricts food supply in relation to the increased demand, helping to lift commodity, and ultimately food, prices. The common view is that higher food prices lead to increased poverty and hunger in poor and food-insecure households.

A key issue regarding the analysis of commodity prices is the extent to which they reflect fundamental supply and demand conditions at any given point in time. Economic theory states that in perfectly competitive markets prices will reflect market equilibrium conditions under certain assumptions, including perfect market information flows. Indeed, the theory underlies the many PE and CGE models developed to explain the impact of biofuels on food prices and land use changes over recent years.

In reality of course, agri-food markets are never perfectly competitive, and many are subject to significant government intervention, including subsidies and trade barriers. It is generally assumed that the main commodity markets are competitive enough to justify the market equilibria assumptions. But even in competitive commodity markets with a high degree of transparency, such as those with long-established futures markets, prices are unlikely to accurately reflect fundamental supply and demand conditions due to constantly changing conditions and market information flows.

In terms of the major influences on food prices, the US maize market is often used as the benchmark baseline value. Maize is the most important staple cereal in terms of global production and consumption and the US accounts for the largest proportion of world exports. Much of the maize produced throughout the world is used for animal feed, linking it to the livestock-based meat and dairy sectors. But maize is the main staple food for human consumption in most food insecure countries in Africa. Given that maize is also the main feedstock used for biofuel production, this study focusses on the impact of biofuels on maize prices rather than other feedstocks. The other main non-cereal biofuel feedstocks are sugar cane and vegetable oils, which are not generally regarded as staple foods, although both are important components of most diets in processed form.

A particular issue for cereal markets is that the crop may only be harvested once or twice a year, and it takes some time for the size of the harvest to become apparent as various surveys and other assessments are made, including demand surveys showing actual periodic (weekly or monthly or quarterly) consumption by domestic users and exporters. Hence, when the USDA issues its monthly update on US and global commodity supply and demand, futures markets respond to those changes, and particularly to changes in key indicators such as the stocks-to-use ratio. As the season progresses, the supply and demand situation becomes more certain and by the end of the season the average price for the marketing year should bear a reasonable relationship with the fundamental market balance. Annual average prices should therefore iron out any irregularities in daily, weekly and monthly prices that may not always accurately reflect the prevailing supply and demand situation.

Over time prices will tend to increase with inflation, creating another distortion in the price relationship with supply and demand fundamentals. It is therefore important to use real prices that have been adjusted for inflation.

It is also important to choose price series that will be consistent over time. In the case of US grain, average farm prices are often used in many analyses as these are calculated from sales revenue data reported by farms and then divided by total quantities marketed. The data includes all types of varieties, contracts and delivery dates, and are weighted by state marketings to create a weighted national average price (Hart, 2014). US average annual farm prices will therefore reflect changing patterns of marketing and varietal, grade and geographical shares from year to year, which may not always reflect the overall supply and demand situation. An alternative is to use a price series of a particular type and grade of commodity at a given geographical location that will not be affected in the same way.

Export prices of US maize and wheat are often used as world benchmark levels, such as the US free on board (fob) maize prices at US Gulf (of Mexico) ports. These are calculated using futures market prices and adding the market "fob premium" for each month of delivery. The export market tends to act as the residual in the supply and demand balance, along with stock changes. Thus, when supplies are tight, as in the 2012/13 drought season, reduced exports provided the main adjustment to the balance. This means that the fob Gulf premia quotations can sometimes fluctuate quite markedly according to market conditions and may also be influenced by futures market volatility, which is usually greater than that for cash or physical markets.

Thus, the US maize price selected for use in this analysis is the physical (cash) market price for deliveries to US Gulf ports, Louisiana, for yellow corn number 2 grade. This provides a consistent price series independent of varietal, quality and geographical changes in the overall harvest each year. The price was adjusted for inflation using the US consumer price index (CPI).

Descriptive charts were used to illustrate relationships between US maize prices and stocks-to-use ratios and other variables, such as wheat and oil prices, as well as African maize prices.

Quantitative analyses, using correlation tests (Spearman's rank) and standard bivariate and multiple regression, were conducted in order to assess the statistical strength of the relationship between US maize prices and key variables. Standard straight-line regression analyses were conducted to test relationships between maize prices and the end-season stock-to-use ratio, as an indicator of the fundamental supply and demand situation. Multiple regression analyses were then performed with the maize price as the dependent variable and the stock-to-use ratio, wheat price and oil price as key predictor variables. A model was built from the regression analyses in order to assess the extent to which the independent variables were a good predictor of maize prices.

An analysis was also conducted of the US maize supply and demand balance over the past decade in order to measure the demand changes in each sector each year, as well as the supply changes. This helped to identify the extent of changes in the stock-to-use ratio over the period accounted for by the increased biofuel demand. The regression models and supply and stock-to-use breakdown were then used to assess the likely extent of the impact of biofuel demand on US maize prices.

5. Findings from the Micro Analysis in Mozambique and Tanzania

The results section for the field research in Mozambique and Tanzania is divided into five sections. The first section (5.1) describes the key findings from the background research, including interviews and focus groups. The second section (5.2) then summarises the main descriptive results from the household survey, the third (5.3) describes the findings from the quantitative analyses, the fourth (5.4) summarises the main qualitative results from the survey and the final section (5.5) then links the results to the food security dimensions and to other studies of the same biofuel sites.

5.1 Background Research

5.1.1 Food security and production statistics

Before and after conducting the household survey, research was undertaken in order to provide background information for each location, including socio-economic profiles. The tables below provide some of the key information related to food security for each of the regions in which the household surveys were located. Most of the statistics relate to government surveys conducted between 2007 and 2011.

Interviews with local government offices and NGOs for the Arusha survey site highlighted the serious food security issues in rural Arusha, despite the fact that poverty rates were generally lower than elsewhere in Tanzania. Official statistics showed that nearly a third of households in Singida and Arusha were estimated to be in a poor to borderline food security situation compared to less than a quarter for Tanzania as a whole (table 5.1).

In Mozambique, food consumption scores were also significantly higher for the three survey provinces than for Mozambique as a whole, particularly for Gaza in the far south. Manica province generally recorded better food security outcomes than Gaza and Inhambane provinces, but had much higher stunting and underweight results for children under-5.

Table 5.1 – Selected Food Security Indicators for Tanzania 2009-2012

	Singida	Arusha	Tanzania	*Notes*
Household size (No people)	5.4	4.7	4.7	*Mean of rural areas for Arusha/Singida*
Average area cropped (ha/farm)	1.9	1.0	2.0	*Mean value per household – 2007/8 Census*
Biomass for cooking	96	94	69	*% of HHs in rural areas for Arusha/Singida*
Poverty MPI	69	55	64	*% of HHs poor calculated by MPI*
Food Consumption - FCS Poor/Borderline	31	32	23	*% of HHs with food consumption score poor or borderline in 2009/10*
Calorie intake (Kcal/ capita/day)	1,686	2,047	2,093	*Mean values for Central zone for Singida and Northern zone for Arusha - 2010*
No of meals / day	2.2	2.5	2.6	*Mean per day for Singida Rural district and Meru district, Arusha – 2007/8 census*
Mortality – under 5s (per 1,000)	84	58	93	*Value for Singida is the mean for the Central zone and value for Arusha is mean value for Northern zone.*
Stunting – under 5s	39	44	42	*% of under-5s (Height for age <-2SD)*
Wasting – under 5s	9	10	5	*% of under-5s (Weight for height <-2SD)*
Underweight – under 5s	19	28	16	*% of under-5s (Weight for age <-2SD)*
Anaemia – under 2s	44	68	59	*% of under-2s anaemic*
Note – Biomass = wood or charcoal. HBS = Household Budget Survey, HH = Household, MPI = Multidimensional Poverty Index. FCS = Food Consumption Score				

Sources: 2007/8 Census of Agriculture, 2010 Demographic and Health Survey, 2010 WFP Comprehensive Food Security and Vulnerability Assessment - Tanzania, 2010/11 National Panel Survey, 2011/12 National Budget Survey and 2012 Population Census.

Table 5.2 – Selected Food Security Indicators for Mozambique 2008-2011

	Gaza	Inhambane	Manica	Mozambique	*Notes*
HH size (No people)	7.3	6.5	5.8	6	*Mean*
Average area cropped (ha/farm)	1.5	1.1	1.5	1.4	*Mean value per household*
Poverty Headcount	63	58	55	55	*% below national poverty line*
Food Consumption FCS Poor/Borderline	53	43	43	27	*% HHs with food consumption score poor or borderline*
Calorie intake (Kcals/capita/day)	1,757		1,837	1,860	*Mean values for rural areas – see note below*
No of meals / day	2.1		2.3	2.3	*Mean per day for rural areas – see note below*
Under 5 mortality	165	117	154	138	*No per 1000*
Stunting	34	35	48	44	*Height for age % of under-5s (<-2SD)*
Wasting	1.4	3.8	3.7	4.2	*Weight for height % of under-5s (<-2SD)*
Underweight	6.8	11.8	19.2	17.5	*Weight for age % of under-5s (<-2SD)*
Note : The number of meals and calorie intake rural averages for Gaza and Inhambane are the combined average of both regions for 2008/9, whilst those for Manica are the combined average of Manica and Tete.					

Sources: Census of Agriculture 2009/10: WFP Comprehensive Food Security and Vulnerability Analysis - Mozambique 2010

The Tanzanian research was conducted during May and June which is at the end of the main hunger season in the unimodal crop production area of Singida, just as the Msimu harvest was starting to get underway, and during the Masika rains in the bimodal production area in Arusha where the Masika harvest does not usually start until July. At the time of the survey, the food security situation around Arusha had deteriorated to such an extent that the USAID Famine Early Warning Systems Network (FEWS) described the area as *"highly food insecure"*, although the villages surveyed were just within the *"moderately food insecure zone*" (FEWS NET, 2009). This was due to an extended dry period following the failure of the Masika rains and the Vuli rains before that. Similarly, the Singida area was designated as *"moderately food insecure"* due to the lack of rain preceding the survey.

The Mozambique research was conducted from August to September, which is usually the period just before the start of the hunger season in October when land is being prepared for planting and, in some northern areas, the second harvest is being completed. At the time of the survey, most regions in Mozambique were *"generally food secure"* following a relatively good harvest, although some pockets close to the sites surveyed were categorised as *"moderately food insecure"* by USAID at the time (FEWS NET Mozambique, 2009).

In terms of food production, maize was the most important food source in all of the survey regions, except Inhambane where cassava and maize were the main sources. The table below shows maize area, yield and production estimates from 2007/8 to 2009/10 for the study regions. This highlights the significant variation in yields recorded in Arusha over the period and the low plantings recorded in Singida in 2007 and 2008 when farmers planted more drought-resistant crops such as sorghum and millet. In Mozambique, maize yields are much higher in Manica Province in the centre of the country compared to Gaza and Inhambane in the drier south. Overall maize yields, at just over 1 tonne per hectare, are much lower than those recorded in developed nations, such as the US and EU where yields of 10 tonnes per hectare are commonly recorded.

In Tanzania, maize accounted for 44 per cent of the cropped area in 2007/8, and 32 and 62 per cent of the Singida and Arusha total crop areas, respectively (MAFSC et al., 2012). In Singida, sorghum and millet comprised 21 and 12 per cent of the crop area, so that total cereals, including maize, accounted for two-thirds of all plantings. The other main crop grown in Singida is sunflower at 21 per cent of the total area. In

Arusha, beans make up most of the non-maize area, at 25 per cent of total plantings (MAFSC et al., 2012).

Table 5.3 – Maize Area, Yield and Production in Tanzania and Mozambique

	Area (000 ha)			**Yield** (t/ha)			**Production** (000t)		
	07/8	**08/9**	**09/10**	**07/8**	**08/9**	**09/10**	**07/8**	**08/9**	**09/10**
Arusha	138	148	118	0.9	0.2	1.5	124	30	175
Singida	49	56	125	0.8	0.7	0.8	39	39	101
Tanzania	***2,848***	***2,961***	***3,051***	***1.2***	***1.1***	***1.6***	***3,556***	***3,326***	***4,733***
	Area (000 ha)			**Yield** (t/ha)			**Production** (000t)		
	07/8	**08/9**	**09/10**	**07/8**	**08/9**	**09/10**	**07/8**	**08/9**	**09/10**
Gaza	127	160	110	0.4	0.6	0.5	67	101	55
Inhambane	111	125	85	0.5	0.7	0.6	53	82	54
Manica	238	255	268	1.2	1.3	1.2	295	317	325
Mozam-bique	***1,480***	***1,612***	***1,573***	***1.1***	***1.2***	***1.2***	***1,676***	***1,932***	***1,878***

Sources: Tanzania - Various AgStats for Food Security Reports, Ministry of Agriculture, Food Security and Cooperatives. Mozambique – FAO/WFP Crop and Food Security Assessment of Mozambique 2010.

Maize accounted for about one-quarter of the cropped area in Mozambique in 2009/10 (INE, 2011). In Gaza, maize accounted for just over a third of the total area, followed by sweet potatoes (22 per cent of the crop area), cassava (15 per cent) and cow peas (14 per cent). In Inhambane, the main crop planted is cassava at 30 per cent of the area, followed by maize (21), cow peas (17), groundnuts (14) and sweet potatoes (10). In Manica, maize accounted for 44 per cent of the area, followed by sweet potatoes (21 per cent) and sorghum (12) (INE, 2011). A full breakdown of crop areas from the Tanzania and Mozambique agricultural censuses are tabulated in Appendix 5.

5.1.2 Key interviews and focus groups

In Dar Es Salaam, Tanzania, the Ministry of Energy and Minerals was coordinating the Tanzania Biofuels Taskforce in mid-2009, in order to produce guidelines for the private sector and to develop a national biofuel policy. At that time the Ministry was considering introducing biofuel blending mandates under the 2008 Petroleum Act, due to the growing interest in biofuel production. Applications for leasing land for biofuel feedstock production were being facilitated by the Tanzania Investment Centre, which reported that few projects had been approved but that they had received a surge in applications that year. But by the end of 2009 the government had suspended all further biofuel projects due to food shortage concerns.

In Ikiwu village, Singida, the focus groups reported that most households had between 1 and 3 acres. The village chief reported that in order to ensure food security, there should be one acre to each person, but that this was not possible to achieve within the limited land available. The farmers reported that their main problems were a lack of modern cultivation options and wildlife damage. The farmers also felt that the new market for jatropha would not make much difference to their livelihoods, due to the very low prices received for the seed. They felt that the jatropha hedges were more useful in deterring wildlife and that sunflower was a more lucrative cash crop for them. The gender group noted that the jatropha seed was collected mainly by women and children who also kept the revenue, albeit small.

In Kingori and Ngurdoto villages in Arusha, farmers reported that the main crops grown in the area were maize, beans and bananas, and that coffee was sometimes intercropped with beans and that those farmers planting jatropha were mainly intercropping with maize. The average farm size was reported to be 3 acres, but many farms were smaller and insufficient to meet the needs of the average family due to low yields. The main problems were reported to be wildlife damage, a lack of inputs and low prices paid by buyers. Both the farming and gender focus groups reported that the returns from the jatropha seed sales were small, but that if scaled up there could be greater benefits in reducing the cost of local maize milling using a generator running on jatropha oil. The gender group also hoped that improved cooking stoves using jatropha oil could help replace open wood fires and time spent collecting fuel.

In Mozambique the Centre for the Promotion of Agriculture (CEPAGRI) reported that the National Biofuel Policy approved in early 2009 had a target national blending rate of 10 per cent for ethanol and 5 per cent for biodiesel by 2015. However, only four projects had been authorised at that time and although more were awaiting approval, some had started to run into funding difficulties following the global financial crisis and due to food versus fuel concerns amongst investors. CEPAGRI also confirmed that a detailed feasibility study had been conducted for the government in 2008 funded by the World Bank and that the government had also conducted a detailed land mapping exercise, identifying many parcels of unused land with more than 1,000 hectares, totalling 7 million hectares.

In Nzeve village near Bilene, Gaza Province, the farmer focus group reported that most farms were between one and five hectares in size and the main crops grown were maize and cassava, both of which had suffered from dry conditions in recent years. A few of the focus group also worked on the Energem jatropha estate and stated that they would not have sufficient food without their wages, but that they had to cut back on their crop production to some extent as the burden for their own food production had fallen on other members of the household. Employment hours were from 0600 to 1500 hours, with a one-hour break: this enabled some work to be conducted on their own farms in late afternoon. One of the focus group had given up land to Energem in return for other land as compensation, but noted that it was further away from the village. The gender group were concerned that most of the employment on the estate was for men, and that some families only received a small proportion of the wages earned to spend on food and other needs. But both groups were generally enthusiastic about the biofuel estate and the potential development of the village.

In Inhassune village, Panda district in Inhambane province, most farms were between one and four hectares in size and the main crops grown were maize, beans, groundnuts and sweet potatoes, with maize and beans often intercropped. The farmer focus group reported that the biofuel company had helped them expand the area cultivated and to grow more vegetables and other crops. The company had also helped to establish water pumps and a school and health centre. But at the time of the survey, the operation had run into financial problems and was negotiating selling, and workers were owed wages. The farmer and gender focus groups were generally supportive of the beneficial impact of the biofuel company on the community, but were concerned that it might close down.

In Chibue village, Sussundenga district in Manica province, the farmer focus group reported that most households had between one and five hectares and that the sugar cane estate had loaned them tractors and equipment to cultivate land for food production. However, employees of the sugar cane estate complained that wages were low and mostly at the minimum level for the province and the hours long. Most of the group felt the biofuel company would benefit the community, as boreholes and water pumps had been established. However, whilst the gender group welcomed the biofuel project and income, they were critical that more women were not being employed.

Semi-structured interviews were also conducted with biofuel company staff and village chiefs in each location. One of the key answers sought was how the companies had selected staff or farmers to supply them. Due to the rural and relatively remote locations of their operations, those employing staff reported that during their establishment phase they had employed as many of the local population as possible who were willing to work for them, employing both young and older men and women. Once established they noted that more people in the locality had requested employment, but all of the operations had been hampered in their expansion phase by financing problems in the wake of the financial crisis and as the policy environment became more uncertain.

Similarly, the biofuel companies collecting jatropha seed supplies from outgrowers, reported that the farmers supplying to them were mostly those already growing jatropha as a field boundary hedge (particularly in Singida) and willing to devote labour to collecting seeds for sale to the collectors. In Arusha some farms had started to grow jatropha as a cash and shade crop, mainly intercropping with maize or coffee so as to avoid reduced plantings of food crops.

5.2 Household Survey Descriptives

5.2.1 Basic food security indicators

The household survey collected 202 useable returns out of 223 households surveyed in the six biofuel feedstock sites. One set of questionnaires from the jatropha estate at Kisaware in Tanzania had to be excluded from the analysis, as there had not been a sufficient period of time since the operation had started for households to fully evaluate the impact it was having on their food security status: this left 166 returns for the analysis.

The survey results on household size and crop areas largely corresponded with the regional averages collected for the background research. In the two Tanzanian rural villages, the average household size was somewhat larger than the respective regional averages and crop areas were slightly smaller. In Mozambique, the villages in Inhassune and Chibue had larger average crop areas per household than the regional averages.

Table 5.4 – Selected Food Security Results from the Household Survey

	Ikiwu, Singida	**King/Ng'Doto, Arusha**	**Nzeve, Gaza**	**Inhassune, Inhambane**	**Chibue, Manica**	***Notes***
Average HH size	6.8	5.7	7.2	5.9	7.6	*Mean per HH*
Average Crop Area (hectares)	1.7	0.9	1.5	1.6	3.0	*Mean per HH*
Average SLUs	3.3	1.1	0.1	1.1	1.7	*Mean per HH*
% of Households Poor	92	83	52	33	69	*% of HHs <$1/day per cap*
% of Households Nutrient Deficient	86	92	77	61	77	*% of HHs with HNDS >0*
Average kilo calorie intake	1,705	1,516	2,160	2,267	1,892	*Mean Kcals/capita/day*
Average Number Meals Per Day	2.5	2.9	2.4	2.3	2.9	*Mean per HH*
Average Number Months Food Shortage	3.1	2.7	2.5	3.1	3.3	*Mean per HH*
Note – HH=Household, SLUs = Standard livestock units						

There were significant differences, however, in the poverty and food security results. The household survey recorded much higher levels of food insecurity in the villages as measured by the household nutrient deficit score (HNDS) indicator than were recorded for the region as a whole by the food consumption score (FCS) indicator. Whilst the household survey recorded nutrient deficits for between 61 and 92 per cent of households in the five villages, the food consumption score recorded poor or borderline food insecurity rates for the regions in which the villages were located of between 31 and 53 per cent of households. In addition to the different geographical coverage and timing of the surveys, the disparity is largely explained by the different nature of the indicators, as the FCS measures the reported frequency of food types consumed in a particular week, whilst the HNDS measures reported food consumption converted into nutrient deficits.

In contrast, the average calorie intake levels were higher in the villages than in their respective regions or zones, except for Kingori/Ngurdoto which recorded a much lower average calorie intake of 1,516 kilo calories per capita per day, versus the average for the Northern zone in Tanzania of 2,047. The Northern zone average in Tanzania includes relatively wealthy urban areas such as Arusha and Moshi, whilst the Kingori and Ngurdoto villages surveyed were in remote rural areas. Ikiwu village recorded a slightly higher average calorie intake of 1,705 compared to the Central zone average of 1,686.

It was notable that all the villages in Mozambique recorded substantially higher average calorie per capita intakes than the regional averages, despite the relatively large proportion of households with nutrient deficits. The proportion of poor households in Nzeve and Inhassune villages was also much lower than the regional average, whilst that for Chibue was higher. The average number of meals eaten each day was higher in all of the villages compared to official regional averages.

The focus group interviews found that those households that had become involved with the recently established biofuel operations as employees or feedstock suppliers had experienced the greatest benefits in terms of improved income and food security status. This suggested that the average values of the various food security indicators recorded in each village may have comprised a distinct range depending on biofuel involvement. In order to test this hypothesis, the survey results were analysed by biofuel involvement, using the household nutrient deficit score as the main indicator of food security status.

5.2.2 Descriptives of household nutrient deficit score analysis

The main dependent variable used in the analysis is the household nutrient deficit score (HNDS), as described in the methodology, and this was found to be relatively normally distributed between the 166 households, as depicted in figure 5.1. There is a noticeable peak between 15 and 30, meaning an overall nutrient deficit of 15 to 30

Fig 5.1 – Distribution of Household Nutrient Deficit Score

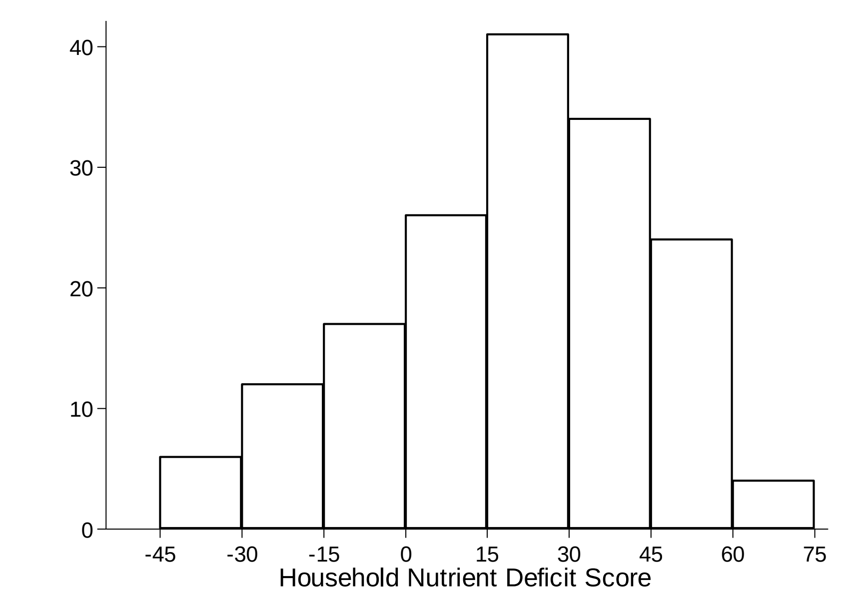
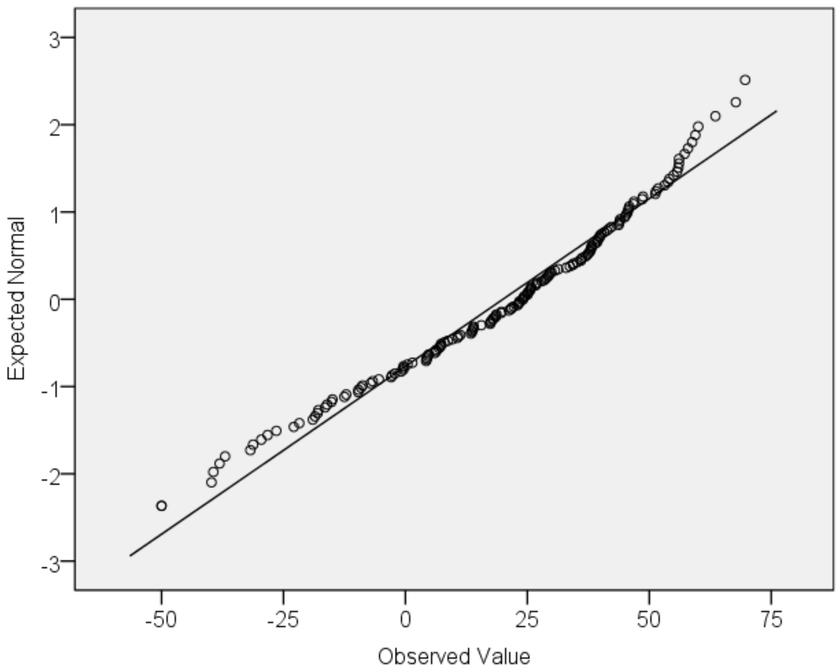


Fig 5.2 - Normal Q-Q Plot of Household Nutrient Deficit Score



per cent, and reflecting the food-insecure nature of the localities surveyed. The histogram is supported by the normal Q-Q plot in figure 5.2 which shows that the observed values are close to the expected straight line for a perfectly normal distribution.

The box plot of the distribution of the HNDS results suggests that there were two outliers (outside more than 1.5 box lengths from the edge of the box comprising 50 per cent of cases), as shown in figure 5.3. Both households had relatively large surplus nutrient scores and were omitted from the regression analysis as it was believed that they might have been reporting food consumption for a greater number of people than had been reported on the questionnaire.

Examining the distribution of results for each of the individual nutrient gaps included in the HNDS, most of the household "calorie" deficits in the survey were in the range 15 to 45 per cent. For "protein" consumption the peak deficit gap recorded was between 0 and 25 per cent (Fig 5.4). For the micronutrients, the iron distribution showed a peak deficit between 40 and 60 per cent, but with no surplus above 40 per cent and no deficit beyond 70 per cent. For vitamin A, the distribution was not normal, with a peak deficit in the range of 40 to as high as 80 per cent, whilst a small number of households recorded a surplus of 100 per cent or more.

Fig 5.3 – Box Plot of Household Nutrient Deficit Scores

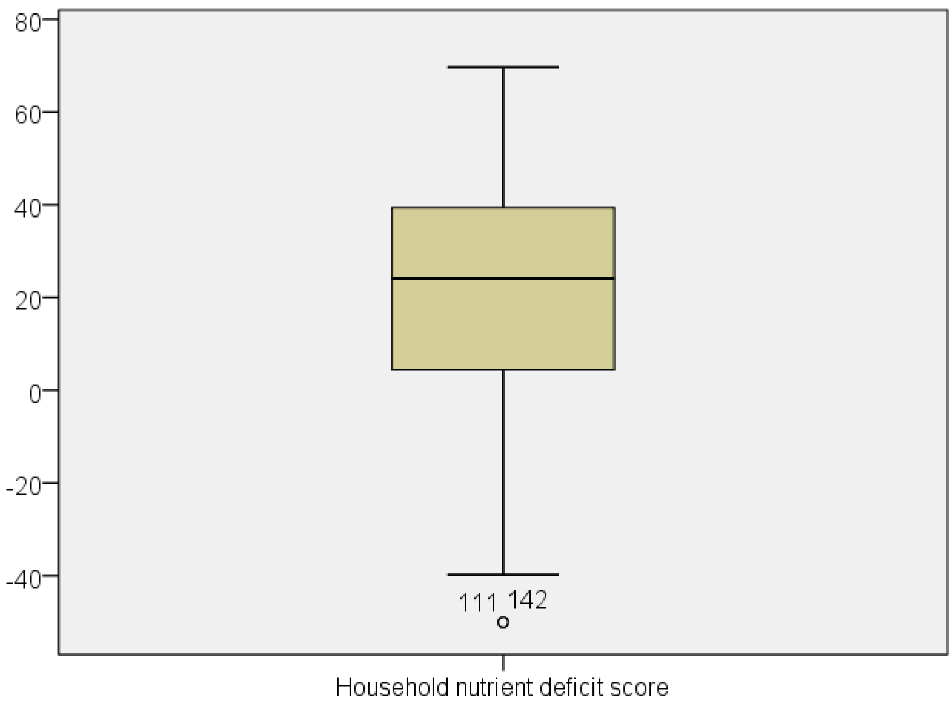


Fig 5.4 - Distribution of Household Calorie and Protein Deficit Gaps[62]

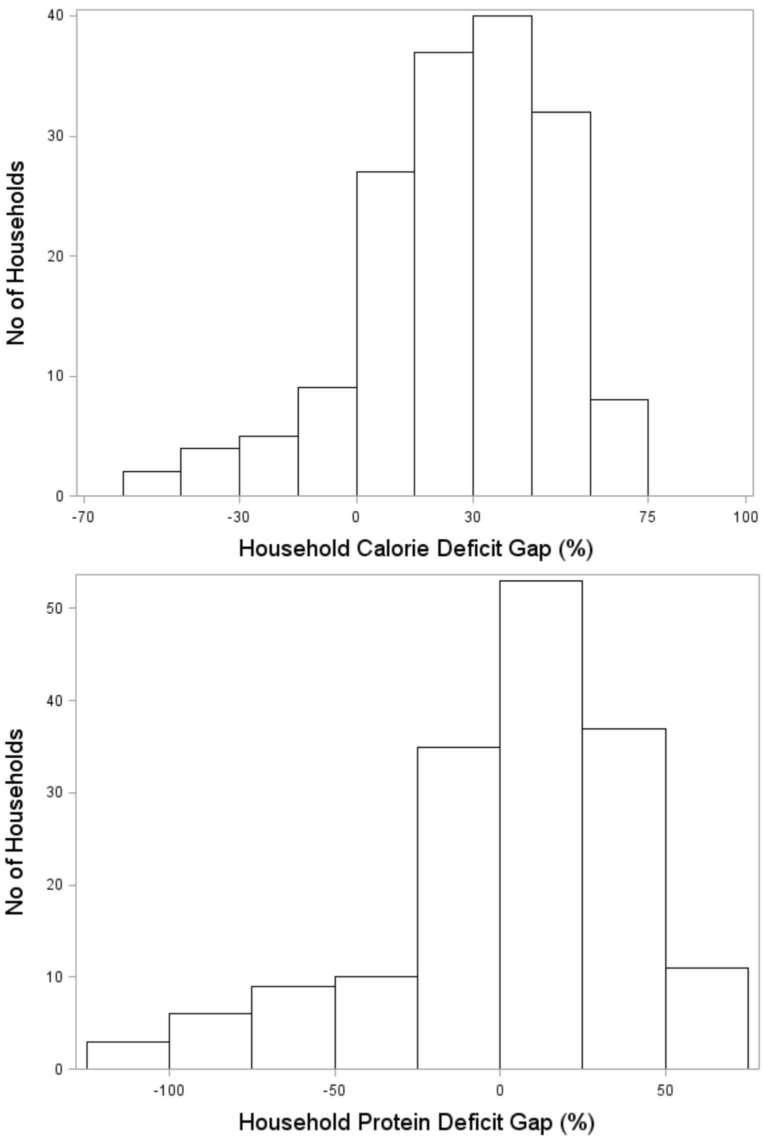


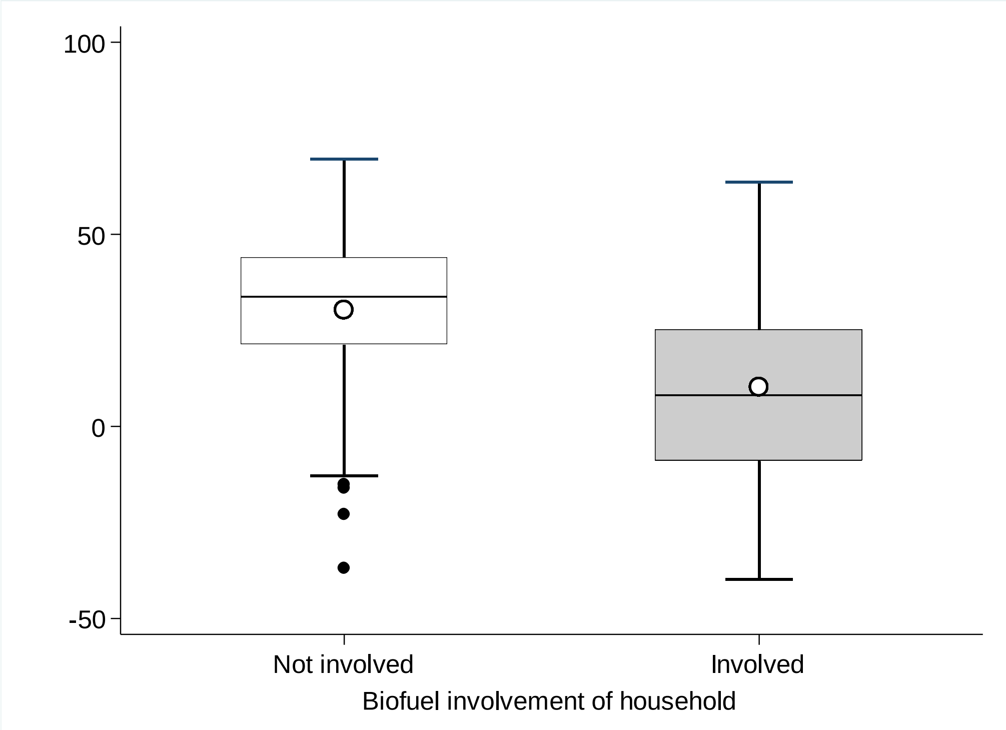
Figure 5.5 shows the box-plot results for the range, quartiles, median and mean HNDS for those households "not involved" with the biofuel project in their locality and those "involved" (shaded box), either as outgrowers or employees[63]. The mean HNDS value, represented by the circle within each box, is clearly much higher for those households not involved in the biofuel operation, suggesting a higher average deficiency of nutrients and, thus, a worse food security status than households

[62] Note that the calorie and protein gaps shown in figure 20 relate to the distribution of results before the 50 per cent surplus cap was imposed in order to calculate the HNDS. This illustrates the small proportion of households outside (less than) the negative 50 per cent surplus nutrient cap, and also outside (greater than) the 50 per cent deficit gap for each nutrient.

[63] Households deemed to be "involved" had at least one member of the household as an employee or outgrower for the biofuel company

involved. The median values, represented by the horizontal line dividing the inner quartiles, are even wider apart[64].

Fig 5.5 – Box-plot of HNDS Results for Households "Involved" and "Not Involved" in Local Biofuel Operations



Although the interviews with the various biofuel companies suggested no bias in the selection of households for employment or as outgrower suppliers, there was a possibility that they were selecting those with more able-bodied people or those with more land in the case of outgrowers. An examination of the survey results showed that the biofuel companies employed a wide range of ages, from 16 to 60 years. Using the number of able-bodied people within that age range in each household, as a proportion of the total people in the household, showed relatively little difference in the averages between households "involved" and "not involved", at 49.8 and 47.3 per cent, respectively.

There was also relatively little difference in the proportion of able-bodied people between the two groups in most locations. In the outgrower location of Ikiwu, the average proportion of able-bodied people was the same for outgrower households, as

[64] Note that there are some outliers in the box-plot for those households not involved, mainly representing more wealthy households.

those not involved, at 45 per cent. In Arusha, the outgrower households recorded a slightly higher proportion, at 54 per cent versus 49 per cent for those not involved. In the biofuel feedstock estate locations of Inhassune and Chibue, households with employees had a marginally larger proportion of able-bodied people, at 47 and 56 per cent, respectively, versus 45 and 54, respectively, for those not involved. Only in Nzeve village was there a notable difference, where those households with employees comprised 50 per cent able-bodied, compared to 40 per cent for those without. On examination of the Nzeve averages it was apparent that the higher average figure for “involved” households was largely due to three large households with over 80 per cent able-bodied people, one of which had nine members.

In terms of land size, the fact that most of the households were already growing jatropha as hedges for wildlife protection and demarcation boundaries on relatively small areas, averaging 0.1 to 0.2 hectares, suggested that farm size was not a major factor in the selection of outgrowers. Also those households in Arusha that had started to produce jatropha recently were mostly intercropping with food and cash crops. The average area cropped in Singida was 1.9 hectares for the outgrower households and 1.6 hectares for those not involved, whilst in Arusha the average for outgrowers was 1.1 hectares versus 0.8 for non-involved.

Table 5.5 displays the household nutrient deficit scores by each survey site, representing the village selected in the vicinity of each of the biofuel operations. The mean and median HNDS results for each site are clearly higher for those households not involved with the biofuel operation, suggesting a higher overall deficiency of nutrients. The differences are very apparent for the survey sites close to the large estate operations in Mozambique, at Nzeve, Inhassune and Chibue, but less so for the outgrower sites in Tanzania, at Ikiwu and Kingori/Ngurdoto.

The table also shows the mean and median values for other selected variables that often affect food security status, such as size of household, land area owned by the household and gender of household head. There was generally little difference in the average values for these variables between the households involved with biofuel operations and those not, suggesting that the profiles of the households which became involved with the biofuel operation were similar to those not involved before the establishment of the biofuel project. This was also evident from the focus group and other interviews in each of the field sites, from which it was noted that alternative sources of employment or income were relatively limited in all of the sites and that most households had previously been engaged in farming and related activities.

Table 5.5 - Descriptive Statistics of Key Variables by Biofuel Involvement

		Biofuel Involvement			
		Yes		**No**	
		Mean	Median (Q_1; Q_2)	Mean	Median (Q_1; Q_2)
Household Nutrient Deficit Score		10.1	8.0 (-9.1; 25.2)	30.3	33.7 (21.2; 43.9)
Village survey site and biofuel company model type and company location	Ikiwu, Diligent-Outgrowers, Singida, Tanzania	25.5	23.8 (8; 53.1)	31.2	30.6 (19.6; 39.8)
	Kingori/ Ngurdoto, Kakute Ltd-Outgrowers, Arusha, Tanzania	25.8	31.3 (6.3; 43.7)	41.4	44.0 (37.3; 46.9)
	Nzeve, Energem Biofuels Estate, Bilene, Mozambique	0.9	7.4 (-18.0; 18.5)	30.5	29.3 (20.3; 40.3)
	Inhassune (Area A), ESV BioAfrica Estate, Panda, Mozambique	-6.2	-1.6 (-18.5; 6.9)	14. 4	18.7 (-0.4; 27.9)
	Chibue, Principle Energy Estate, Dombe, Mozambique	0.6	1.9 (-9.4; 12.2)	29.6	31.8 (23.5; 39)
Household Per Capita Income (US$ per capita per annum)		474	374 (278; 643)	290	205 (169; 277)
Household Size (adult- equivalent)		3.2	2.9 (2.4; 3.8)	3.2	3.0 (2.5; 3.8)
Land Area Owned (hectares)		2.6	1.4 (1.0; 2.8)	2.6	1.6 (0.8; 3.0)
Gender of Household Head, Male (%)			68		69

There was also a marked difference in the average per capita (adult-equivalent) annual income (including the value of home-grown foods consumed) between those households involved and those not, amounting to over $180 in favour of those involved, with a median difference of some $170. This also supports the wider evidence from the focus groups and survey of few alternative income opportunities available in the survey sites to farming activities. Thus, income-earning opportunities, such as wages from employment and new markets for crops were highly sought in all the locations before the establishment of the biofuel operations. It is therefore likely that waged-employment offered by the biofuel estates would have played an important role in the improved level and stability of incomes of those households with employees.

5.3 Quantitative Analyses

In order to assess whether differences in the food security status of households "involved" and "not involved" with biofuel operations were statistically significant, quantitative analyses were conducted, using the HNDS as the dependent variable. Quantitative analyses were also conducted in order to assess the influence of likely predictor variables on the HNDS.

5.3.1 Correlation results

A one-way between groups analysis of variance (one-way ANOVA) was conducted to explore the impact of biofuel involvement, whether as outgrowers, employees or no involvement, on the HNDS. There was a statistically significant difference at the $p<0.0005$ level (ie Sig = 0.000) between the households with employees, which recorded the smallest average nutrient deficits, with each of the outgrower and non-involved groups, which recorded larger average deficits. There was no significant difference between the outgrower and non-involved groups. The effect size of the analysis, calculated using eta-squared, was 0.32, indicating a large effect.

5.3.2 Linear regression

Given the statistical significance of differences in the HNDS between the household groups, a multiple regression analysis was conducted in order to assess the predictive ability of a group of independent variables. The variables were selected as those most likely to affect food security status in the survey locations, and were organised into four stages. The first stage of the multiple regression analysis incorporated the "non-involved" and "involved" household groups, to assess the extent of the influence of biofuel involvement. The second stage introduced the different locations of the biofuel operation sites in order to assess the geographical influence on household food security status.

The third group of independent variables were chosen as those less likely to be influenced by the recently established biofuel operations, but expected to be influential on food security status. Thus, household size is commonly associated with food security (larger households tend to be less food secure), but is unlikely to have been influenced by the recently established biofuel operation in the locality. Similarly, the land area owned and cropped by the household is usually positively correlated with food security, in that the larger area farmed tends to yield better food security outcomes. The gender of the household head was also added as an independent variable at this stage, as female-headed households are often associated with lower food security status.

The fourth stage then introduced household income as an independent variable to assess its influence on the HNDS. This variable was separated from the third stage group because income was expected to be influenced, to some extent, by biofuel involvement. By isolating income as a fourth step, it was then possible to assess its influence on the HNDS score in relation to the biofuel involvement variable.

The 4-step linear regression model identified significant associations between biofuel involvement and the nutrient deficit score. In the first step, biofuel involvement of households resulted in an average HNDS some 21 percentage points lower than "non-involved" households. Controlling for geographical location (village site) reduced this impact slightly, to just less than 20 percentage points lower. The impact of the group of variables believed to be less influenced by the biofuel operation, including household size and land area owned, reduced the impact to just under 19 per cent in the third step. Thus, after controlling for the influence of location, household size, farm area owned and gender of household head, households involved in biofuel operations recorded, on average, a nutrient deficit score some 19 percentage points below those households not involved.

The regression model then incorporated a fourth step by assessing the influence of household income. This step reduced the impact of biofuel involvement on the

HNDS from -19 to -8.5 percentage points. Since it was known from the descriptive results that households involved with biofuel operations had a higher average income, this would suggest that much of the impact of the biofuel operation on food security is through the income effect. All steps produced results that were statistically significant (p-value of less than 0.05), as shown in table 5.6.

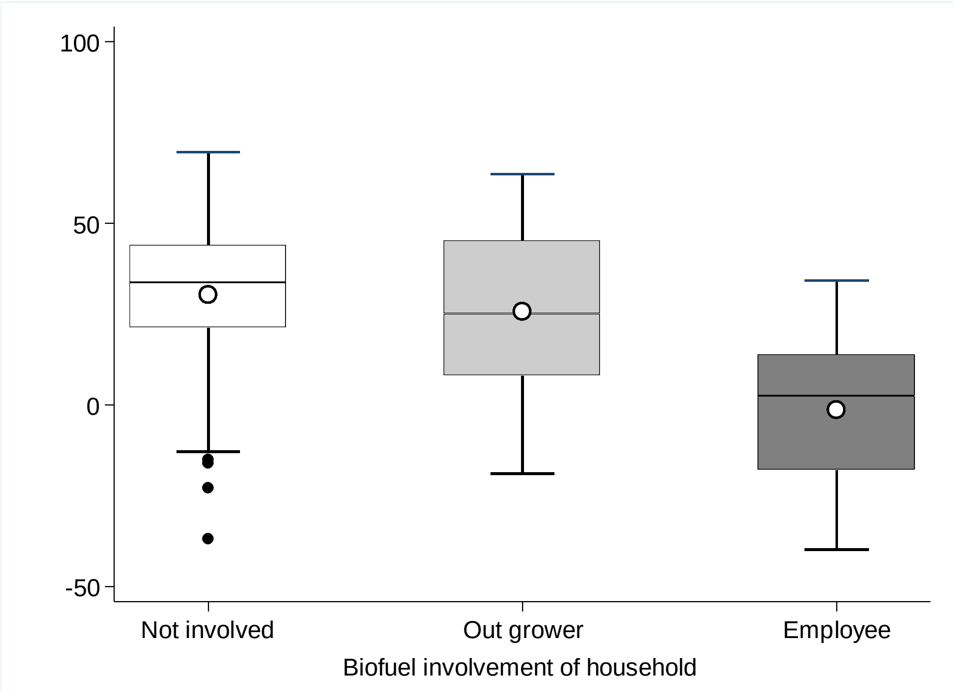
Table 5.6 – Linear Regression Model Summary by Biofuel Involvement

Regression Steps		Difference in Mean HNDS (95% confidence interval)	p-value
1.Biofuel Involvement		-21.0 (-27.9 to -14.0)	<0.001
2.Controlled for Village Sites		-19.9 (-26.3 to -13.5)	<0.001
3.Controlled for	HH Size Gender of HH Head Area Owned	-18.9 (-24.7 to -13.1)	<0.001
4. Controlled for Income		-8.5 (-14.1 to -3.0)	0.003

The regression analysis was then conducted with the two main types of biofuel production model, where “involved” households acted either as “outgrowers” or as “employees”. Figure 5.6 shows the box-plots of household nutrient deficit scores from the survey, clearly showing the lower mean and median of deficits recorded by households with employees of biofuel operations, whereas the mean and median of deficit scores for outgrowers were only slightly lower than those for households not involved.

Table 5.7 presents the results of the linear regression model using the two different biofuel involvement groups compared with the non-involved households. The model again shows statistically significant differences in most cases between involved and non-involved households. Households with employees on the biofuel feedstock estates had an average HNDS some 33 percentage points below that for non-involved households. Controlling for geographical location and then the independent variable group of household size, land area owned and gender of household head, reduced this impact to just less than 28 percentage points. A 28 percentage point gap is still substantial and represents the difference between food and nutrition security and insecurity for many of the households surveyed.

Fig 5.6 – Box-plot of Household Nutrient Deficit Score by Involvement as Outgrowers, Employees or No Involvement



Note - the line dividing the inter-quartile boxes depicts the median, whilst the circle depicts the mean

Once again when income is introduced as a fourth step in the regression, the influence of biofuel involvement, without the estimated effect of income on the HNDS, is reduced by some 18 percentage points to 10 per cent. This again suggests that there is a strong income effect within biofuel involvement. One assumption that might be drawn from this is that with higher incomes from the salaries of household members on a regular basis over the year, such households recorded much lower nutrient gaps and were therefore more food secure.

Table 5.7 – Linear Regression Model by Biofuel Involvement Groups

Linear Regression Model Steps		Outgrowers versus Non-involved Households		Employees versus Non-involved Households	
		Difference in Mean HNDS (95% CI)	p-value	Difference in Mean HNDS (95% CI)	p-value
1.Unadjusted		-5.47 (-13.7; 3.80)	0.19	-32.6 (-40.0; -25.1)	<0.001
2.Adjusted for Village Sites		-10.5 (-19.8; -1.23)	0.03	-27.7 (-36.2; -19.3)	<0.001
3.Adjusted For	*HH Size* *Gender Head* *Area Owned*	-8.22 (-16.4; -0.02)	0.05	-27.9 (-35.4; -20.3)	<0.001
4.Adjusted for Income		-7.27 (-14.5; -0.05)	0.05	-10.2 (-18.6; -1.8)	0.018

In contrast the results for the outgrower households were not significant and recorded only a small improvement in food security status through a smaller reduction in the household nutrient deficit score. The outgrower results also suggest only a small impact from income, which largely reflects the small volumes of feedstock sold and relatively low prices achieved. However, it should be noted that the outgrower results combined two different models, with the collection of seed from traditional hedges in Singida having little impact on improving food and nutrition security whilst the community-based scheme near Arusha recorded better outcomes for those households involved than those not.

5.3.3 Robust regression

The results of the initial regression analyses supported evidence from the focus groups that biofuel feedstock operations employing local staff had resulted in better food security outcomes for those households with employees, mainly through improved incomes. In order to strengthen these claims, further regression analyses were undertaken with stricter criteria for outliers, more independent variables and using a robust linear regression, as described in the methodology.

Also, because food consumption is closely related to income, there is an endogeneity issue in incorporating income within the regression model. Thus, it was decided that source of income should be used as a dummy variable in the model rather than actual incomes in order to overcome the endogeneity problem.

The two marginal outliers identified from the distribution of HNDS results in the initial review were again omitted. On reviewing the independent variables in the analysis another two households stood out. The farmed area of one household, at 12 hectares, was more than double that of the next largest and the z-score for this outlier was also greater than 2.5, so that household was also excluded. The per capita income of another household was over treble that of the next largest, so this household was also excluded. The remaining 162 households were again tested for normality on the dependent variable and the Kolmorgorov-Smirnov score was 0.055 again indicating normality.

On reviewing the survey data, more independent variables were identified for which full data was available for the 162 households. The age of the household head and phone ownership were added in terms of the education and social capital within each household. Also the source of income was added in relation to those households earning most of their income from farming and those earning most outside of farming, such as through employment or non-farm business.

5.3.3.1 Descriptives for robust regression

Table 5.8 displays the HNDS descriptives for each household biofuel grouping (non-involved, outgrowers and employees) by each survey site for the 162 remaining households, together with results for the new independent variables. The mean differences in the HNDS between the involved and non-involved households are most apparent for the large estate operations in Nzeve, Inhassune and Chibue, but less so for the outgrower sites at Ikiwu and Kingori/Ngurdoto.

The table also shows descriptive values for other selected variables affecting food security status by the type of biofuel involvement. The mean age of the household head for those households with biofuel employees, at 40 years, was some 5 years below that for the non-involved, whilst the non-involved households also had a slightly higher proportion of female household heads.

Table 5.8 - Descriptive Statistics of Key Variables by Biofuel Involvement

		Biofuel Involvement		
		None (n=85)	**Outgrower (n=33)**	**Employee (n=44)**
Household Nutrient Deficit Score - *Mean (SD)*		31.5 (18.4)	25.6 (24.6)	-1.5 (20.1)
Village survey site and biofuel company model type and company location - *Mean (SD)*	Ikiwu, Diligent-Outgrowers, Singida, Tanzania	31.2 (18.2)	25.5 (27.0)	
	Kingori/ Ngurdoto, Kakute Ltd-Outgrowers, Arusha, Tanzania	41.4 (16.9)	25.8 (22.3)	
	Nzeve, Energem Biofuels Estate, Bilene, Mozambique	30.5 (15.4)		-0.8 (23.8)
	Inhassune, ESV BioAfrica Estate, Panda, Mozambique	18.1 (22.2)		-6.2 (18.0)
	Chibue, Principle Energy Estate, Dombe, Mozambique	31.5 (13.4)		0.6 (16.9)
Age of HH Head in Years – *Mean (SD)*		45.4 (11.6)	47.6 (13.4)	40.7 (11.7)
Gender of Household Head, Male – *Number (%)*		67 (79%)	29 (88%)	39 (89%)
Household Size in Adult-Equivalent – *Mean (SD)*		3.2 (1.0)	2.95 (0.76)	3.41 (1.40)
Household Ownership of Phone – *Number (%)*		26 (30.6)	17 (51.5)	28 (63.6)
Land Area Farmed in hectares – *Mean (SD)*		1.75 (1.1)	1.56 (0.9)	1.74 (1.32)
Main Source of Income from Farming – *Number (%)*		70 (82.3)	29 (87.9)	7 (15.9)
Household Per Capita Income in US$ per capita per annum – *Median (Q1, Q3)*		203 (169, 257)	256 (149, 341)	607 (365, 884)

Results presented as mean (SD), median (Q_1, Q_3) or n (%) as appropriate.

There was a marked difference, in the median per capita income between households involved and not, amounting to over $400 per annum in favour of those involved as employees and just over $50 for those involved as outgrowers[65]. The much larger incomes in households with biofuel employees may also have accounted for their higher proportion of phone ownership. The sources of income were also different between the groups, with only 16 per cent of households with employees earning most of their income from farming compared to over 80 per cent of the non-involved and outgrower households. This also supports the wider evidence from the focus groups and survey of few alternative income opportunities in the survey sites to farming. It should also be noted that the average land area farmed by households with biofuel employees was not far below that of the non-involved households.

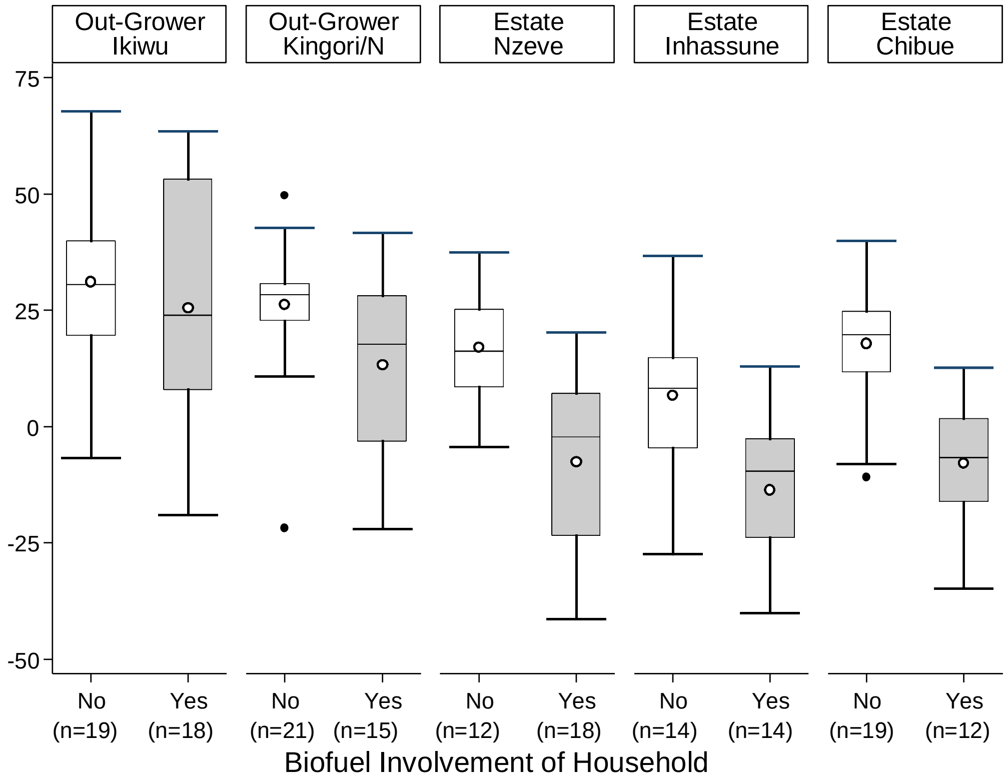
Figure 5.7 shows box-plots of the range of HNDS results, including mean and median and inter-quartile values, for each survey site, divided into those households involved and those not. This illustrates the lower nutrient deficit scores, and hence, better food security status, recorded by the households involved as employees in the estate-model biofuel operations at Nzeve, Inhassune and Chibue villages, compared to other households in the same village. The p-value results suggest little association between biofuel involvement and better food security status for the outgrower households in the Ikiwu, Singida area of Tanzania, but strong associations in all the other four sites.

5.3.3.2 Quantitative results of robust regression

As in the initial multiple regression analyses, the robust regression analysis examined four separate models in order to assess the impact on food security of each variable or group of variables. After excluding the outliers, the first model assessed the impact on the HNDS of household biofuel involvement as outgrowers or employees compared to the non-involved households, the second model incorporated the geographical influence of the different village sites, the third model used a group of variables less likely to be affected by the establishment of the biofuel operation, including household size, area farmed, phone ownership and then age and gender of the household head. The final model then incorporated the source of income variable.

[65] Household income data was collected during the survey on all farming income, off-farm income and remittances. The household income data also included the value of own production consumed and was expressed in per capita adult equivalent in US$, using the prevailing exchange rates in 2009.

Fig 5.7 – Box-plot of HNDS Results for Households Involved and Not Involved in Local Biofuel Operations by Village Site



Robust-to-outlier regressions were first performed to estimate the difference in average food security between the different biofuel groups before and after controlling for potential confounders. No outliers were eliminated based on a Cook's distance greater than one so all analyses used 162 observations. Multi-collinearity was again checked between dependent variables using variance inflation factors (VIF), where a value of 10 or higher suggests multi-collinearity. All variables had a VIF less than four and were thus considered not to be collinear.

Table 5.9 presents the results of the four linear regression models conducted. In the first section of the table (biofuel involvement), in model 1, households with employees on the biofuel feedstock estates had an average nutrient deficit score more than 33 percentage points below that for non-involved households, with a p-value of less than 0.001. Controlling for geographical location in model 2 reduced the gap to some 28 percentage points and then controlling for the non-income variable group (household size, land area farmed, phone ownership and age and gender of household head) in model 3 reduced this to 27 points, whilst maintaining a significant association.

Table 5.9 – Robust Linear Regression by Biofuel Involvement Groups

Model Stages	**Model 1** Coefficient (Standard Error)	**Model 2** Coefficient (SE)	**Model 3** Coefficient (SE)	**Model 4** Coefficient (SE)
1.Biofuel Involvement[1]				
Outgrower	-5.71 (4.39)	-10.64* (4.87)	-6.80 (4.09)	-6.03 (4.03)
Employee	-33.27*** (3.97)	-27.76*** (4.45)	-26.96*** (4.00)	-22.12*** (4.54)
2.Village Sites[2]		.	.	.
Kingori/Ngurdoto, Arusha; Outgrower model		7.78 (4.85)	10.69* (4.39)	10.63* (4.33)
Nzeve, Bilene; Estate model		-2.92 (6.20)	-2.86 (5.15)	-1.49 (5.09)
Inhassune, Panda; Estate model		-13.22** (6.11)	-6.82 (5.18)	-4.97 (5.14)
Chibue, Dombe; Estate model		-2.82 (5.82)	2.17 (5.19)	5.42 (5.23)
3. Key Variables				
Age of HH Head (years)			0.21 (0.12)	0.22 (0.11)
Gender of HH Head (female versus male)			3.73 (3.75)	4.05 (3.70)
HH Size (adult-equivalent)			10.04*** (1.37)	10.02*** (1.35)
HH Phone Ownership			-8.00* (3.09)	-7.87* (3.05)
Area Farmed (hectares)			-5.40*** (1.54)	-6.65*** (1.60)
4. Income Source				
Main Source of Income from Farming				8.46* (3.84)
Adjusted R-square	0.30	0.33	0.54	0.55
N	162	162	162	162

* p<0.05, ** p<0.01, *** p< 0.001

Note: Results of a robust regression in four different models. Coefficients represent the difference in mean Household Nutrient Deficit Score (HNDS) when all other variables in a given model are held constant.

1. Mean HNDS compared to households not involved in biofuels.

2. Mean HNDS compared to Ikiwu, Singida; Outgrower model.

Model 3 has an R-squared value of 54 per cent, suggesting that it captures over half of the variation in the nutrient deficit score. The independent variables with a high significance within the model are “biofuel involvement as employees”, “household size” and “area farmed”. All three variables show a strong impact on household nutrient deficits, with each additional adult-equivalent likely to raise the HNDS by 10 percentage points on average and each additional hectare of land farmed likely to decrease the HNDS by just over 5 percentage points. Then if a household has at least one employee of a biofuel operation, it is likely to result in a 27 percentage point reduction in the HNDS on average, which would have by far the most significant impact on its food security status.

When source of income is introduced in the fourth regression model, the effect of biofuel involvement on the HNDS is reduced by some 5 points to 22 per cent, again with a p-value of less than 0.001. Compared to the employee households, outgrowers recorded a smaller and non-significant reduction in the average nutrient deficit score of some 6-percentage points in model 4. The R-squared value for model 4 indicates that 55 per cent of the HNDS variation was accounted for by the model.

In assessing why the households with biofuel employees had significantly lower nutrient deficits than both the outgrower and non-involved households, a key influence is likely to be the large difference in average per capita incomes between the groups, as shown in table 5.8. The result for section 4 in table 5.9 on source of income suggests that those households relying mainly on farming income, as was the case for most non-involved and outgrower households, were likely to have a higher nutrient deficit score, averaging some 8.5 percentage points above that for other households relying mainly on employment or other non-farm income.

It should also be noted that, although the households were sampled randomly in each location, there is a potential problem of self-selection bias, as those households where members gained employment in biofuel operations may already have been more food and income secure. However, the qualitative evidence from the fieldwork suggested a more even distribution of income within the various villages prior to the establishment of the biofuel operations. During the pre-survey focus groups it was noted that the households where people had gained employment were now much better off than others in the same area, but that before the operations were established most households practised similar farming activities and had more similar income levels.

Given the qualitative evidence regarding the impact of biofuel involvement on incomes (see next section), it was decided to run a fifth regression model incorporating the household per capita income variable as a means of comparison with the initial regression analyses.

As expected from the initial analyses, the results for biofuel employment became insignificant when income was included, with the difference in the mean HNDS compared to non-involved households falling from 27 percentage points below in model 3 to a non-significant 5 points below in model 5. The per capita income variable in model 5 recorded a highly significant result of a mean HNDS some 4 percentage points lower for each 20 per cent difference in income. Also the R-squared value for the model, at 67 per cent, suggested the model accounted for over two-thirds of the HNDS. Whilst, acknowledging the endogeneity issue, this again suggests that improved income was a key reason for the lower nutrient deficits in households with biofuel employees.

The qualitative results in the following section provide evidence of other factors affecting household food security, as well as changes in food security status since the establishment of the biofuel operations and the reasons for such changes.

5.4 Qualitative Findings from the Household Survey

Although the survey results show a clear advantage in food security status for those households involved in biofuel operations as employees over other households in the same locations, and the regression models suggest that biofuel involvement and associated improved incomes are major factors behind the difference in food security, the regression analysis in itself cannot prove that the biofuel operation has had a positive impact on food security as there is no baseline data to verify the change in status before and after the involvement of the households with the biofuel companies.

However, the survey questionnaire also collected retrospective information on the household's perceived change in food security status since the biofuel operation had been established. As all the biofuel projects had started within the previous three years, it was believed that recall bias would not be a major problem.

Table 5.10 shows that over three-quarters of the households with biofuel employees felt their food security status had improved compared with just over half of outgrowers and fewer than 10 per cent of households "not involved". Only two households reported a perceived worsening of food security since a biofuel operation had been established and no households with biofuel employees reported any worsening of food security in any location.

Table 5.10 – Perception of Change in Food Security Status since Biofuel Operation Established

		Biofuel Involvement			Total
		Households (HHs) not involved (% total)	Outgrower HHs (% total)	HHs with Employees (% total)	
Food security change resulting from biofuel operation establishment	Reduced food security	1 (1.1)	1 (3.0)	0	2
	No change	71 (81.6)	15 (45.5)	8 (18.2)	94
	Improved food security	7 (8.1)	17 (51.5)	34 (77.3)	58
	Don't Know	8 (9.2)	0	2 (4.5)	10
Total		87	33	44	164

The "no change" and "improved" food security change results were then compared with the food security status results according to two HNDS groupings: those deemed to be extremely food insecure with an HNDS of 20 or more (not secure) and those deemed most likely to be secure or only moderately insecure, with an HNDS of less than 20. The cut-off point of 20 was chosen as the mean value of all the HNDS results, or the peak of the distribution. The two households reporting a reduced food security status and the 10 households answering "don't know" were excluded.

Table 5.11 shows that, of the 34 households with biofuel employees reporting an improved food security status, 30 were deemed to be food secure or only moderately food insecure, using the HNDS results, versus four households deemed to be in the food insecure group. This suggests a possible relationship between a perceived improved food security status since the biofuel operation started and a low HNDS, and hence a better food security status, for the biofuel-employee households. Of course, the other four households reporting an improved food security status but deemed to be food insecure, may still have seen an improvement in the degree or severity of their food insecurity (ie their food insecurity may have become less severe). An investigation of these four households found that three were just over the HNDS cut-off point of 20 and one had an unusually large household size of 17 people.

Table 5.11 – Perception of Change in Biofuel Status versus Calculated Food Security Status Group (from HNDS)

		Biofuel involvement and food security status*						Total
		Not involved		Outgrower		Employee		
		Not secure*	Mostly secure*	Not secure	Mostly secure	Not secure	Mostly secure	
Self-perceived food security status change resulting from new biofuel operation	No change	55	16	9	6	2	6	94
	Improved food security	5	2	10	7	4	30	58
Total		60	18	19	13	6	36	152

** Note that households were deemed to be "not secure" with an HNDS of 20 or more (a weighted average percentage deficit of 20 per cent or more of the four nutrients measured), and "mostly secure" with an HNDS of less than 20.*

In contrast, of the 78 households not involved in biofuel operations, over three-quarters (77 per cent) were deemed to be food insecure with an HNDS of 20 or more. Given the absence of alternative employment and other income generating opportunities before the biofuel operations started, and the similarity of the household profiles in terms of number of people, land area owned and gender of household head, it could be assumed from the preponderance of “no change” responses that a similar food security profile may have applied to the whole population before the biofuel operations were established.

Further analyses were undertaken on the qualitative elements of the survey questionnaire, particularly the household responses on how their food security status had changed since the establishment of the biofuel operation and how they felt about the nearby biofuel operation?

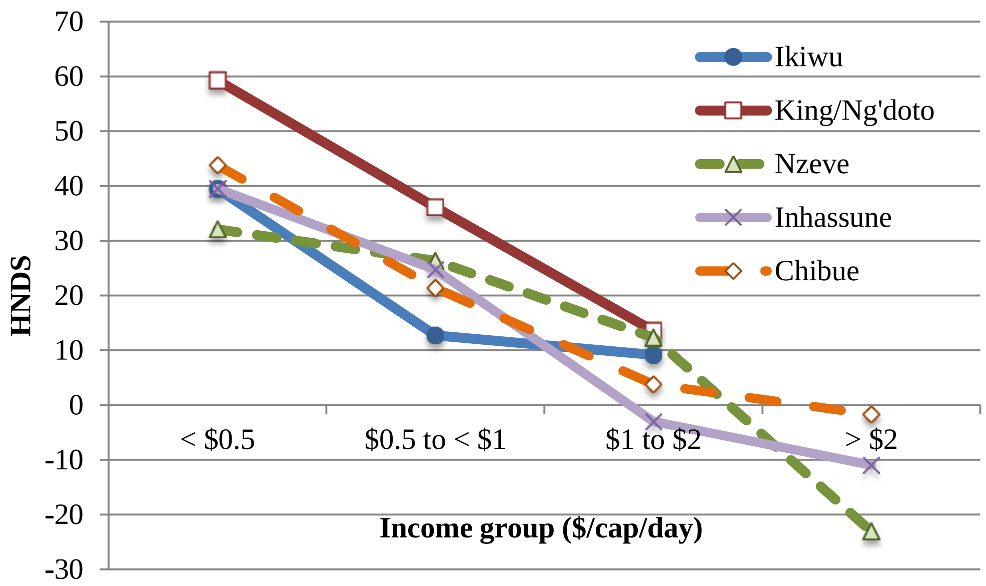
Of the households with employees perceiving an improvement in food security since the biofuel operation was established, almost all (30 households) reported improved income through employment as the main factor, whilst two reported improved food production as the main factor. For the outgrowers who reported improved food security there were a wider variety of reasons put forward including improved income from feedstock and other crop sales, and higher food production. For the fewer households not involved in biofuel production reporting improved food security, the main reason was increased sales of food crops due to increased demand resulting from the biofuel operation.

The largest grouping in the food security change category in table 5.10 was the households not involved in biofuel production reporting an unchanged food security situation since the biofuel operation had been established. Even though this group reported no change in food security status, 49 of the 71 households were happy with the establishment of the biofuel operation in their locality and 18 were unsure of its impact. Some 37 of all such households stated they believed the biofuel operation improved income prospects for households in the community, either through improved sales of crops and other food or through employment, whilst 14 felt that the operation had improved the general development of the village through better infrastructure and social facilities

The household survey also attempted to capture food production responses in each location by asking how food production had changed since the biofuel companies had been established. Many householders found it difficult to answer this question as so much of the variability in food production was attributed to weather. Nevertheless some 34 households reported improved yields and none reported lower yields as a result of the biofuel projects. It was also noted that most households with biofuel employees had continued to farm the majority of their land[66], partly helped by the biofuel companies providing flexible working hours to enable key farming tasks to be performed, although it was also generally reported that more of the farm-work burden had fallen on the non-employee members of the household.

Given the reported importance of improved income, fig 5.8 shows the average HNDS values for different income groupings in each location. The recorded nutrient deficits are clearly largest in the extremely poor households with an average per capita income (adult-equivalent) of less than \$0.5 per day. The percentage deficiency then falls as average household income improves in every location (table 5.12). This provides further evidence of the importance of income on food security.

Fig 5.8 – Average Household Nutrient Deficit Score by Income Group



[66] The averages for the biofuel employee groups in each location were over 90 per cent of the owned land continuing to be farmed.

Table 5.12 – Average Household Nutrient Deficit (HNDS) by Income Group

	Average HNDS by household income group in $ per adult-equivalent capita per day				
	< $0.5	$0.5 to < $1	$1 to $2	>$2	Average
Ikiwu	40	13	9	-	28
Kingori/Ngurdoto	59	36	14	-	35
Nzeve	32	26	12	-23	13
Inhassune	40	25	-3	-11	6
Chibue	44	21	4	-2	20
Average	**43**	**24**	**7**	**-12**	**20**
Note that household income groups are in 2009/10 values					

5.5 Overall Food Security Findings from the Household Surveys

5.5.1 Linking the HNDS to the food security dimensions

The HNDS indicator used in this analysis distils the reported consumption data of the various foods during the year by each household, into estimated intakes of four main macro and micronutrients. By comparing these intakes against the recommended requirements for the individuals comprising each household, an approximate measure is achieved of significant nutrient deficits in each household, which are then weighted to give an average deficit score.

As such, the HNDS covers the four main dimensions of food security: availability (quantities consumed), access (home-produced and purchased food consumed), stability (seasonal and monthly changes in consumption) and utilisation (nutritional elements). However, it is also based on typical diets, adjusted for seasonal shortfalls, and may therefore be subject to some recall error. The conversion of the foods consumed into macro and micronutrients using composition tables, as well as the use of moderate activity dietary requirements, may also lead to some under or over-reporting of nutrient deficit gaps. The HNDS should, therefore, only be used as an approximate estimate of food security status and would need to be combined with other relevant indicators where possible.

In addition, the analysis does not cover any impacts the biofuel operations may have had on households outside that locality. It might be argued, for example, that the improved purchasing power of households involved in the Mozambique biofuel operations could have reduced the availability of food supplies and led to higher food prices outside that locality.

A review of staple food prices in local markets, together with focus group feedback, indicated that prices, particularly for maize, were low at the time of the survey in mid-2009 following a bumper harvest in Mozambique. Most of the maize is grown in the centre and north of the country (where the Dombe biofuel company is located), and much of the surplus from there flows down into the deficit southern regions (where the Inhassune and Bilene biofuel operations are situated), with the largest volumes flowing down to the major consuming centre of Maputo. The central and northern maize prices are therefore usually the lowest prices, whilst those in the main deficit market of Maputo are highest. Prices of maize in markets such as Xai Xai (the nearest major market to the Bilene operation) and Massinga (the closest maize exchange to the Inhassune biofuel estate) generally fluctuate between the central and Maputo prices in more thinly traded markets. There was little evidence from price trends between 2008 and 2011 that increased demand triggered by higher incomes from households with employees of biofuel operations, reduced availability and raised prices[67] in any of the main wholesale markets closest to the three sites surveyed.

Evidence from the focus groups and interviews suggested that the introduction of waged employment into the three estate sites in Mozambique led to a multiplier effect in each locality. For example, the establishment of the jatropha estate in Inhassune encouraged the expansion of the village market from 3 to 20 shops, whilst local farmers outside the village benefitted from increased demand for food boosting their incomes. Within the village there was evidence that the biofuel operation led to increased food production through the provision of food plots, loan of farming equipment such as tractors and ploughs to cultivate new land and other technology

[67] In other words prices did not appear to rise above the levels that would have prevailed according to national and regional supply and demand conditions

transfer impacts. This, together with the survey results showing increased local food yields and production, suggests it is unlikely that any of the biofuel operations were negatively affecting access to food in surrounding villages.

So, in terms of availability and access, the quantitative results using the HNDS methodology, together with the qualitative findings on perceived changes in food security status and the review of local market dynamics, indicate that biofuel involvement had a positive impact on food security status, particularly for households with employees of biofuel feedstock operations. This suggests that income is perhaps more important in determining food access than food prices.

In terms of stability the following charts show the calorie deficit component of the HNDS for each month during the year. These were calculated from household responses on changes in food types, meal numbers and portion sizes in typical shortfall months over the year preceding the survey. Where untypical events had occurred households were asked what the normal consumption patterns would be in a shortfall month.

For the outgrower locations there was little difference in the seasonal pattern of calorie deficits over the year, as illustrated in figure 5.9. In Ikiwu, the average calorie deficit for outgrowers remained just under that for non-involved households for all but one month of the year. The small contribution of jatropha seed sales to incomes during the year is one possible reason for this.

The gap between calorie deficits for outgrowers and non-involved households in Kingori and Ngurdoto villages also remained fairly consistent, but larger than that for Ikiwu, throughout the year. Although the average calorie deficit was much greater for non-involved households, the variation, at 7 percentage points, was slightly less than the 13 percentage point variation for outgrower households.

Fig 5.9 – Household Monthly Calorie Deficits (%) for Outgrower and Non-Involved Households in Ikiwu and Kingori/Ngurdoto

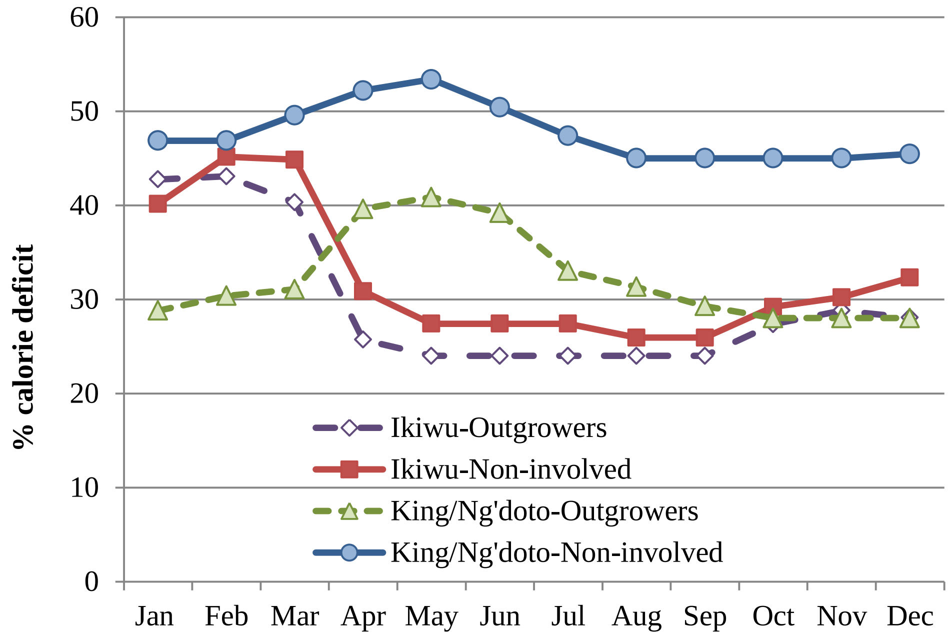
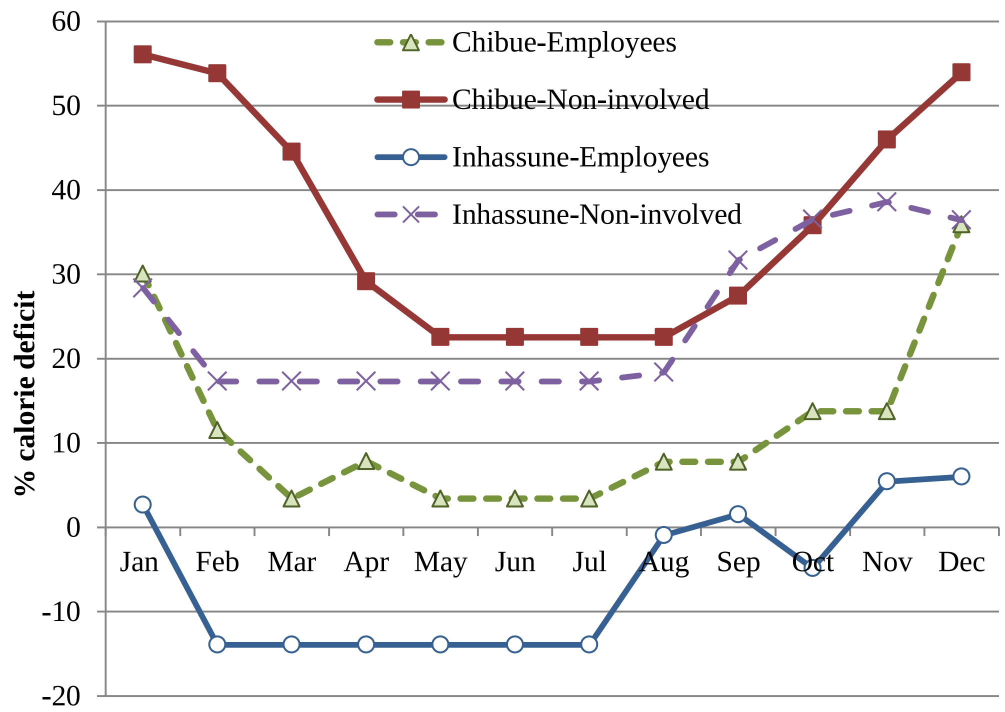


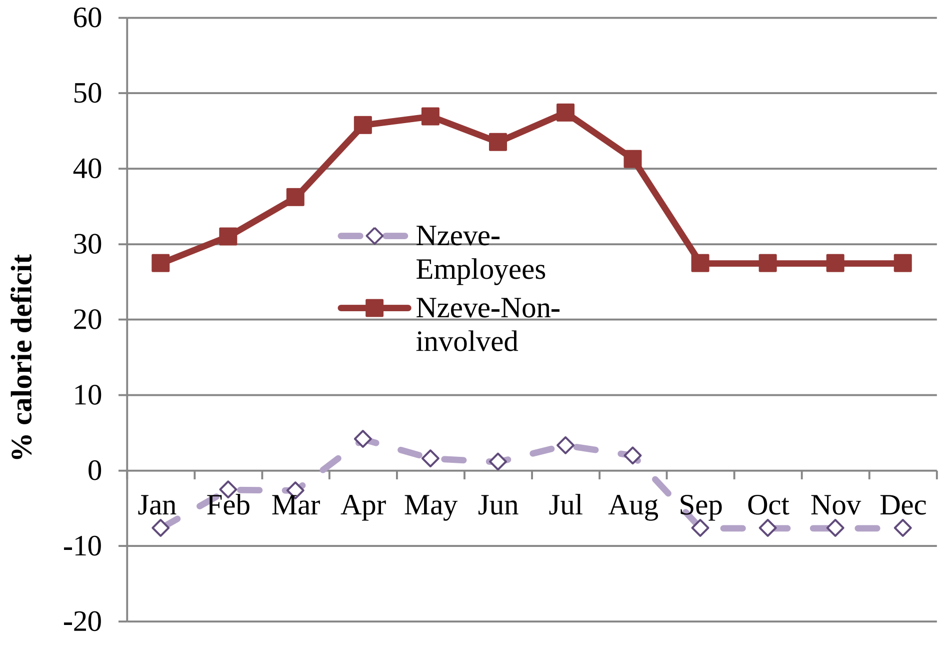
Fig 5.10 - Household Monthly Calorie Deficits (%) for Employee and Non-Involved Households in Chibue and Inhassune



In the villages of Inhassune and Chibue, those households with employees of the local jatropha feedstock operations exhibited relatively small calorie deficits in most months, or surpluses in the case of Inhassune. The non-involved households in both locations recorded much larger seasonal deficits, but the seasonal pattern was again similar for involved and non-involved households (fig 5.10).

Only in Nzeve village (fig 5.11) was there a noticeable difference in the extent of the monthly calorie deficits. Households with biofuel employees in Nzeve recorded relatively little change during the year, from an average deficit of 4 per cent in April to an average surplus of 8 per cent from September to January, or a 12 percentage point variation in the monthly mean. Non-involved households in the same village recorded monthly calorie deficit means ranging from 18 to 48 per cent during the year, a 30 percentage point variation.

Fig 5.11 - Household Monthly Calorie Deficits (%) for Employee and Non-Involved Households in Nzeve, Bilene, Mozambique



It is notable, in terms of the depth of food security, that the average household nutrient deficit score was over 50 per cent for some months of the year for the non-involved household groups in Kingori/Ngurdoto and Chibue, and was over 40 per cent in some months for all households in Ikiwu and the non-involved groups in

Nzeve and Inhassune. There was only one month in which the calorie deficit was over 30 per cent in any of the biofuel employee groupings; that for the Chibue sugar cane operation in December. This finding would have enabled the operation in question to take mitigating action to address this large average monthly deficit and any other significant monthly gaps, not only for calories but also for any other excessive nutrient gaps.

The survey also recorded the number of months in the past year that households had a food shortage. For the non-involved households the average number of shortage months was 3.28, for the outgrowers 2.88 and for the households with biofuel employees the average was 2.28, a full month less than non-involved households.

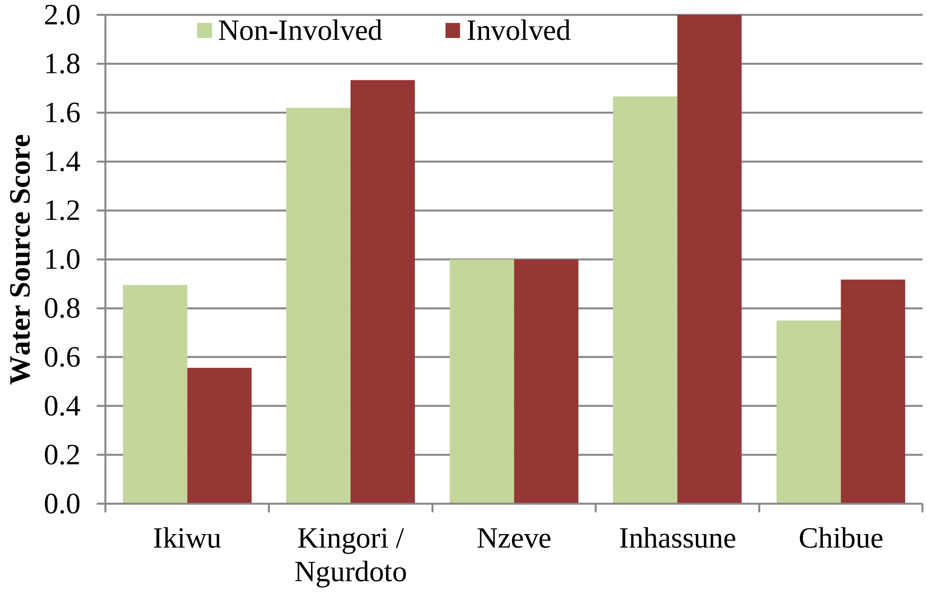
So the impact of biofuel involvement on stability appears to have been more mixed, with fewer shortage months for those households with employees of biofuel operations and less monthly variation in calorie deficits compared with non-involved households in Nzeve and Kingori-Ngurdoto, but little difference in the other locations. Nevertheless, the fact that the employee-based households recorded much lower calorie deficits overall (and in many cases surpluses) means that they would have been better placed to cope with any seasonal shortfall, whilst outgrowers in Kingori-Ngurdoto also recorded consistently lower deficits throughout the season and outgrowers in Ikiwu, marginally lower.

In terms of utilisation the household survey also collected data on access to improved water sources, time spent collecting fuel and water and cooking facilities. Average results for the biofuel involved and non-involved groups of households were fairly similar in each location, suggesting biofuel involvement had less impact on these aspects of utilisation.

However, there were differences between the biofuel sites, as some biofuel companies had installed improved wells and boreholes, or even water pumps and taps (eg in Inhassune), providing access to safer water and reducing collection times. In these cases most households benefitted from improved access to safe water and better sanitation, whether involved with the biofuel operation or not.

In order to assess the water access status of each household, a score of 0 was given to households collecting from rivers, ponds and dams, 1 for those collecting from wells and boreholes and 2 from improved sources such as pumps and taps. The mean scores for each location are shown in figure 5.12. This highlights the better score recorded for Inhassune where improved wells and taps had been established by the biofuel operation.

Fig 5.12 – Mean Water Source Score for Households Involved and Not Involved with Local Biofuel Operations



Note: Water Source Score **-** *0=rivers, ponds and dams; 1= improved wells and boreholes; 2=taps and pumps from improved sources*

The community-based outgrower scheme collecting seed in Kingori and Ngurdoto in Aremeru District, Tanzania was also involved in a project to introduce cooking stoves using jatropha oil in order to reduce smoke-inhalation related illnesses from indoor cooking. However, that was at too early a stage of development to assess impact.

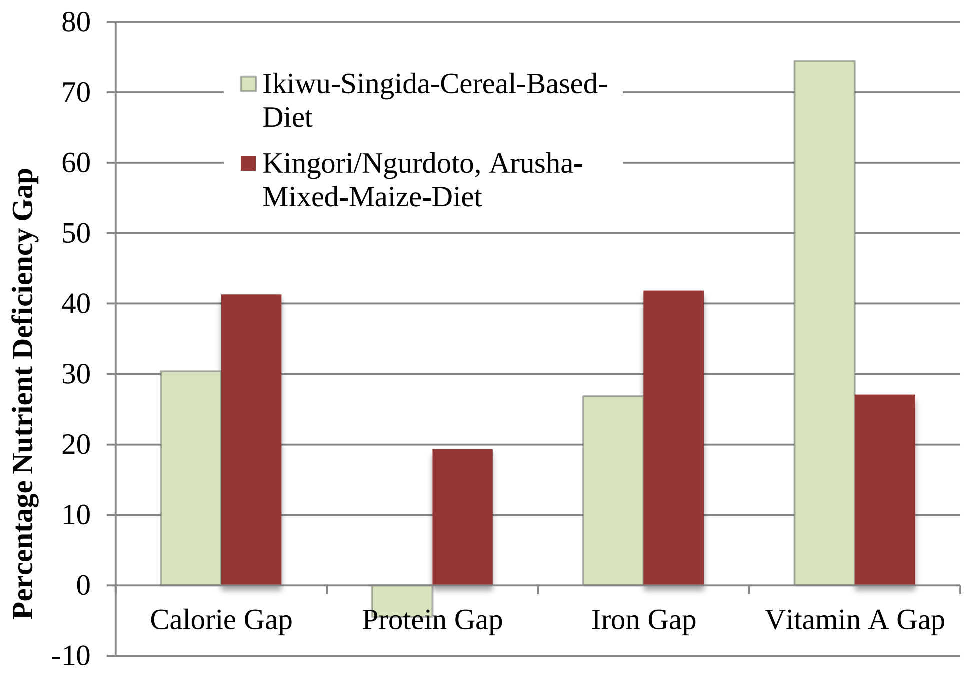
Health status is another important aspect of utilisation, but is also difficult to measure. Households were asked how many members of their household were sick or disabled and how many days per month would they require assistance and who would the carers be within the household. The level of sickness and disability in each location did not differ significantly between involved and non-involved households.

5.5.2 Breakdown of the HNDS indicator

Another aspect of utilisation measured by the HNDS is the individual nutrient gap. As well as highlighting those households or areas most likely to be food insecure based on their reported food consumption, the HNDS can also be broken down into its constituent components in each locality to assess the key nutrient issues within the overall score and potential mitigating actions.

For example, the average diet in the surveyed households of Ikiwu village in the Singida region of Tanzania, displayed adequate protein intake, but a very high deficit gap for vitamin A, due to the largely cereal-based diet (fig 5.13). In comparison, the average diet in the Kingori and Ngoroduto villages of Arusha recorded a better vitamin A intake but high calorie and iron deficits. These results can be compared with other indicators in each locality to guide mitigating actions, such as the possible promotion of vitamin A enriched crops in the Singida area.

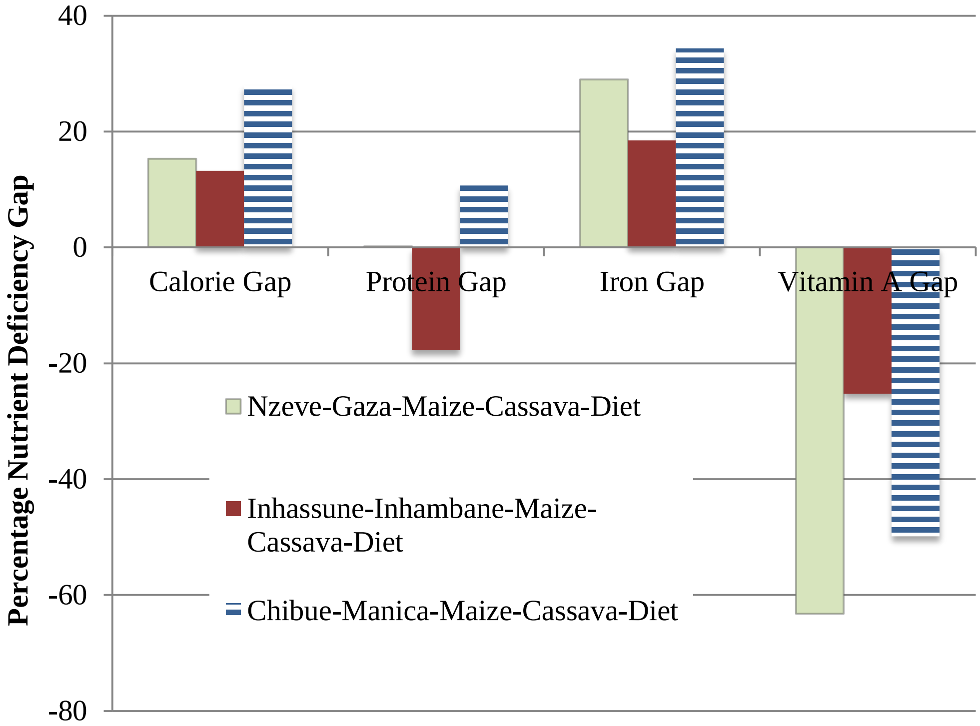
Fig 5.13 – Breakdown of Average Household Nutrient Deficit Gaps in Ikiwu and Kingori/Ngoroduto Villages



The results also highlight potential weaknesses with existing indicators, as the more varied Arusha mixed diet scored better on a household dietary diversity score, but was significantly worse in terms of the amount eaten per capita and thus had much larger deficits of calories, protein and iron.

For the Mozambique sites the consumption of orange-fleshed sweet potato and some meat in the diets helped to ensure there was little vitamin A deficiency, but iron and calorie gaps remained high overall[68]. Although only the main macro and micro nutrients are included in this analysis, this also illustrates how mitigating actions could be guided by the HNDS.

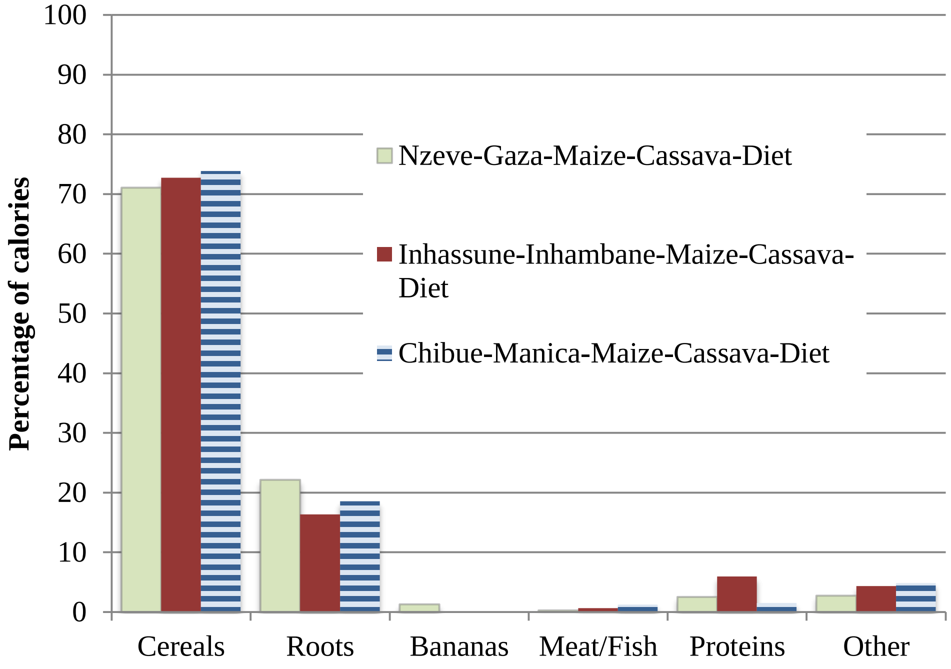
Fig 5.14 – Breakdown of Average Household Nutrient Deficit Gaps in Nzeve, Inhassune and Chibue villages



The HNDS can also be broken down into the main food sources or categories of each nutrient. For example, calories can be broken down into cereal, root crop, protein crop, bananas, meat and fish sources, as depicted in figure 5.15, which shows that 70 per cent of calories were derived from cereals in the Mozambique survey sites.

[68] Note that further investigation would be needed in terms of the bio-availability of vitamin A and the impact of other foods eaten in this regard.

Fig 5.15 – Percentage of Calories from Different Food Sources in Nzeve, Inhassune and Chibue villages

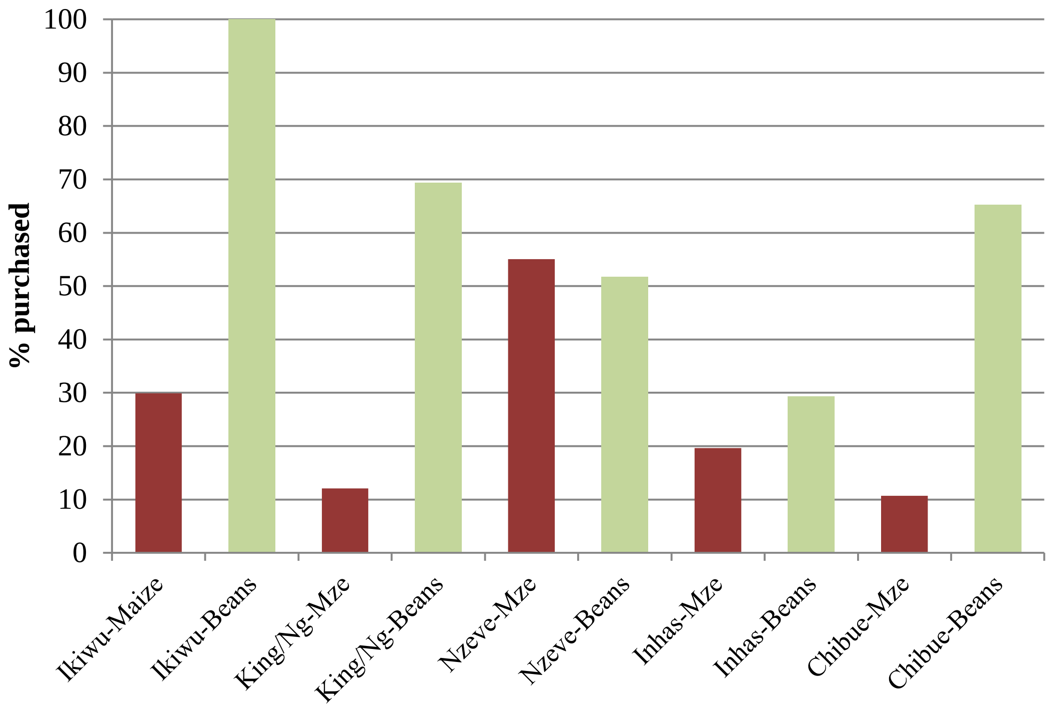


The results can also be broken down into the nutrient amounts from home food production and from purchases in order to assess potential improvements in cropping plans or shopping behaviour. This helps to provide a detailed picture of availability of, and access to, food for each locality and each household. The locality averages can also be broken down into groups.

For example, the average percentage of purchased maize and beans is shown for each location in figure 5.16. This shows that in general, beans are more likely to be purchased than home-grown, but maize is more likely to be home-grown. So price developments are more likely to have a greater impact on bean consumption than maize.

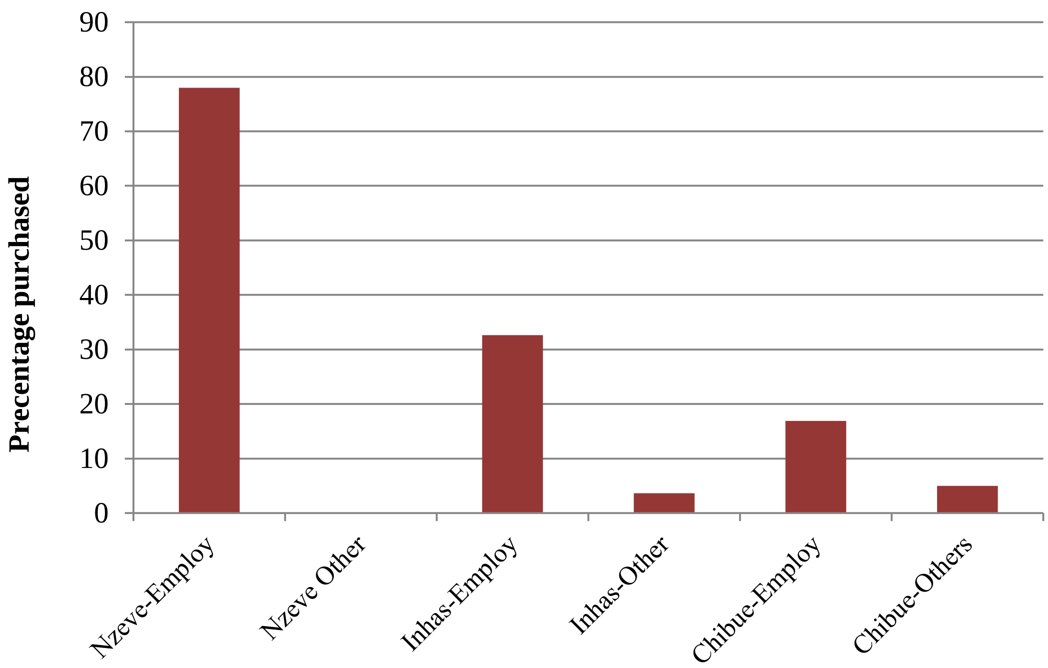
But breaking the average figures down into those households involved with biofuels and those not can provide further insight into the food consumption patterns. For example, whilst the average percentage of maize purchased by households in Nzeve was just over half, those households with biofuel employees purchased over three-quarters of their maize consumption. Indeed, households with employees tended to

Fig 5.16 – Average Percentage of Maize and Bean Use Purchased in Each Study Site



Note: King/Ng = Kingori/Ngurdoto, Inhas = Inhassune, Mze = maize.

Fig 5.17 – Average Percentage of Maize Purchased by Households - Mozambique Sites



Note – "Nzeve Employ" = Households with employees of biofuel operations in Nzeve. "Nzeve Other" = Non-involved households in Nzeve. "Inhas" = Inhassune.

purchase more of their food than other households in all locations, largely due to the higher incomes earned from employment (fig 5.17).

This illustrates how the HNDS indicator and methodology can be used to provide more detailed nutritional information in order to guide mitigation, and help link nutritional outcomes with agricultural interventions and shopping behaviour.

5.5.3 Comparing results with other studies of the same operations

Other research projects have covered the same biofuel operations surveyed in this study, the results from which tend to corroborate the survey findings.

A study of three villages in the vicinity of the Bilene, Energem biofuel operation in 2009, concluded that households working on the plantation were better off in socio-economic terms than households not involved, when looking at income and expenditure measures (Peters, 2009). This corresponds with the survey findings that households with biofuel employees in Nzeve village were significantly more food secure than other households in the same village, and that such households also perceived an improvement in food security after the arrival of the biofuel operation.

Another study describes a visit to the Inhassune ESV jatropha estate in 2008 when *"the plantation was thriving, the nursery was bustling and the area had an atmosphere of activity and growth, with 1,200 villagers employed well above the minimum wage rate"*. The researchers note that the community was in favour of the proposed biofuel development and that they preferred to be employed rather than growing biofuel feedstocks themselves, so that *"they would be assured of a monthly income and thus not have to deal with the two to three months of food insecurity that accompanied their subsistence farming"* referring to their previous livelihoods (von Maltitz et al., 2012).

Portale describes the socio-economic benefits to rural households of the Diligent outgrower operation in Tanzania, including a positive relationship between involvement as an outgrower with household perception of food security status. Over

100 households were interviewed in the study, including outgrowers and non-participants as a control group. The outgrowers had a higher perception of food security and reported lower food shortages over the preceding year, which was largely explained by the more regular income pattern from selling jatropha seeds over the longer harvesting period (Portale, 2012).

These studies of the same biofuel operations used in this analysis support the results from the household survey for the larger-scale estate operations, although the outgrower households in Singida had less positive food security outcomes than Portale's wider study. This may be partly attributed to the fact that most of the outgrowers in Ikiwu were supplying jatropha from old jatropha hedges used mainly to protect crops from wildlife damage. Hence, the planted area and yields of jatropha were very low in this area, restricting the amount of income earned from sales of the seed, whilst the positive impact of reduced damage to food crops was difficult to evaluate.

Another important issue for biofuel impacts on household food security has been the closure or suspension of many biofuel feedstock projects in Africa in recent years: two of the operations investigated in this study have experienced a similar fate.

The Energem jatropha estate in Bilene, Mozambique closed due to financial reasons in 2010 before the promised community projects of electricity, a new school and health centre were delivered. Equivalent land had been provided to those households who agreed to transfer land when the biofuel operation was established. The household survey recorded that in Nzeve village, of the 16 households reporting that they had transferred some land to the Energem operation, 13 had been given other land as compensation but further away from the village. When the operation closed down the company eventually paid back wages and redundancy payments amounting to some $136,000 (Hanlon et al., 2011). However, some households were left with less land or land further away from their household, making them potentially more vulnerable to food insecurity.

The ESV jatropha plantation also ran into funding problems in 2009, leading to the suspension of operations and wages until it sold the estate to SAB Mozambique in late 2009. SAB Mozambique reported they had paid back-wages and planned to resume work to expand jatropha plantings. In 2010 it was announced that 80 full-time workers had been taken back and that there would also be 1,000 seasonal jobs (Hanlon et al., 2011). Since none of the households lost land to the company, the main impact on food security was the loss of wages for an extended period.

Principle Energy also suspended its sugar cane operations near Dombe due to financing issues and a reported takeover battle in 2009 (Hanlon et al., 2011). Only four of the 32 households surveyed in Chibue village reported losing land to Principle Energy due to government purchasing orders, but only one of those reported receiving compensation. The company had been surprised to hear about the three households not compensated and had promised to investigate them.

In the jatropha outgrower sites surveyed, very little land had been transferred from food to jatropha trees. Diligent Tanzania is reported to have recently sold its jatropha outgrower operation (Sulle, 2013). In the villages supplying jatropha seed to Kakute Ltd, some additional land had been allocated to jatropha, but this was often intercropped with maize to reduce its impact on food production whilst at the same time providing some cash income.

6. Findings from the Global to Local Analysis of Land Use and Food Prices

The literature review highlighted the greater academic and media focus on macro rather than micro impacts of biofuels on food security. In other words, there has been a much greater emphasis on how global biofuel production, which is concentrated mainly in food-secure countries, has affected the world availability and prices of staple foods, and how this is estimated to have influenced households in food-insecure countries.

It is also evident from the review that the lack of consensus on the extent to which biofuels have influenced food security is partly due to the use of diverse data and assumptions on biofuel production, feedstock areas and yields, world food prices, supply and demand elasticities and future scenarios, as well as differences in modelling approaches and food security measures used.

The various studies have also had limited time series data to work with, as many of the analyses were conducted in the early years of the so-called “biofuel boom”. However, the experience of a decade since then can provide better evidence of how biofuel production has affected the availability of land and how world commodity and food prices have responded.

Given the many econometric studies that have been undertaken using diverse assumptions and resulting in a wide range of findings, a different approach is undertaken in this analysis, focussing on a retrospective data-driven analysis of key supply, demand and price information related to the global biofuel sector over the past decade.

This chapter focusses on the results of this macro analysis, with the first section describing the findings of the global biofuel and feedstock analysis and its implications for land availability for food production. The second section then focusses on the relationship between biofuel production and global and national food prices, with a particular focus on maize.

6.1 Global Land Use of Biofuel Feedstocks

The main food security issue related to land is the extent to which biofuel feedstocks absorb existing, and divert additional, land resources away from food. The findings of this first section of the macro analysis have been divided into the two main types of biofuels produced: fuel ethanol and biodiesel.

6.1.1 Usage of land for fuel ethanol production

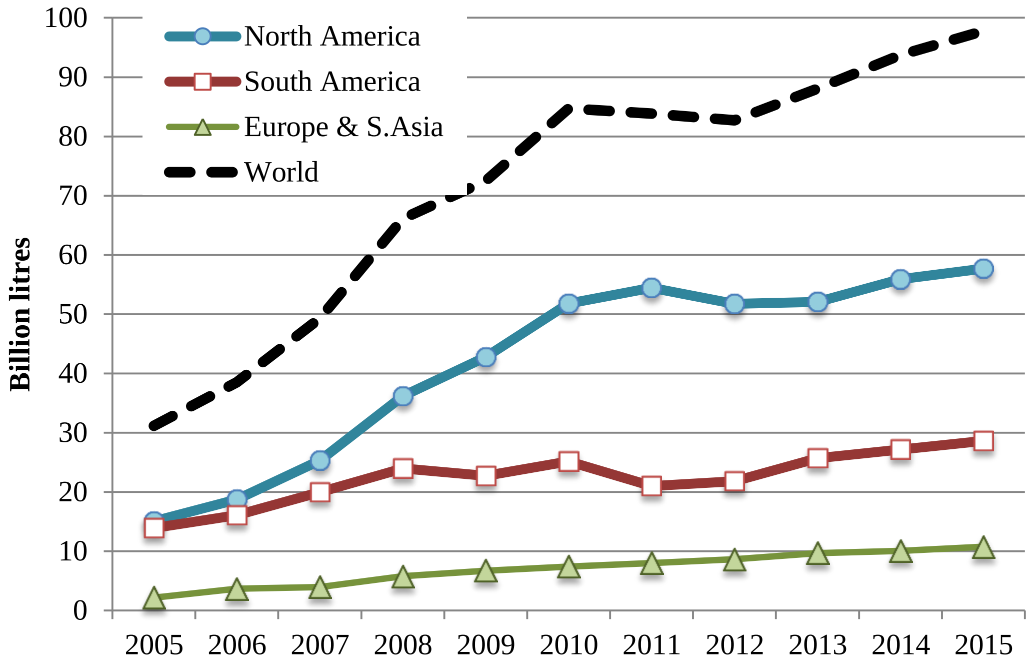
Ethanol is the main biofuel produced globally representing some three-quarters of total biofuel production on an energy-basis in 2015. Not all of the ethanol produced globally is used for fuel, so estimates of fuel ethanol production are based on survey details of production by ethanol processors and information from fuel blenders on how much ethanol they have used.

Global ethanol production for fuel use is estimated by this analysis at just under 100 billion litres in 2015, equivalent to some 50 million tonnes or 400 million barrels of oil.

The US accounts for nearly 60 per cent of the ethanol produced for fuel use globally, followed by Brazil with just under a third of the total. Most of the rise in US production occurred between 2005 and 2010, with output remaining fairly flat from 2010 to 2013. Over the past two years, however, there has been a renewed surge in US ethanol output, largely due to lower oil prices and the resulting increased demand for fuel (and, hence, biofuel blending), but also exports. Brazilian ethanol production has also increased in recent years, as margins have proved more profitable than sugar conversion, due to low world sugar prices (fig 6.1).

Appendix 3 shows the breakdown of estimated fuel ethanol production by country from 2005 to 2015, from various national sources. This highlights the sharp rise in production in recent years in new producers, such as Thailand, India, Colombia and Peru.

Fig 6.1 – World Fuel Ethanol Production – 2005 to 2015



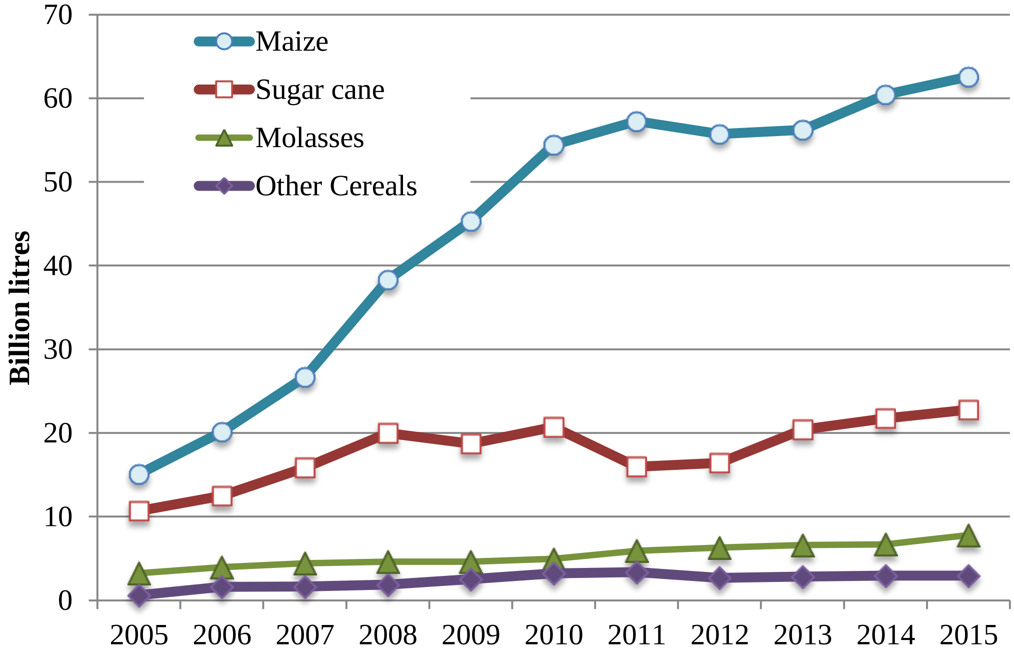
Source: Authors' analysis from various international and national sources – see Appendix 3

The analysis shows that feedstock use follows a similar pattern to geographical production, given that nearly all US production is from maize and most Brazilian production is from sugar cane (fig 6.2). In the case of Brazil, it is notable that the molasses by-product of sugar production accounts for a significant proportion of biofuel output, although cane juice remains the major feedstock[69]. In many other countries, molasses are the preferred feedstock for ethanol production as a by-product of the sugar industry, particularly in India and Pakistan but also some Latin American and African countries.

The use of molasses as a feedstock has important implications for land use, as molasses are often treated as a waste product with limited alternative markets. Some countries also use other by-products: for example, maize cobs are used in China, waste wine is used in Italy and waste wood and paper are used in Finland and Sweden. These low-value by-product feedstocks are excluded from the land use estimates in this analysis.

[69] In other words, most Brazilian ethanol output uses all the juice extracted from the cane, but some uses the molasses by-product left after the cane juice has been processed into sugar.

Fig 6.2 – World Fuel Ethanol Production by Feedstock



Source: Authors' analysis from various international and national sources – see Appendix 3

Land use estimates for ethanol production were derived by dividing the amount of each relevant feedstock used by its average annual yield in each country concerned using data from FAO, USDA, UNICA, Eurostat and other national sources[70].

The resulting totals show that some 20 million hectares were harvested globally to produce fuel ethanol, 15 million hectares of which comprised maize, with sugar cane and other cereals accounting for most of the difference. It is worth noting here that although fuel ethanol production has increased in recent years, the harvested area has remained fairly flat since 2010, with the exception of the 2012 US drought-affected crop[71]. Similarly, the continued rise in Brazilian ethanol output has occurred with relatively little increase in harvested area over recent years (fig 6.3).

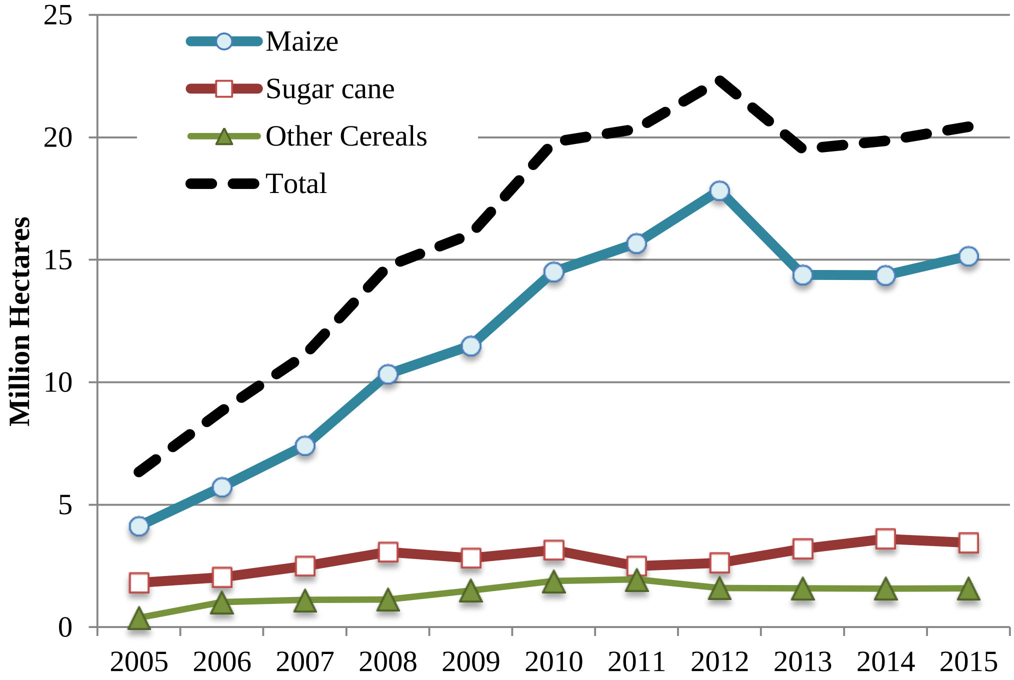
However, these calculated feedstock areas also tend to overestimate the areas devoted to feedstocks used in ethanol production due to the fact that valuable co-

[70] It is noted again here that the use of average national yields will tend to overestimate the amount of land used, as many biofuel operations source their feedstocks from large-scale producers or have their own feedstock operations, both of which tend to produce higher feedstock yields than national averages.

[71] Average US maize yields were exceptionally low in 2012 leading to a larger area being required to meet the same level of supply

products are also produced. In US maize ethanol production, for example, about one-third of the grain is used for ethanol production, whilst another third results in the high-protein feedstuff known as distiller dried grains solubles (DDGS).

Fig 6.3 – Global Areas Devoted to Fuel Ethanol Feedstocks



Source: Authors' analysis from various international and national sources – see Appendix 3

However, the value of co-products is often less than the biofuel revenue, so apportioning the area on a mass volume basis would not reflect the influence of the biofuel and its co-products on the decision to plant feedstocks. As explained in the methodology section, this analysis therefore uses a revenue-based allocation of land area to the various co-products.

Co-product revenues from maize ethanol production were calculated from information provided by ethanol processors to the US National Agricultural Statistical Service (NASS) each week. An average ethanol price for recent years of $1.5 per gallon was used, together with an average value of $150 per tonne for DDGS and 35 cents per pound for the maize oil recovered. Some analyses also include values for the remaining corn cobs and straw/stover, often used as energy sources, as well as CO_2 gas sales to beverage producers and other users.

Table 6.1 shows two examples of the revenue breakdown between co-products in US maize ethanol production, using processing information from two different sources and rounded average prices over recent years. This suggests that ethanol revenue is about three-quarters of the total revenue earned from one tonne of maize given the volume breakdown and average prices of different co-products. Similar analyses for sugar cane and other cereals resulted in average ethanol revenue proportions of 90 and 70 per cent, respectively.

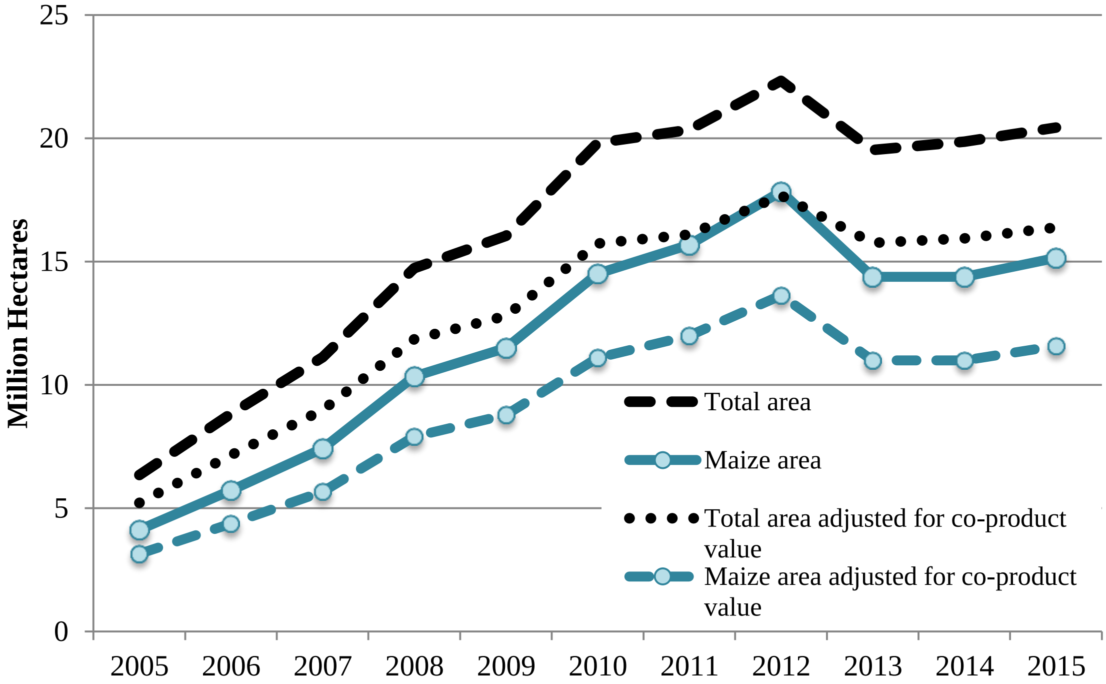
Table 6.1 – Example Revenue Calculations from the Processing of 1 Tonne of Maize for Ethanol

	Example 1 using data from			**Example 2 using data from**		
	USDA, 2016	**Unit**	***Notes***	**Mumm et al, 2015**	**Unit**	***Notes***
Mass of ethanol	0.330	tonnes	*417 litres/t*	0.327	Tonnes	*414 litres/t*
Price of ethanol	502.00	$/tonne	*$1.5 per gallon*	500.00	$/tonne	
Revenue from ethanol	165.66	$		163.42	$	
Mass of DDGS	0.314	tonnes	*17.75 lb per bushel*	0.308	Tonnes	*308kg/t of maize*
Price of DDGS	150.00	$/tonne		150.00	$/tonne	
Revenue from DDGS	47.17	$		46.20	$	
Mass of maize oil	0.005	tonnes	*5kg/t of maize*	0.004	Tonnes	*4.29kg/t of maize*
Price of maize oil	771.61	$/tonne	*35 cents/lb*	750.00	$/tonne	
Revenue from maize oil	3.86	$		3.22	$	
Other co-product revenue	10	$	*CO2, corn cobs & stover*	0	$	
Total revenue	**226.69**	**$**		**212.83**	**$**	
% revenue from ethanol	**73**	**%**		**77**	**%**	

Note –The data in this table are typical values based on standard processing coefficients and average approximate prices for co-products over recent seasons.
USDA figures are derived from the USDA AMS Bioenergy Market News series (USDA, 2016a) which incorporate standard coefficients for ethanol, DDGS and oil yields from US ethanol plants. Prices of ethanol, DDGS and corn oil are also derived from USDA reports, using rounded average figures recorded over the past five years. For other co-product revenue, a nominal figure has been used within the USDA analysis due to the lack of data on CO_2, corn cob and stover/straw sales and prices.
The analysis by Mumm et al (2014) did not include values for other co-products and rounded average prices have been used for ethanol, DDGS and corn oil within this example.

Applying the 75 per cent revenue proportion to the area devoted to maize ethanol, plus calculated revenue proportions for other cereals and sugar cane and beets and other feedstocks, results in a global area of just over 15 million hectares devoted to fuel ethanol production, an increase of 10 million hectares over the past decade (fig 6.4). The 2015 estimated harvested area represents just under 1 per cent of the global arable area according to FAOSTAT data.

Fig 6.4 – Global Harvested Area Devoted to Fuel Ethanol Feedstocks Adjusted by Co-product Revenue



Source: Authors' analysis from international and national sources – see Appendix 3

Whilst the global land area devoted to ethanol production has increased from 5 million hectares to just over 15 million, much of the trebling of global fuel ethanol output over the past decade can be attributed to yield growth and a larger share of less land-intensive feedstocks such as molasses. It is also clear that by far the largest area increase has been caused by US maize-based ethanol.

It should also be noted here that the increases in harvested areas devoted to biofuel feedstocks may not necessarily result in a similar increase in the overall arable area. Harvested area incorporates double-cropping where more than one crop is harvested in the year. There may also be an increased proportion of arable land harvested over time as better practices encourage reduced crop losses or less fallow and fodder crops.

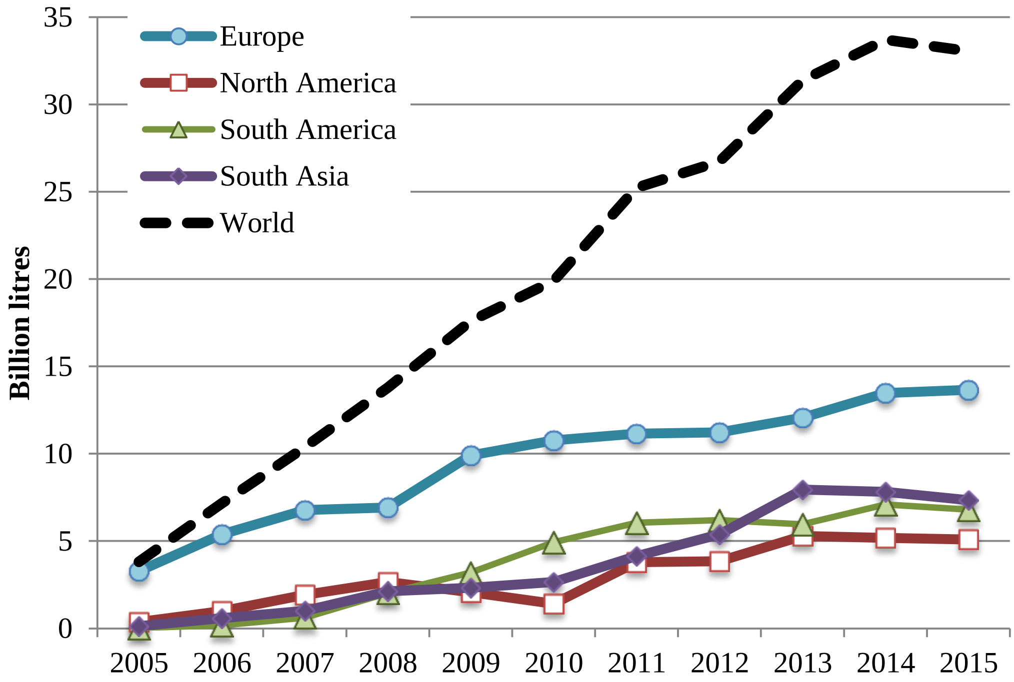
6.1.2 Usage of land for biodiesel production

Biodiesel production is defined in this analysis as conventional fatty acid methyl ester (FAME) biodiesel, plus hydro-treated vegetable oil (HVO). Production has risen from some 4 billion litres in 2005 to 33 billion in 2015, when there was a slight reduction in output for the first time over the past decade (fig 6.5). The EU is the leading producer, but South Asia, South America and North America have all seen a steady rise in production from virtually zero output in 2005. The fall in production between 2014 and 2015 was mainly due to reduced volumes produced in Indonesia and Argentina, as reflected in the table of world biodiesel and HVO production by country in appendix 4.

The main feedstock used in biodiesel production is soyabean oil, which accounts for most production in the Americas. However, global biodiesel output from used cooking oil (UCO) and animal fats (tallow, lard and chicken fats) has been the fastest rising feedstock category, and production from these sources was close to that of soyabean oil in 2015. Rapeseed was the largest world feedstock source until 2011, whilst palm oil-based biodiesel rose sharply to 2013, but fell back to fourth-highest in 2015 (fig 6.6).

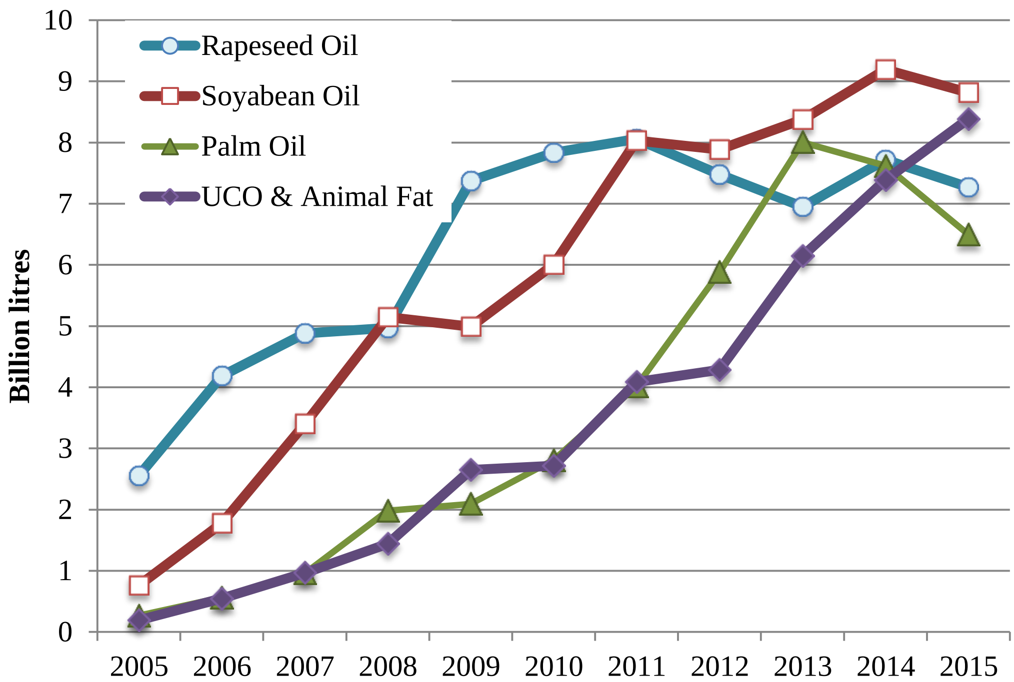
In terms of land use, the total area devoted to all biodiesel feedstocks was about 22 million hectares in 2015, with soybeans accounting for 15 million (70 per cent) of that (fig 6.7). However, adjusting for co-product market value (mainly protein meals used in animal feed), produces a total area devoted to biodiesel production of just under 10 million hectares, with soyabeans accounting for just under 5 million (50 per cent), rapeseed and sunflowerseed 3.5 million and palm and coconut, 1 million (fig 6.8).

Fig 6.5 – World Biodiesel Production – 2005 to 2015



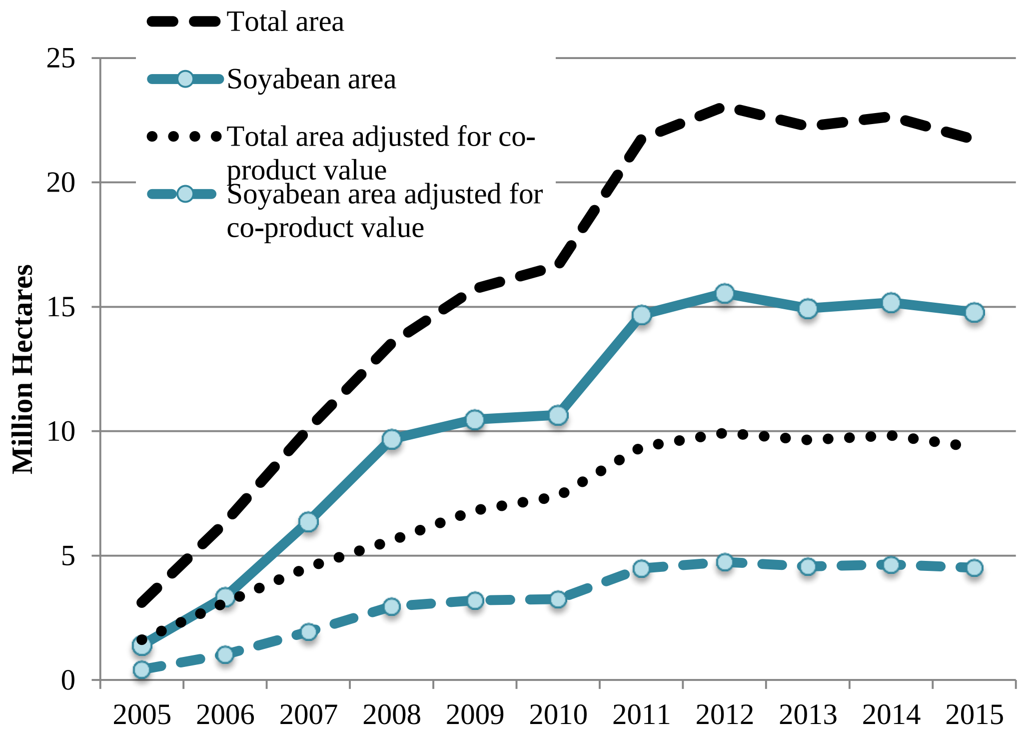
Source: Authors' analysis from international and national sources – see Appendix 4

Fig 6.6 – World Biodiesel Production by Feedstock – 2005 to 2015



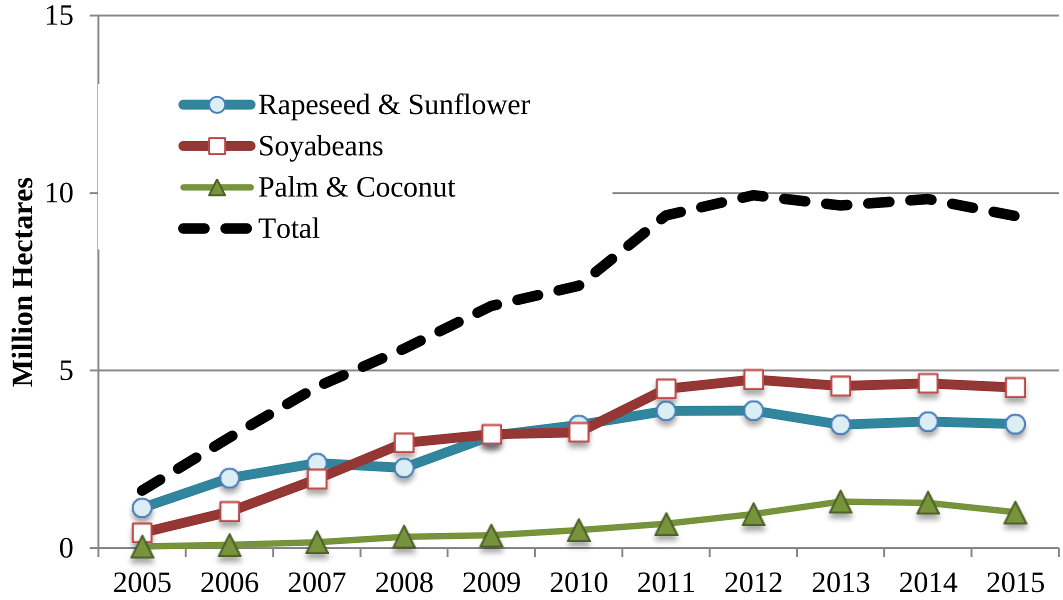
Source: Authors' analysis from international and national sources – see Appendix 4

Fig 6.7 – Global Biodiesel Harvested Area Devoted to Total Biodiesel Feedstocks and to Soyabeans, and Areas Adjusted by Co-product Revenue



Source: Authors' analysis from international and national sources – see Appendix 4

Fig 6.8 – Global Harvested Areas Devoted to Biodiesel Feedstocks Adjusted for Co-product Revenue



Source: Authors' analysis from international and national sources – see appendices 3 and 4

As with ethanol, the global area devoted to biodiesel has remained relatively constant over the past five years at 10 million hectares, despite the rise in biodiesel production, as UCO, animal fats and HVO from waste products have captured a greater share of world output, and as feedstock yields of soyabeans and rapeseed have increased. The large difference between the total feedstock areas and that adjusted for co-products, largely reflects the substantial volume of protein meal output that entered the animal feed sector.

6.1.3 Total biofuel land use

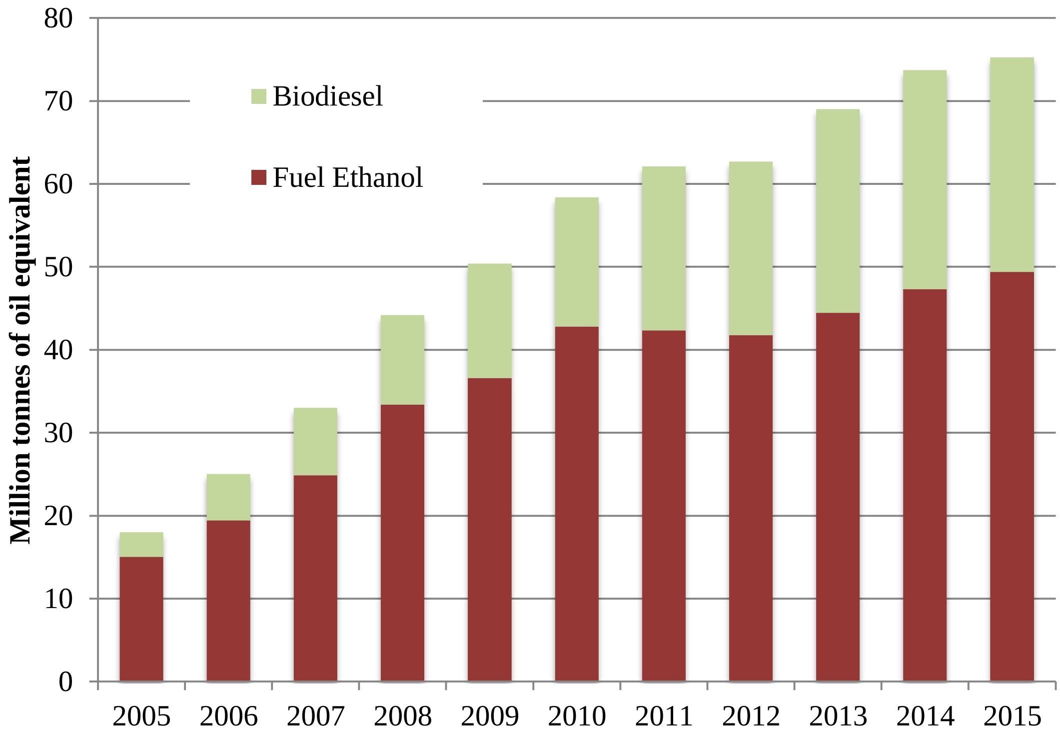
In order to illustrate total biofuel production within a single metric, ethanol and biodiesel production estimates must be converted to an equivalent energy basis, as a litre of ethanol provides only 70-75 per cent of the energy of a litre of biodiesel. The volume totals are therefore converted into comparable energy values, using standard conversion factors into tonnes of oil-equivalent. Global biofuel production was calculated at some 75 million tonnes of oil-equivalent (toe) in 2015, ethanol accounting for some two thirds and biodiesel a third (fig 6.9). This represents some 2 per cent of global crude oil production and about 12 per cent of US crude oil production.

When translated to feedstock areas, this represents over 40 million hectares. However, when the value of co-products is accounted for, the area devoted to biofuels has been about 25 million hectares per annum over the period 2013 to 2015. Accounting for co-products on a mass-equivalent basis, rather than market-value, results in a global area devoted to that part of the feedstocks from which biofuels are produced, of some 15 million hectares in 2015 (fig 6.10).

It is arguable which method provides the most realistic assessment of the land area devoted to biofuels, as opposed to the amount allocated to producing animal protein meals and other co-products. Acknowledging that the market-value methodology employed is more likely to over than underestimate biofuel land use, but that mass-based methods tend to underestimate the influence of co-product revenues on feedstock plantings, it could be argued that an average value in between the market and mass-based results might be the most appropriate, at about 20 million hectares.

However, this study uses a market value method as the likely most influential factor in planting decisions.

Fig 6.9 – Global Biofuel Production in Oil-Equivalent Tonnes

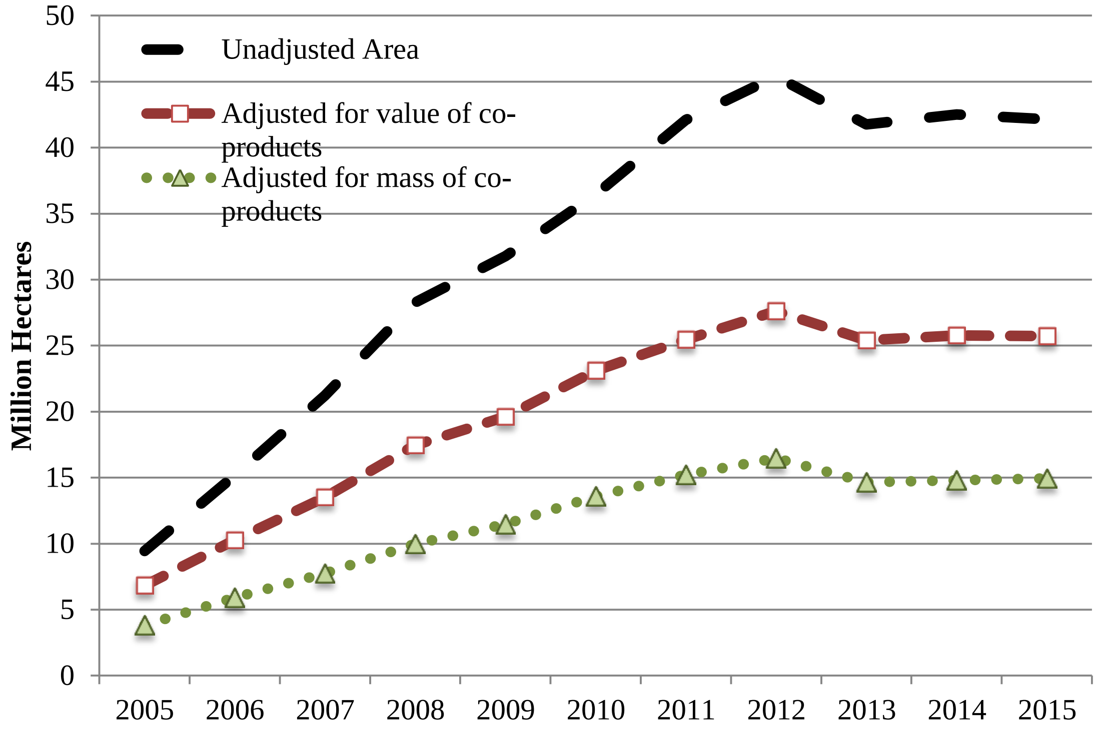


Source: Authors' analysis from international and national sources – see appendices 3 and 4

The global area devoted to biofuel feedstocks has been relatively stable since 2011, and only rose slightly in 2012 due to the US maize drought and low yield of maize that year (hence, requiring more land to meet ethanol demand). Whilst North America accounted for 46 per cent of the global area on which biofuel feedstocks were produced in 2015, Africa accounted for only 0.1 per cent.

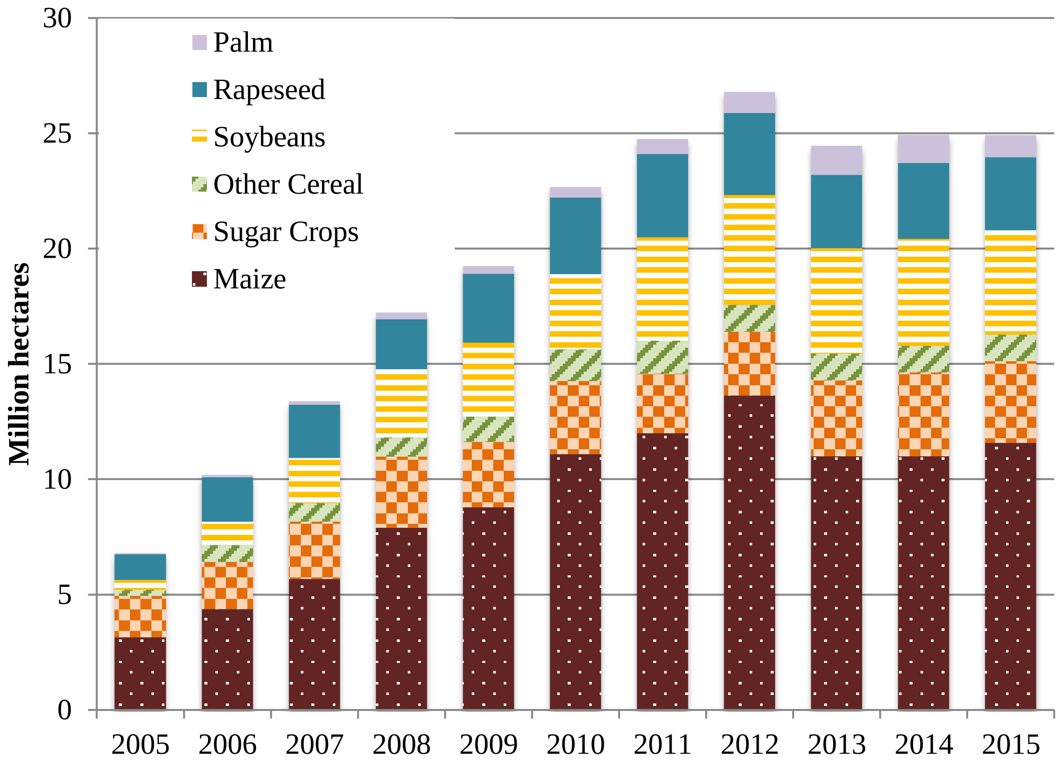
Breaking down the global biofuel area by feedstock, shows that ethanol feedstocks accounted for some 16 million hectares in 2015 and biodiesel 9 million, after adjusting for co-product values. Maize accounted for the largest land use of the biofuel feedstocks in 2015, at 11.6 million hectares, followed by soybean with 4.5 million, sugar feedstocks (cane, beet and molasses) at 3.5 million and rapeseed at 3.2 million hectares (fig 6.11).

Fig 6.10 – Global Harvested Area of Biofuel Feedstock – 2005 to 2015



Source: Authors' analysis from international and national sources – see appendices 3 and 4

Fig 6.11 – Global Harvested Area by Type of Biofuel Feedstock adjusted for Co-product Values – 2005 to 2015



Source: Authors' analysis from international and national sources – see appendices 3 and 4

The global harvested area figures since 2011 show that the increased biofuel production since then has been met without any significant increase in land use, as the 2012 jump was due almost entirely to the drought-hit US maize yields. The rise in biofuel production during that period, from just over 60 billion litres to some 75 billion, was therefore largely met through a combination of improved feedstock productivity (through higher yielding varieties, better farming practices to boost yields of existing varieties, more double cropping, increased intensity of planting, etc), a larger share of higher biofuel-yielding feedstocks in the overall mix, a larger share of feedstocks with no land use implications, such as UCO and animal fats, and improved plant efficiency.

6.1.4 Biofuel land use changes in the context of global land use

The overall increase in land area since 2005, when the US introduced its first biofuel blending mandates, and the first year of the EU indicative blending targets, is estimated at 33 million hectares in total and at 19 million hectares when adjusted for co-product values. The latter figure is about 1.2 per cent of the total world area under arable and permanent crops in 2013, and similar to the net 21 million hectare increase in the global arable and permanent crop area between 2005 and 2013 (FAO, 2016a).

In terms of co-products, livestock protein meals in the form of oilseed-based meals and DDGS would have accounted for the majority of the difference, at some 14 million hectares. Since most of the co-products have entered the animal feed sector, it could be argued that biofuel and co-product demand has contributed to food supply to that extent whilst utilising 19 million hectares for actual biofuel production, in terms of the revenue share.

However, it is difficult to gauge the extent to which the 33 million hectare additional crop area for biofuels and animal protein meals combined, has replaced the area planted to other crops or whether the new demand has added to overall feedstock plantings. The increased production of animal protein feeds from biofuel production should help to displace feed use of other raw materials by a similar amount depending on the feed value. But in terms of food security, the key question is to what extent does the increased area devoted to biofuel production reduce existing and potential food production?

As noted above, according to FAO the global arable and permanent crop area rose by 21 million hectares from 2005 up to 2013 when the latest figures are available. The estimated 19 million hectare rise in the global biofuel feedstock area suggests that biofuels could have contributed to a significant proportion of this increase. But table 6.2 shows that most of the 21 million hectare increase in the arable area was due to a significant rise in the area under permanent crops, particularly in Asia. The overall world arable area increase during this period was estimated at just 2 million hectares[72].

The areas in table 6.2 relate to land use rather than harvested areas. Thus, increased double-cropping and inter-cropping, would show a larger increase in the harvested area of arable crops compared to arable land use. A smaller gap between areas planted and harvested as farming techniques improve and less crops are lost to bad weather and disease, would also show a larger increase in harvested area compared to arable land cover. Some parts of the world are also recording losses in arable land to non-cropping and pasture uses, such as forestry, whilst increased arable land in Africa is largely at the expense of forest.

Table 6.2 – Changes in Global Land Use – 2005 to 2013

Million hectares	**Africa**	**Americas**	**Asia**	**Europe**	**Australasia**	**World**
Arable & Permanent Crops	20.8	0.2	5.8	-2.9	-3.0	**21.0**
Arable Land	*15.2*	*1.8*	*-9.9*	*-2.0*	*-3.1*	***2.0***
Permanent Crops	*2.9*	*-1.6*	*15.7*	*-0.9*	*0.1*	***16.3***
Meadows & Pasture	1.1	13.1	2.5	-3.7	-46.1	**-33.1**
Agricultural Area	22.0	13.3	8.3	-6.6	-49.1	**-12.1**
Forest	-24.9	-20.0	10.9	10.6	-3.5	**-27.0**
Other Land	3.5	5.3	-19.4	-4.8	52.7	**37.2**
Net Land Change	*0.5*	*-1.4*	*-0.2*	*-0.8*	*0.0*	***-1.9***

Source: FAOSTAT

[72] Note that the FAOSTAT data for the individual Arable and Permanent Crop global area changes do not add up to the combined Arable and Permanent Crop global area change due to an imbalance of some 2.7 million hectares in the figures for Africa. Thus the arable area and/or permanent crop area increase in Africa may be up to 2.7 million hectares more than was estimated in the FAOSTAT database at the time of writing.

It is difficult to identify the reasons behind the global land use changes given the available data. There has clearly been a significant increase in the global harvested areas of maize and oilseed crops, but it is less straightforward to gauge the extent of land-saving practices such as double-cropping as these are not always measured in surveys or reported in official statistics.

As noted in the literature review, one way of estimating such land-saving practices is the multiple cropping index, which reflects the proportion of the arable area that is harvested each year. This has been used by Langeveld et al (2014) to show that, over the period 1980 to 2010 a rising proportion of the world's available arable land was harvested, with the MCI rising from 0.85 in 1980 to 0.99 in 2010. Similarly Babcock and Iqbal (2014) found that the main response of the world's farmers between 2004 and 2012 was to use land more efficiently rather than bringing new land into production.

Using FAO data from table 6.2 and slightly lower world harvested areas of the main crops than used by Langeveld et al, suggests that the global MCI rose from just under 0.87 in 2005 to nearly 0.94 in 2013, allowing for a sharp increase in harvested areas during that period despite the small increase in the net arable area.

The 19 million hectare biofuel-related addition to the global harvested area between 2005 and 2015 is also a relatively small amount of the estimated potential global availability of additional land thought to be suitable for additional crop production, which is conservatively estimated at 200 million hectares from the literature review[73].

The scope for further increases in biofuel feedstock acreage largely depends on food needs over the coming decades. FAO estimates that a further 70 million hectares are required to meet food needs by 2050. However, this may not fully incorporate the substantial potential savings in land use from reduced food waste, reduced

[73] This is deemed a "conservative" estimate, as it is the lowest of the range of estimates found within the literature review for this study.

consumption per capita of livestock products in the developed world and the potential of urban agriculture to feed a growing proportion of city inhabitants.

Although the estimated additional land for global rainfed crop production, at 200 million hectares, seems large in relation to the additional 70 million hectares projected by the FAO as being needed by 2050 to meet food needs, climate change impacts could also affect productivity and result in more land being needed for food production

African and other developing countries have the greatest potential for increased crop acreages to meet future food and bioenergy needs and should be facilitated to exploit this where deforestation is avoided, valuable ecosystems are protected and local communities are not disadvantaged, particularly as current biofuel feedstock areas in Africa account for only 0.1 per cent of the global total.

6.2 The Impact of Biofuel Feedstock Demand on Food Prices

It is commonly claimed that increased demand for biofuels has been a major factor behind the rise in food prices around the world. The following section describes the findings from the analysis of biofuel impacts on US maize prices.

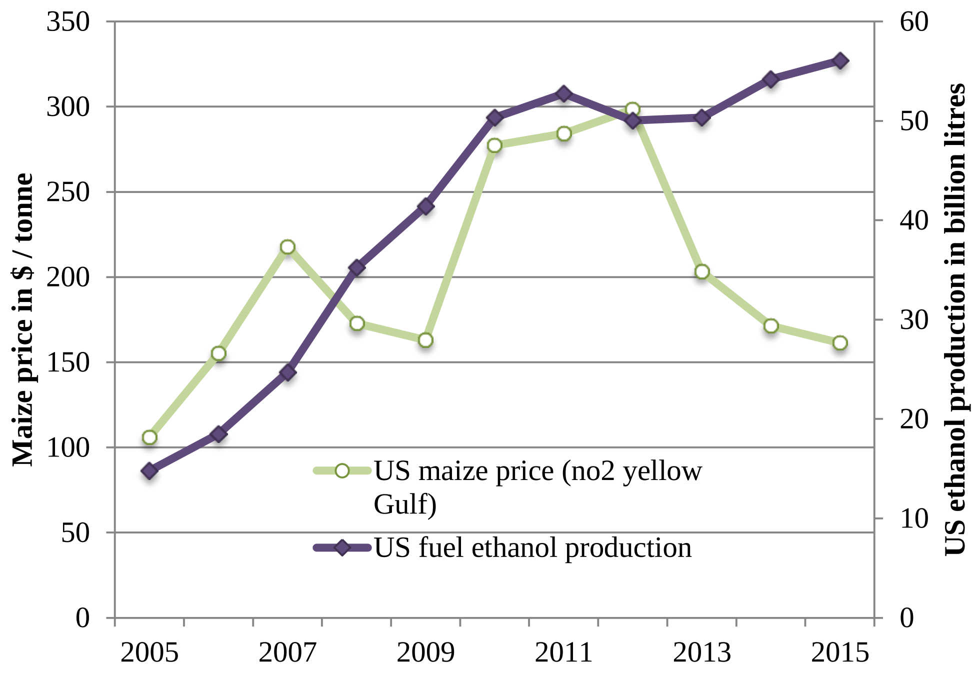
6.2.1 Analysis of US maize prices and biofuel production

Much of the increase in global food prices over the past decade has been attributed to the sharp rise in US ethanol production using maize as a feedstock. US maize prices are often regarded as a benchmark for the cereal complex as the US accounts for over a third of world trade (Berg et al., 2014). Maize is also the most important cereal in terms of volume, with some 1 billion tonnes produced and consumed globally (USDA, 2016b). Most of the maize consumed is for animal feed: hence, maize values also influence prices in the livestock complex. Maize prices also tend to be the lowest of the major cereals, forming a base from which other prices are compared. For example, if wheat prices fall toward maize values, they become more competitive in feed value and animal feed processors will, at some point, start to replace maize with wheat in livestock rations.

Given the importance of US maize prices on world commodity markets, any increase in maize prices would tend to support values of other commodities. Thus, biofuel policies that encourage increased consumption of maize were thought to be a primary factor in the sharp rise in US maize prices and other related commodities such as wheat and soyabeans, particularly between 2005 and 2013. Indeed, the ethanol sector went from using under 5 per cent of all US maize use during the 1990s to just under 40 per cent in 2015.

Given the importance of ethanol use within US maize demand, it might be expected that there would be a strong correlation between US ethanol production and maize prices, particularly over the past decade when US ethanol production rose sharply to meet the growing demand. However, figure 6.12 shows that whilst US ethanol production increased over that period (with a slight fall in 2012), US maize prices dipped sharply in two periods during the past decade, and particularly over the three years since 2012. Clearly, there are other factors that influence maize prices as well as the rise in ethanol demand and production.

Fig 6.12 – US Fuel Ethanol Production and US Maize Prices – 2005 to 2015



Source: Adapted from USDA data

6.2.1.1 Understanding the main drivers of US maize prices

In order to understand the main influences on US maize prices over the past decade, it is necessary to look back at how prices have developed and which fundamental supply and demand forces and other factors influenced them. Some of the literature notes the importance of marketing year end-stocks in explaining US maize price developments (eg Good and Irwin, 2014).

A related indicator that is often used in the commodity trading complex is the end-season "stock-to-use ratio", reflecting the estimated level of stocks remaining at the end of the year or season, as a proportion of domestic use and exports. It therefore encapsulates the fundamental supply and demand situation in the market for that commodity, as any fall in the stock-to-use ratio should reflect demand exceeding supply and vice versa.

The relationship between the expected end-season stock-to-use ratio and the average price of a particular commodity and location will partly depend on the accuracy of the supply and demand estimates for that commodity and location at a given point in time, and partly on the degree to which prices are influenced by other factors, such as government policies and prices of other goods.

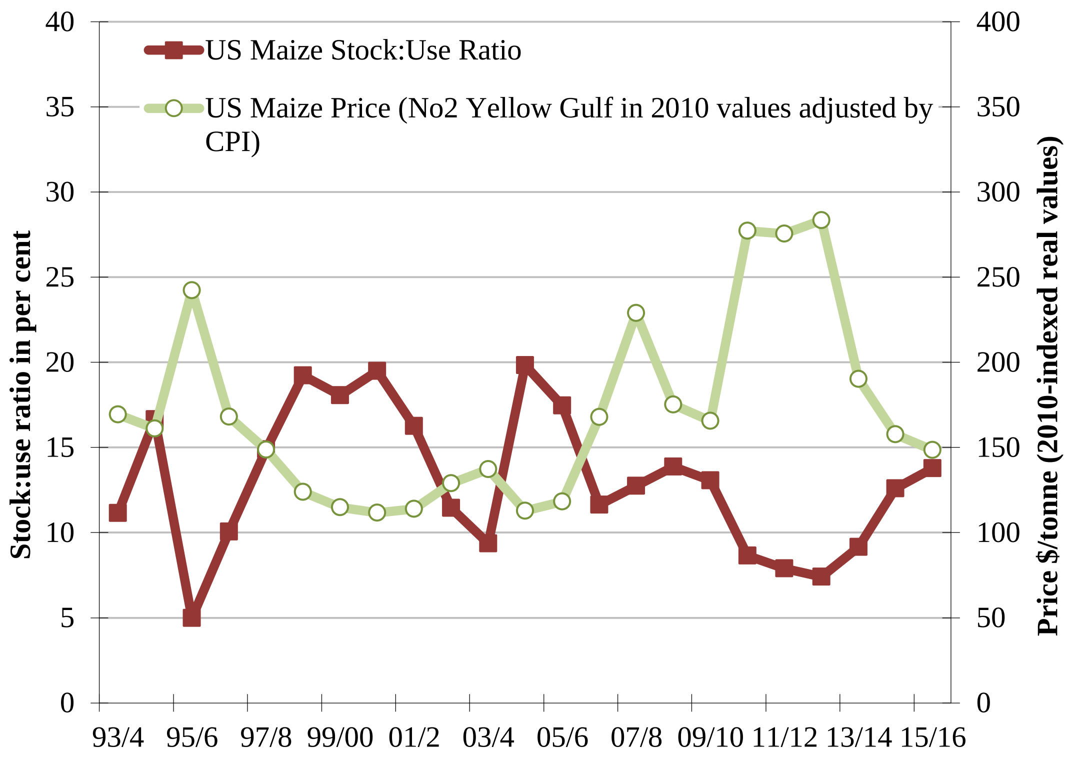
An analysis of US maize prices against the US stock-to-use ratio for maize was conducted, using annual average values for Number 2 grade yellow corn delivered to US Gulf ports, as this represents the major market for US maize exports, whilst annual average prices help to ameliorate the impact of short-term changes in prices. The prices were also adjusted by the US Consumer Price Index (CPI) in order to show real trends over the period covered from 1993 to 2015 (the prices are denominated in 2010 values).

The stock-to-use ratio is calculated as the end-season stock, resulting from the balance of supply (opening stocks, plus production, plus imports), minus demand (domestic use and exports), as a proportion of demand (domestic use and exports).

This reflects the relative scarcity or abundance of supplies in relation to demand in each season, which should then be reflected in market prices.

The resulting chart (fig 6.13) shows a relatively good inverse correlation, or mirror image, between the fundamental supply and demand situation, as reflected in the end-season stock-to-use ratio, and the real average seasonal price of US maize. In the years in which demand exceeds supply, such as in the event of a poor harvest, the stocks-to-use ratio falls and the price usually rises, in line with standard economic theory.

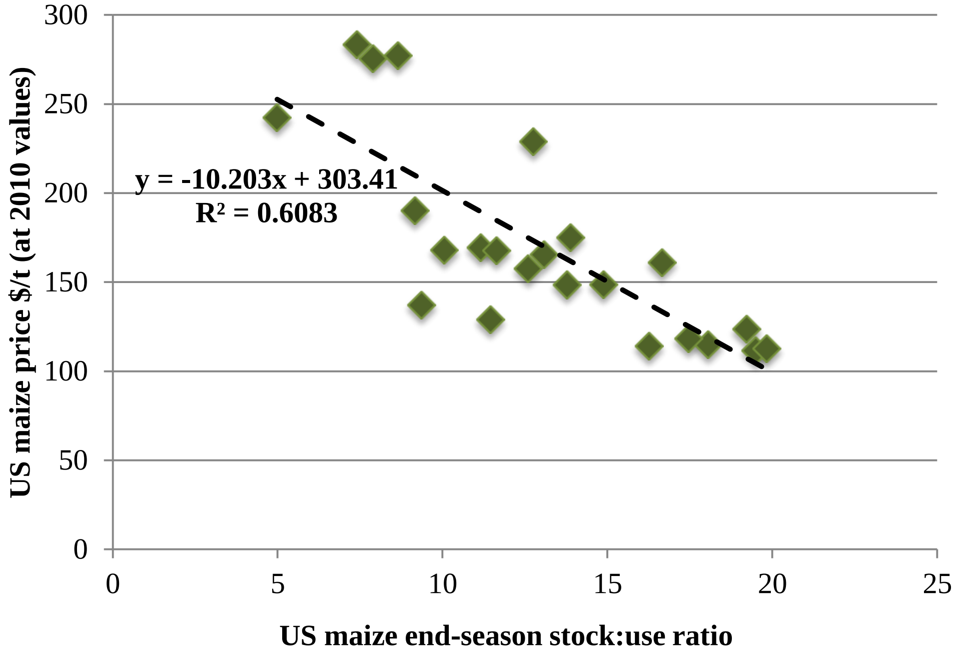
Fig 6.13 - US Maize Stock-to-Use Ratio and Real Price of US Maize



Source: Author's analysis from USDA data

A scatter plot of the two variables over the period covered, together with a best-fit straight line regression (figure 6.14), suggests a reasonable relationship between real US maize prices and US maize stocks-to-use ratios, but with an R-squared value of only just over 0.6. Many of the annual average prices below the best-fit straight-line regression are from the period before the biofuel boom and vice versa. This suggests a better fit could be achieved by dividing the time series into two periods: pre and post the introduction of the US Energy Policy Act in 2005.

Fig 6.14 – Relationship Between US Season-Average Maize Prices and US Maize End-Season Stock-to-Use Ratios – 1993 to 2015

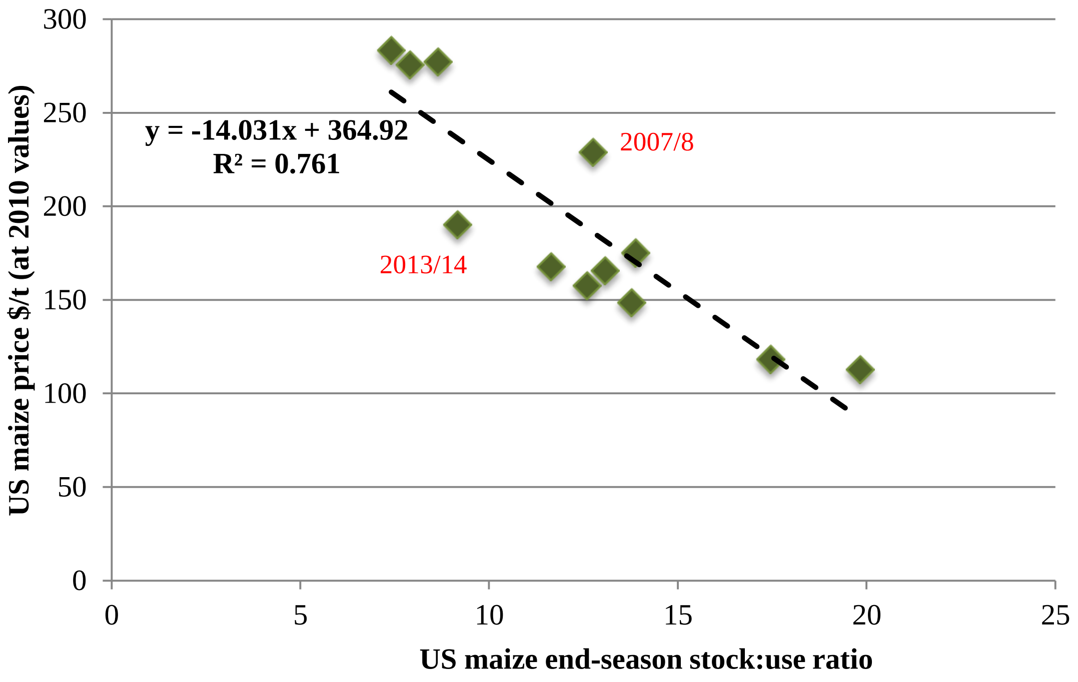


Source: Author's analysis from USDA data

This follows the argument of Irwin and Good (2009) that the biofuel boom created a new "era" of US maize price relationships to fundamental supply and demand forces. They argue that the sharp rise in ethanol demand for maize began in the 2007/8 season when prices also jumped sharply, and that since then supply has struggled to keep pace with the strong rise in demand.

An alternative view is that the main policy influences behind the US biofuel boom started in 2004 when a 10 per cent blending rate was authorised. US biofuel production up till then had mainly responded to the ban on MTBL as an oxygenate in some US States and was therefore restricted to a relatively low inclusion rate. Using the same analysis from 2004/5 at the start of the biofuel boom, figure 6.15 produces a steeper and better-fit straight line regression with an R-squared value of 0.76[74]. Similarly, a scatter plot of US maize prices adjusted for inflation against stock-to-use ratios from the pre biofuel expansion period of 1993 to 2003 also produces a better fit trendline, as in figure 6.16[75].

Fig 6.15 – Relationship of Real US Season-Average Maize Price and Stocks-to-Use Ratio – 2005 to 2015



Source: Author's analysis from USDA data

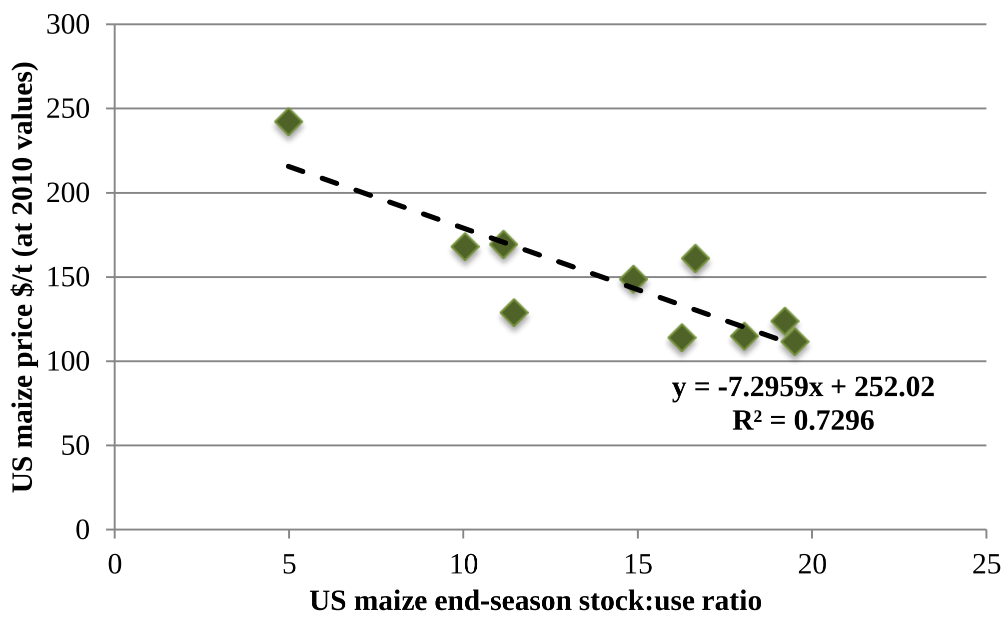
The steeper best-fit line in the most recent period suggests that the same stock-to-use ratios now result in more volatile US maize prices in real terms than they would have done in the previous decade. It suggests that as the stock-to-use ratio declines, US maize prices would tend to be higher in the more recent period than in the previous

[74] Note that other regressions were performed for the period concerned, and a logarithmic curvilinear regression produced a slightly better R-squared value of 0.808, but the constant within the equation suggested a current maize price of some $700 per tonne at a stock-to-use ratio of 1 per cent, which seemed difficult to justify. Whilst the regression calculation is only calculating the best-fit line from the period concerned, the logistic nature of the curvilinear equation suggested price predictions would be too high at more extreme low and high stock levels. It is, however, acknowledged that the straight line regression equation may underestimate prices at extreme high and low levels, but these differences appear to be less significant than those for the logarithmic equation.

[75] The season 2003/4 is omitted from the previous decade analysis as it represents a transition year between the two periods when it became apparent that a relaxation of blending restrictions could lead to sharply increased maize use over the following years.

decade, but prices could also be lower as stocks rise. This suggests a significant change in the relationship between US maize prices and fundamental supply and demand factors over the past decade than in the previous decade to that.

Fig 6.16 - Relationship Between Real US Maize Price and US Maize End-Season Stocks-to-Use Ratio – 1993 to 2003



Source: Author's analysis from USDA data

This relationship change could be attributed to the perceived greater risk for upside price potential associated with declining stocks-to-use ratios. This follows a period in which US maize supply struggled to keep pace with rising biofuel demand in the early years of the biofuel boom, leading to falling stocks. The tightening supply situation was then exacerbated by the drought-affected harvest of 2012, when lower exports helped to cushion the stock decline. Since 2012 stocks have started to rise again and prices have fallen, but the stocks-to-use ratio is still well below the 20 per cent levels recorded just before and after the millennium and also just before the biofuel expansion in 2004/5.

A prolonged period of high stocks might lead to a return to the lower price responsiveness recorded in the decade before the biofuel boom, in which case prices would not fall as steeply as the recent relationship (ie most recent decade) suggests.

In that case the relationship between maize prices and the stock-to-use ratio would need to be revisited and a new regression equation calculated for the new "era".

Although it is evident from the standard bivariate regression analysis that the stocks-to-use ratio has been a relatively good predictor of prices over the 2005 to 2015 period, there are clearly some years where prices do not respond as expected to the fundamental forces.

For example, figure 6.13 shows that in the 2007/8 season the maize stock-to-use ratio rose slightly yet the average price also increased sharply. In 2013/14, the stock-to-use ratio recovered slightly after the drought-affected season of 2012/13, and the annual average price did, as expected, fall. But the extent of the price decline was much greater than the supply and demand fundamentals suggested. Figure 6.15 also confirms that the two outliers in the relationship between maize prices and stocks-to-use over the past decade were 2007/8 and 2013/14.

There are many reasons why prices might diverge from the apparent market supply and demand situation. One reason could be that prices are responding to short-term market conditions that may change over the course of the season. For example, if sellers are holding onto stocks, this could create higher prices in the short-term. If the estimated supply and demand balance suggests that stocks will rise by the end of the marketing year, then one would expect a sharp fall in prices at some stage during the season. But this could still leave an average annual price that may not be entirely consistent with the fundamental situation reflected in the stocks-to-use ratio.

Also, the strength of the correlation depends on the accuracy of the supply and demand estimates, which may change over time as market conditions reveal prevailing inaccuracies. For example, harvest estimates may be revised during the course of the season if greater or less than anticipated supplies enter the market. The stock-to-use ratio should reflect such changes by the end of the season, but price developments could be affected in the short-term. Again, the use of annual average prices helps to offset short-term fluctuations for the most part, but the overall average may not fully correspond with the final supply and demand balance.

The US maize market is also affected by other factors besides its own fundamental supply and demand situation. For example, the maize price is also influenced by prices of other cereals that may act as a substitute for maize if the price differential moves in their favour. Thus, if maize prices rise too high in relation to wheat then some users, such as animal feed processors, will switch to wheat use, which, in turn, will then dampen down maize prices. Similarly if maize prices fall too far below wheat values then some users may be attracted to using more maize than wheat (eg distillers), supporting maize prices and acting as a price floor.

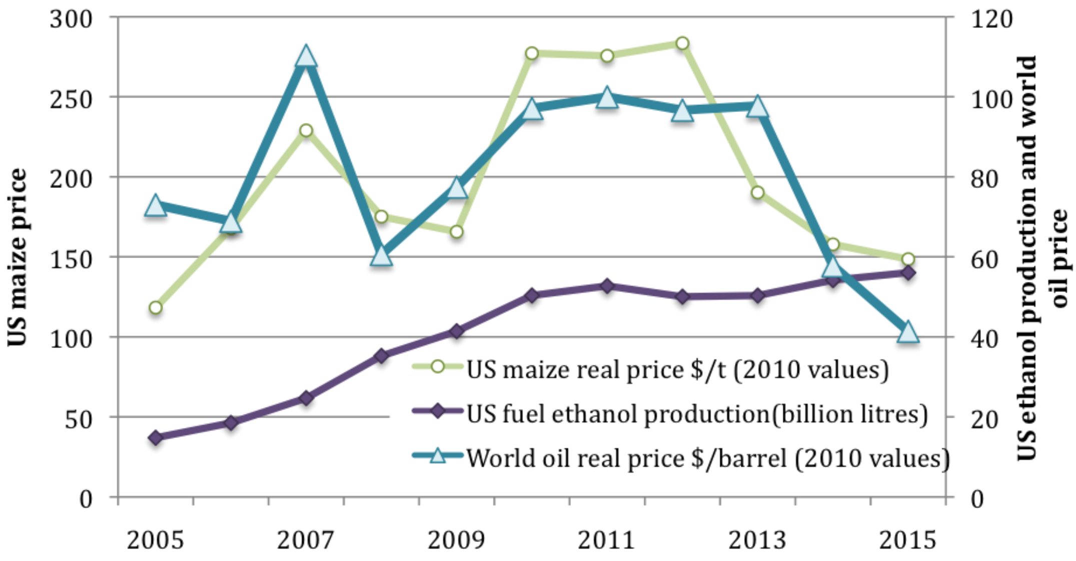
In terms of policy, minimum support prices and import parity prices (after any import tariffs or levies) can also create floor and ceiling prices, respectively, to the market. In the US, the loan rate support floor has had much less influence in recent years, but would, in previous decades, have prevented prices falling too far in response to any significant rise in the stock-to-use ratio. The effective ceiling for US maize prices is usually related more to the price of domestic cereals and other feedstuffs, including wheat, than the import parity calculation, since the US is the largest maize exporter in the world and imports are therefore always very small.

Another factor that may influence the maize price is the oil price, as this can influence the demand for maize through ethanol demand, as well as the supply of maize as a major input cost in production. World oil and maize prices appear to show a relatively close relationship, as illustrated in figure 6.17. It might be expected then that if oil prices were to rise this would increase the demand for ethanol as a substitute, and, hence, the demand for maize. But there appears to be little correlation between US fuel ethanol production and world oil prices. Thus, when oil prices have fallen, US ethanol demand has continued to rise.

This can be partly explained by the fact that ethanol production may remain profitable even when oil prices fall, and even if ethanol prices fall in line with oil prices, due to reduced feedstock costs in the form of lower maize prices. Given the importance of ethanol demand in the US maize balance, it is argued that maize prices are now linked to oil prices through the need to maintain profitable ethanol production.

It can also be partly explained by the requirement for US petrol manufacturers to blend a certain volume of ethanol prescribed each year. On blending ethanol, petrol processors are issued a certificate known as a Renewable Identification Number or RIN, which can be traded. Up till about 2013 petrol manufacturers blended more ethanol than was needed and a RIN surplus developed. At this point the amount of ethanol blended had reached 10 per cent of petrol, but manufacturers have been reluctant to raise their petrol products above the E10 blend by introducing E15 and higher blends, due to concerns regarding the impact on older engines.

Fig 6.17 – Relationship between US Maize Prices, US Fuel Ethanol Production and World Oil Prices



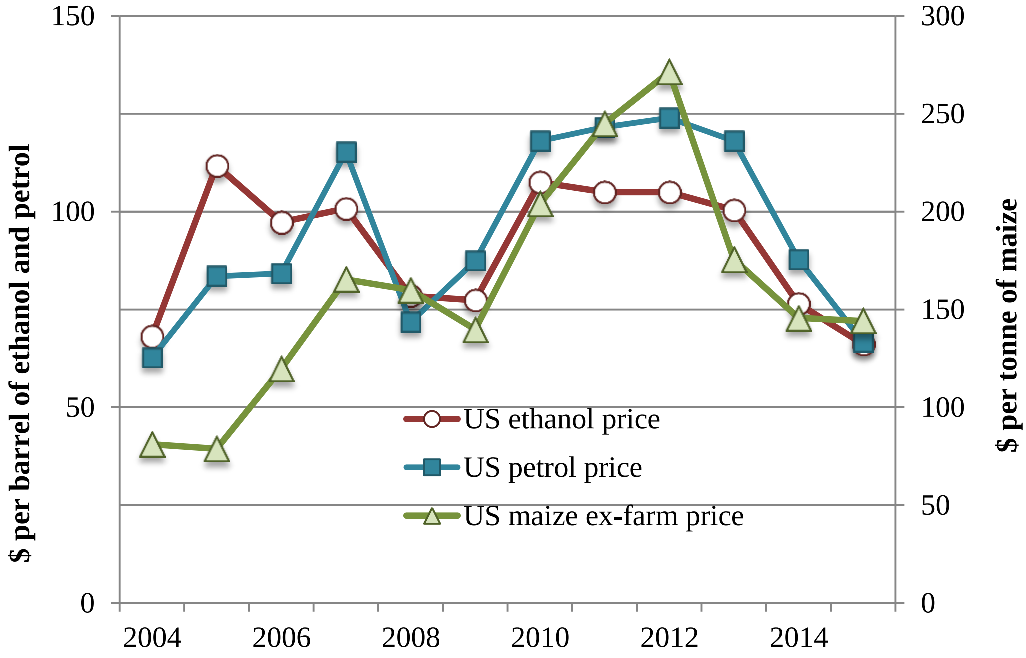
Sources: USDA and EIA reports

Another interlinked factor that has been particularly evident in recent years is the impact of oil prices on the demand for petrol. As oil prices have fallen in recent years this has increased the demand for fuel in the US, thereby increasing the demand for ethanol as blending rates were maintained at prevailing levels. Thus, falling oil prices can boost ethanol demand, which could, in theory, increase maize prices if ethanol prices did not need to compete with oil prices due to the blending mandates.

Since 2007/8 US ethanol prices have tended to trade below petrol prices in the US, at an average ratio of about 0.9. This does not reflect the much lower energy value of ethanol compared to petrol[76], but appears to be a level where ethanol is deemed competitive as an oxygenate and octane booster and has encouraged the blending of ethanol up to the maximum 10 per cent rate. However, at times US ethanol prices have traded at a premium to petrol prices, such as during December 2015 to February 2016. This can be largely explained by the requirement for fuel blenders to meet renewable volume obligations under the Renewable Fuel Standard.

Figure 6.18 shows average yearly US ethanol and petrol prices, together with average US ex-farm maize prices. This highlights the fact that ethanol, petrol and maize prices (on a different scale) do not always follow the same direction. However, there appears to be a closer relationship between the prices since US biofuel production began to surge from about 2007 onwards.

Fig 6.18 – US Ethanol, Petrol (Gasoline) and Maize Prices



Source : USDA and EIA

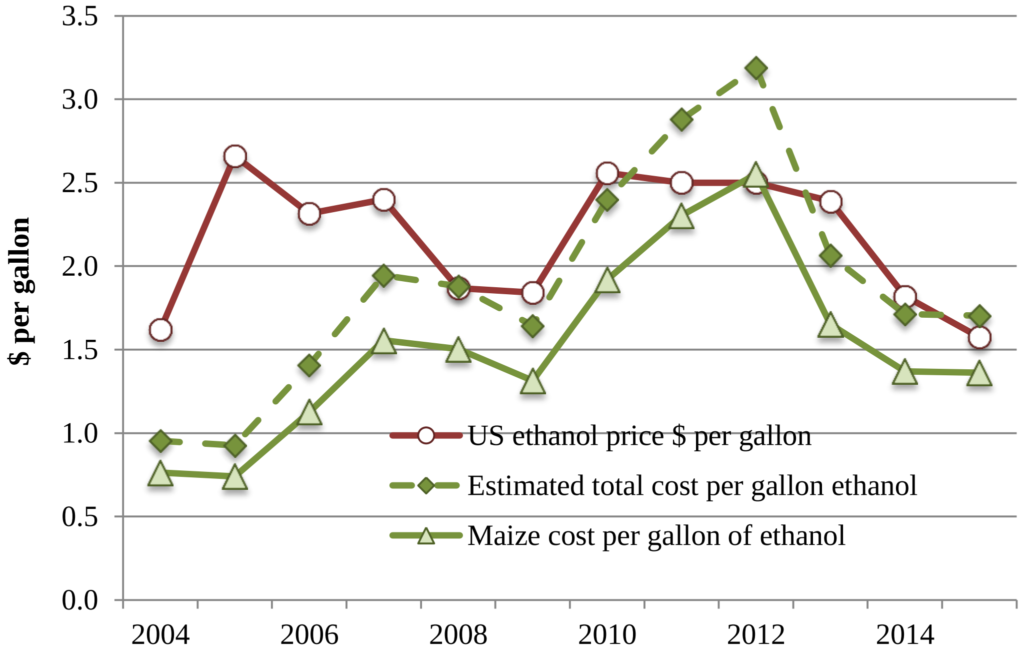
Maize usually accounts for some 70-80 per cent of the cost of ethanol production, so by charting ethanol prices against costs an average annual margin can be estimated. This suggests that average margins were negative for many producers during

[76] Ethanol only has an energy value of two-thirds that of petrol or a ratio of about 0.66

2011/12 and the drought-affected 2012/13 season when maize feedstock prices were high. However, with the exception of those two years, since 2007/8 ethanol and maize price trends appear to have resulted in narrow margins each year for ethanol producers (fig 6.19).

This suggests that the energy complex, comprising oil, petrol (gasoline) and ethanol prices, also exerts some influence over US maize prices, in addition to the influence of other competing cereal prices, such as wheat, and the end-season stock-to-use ratio. But the relationship between maize prices and those in the energy complex is less clear. This is particularly so between maize and ethanol average prices, even though maize comprises most of the cost of ethanol production. In fact maize prices appear to track petrol and oil prices more closely on the evidence of the past decade. Indeed, the correlation coefficients (Pearson's) for US maize prices and US petrol and world oil prices in real terms over the past decade were 0.8, both with p-values less than 0.01, whilst the coefficient for US maize prices and US ethanol prices was less than 0.4, and not significant.

Fig 6.19 – US Ethanol Prices versus Estimated Maize and Total Ethanol Costs per Gallon



Source : USDA and EIA reports

De Gorter, Drabik and Just (2013) argue that biofuel policies played a key role in the development of maize and other cereal prices, whilst allowing for the possibility of other factors having an important influence. They argue that of the different types of biofuel policies, some had long-run affects, some short-term impacts that may have been fleeting and some only influencing prices under certain circumstances and in certain time periods. They calculate that the impact of a change in the ethanol price on the maize price is very large from 2007 onwards, but that this is not always fully reflected in the maize price due to the economic concept of "water", representing the difference between the ethanol supply curve intercept and free market ethanol price.

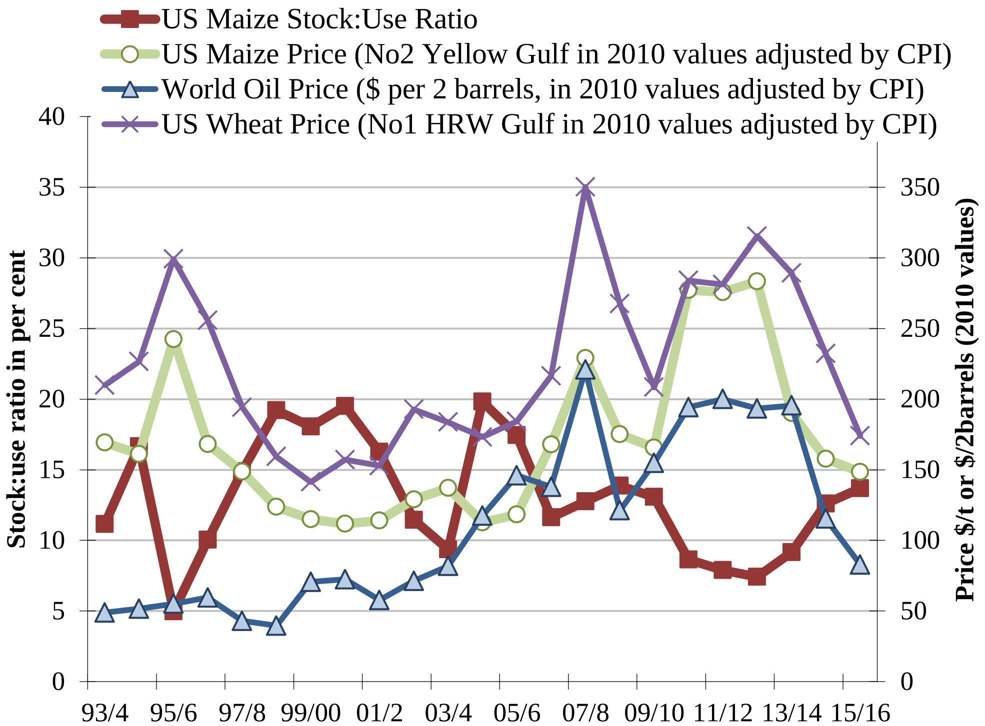
Indeed, the average annual price relationships between US ethanol and maize prices illustrated in figure 6.18, show quite a lot of divergence. Hence, the argument that US biofuel policies were the major influence on US maize prices over the past decade, even though ethanol demand accounted for only one part of the overall supply and demand balance, does not seem as intuitive as an argument based on the full supply and demand balance. The US biofuel policy targets provided a reasonably predictable level of demand for US maize from season to season that would have been factored into the market. US maize prices would have been influenced by ethanol and oil prices, but other parts of the balance would also have affected prices, including supply changes and exports, which would need to have remained competitive against supplies from other maize exporting countries. Thus, in 2012/13 US maize prices increased when ethanol prices fell, as shown in figure 6.19, leading to some ethanol producers recording losses that season.

In order to illustrate whether, and the extent to which, wheat and oil prices may have influenced the outlier maize prices in 2007/8 and 2013/14, figure 6.20 adds real US hard red winter (HRW) wheat and real world oil prices (average of Brent and Western Intermediate Texas) to figure 6.13. The world oil price is used as a more exogenous variable than the US petrol price, given that US petrol generally comprises 10 per cent maize-based ethanol[77]. The HRW wheat price is used as this

[77] In fact US petrol and world oil prices are highly correlated with a coefficient of 0.98 over the past decade.

represents the most common type of wheat produced in the US, and is generally regarded as the benchmark price for the world wheat market[78].

Fig 6.20 – US Maize Stock-to-Use Ratio and Price versus US Wheat and World Oil Price



Sources: USDA Feedgrain and Wheat Monthly Outlooks for US maize and wheat prices, adjusted by the US CPI and US maize end-season stock-to-use ratios, and EIA for world oil prices, which are the average annual season prices for Brent Crude oil and West Texas Intermediate oil at Cushing, Oklahoma.

Over most of the period covered US wheat maintains a significant premium over maize prices. In 2007/8, the US wheat price jumped higher as world wheat stocks fell sharply, pulling maize prices up as both domestic and export demand switched to maize instead of wheat. Even though the US maize stock-to-use ratio still increased that year, the influence of the wheat price spike was strong as it created increased demand for maize and did not allow the maize price to fall too far below that for wheat on a feed-value basis. Thus, maize prices were far enough below wheat to attract additional demand, helping to support prices at that level rather than any

[78] In practice it is often Soft Red Winter (SRW) wheat that replaces maize in animal feed rations when the price of maize rises to an uncompetitive level. Usually the SRW price discounts HRW by a relatively stable amount. However, the SRW market is thinner and sometimes subject to more localized influences that may not always reflect the general market conditions for the wheat complex.

lower. This effect may have been exacerbated by stock holding of maize in anticipation of higher prices given that wheat stocks were at an all-time high. The world oil price spike at the time would also have lent support to maize prices, allowing prices to increase whilst still maintaining the competitiveness of ethanol supplies for blending.

It is more difficult to explain from the chart why the 2013/14 average US maize price fell so sharply compared to the relatively small rise in the stock-to-use ratio. The bivariate regression analysis in figure 6.15 suggests the average US maize price should have been higher and there appears to have been no major influence from wheat prices, which remained high that season. The chart also shows that the average world oil price in 2013/14 rose slightly compared to the previous year and did not, therefore, appear to be exerting any downward pressure.

However, trade reports suggested that for much of the marketing year, the industry believed that the USDA had overstated its maize export forecast and, hence, understated its forecast end-season stocks (eg Good and Irwin, 2014). Thus, traders were working from a much higher end-season stock-to-use ratio and this perception within the market may have kept maize prices below the level they should have been given the actual end-season stock. It was argued that only toward the end of the marketing year did it become apparent that end-season stocks were lower than anticipated, by which time market corrections were unable to influence the average annual price to any great extent.

This raises an important factor that is rarely mentioned within the literature on biofuel linkages with food prices: that of market information. Where market information is lacking or inaccurate, prices may diverge from fundamental supply and demand conditions until the error becomes apparent or the absence is rectified. Thus analyses using daily, weekly and even monthly prices may significantly diverge from the prevailing supply and demand situation, which will ultimately be reflected in the end of season stock-to-use ratio. Annual average prices are more likely to correct for such discrepancies, as they usually become apparent as market conditions change, but sometimes the inconsistency may prevail for an extended period.

This data-driven, descriptive analysis provides the key factors behind the movement of US maize prices over the period covered, with prices largely responding to fundamental supply and demand conditions, as reflected in the stock-to-use ratio. But prices also appear to have been influenced at times by the replacement feed value of wheat, and the energy complex given that ethanol accounts for some 40 per cent of total domestic use, as well as imperfect market information flows.

An analysis was therefore conducted to assess the relationship between the average annual real US maize price, the US maize end-season stock-to-use ratio, US real wheat price and world oil price. The market information factor was omitted from the analysis given the difficulty in creating values for such a variable.

In order to assess the predictive ability of the three variables on the US maize price, a standard (simultaneous) multiple regression was conducted with the US maize price as the dependent variable and the US maize stock-to-use ratio, US wheat price and world oil price as the independent predictor variables. Because the sample size was small, a number of tests were performed to assess the suitability of the data for such an approach.

The sample size was restricted due to the problem that biofuel demand in the US only started to take-off from about 2005, before when there appeared to be a different relationship between maize prices and stock-to-use ratios as noted earlier. Also annual prices are used in this analysis due to the nature of the crop growing year and problems of seasonality, imperfect market information flows and different marketing patterns during and between years, which can distort the relationship between prices and the stock-to-use ratio.

The period covered only provides 12 years of data per variable. This is slightly below the minimum 15 subjects per predictor suggested by Stevens (1996) for multiple regression analyses, although a later study suggests that a minimum 9 subjects per variable can suffice where there are only 3 predictor variables (Knofczynski and Mundfrom, 2007).

The standard multiple regression output provides a means of assessing whether assumptions on multi-collinearity, normality and outliers are acceptable. The Pearson correlation coefficients in the multiple regression model were high for US maize prices and the US stock-to-use ratio at -0.872 and highly statistically significant ($p<0.0005$), with slightly lower correlation values and significance for US maize and wheat prices (0.813 and 0.001) and then slightly lower values again for US maize and world oil prices (0.765 and 0.002). But all values suggested strong associations between each of the independent variables and the US maize price.

Table 6.3 – Pearson Correlations Between US Maize, US Wheat and World Oil Prices and the US Maize Stock-to-Use Ratio

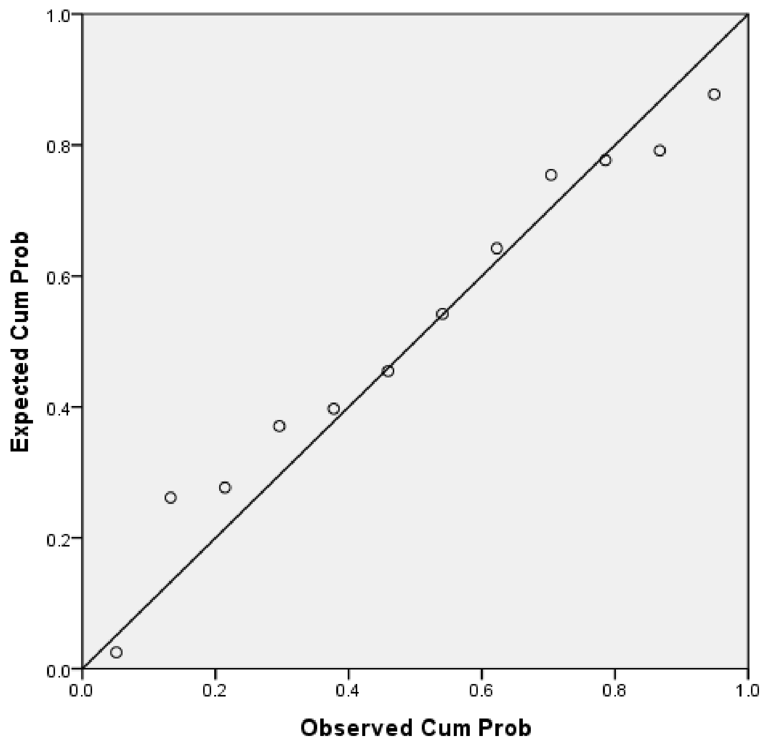
	US real maize price ($/t)	**US maize stock-use ratio (%)**	**US real wheat price ($/t)**	**World real oil price ($/barrel)**
Pearson Correlation				
US real maize price ($/t)	1.000	-.872	.813	.765
US maize stock-use ratio (%)	-.872	1.000	-.694	-.622
US real wheat price ($/t)	.813	-.694	1.000	.832
World real oil price ($/barrel)	.765	-.622	.832	1.000
Sig. (1-tailed)				
US real maize price ($/t)	.	.000	.001	.002
US maize stock:use ratio (%)	.000	.	.006	.015
US real wheat price ($/t)	.001	.006	.	.000
World real oil price ($/ barrel)	.002	.015	.000	.

A bivariate correlation between the independent variables of more than 0.7 is usually regarded as too high for inclusion, requiring adjustments to be made. The bivariate correlations of the US maize stock-use ratio and wheat and oil prices were below 0.7, but the correlation coefficient for US wheat and world oil prices, was higher, at 0.832 (higher than that for maize and oil prices).

Collinearity diagnostics were also performed as part of the multiple regression procedure. The tolerance values for both US wheat and world oil prices, at 0.258 and 0.305, respectively, were sufficiently far above the 0.1 threshold as to suggest that multicollinearity was not a major issue between the independent variables, whilst the tolerance level for the stock-to-use ratio, at 0.512, was also at an acceptably high level. The inverse of the tolerance level, known as the variance inflation factor (VIF), is also sometimes used to indicate multicollinearity at values of 10 and above. VIF scores for the variables in the model were between 1.95 and 3.88.

In terms of normality, the normal P-P plot for maize prices in the model is shown below, indicating a reasonable distribution and no major deviations from normality. There also appear to be no major outliers, with the Cook's distance maximum value of 0.245, well below the problem threshold of one (Tabachnick and Fidell, 2007).

Fig 6.21 – Normal P-P Plot of Regression Standardised Residual Dependent Variable: US Maize Price



Following the validation of the assumptions from the initial tests, a standard multiple regression analysis was undertaken to identify the influence of the independent variables on US maize prices. Table 6.4 shows the main results for the standard multiple regression of model 1. The model had an R-square value of 0.857, suggesting that the three independent variables explained some 86 per cent of the US maize price variance over the period covered. However, with such a small sample the adjusted R-square value of 0.803 (or just over 80 per cent of the variance) is considered to be a safer estimate of the model's ability to explain US maize prices over the period concerned (Tabachnick and Fidell, 2007). The p-value, at 0.001, shows that the model reached statistical significance.

Table 6.4 – Model 1 - Standard Multiple Regression Summary and Coefficients

Model	R	R-Square	Adjusted R-Square	Std. Error of Estimate	Sig
Model 1[a]	.926[b]	.857	.803	26.857	0.001[b]

a = Dependent variable is US real maize price (in 2010 values) in US$ per tonne.
b = Predictors – (Constant), US maize stock-to-use ratio (%), US wheat price ($/t), World oil price ($/barrel)

	Unstandardized Coefficients		Standardized Coefficients		Collinearity Statistics	
Predictors	B	Std. Error	Beta	Sig.	Tolerance	VIF
(Constant)	199.111	78.924		.036		
US maize stock-to-use ratio (%)	-9.279	3.006	-.577	.015	.512	1.952
US real wheat price ($/t)	.251	.273	.242	.385	.258	3.880
World real oil price ($/barrel)	.573	.677	.205	.422	.305	3.283

The model formula using the unstandardised coefficients was:

$$y = 199.111 + -9.279x_1 + 0.251x_2 + 0.573x_3$$

where y = the US real maize price (2010 value), x_1 = the end-season maize stock-to-use ratio, x_2 = the US wheat price and x_3 = the world oil price.

The contribution of the three variables to the prediction of the US maize price is given by the beta-standardised coefficients of -0.577 for the maize stocks-to-use ratio, 0.242 for the US wheat price and 0.205 for the world oil price. This suggests that the stocks-to-use ratio made the largest contribution to explaining US maize price movements in the model. In fact, the stock-to-use ratio was the only variable to make a statistically significant contribution to the prediction, with a p-value of 0.015.

The bivariate linear regression analysis of the US maize price and the single independent variable "stock-to-use ratio" in figure 6.15 gave an R-squared value of 0.76, and adjusted R-squared of 0.74, suggesting that just under three-quarters of the US maize price movement since 2004 was accounted for by the US maize stock-to-use ratio. The multiple regression model of the three independent variables then produced an adjusted R-squared value of 0.803. This suggests that the model has a better predictive ability for maize prices than the stock-to-use ratio alone, due to the addition of US wheat and world oil prices within the equation. However, only the maize stock-to-use ratio variable had a statistically significant influence on the prediction of the US maize price over the period within the model.

A second regression analysis was therefore conducted removing the world oil price. Although the collinearity tests for model 1 suggested no multicollinearity between the independent variables, there was a high correlation coefficient for US wheat and world oil prices. Since there was a higher correlation coefficient and more significant p-value between US maize and wheat prices than between US maize and world oil prices, it was decided to omit the world oil price.

Model 2 had a slightly better adjusted R-squared value than model 1, accounting for nearly 81 per cent of the US maize price variance at $p<0.001$. Although the p-value for wheat at 0.056 was more significant than in model 1, it was still above the 0.05 threshold and therefore only moderately significant[79].

Whilst acknowledging the small sample size, these standard linear multiple regression models provide further evidence that the end-season maize stock-to-use ratio provides a significant contribution as a predictor of US maize prices over the past decade. The model results also fit the hypothesis that the end-season maize stock-to use ratio is the main determinant of US maize prices. The model results for wheat also support the assumption that the wheat price is unlikely to be as consistent an influence as the stock-to-use ratio, but may, from time to time, pull the maize

[79] A third model was also conducted replacing the US wheat price with the world oil price, but this generated a slightly lower adjusted R-squared value and the world oil price variable was less statistically significant than the value for wheat in model 2.

price away from its expected trajectory based on the supply and demand fundamentals.

Table 6.5 – Model 2 - Standard Multiple Regression Summary and Coefficients

Model	R	R-Square	Adjusted R-Square	Std. Error of Estimate	Sig
Model 2[a]	.919[b]	.844	.809	26.431	0.000[b]

a = Dependent variable is US real maize price (in 2010 values) in US$ per tonne.
b = Predictors – (Constant), US maize stock-to-use ratio (%), US wheat price ($/t).

	Unstandardized Coefficients		Standardized Coefficients		Collinearity Statistics	
Predictors	B	Std. Error	Beta	Sig.	Tolerance	VIF
(Constant)	206.839	77.151		.025		
US maize stock-to-use ratio (%)	-9.566	2.939	-.595	.010	.519	1.928
US real wheat price ($/t)	.415	.190	.400	.056	.519	1.928

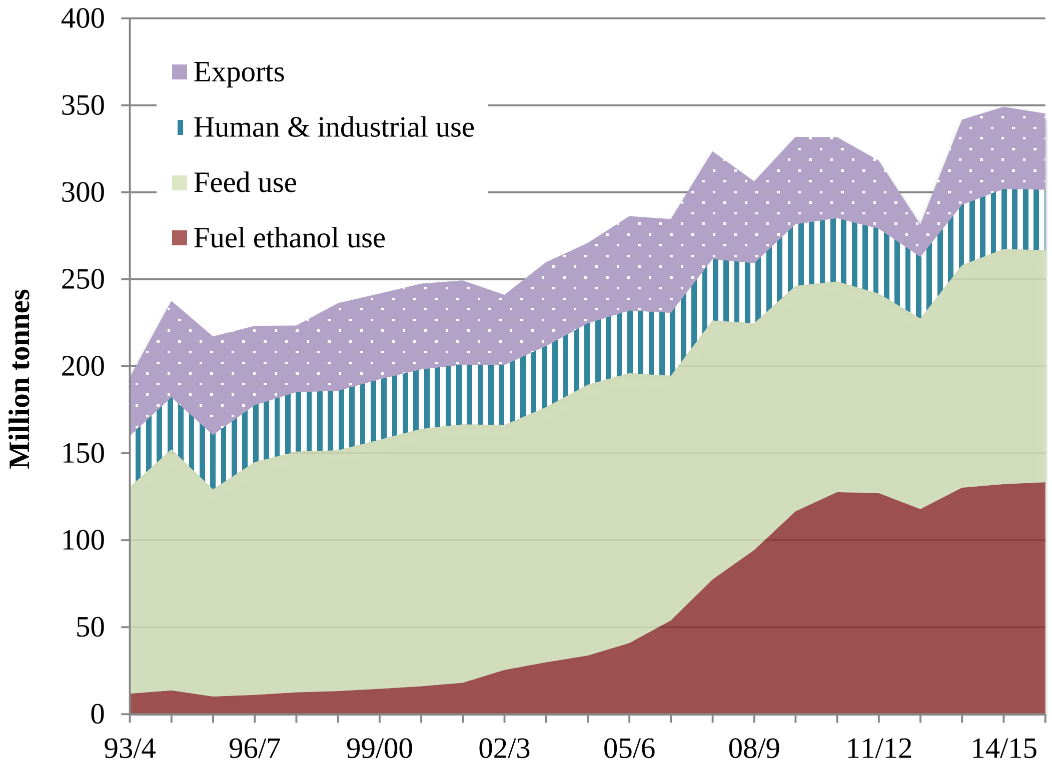
6.2.1.2 US maize supply and demand drivers

Having established that the stock-to-use ratio has been the main explanatory predictor of US maize prices over recent years, the key changes within the supply and demand balance can then be identified: these are the components that result in the stock-to-use ratio, which, in turn, largely determines the direction and size of US maize price movements. By analysing these data, the contribution of key supply and demand factors to changes in the stocks-to-use ratio can be assessed.

The use of maize by US ethanol processors has jumped sharply over the past decade. Figure 6.22 shows how maize use for fuel ethanol production rose from about 20 million tonnes at the turn of the millennium to some 130 million tonnes by 2010/11, since when it has stabilised. One of the key concerns regarding biofuels is that they transfer feedstock away from food and other uses. But the sharp rise in US domestic use of maize by ethanol processors has not caused an offsetting decline in use by either domestic processors or exporters, and instead, the total use of maize has risen by almost the same amount as that for ethanol production, with only a partial reduction in other uses.

Figure 6.22 shows that rising ethanol use appears to have mainly eaten into animal feed use of maize, which had reached over 150 million tonnes per annum just before the ethanol boom, compared to the 2015/16 level of some 130 million. The chart also shows that in 2012 when the US maize harvest was hit by drought, most of the compensatory fall in usage was experienced by the export sector, although ethanol plants also used less maize that year.

Fig 6.22 – US Maize Usage by Domestic Sectors and for Export



Source: USDA data

However, these statistics do not tell the full story of the impact of the ethanol sector on maize use. As previously noted, much of the maize processed into ethanol results in the production of distillers dried grains with solubles (DDGS), which are then fed as animal feed. Whilst DDGS is the main product from dry mills, there are also some wet-mill producers who produce corn gluten feed (CGF) and high-protein corn gluten meal (CGM). The wet-mill process is similar to that used by starch and high fructose corn syrup (HFCS) processors who also produce corn gluten feed and meal.

The US ethanol and other human and industrial (H&I) use survey data can be used to estimate yields of these maize protein feed products. Some data are also available from USDA reports on co-product production, use and trade. Using these figures, the maize use estimates have been adjusted for the maize protein feed co-products moving from the ethanol and other human and industrial (H&I) users into the animal feed and export sectors. It is assumed that there is a one-to-one replacement of these protein feeds to maize, although this may slightly understate the higher nutritional value of the protein feed products.

Figure 6.23 shows that the adjusted maize use for ethanol production (ie total use minus that used in the production of protein feeds), is currently less than a third of total US maize demand. Also, although US feed use of maize has fallen by about 20 million tonnes since 2005, total use of maize and maize protein feeds (DDGS, CGF and CGM) is almost the same today (2015) as that before the ethanol boom in tonnage terms. Similarly, whilst maize exports have fallen, total maize and maize protein-feed exports are currently similar to the levels pre-2005.

Nevertheless, there has still been a significant increase in net (adjusted) maize use for ethanol production over the past decade, which is now approaching 100 million tonnes per annum net of protein feed co-products[80]. This has been driven by the US Energy Acts of 2005 and 2007, and particularly the Renewable Fuel Standards (RFS), setting blending mandates for ethanol use in fuel[81]. The rise in ethanol use is also responsible for all of the increase in total domestic use of maize over the period covered.

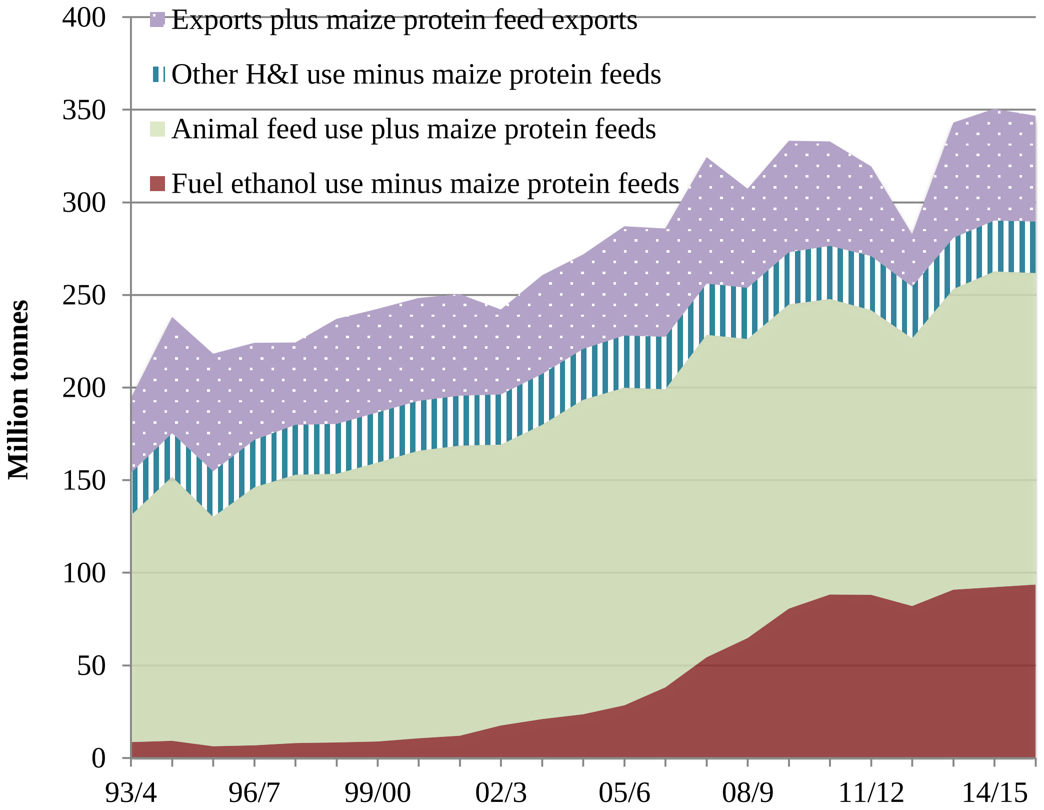
The overall rise in US maize usage over this period has been largely met by increased production given that net feed use and exports have not fallen, bar the drought-affected 2012/13 season, and that stocks-to-use ratios had, by 2015/16, recovered back to 2005/6 levels. But this has led to concerns that greater US maize

[80] It should also be noted that there are other minor co-products such as corn oil that are now separated in the production process by most ethanol processors, but these have not been accounted for in this part of the analysis.

[81] RFS-1 in 2005 set a target of 7.5 billion gallons of corn ethanol whilst the 2007 act raised this to 15 billion

production to meet the additional ethanol demand, has been at the expense of other crop production, such as soyabean and wheat through direct land use change.

Fig 6.23 – US maize use adjusted for maize protein feed use and exports



Source: Author's calculations from USDA data

Furthermore, it is argued that when the US produces less of these other crops, such as soyabeans and wheat, the resulting reduced supplies and exports of those crops have to be compensated by other countries raising production, particularly through increased plantings. This concept of indirect land use change (ILUC) has been widely debated and has been the subject of many studies associated with both the land use and greenhouse gas implications of biofuels, as reviewed in chapter 2.

In order to assess the extent to which increased US maize production has affected the availability of other US food crops, it is necessary to break the supply down into planting and yield responses. But area and yield changes each year do not only correspond to expected responses by producers in terms of market influences.

Weather and crop management impacts often have the greatest influence on planting decisions, where, for example, winter plantings may be prevented by bad weather or crop rotation practices require nitrogen-fixing crops to be planted. Similarly, yields are mainly influenced by weather patterns, although technological improvements in crop varieties and better management practices also influence yields, in both the short and long-term.

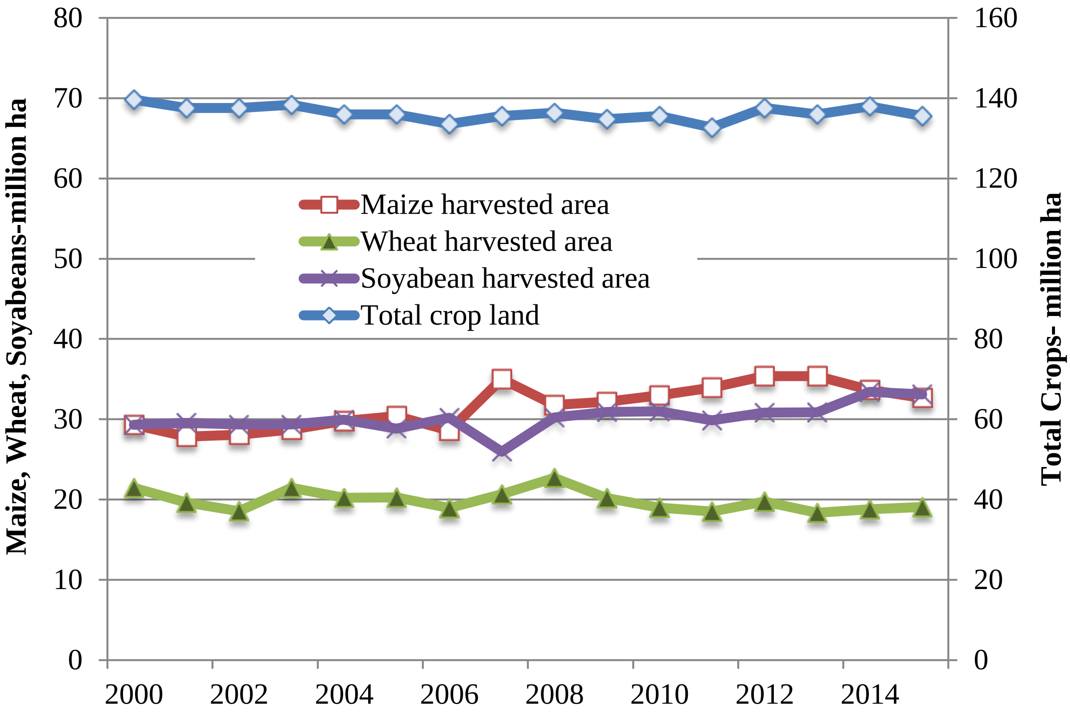
This makes it difficult to attribute supply responses to market and policy conditions in terms of the price elasticity of supply, as outlined in the literature review. It seems plausible, however, to conclude that the US biofuel policy targets led to increased demand for maize, which, in turn, has encouraged increased supply, partly through higher prices. And it also seems plausible to conclude that this has been achieved through producers planting more area to maize and also increasing their yields through better-performing varieties and management practices.

In terms of plantings figure 6.24 shows the trend in total US cropland and harvested areas of maize, soyabeans and wheat, the three major crops grown. The total cropland comprises all planted and harvested crops, including cultivated summer fallow and areas on which planted crops failed.

The overall US crop area has fallen slightly since the early part of the millennium, as is the case for the wheat harvested area, whilst the maize and soyabean harvested areas increased slightly. The maize area was slightly less than 30 million hectares in 2000, and about the same prior to the introduction of RFS-1 in 2005 and the subsequent boom in ethanol production. It then rose to just over 35 million hectares in 2012 and 2013 (due to the exceptional drought) and then fell back to around 33 million in 2014 and 2015.

As noted from the demand side analysis, US maize use for fuel ethanol has increased by some 93 million tonnes since 2005. At an average yield of just under 10 tonnes per hectare over the period (excluding the exceptionally low yield recorded for the drought-affected 2012 crop), this equates to a 9.5 million hectare additional harvested land requirement since 2005.

Fig 6.24 – Total US Cropland and Maize, Wheat and Soyabean Harvested Areas



Source: USDA

However, the total US maize area harvested has shown a much smaller rise of some 2.3 million hectares between 2005 and 2015. Part of the 7.2 million hectare difference can be attributed to the 22 million tonne lower maize requirement in the animal feed sector (before adjusting for protein feed flows from the ethanol to animal feed sectors) and 10 million tonne drop in maize exports (again before adjusting for protein feed exports), amounting to a combined 3.3 million hectares[82]. In other words, 3.3 million hectares of the calculated 7.2 million hectare net requirement were offset by lower animal feed use and exports of maize, which, in turn, was mostly offset by a similar increase in protein meal use mainly produced by the ethanol sector.

This still leaves a sizeable difference of almost 4 million hectares between the increased harvested area suggested by the demand side of the balance (6.2 million hectares) and the actual increase in area harvested on the supply side (2.3 million). Production of maize has increased by just over 60 million tonnes over that period.

[82] Note that this has been largely offset by the increased use of ethanol co-products for animal feed and export over that period

This means that the 2.3 million hectare rise in the harvested area accounted for just over a third (35 per cent) of that increase, with the remaining two-thirds (65 per cent) from productivity increases as the average yield increased by some 1.3 tonnes per hectare.

So the majority of the increased fuel ethanol demand for maize between 2005 and 2015 has been met by increased productivity within the supply response, which may be attributed to better farming practices, including more optimum inputs, better varieties and increased cropping intensity. But yields may also have improved due to climatic and weather conditions, as well as changes in the prevalence of pests and disease. At the same time the harvested area increase of 2.3 million hectares could in theory include more double cropping and other changes affecting the difference between planted and harvested areas, although planted area estimates suggest there was relatively little change in the cropping intensity (harvested area as a proportion of planted area) between the years, at 91.8 per cent in 2015 versus 91.9 per cent in 2005.

This analysis is based on actual changes in plantings, yields and production between 2005 and 2015. Changes in area and yields each year can be affected by particular weather events or other shocks that may not be representative of normal patterns. Analyses were therefore also performed over different periods, including an extended 15-year period from 2000 to 2015, which resulted in a similar outcome, in that one-third of the production increase was accounted for by increased area and two-thirds by yield.

However, it is clear that the choice of base and end-years would affect the apportionment of area and yield responses. For example, any periods that included the 2012/13 season, would be distorted by the exceptional drought-affected yields that year and larger areas harvested as farmers tried to adjust to the anticipated low yields and failed crops by planting more maize. This also had a knock-on effect in 2013/14 following high prices in 2012/13, as farmers maintained high plantings in order to replenish stocks. Similarly if 2007/8 were chosen as a base year, the area harvested in 2015/16 would show a reduction, with all of the production increase coming from productivity improvements.

Nevertheless, the area planted to US maize between 2005 and 2015 still increased by 2.3 million hectares, so it is important to determine how this may have affected other crops? There was indeed a reduction in the area harvested of wheat and other crops such as barley, oats and rye over the same period. But the decline in these crop areas has been part of a long downward trend, so it is probable that these area reductions would have occurred anyway, even without the surge in biofuel demand for maize. A conclusion one might draw, therefore, is that the increased maize and soyabean area in recent years has halted the long-term decline in the total US cropped area.

It is therefore difficult to make a case for substantial direct land use change given the relatively small changes in US maize harvested areas over the period, let alone significant indirect change elsewhere. Indeed, it could be argued that the demand created by the ethanol sector has maintained land use that might otherwise have been abandoned or converted to other non-productive or non-agricultural use. Farmers therefore appear to have responded to the additional biofuel demand primarily by increasing productivity on existing land, whether that be through normal technological trends, weather-induced impacts or management practices.

Furthermore, the additional demand from the ethanol sector has also led to increased supplies of protein meals as co-products. These meals have added to both domestic animal feed processing use and exports for feed processors elsewhere in the world. Thus, from a relatively small increase in harvested area, not only has there been an increased supply of biofuel to help replace fossil fuel use, but there has also been an increased supply of protein feeds to offset the reduction in maize use in the animal feed sector and for export. It should, however, be acknowledged that the increased maize production may also have led to increased use of fertilisers, water and other inputs given the increased area planted.

It is difficult to predict what might have happened to US maize output if US policies had not encouraged ethanol production, both within the domestic market and externally. It could be argued that without such policies more US maize would have been available for export helping to prevent US, and thus international, maize prices from rising during the period. This might then have restricted other countries, such as

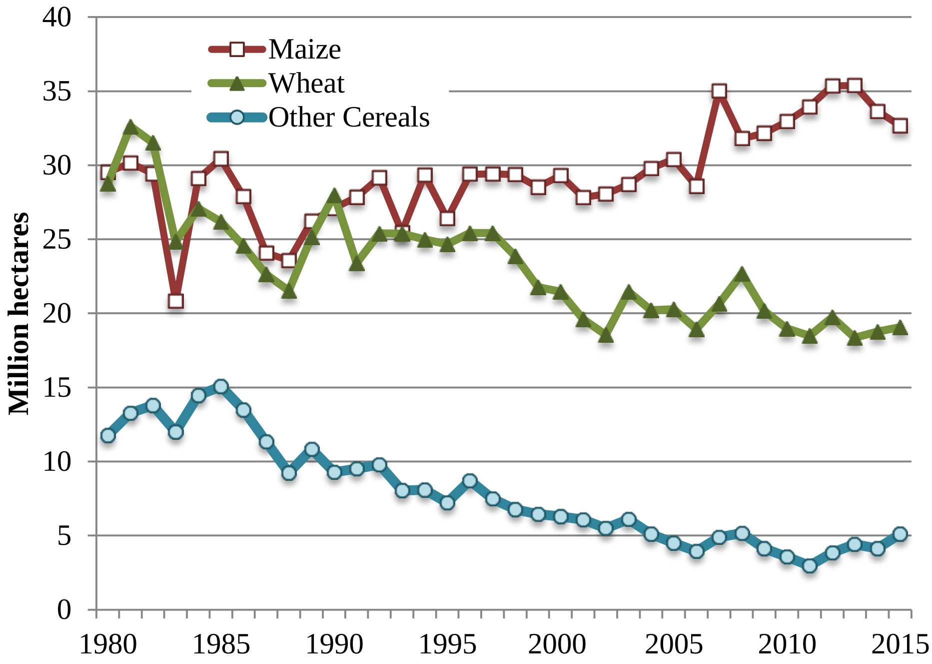
Argentina and Brazil, from expanding their own maize production and cultivating new land, with any associated land-grabbing and greenhouse gas emission implications.

But the evidence from the FAO data, albeit up to 2013 at the time of writing, is that the global arable acreage (as opposed to the harvested area) has only marginally increased over the past decade. There appears to be more evidence that much of the increased global food production has been achieved through increased productivity improvements.

The evidence of the past decade also suggests that some of the increase in US maize production over the period may have been in response to the increased ethanol demand. In other words, the price elasticity of supply of US maize, and particularly that related to productivity rather than area, appears to have been more significant than much of the literature, and notably that analysing indirect land use change, had assumed. But it is difficult to assess how much of that productivity increase, if any, was directly related to biofuel demand and how much was part of the general technological trend toward improved varieties, better management practices and other productivity improvements, and how much was due to weather, climate and reduced pest and disease outbreaks.

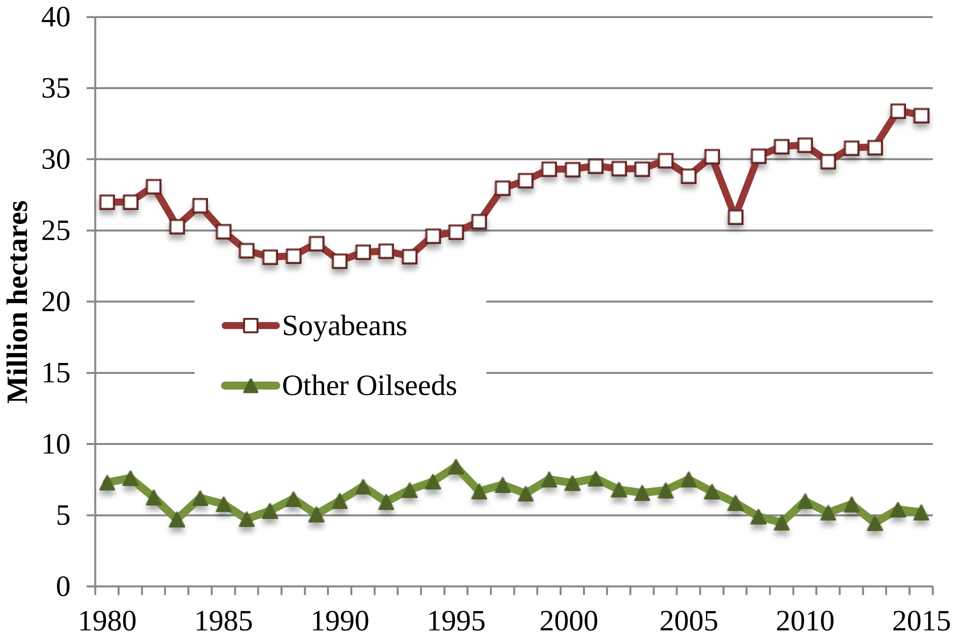
Nevertheless, the sharp rise in US maize ethanol demand over the past decade appears to have been achieved with relatively little increase in the harvested area of maize. This did not significantly alter the general trend of declining harvested areas of wheat and other cereals. Nor did it lead to the expected decline in the soybean area, which instead has also risen over the past ten years. Neither did other domestic use and exports of maize and maize products suffer any significant decline.

Fig 6.25 – Long-term Trend in US Cereal Harvested Areas



Source: USDA NASS

Fig 6.26 – Long-term Trend in US Oilseed Harvested Areas



Source: USDA NASS

Instead, the sharp rise in US biofuel demand for has been largely met by improved productivity, as supply rapidly caught up and prices fell back to pre-food crisis levels. During the sharp rise in US biofuel production from 2005 to 2011, rising maize demand would have contributed to the various forces pulling US cereal prices higher, as the stocks-to-use ratio fell. The 2012 US drought then exacerbated the supply tightness for maize supporting prices at very high levels as biofuel production flattened out. In recent years the maize stock-to-use ratio has recovered with more normal harvests and maize prices have fallen.

So biofuel policies have clearly had some impact on maize prices through both increased demand, particularly in the earlier years of the biofuel boom, and through the extent to which biofuels may have influenced any supply response. Many studies have therefore sought to identify the relative impact of biofuels demand on maize prices compared to other factors.

This study has established the strong relationship between maize prices and the stock-to-use ratio. From this an approximate impact of biofuel demand on maize prices can be estimated by combining the regression model results with the share of biofuel demand changes as a proportion of total supply and demand changes. By recording the past decade changes in the components of the US maize supply and demand balance that make up the change in the stock-to-use ratio, weightings can be attributed to each in order to identify which parts of the balance had the most impact.

The US maize balance from 2004/5 to 2015/16 is detailed in appendix 6. This shows that between those years, a 100 million tonne increase in maize use for ethanol was largely offset by a 22.5 million tonne decrease in feed use and a 66 million tonne increase in supply. On that basis, ethanol demand accounted for at least half the overall changes to the US maize balance comparing the 2015/16 season with that for 2004/5.

However, a comparison of changes between the start and end years of the period fails to take into account the changes that occur from year to year in response to changing conditions. In econometric models, supply and demand elasticities are employed to predict quantitative changes influenced by prices and income. Despite the fact that these are calculated from historical data and trends, there is little consistency in the elasticities used between models due to the different approaches adopted in their calculation, as noted in the literature.

Analysing the annual changes that occurred in the US maize balance over the past decade can provide an indication of how US biofuel volume targets, first introduced in 2005, may have influenced total demand changes. The adjustments in the individual elements of the supply and demand balance each year combine to determine the stock-to-use ratio, which has been established as the key influence on the US maize price. Changes occur on both the supply and demand side of the equation, with increased supply helping to increase stocks and increased demand reducing stock levels[83]. Since all of these changes combine to influence the stock-to-use ratio, they can be combined into an overall sum of changes for the period under review in order to weight the changes recorded each year.

Appendix 7 shows the annual adjustments in the US maize supply and demand balance each year from 2005 to 2015. The change in each main component of the balance, such as production and imports on the supply side and ethanol, feed, other H&I use and exports on the demand side, can then be calculated as a percentage of total changes for the period. These were then summed to provide a total percentage for each component of the balance for the 2005-15 period, as tabulated in appendix 8.

The analysis in appendix 8a shows that ethanol accounted for 16 per cent of the combined annual adjustments, with animal feed at 12 per cent, exports at 14 per cent and supply responses accounting for 57 per cent of all the changes. So, for example, whilst exports only changed slightly between 2005 and 2015, the annual changes in response to changing market conditions were more important, amounting to 14 per cent of the total supply and demand changes that made up the stock-to-use ratio.

Analysing the changes for the adjusted maize balance (appendix 8b) which accounts for the protein feed co-product flows from ethanol and other H&I use to animal feed

[83] Increased demand also raises the stock level requirement to maintain the stock-to-use ratio level.

and exports, resulted in attributed changes of 12 per cent for ethanol use, 12 per cent animal feed and 16 per cent exports, with supply changes accounting for 60 per cent of the adjustments. These findings suggest that ethanol demand, net of co-products, accounted for 12 per cent of all changes within the US maize supply and demand balance that comprised the changes in the stock levels each year.

In terms of price effects, the standard regression analysis of the US maize price and US stock-to-use ratio over the same period gave an R-squared value of 0.761, with an adjusted R-square of 0.737. Given the small sample size, the adjusted R-squared value is a safer estimate of the regression model's predictive ability of the US maize price, at just under 74 per cent.

Given that ethanol demand accounted for 12 per cent of all changes in the stock-to-use ratio over the period, and that the stock-to-use ratio's predictive ability of the US maize price was 74 per cent, a plausible conclusion would be that ethanol demand probably accounted for a relatively small proportion of US maize price changes, and probably no more than about 10 per cent.

Supply adjustments accounted for a larger proportion of changes in the stock-to-use ratio, but it is more difficult to identify the components of the supply response. Most supply changes in the crop sector are usually attributed to weather, disease and technological trends, such as the increased uptake of higher-yielding and more disease and pest resistant varieties, including genetically modified crops. From the literature review, the price response of supply for US maize and other crops is generally regarded as zero to small, but some studies suggest it could be as high as 25 per cent[84]. Even at the higher figure, the attribution of biofuels to that price response still might only be a fraction of that.

For example, if a price elasticity of supply of 10 per cent (0.1) was calculated, and it was estimated that biofuel demand was responsible for 25 per cent of the price

[84] Much depends on the assumptions included within the supply elasticity calculations. For example, some studies argue that technological developments, such as improved varieties, may be influenced by policies, such as those aimed at encouraging biofuel demand. Hence, some US maize varieties have been developed to produce a higher starch, and, therefore, ethanol, yield. Improvements in technology are then viewed as a response to markets and policies, in addition to the long-term trend toward greater productivity.

elasticity of supply, then the overall impact of biofuels on maize prices through supply responses would be 1.5 per cent (0.6 x 0.1 x 0.25) using the supply and demand balance changes over the past decade.

Following the majority of the literature in assuming that biofuels had a limited impact on US maize prices through supply responses, and given the relatively limited role played by US ethanol demand in the total stock-to-use changes, it seems unlikely that US biofuel demand would have influenced US maize prices by any more than about 10 per cent over the 2005-2015 decade.

If, however, it is assumed that increased biofuel demand encouraged a significant supply response in addition to other supply and demand factors and technological trends, then the overall impact of biofuels on maize prices might be greater than 10 per cent. However, because a significant positive supply response would generally be negative toward prices, whilst the rising biofuel demand has been price enhancing, the net effect would then be a smaller price increase, or even a price decrease.

The extent of any biofuel influence would also have been greater at different times during the past decade. For example, in the 2005 to 2010 period when biofuel usage of maize was growing strongly, ethanol demand accounted for nearly 17 per cent of the stock-to-use ratio changes, suggesting it would have had slightly more influence on US maize prices during that period.

The bivariate regression analysis of maize prices and stock-to-use ratios for 2005 to 2015 also indicates that other factors accounted for a significant proportion of US maize price movements. There is evidence from industry reports, and indeed the multiple regression models in this study, that US wheat, and perhaps also world oil prices, diverted the average US maize price in 2007/8 away from its expected value based on supply and demand fundamentals. In 2013/14 it seems more likely that imperfect market information flows were responsible for the sharper fall in the average US maize price than that suggested by the stock-to-use ratio. If biofuels were implicated with these or any other predictive factors outside the regression analysis, then its influence on the US maize price would be larger than that suggested by the combination of the bivariate regression model and the contribution of biofuel demand to changes in the stock-to-use ratio.

Using this data-driven descriptive analysis of changes in US maize supply and demand from 2005 to 2015, it can therefore be argued that the increase in US ethanol use of maize, driven by the introduction of US biofuel policies in 2005, probably accounted for a relatively small proportion of US maize price formation during that period.

Even during the 2005-2010 period when biofuel demand was increasing sharply, it seems unlikely from the combination of the regression analysis and stock-to-use ratio changes, that biofuel demand would have accounted for more than 10 to 15 per cent of the maize price increase during that period, as biofuel demand only accounted for 17 per cent of the stock-to-use changes. Indeed, any supply-enhancing response directly encouraged by biofuel policies during this period would have dampened prices down and ameliorated the upward impact on prices from biofuel demand. This contrasts with many of the findings from the literature suggesting that biofuels accounted for much larger shares of US maize price increases.

As well as determining the influences on the overall formation of maize prices, the combination of the regression model and breakdown of the stock-to-use ratio also provides an indication of the role that biofuel demand played in the increased volatility of maize prices over the past decade to that previous.

A comparison of the bivariate regressions of maize prices and stock-to-use ratios for the periods 1993 to 2003 and 2004 to 2015, indicates that price responses to changes in the stock-to-use ratio were more volatile in the more recent period. The range of US maize stock-to-use ratios over the past 20 years is from a minimum of 5 to a maximum 20 per cent. Over such a range, the regression model for the 2004 to 2015 period would have predicted prices on average 20 per cent higher or lower than that for the earlier period. The percentage variance would be higher for the more extreme values. For example, at a 5 per cent US maize stock-to-use ratio, the predicted price for the regression model covering the 2004 to 2015 period would be $295 per tonne, whereas the model for the 1993 to 2003 period predicted a price of $216, a difference of $79 per tonne or a 37 per cent increase from the base period of 1993 to 2003.

However, it is difficult to assess the reasons behind the more volatile US maize price movements over the past decade to that previous. The literature points to the surge in biofuel demand since 2007/8 as the main factor for the steeper increase in prices at that time than would have been the case at the same stock-to-use ratios in the decade previous to that. But there were many other forces influencing prices at that time.

The increased volatility of maize and other commodity prices in recent years can be attributed to a greater perception of, and valuation of, risk within the industry of supply shortages[85]. The extent to which this can be attributed to biofuels, as opposed to other factors, is difficult to assess. For example, if the greater valuation of risk is associated primarily with falling stocks in relation to demand needs, it is clear that biofuel demand accounted for a relatively small share of changes in the stocks-to-use ratio over the past decade. If, however, the perception in recent years has been that biofuel demand would continue to rise steeply and even outpace the supply response, then much of the increased volatility might then be attributed to biofuel demand. But even in the case of the latter, the real cause would be the market perception of how biofuel demand and maize supply changes would evolve rather than biofuel demand per se. Either way, it also seems difficult to apportion a large share of the increased price volatility on biofuel demand.

Nonetheless, since maize is the main feedstock used in global biofuel production and is also the main biofuel feedstock linked to food prices, even a 10 per cent increase in US prices or price volatility, if transmitted around the world, could mean that US biofuel production-enhancing policies had a significant impact on food insecurity in developing countries. It is therefore important to review how US maize price changes may have affected prices in food insecure countries.

[85] The risk of supply shortage is associated not so much with supply falling short of demand, which is a regular occurrence, but more with the level of end-season stocks in relation to requirements that can cushion any significant supply shortfall.

6.2.2 Transmission of world maize prices

Within the literature covering biofuel impacts on food prices, it is often assumed that developments in world benchmark values, such as US maize prices, are easily transmitted to domestic markets in food insecure countries. However, there is also an extensive literature disputing this assumption, as summarised in the literature review.

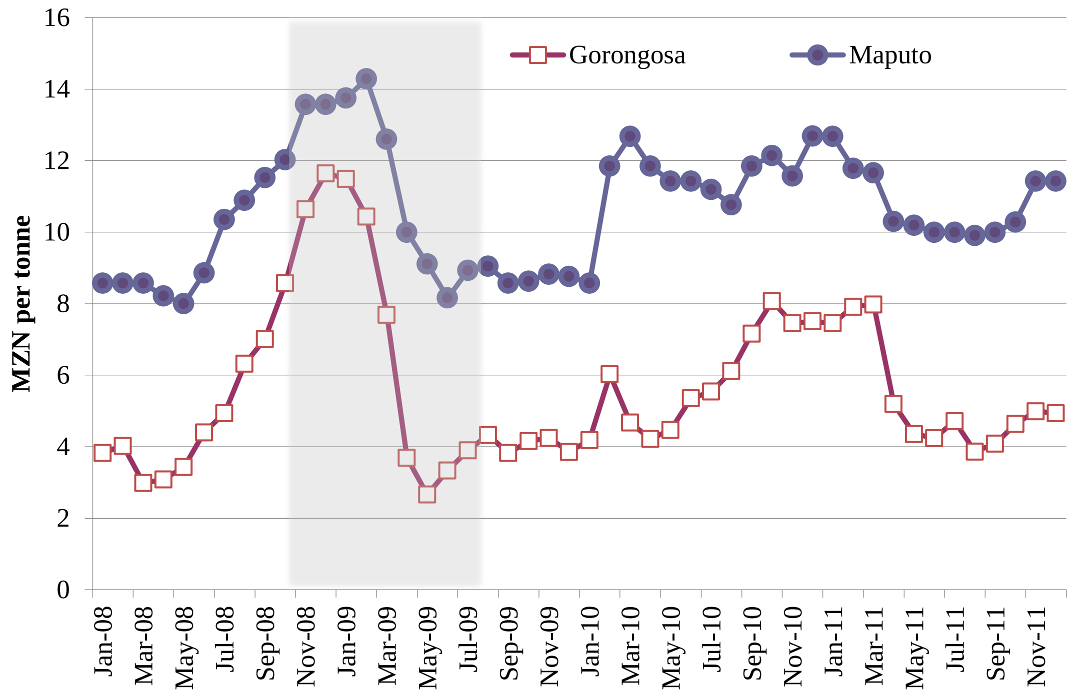
In order to link the two parts of this study, moving from the macro to the micro, world maize values, as denoted by US maize prices, were compared to prices on the main markets in Mozambique and Tanzania, in order to assess the extent to which US maize prices may have influenced food security in both countries. Prices at farm, wholesale and retail level were collected from government departments and national statistical agencies during the fieldwork and follow-up trips in both countries from 2009 to 2012.

In Mozambique, which is usually self-sufficient in maize, prices are usually highest in the main market of Maputo and lowest in the main producing areas in the centre and north of the country, as noted in the micro findings in chapter 5. The range of prices throughout the country is illustrated by figure 6.27, which depicts wholesale maize prices from 2008 to 2011 in the major consuming centre of Maputo and one of the major producing areas in the Gorongosa region in the centre of the country.

The chart highlights the large costs involved in transporting grain from surplus to deficit areas in Mozambique, with distances of well over 1,000 kilometres from the central growing areas to Maputo. The large costs also reflect a number of inefficiencies in the marketing chain, including the lack of reliable and timely market information, high transport costs due to poor infrastructure, a lack of good quality storage and a large number of middlemen and unofficial tolls and taxes.

A rapid appraisal of the marketing chain for maize was conducted during the field survey in Mozambique. The appraisal found that local traders in the centre and north buy from farmers and sell to transporter traders who deliver to wholesalers in Maputo who then sell on to retailers, each earning a sufficient profit margin. Additional costs were also reported in the form of unofficial taxes and penalties applied in the course of transporting goods between regions. The appraisal suggested that the cost of transport alone from the surplus centre of the country to the deficit south should be in the range $50 to $75 per tonne, which is confirmed by other studies (eg Dias, 2013).

Fig 6.27 – Wholesale Prices of Maize in Maputo and Gorongosa Area of Mozambique



Sources: Ministerio da Agricultura, Sistema de Informacao de Mercados Agricolas and Instituto Nacional de Estatistica (INE). Note – grey shaded area denotes period related to household survey questionnaire

However, the recorded price gap was much higher between Gorongosa and Maputo in the 2008 to 2011 period, at an average $140 per tonne, suggesting high middlemen margins and unofficial taxes. It should also be noted that the gap between centre/north markets and Maputo widens even further from time to time when surpluses are low in the centre/north and Maputo has to import maize from South Africa instead, which incurs a high VAT rate[86]. During the year May 2009 to May 2010 a food security assessment mission calculated that South African maize was

[86] Some larger processors are able to avoid VAT in order to secure high quality supplies of certain goods, such as milling wheat

between $20 and $150 per tonne cheaper than supplies from Manica in the centre of the country (FAO and WFP, 2010).

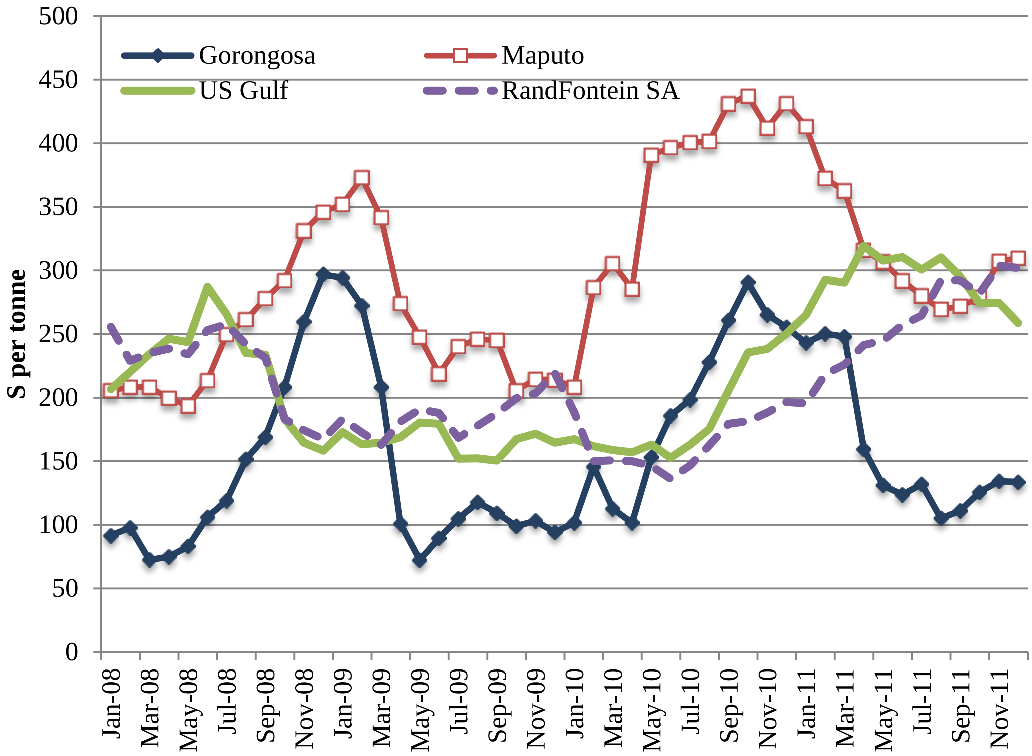
The chart also shows the period covered by the household survey records of prices in 2009, shaded in grey. The sharp drop in prices of maize during that year following the previous steep rise, confirms household reports of "more normal" food prices at the time of the survey following the steep rise in 2008. Yet prices paid by households varied significantly from 7.5 to 10 Metical (MZN) per kg in Bilene ($280 to $375 per tonne), 8 to 10 MZN in Inhassune and 7.5 to 10 MZN in Dombe. The lowest retail prices tended to be recorded for larger amounts purchased, disadvantaging poor households, but quality differentials also accounted for some of the variation in household purchase prices.

As noted above, US maize use has been the main biofuel-related influence on agri-food markets, and has been linked with the world commodity price spikes in recent years. However, for both Mozambique and Tanzania, the main international influence on domestic prices is traditionally viewed as South African white maize, due to the geographical proximity and type of maize, since most maize production in Southern Africa is of the white variety used for human consumption rather than the yellow maize grown in the US and used as animal feed.

Despite the different types of maize, South African white maize often competes with US on world export markets, so there is a relatively good relationship between them as illustrated in figure 6.28. But this also appears to show a relatively limited influence of both US and South African maize prices on Mozambique markets over that period.

The rising price of maize in Mozambique during 2008 was partly due to a delayed effect from the sharp rise in US and South African maize prices in 2007/8. But it was more to do with a tight domestic balance and as prices of maize rose that year, South African prices became more and more competitive, and imports started to flow into Maputo from South Africa, even though Mozambique was generally regarded to be self-sufficient that season.

Fig 6.28 – US Yellow, South African White and Mozambique White Maize Prices – 2008 to 2011



Sources: Ministerio da Agricultura, Sistema de Informacao de Mercados Agricolas (SIMA) and Instituto Nacional de Estatistica (INE). US Department of Agriculture (USDA) and Department of Agriculture, Forestry and Fisheries (DAFF), South Africa.

Domestic maize prices fell back in 2009 with the better crop that year. Then from the start of 2010 figure 6.28 shows a sharp rise in Mozambique maize prices even though US and South African prices remained low and only started gradually rising from the middle of that year. A comparison of figures 6.27 and 6.28 shows that prices on the domestic market in metical (MZN) rose gradually from the start of 2010 whereas US dollar denominated values (figure 6.28) rose steeply throughout the year. This difference can be attributed to the sharp devaluation of the Mozambique metical that year[87]. This illustrates the importance of exchange rate influences, particularly for importing countries. Thus domestic maize prices in Mozambique, which is mainly self-sufficient, were relatively stable in 2010, but when denoted in US$, it appeared that prices had risen sharply.

[87] The metical devaluation was enforced by IMF policy, leading to a 33 per cent devaluation of the metical from MZN28 to the US$ in late 2009 to MZN37 in mid-2010.

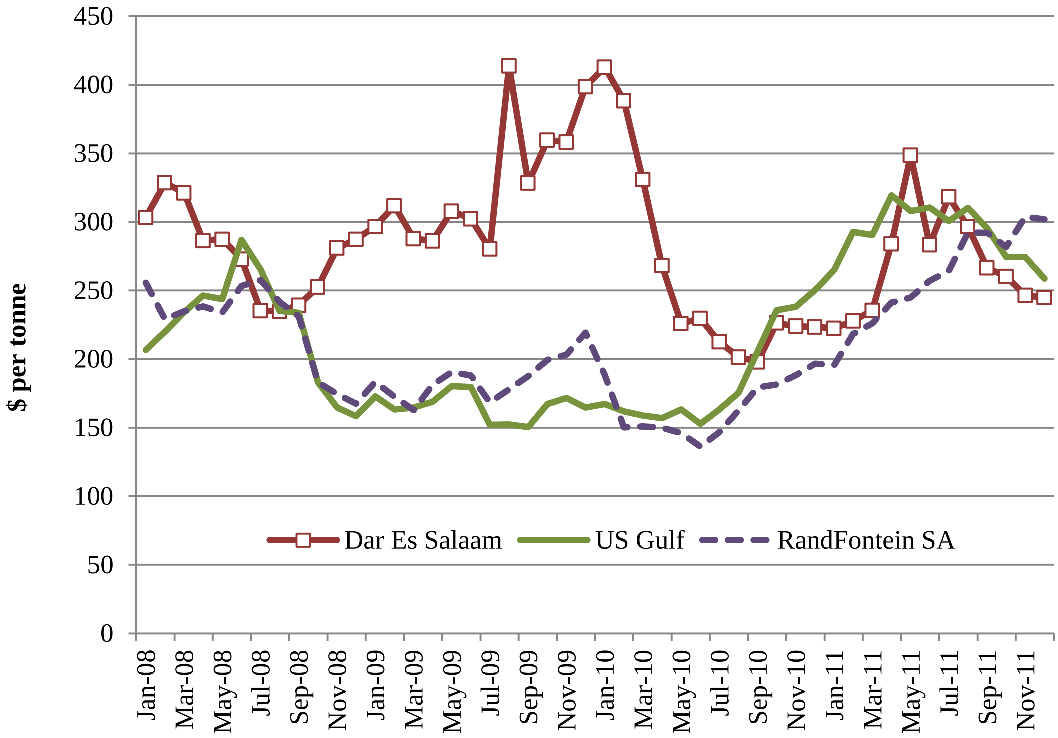
So in the case of Mozambique US maize prices appear to have had relatively little impact on domestic maize prices for the period covered. The linkage between US and South African maize prices is not always strong, particularly when the export availability from the South African maize crop is low. Even when there is a relatively close relationship, this would only affect the Maputo market in the odd years when significant imports are required from South Africa. Otherwise, prices of the staple cereal in Mozambique tend to fluctuate with local supply and demand conditions in between the wide band denoted by import and export parities. This corresponds with many recent findings in the literature. For example, Minot (2011) found that none of the six regional maize markets in Mozambique showed evidence of a long-run relationship between local and international prices.

Tanzania is also generally self-sufficient in maize, with local prices generally having a limited relationship with world benchmark values. Prices tend to be lowest in the southern maize-surplus locations of Mbeya and Songea and highest in the main markets of Dar Es Salaam and Arusha and Mwanza in the north. Figure 6.29 shows wholesale maize prices in the Dar Es Salaam market against US and South African prices from 2008 to 2011 inclusive. The steep rise in Tanzanian maize prices in 2009 was due to the poor harvest that year and record low end of season stocks. Imports were negligible over the period, and have been since then, with domestic production and stocks generally sufficient to meet domestic demand. This has been helped by the imposition of export bans at times of rising prices. Nonetheless food insecurity remains a problem for many regions, particularly in the north where there is a deficit of maize and it is difficult to prevent exports, particularly to the Nairobi market.

This brief review of maize price developments in Tanzania corresponds with the recent literature. Minot (2011) found that of the eight main maize markets in Tanzania, only Arusha appeared to have any significant long-run relationship with world prices, whilst a World Bank study of 18 Tanzanian maize markets between 2002 and 2012, concluded that in the long-run domestic prices were weakly influenced by US and South African markets, but that markets in the north of the country were more closely associated with the Nairobi market (Baffes et al., 2015). In the short-run, the World Bank study states that Tanzanian maize prices are "*governed by a constellation of domestic factors*". Furthermore, Maro and

Mwaijande (2014) found limited transmission and slow adjustment of prices between markets within Tanzania, which they attribute to market power within the supply chain, particularly by traders and middlemen, with many layers of markets, poor infrastructure and a lack of reliable and timely market information systems.

Fig 6.29 – Tanzanian, US and South African Maize Prices – 2008 to 2011



Sources: Ministry of Agriculture - Tanzania, US Department of Agriculture (USDA) and Department of Agriculture, Forestry and Fisheries (DAFF), South Africa

A lack of price transparency at the local level was also evident during the household survey where households reported a wide range of purchase prices for staple foods. In Ikiwu, Singida, households reported purchases of maize at between 250 and 400 Tanzanian Schillings (TS) per kilogramme during April and May 2009 (from just under $200 to just over $300 per tonne), whilst maize retail prices in the villages of Kingori and Ngurdoto in Arusha ranged between 400 and 500TS/kg (just over $300 to about $385). A number of reasons were given for the price variance, with some householders purchasing directly from producers rather than retailers, some minor quality differentials and some social factors.

In conclusion, US maize prices, which are deemed to have been the main influence of the recent biofuel boom, and which are viewed as a key driver of global food prices, appear to have had little, if any, influence on staple maize prices in the two food-insecure countries covered in this study. So even if biofuels were deemed to have accounted for a significant proportion of US maize price changes, a lack of price transmission to many food insecure countries, where markets remain imperfectly competitive, with high transaction costs, poor infrastructure and a lack of reliable and timely market information, means that little of the US price increases would be felt by households in such countries, based on the above evidence.

The fact that US biofuel policies appear not to have led to significant maize, and, hence, staple food price increases in Mozambique and Tanzania, might be considered as positive for food security within both countries. However, the surveys of households in both countries highlight the large nutrient deficits of many rural farmers who depend on revenue from crop and livestock sales to meet their food needs. Since many of the most food insecure households in sub-Saharan Africa are located in rural areas, this suggests that higher staple prices might, in fact, help to alleviate poverty and improve food security, as noted in the literature review.

Whether households would benefit from increased commodity and food prices or not would largely depend on their status as either net purchasers or net sellers of food, as the latter group would be more likely to benefit than the former. However, some households that were net purchasers before any price increase might also benefit if their increased revenue from farm sales outweighed any increase in expenditure on food. This could happen if households were able to maintain their nutrient intake with a relatively cheaper basket of foods, or if the higher prices incentivised increased production and revenue from sales. Much therefore depends on how each household responds to price changes through their price and income elasticity of demand and their price elasticity of supply, as each household will have a different response and that response will change over time.

Furthermore, the extent to which each household can improve its bargaining power in terms of both buying and selling food within the supply chain, would also have a significant impact on incomes, given the wide variation of purchase and sale prices reported within the household survey. Linked to this is the degree of price transmission from producer to retail level, as retail food prices can often be multiples of the producer price due to large costs within the supply chain.

7. Conclusions

This study set out to answer, or at least provide insights on, four key questions arising from the ongoing food versus fuel debate.

i) Whether biofuel operations in developing countries affect the food security status of local households?

ii) How different models of biofuel feedstock production influence food security outcomes?

iii) Whether global biofuel production reduces the availability of food by diverting crops and land away from food production?

iv) Whether global biofuel production leads to higher food prices, and whether this reduces access to food in developing countries?

The study also sought to find a way of best measuring food security in relation to the first two questions posed above. This led to the development of a novel indicator called the Household Nutrient Deficit Score (HNDS). This was designed to incorporate all four dimensions of the food security concept within a single score, which could also be disaggregated to provide more in-depth information.

Furthermore, the methodology employed for capturing the information required for the HNDS, allows the analyst to trace back any macro or micro nutrient problems to food production and purchasing decisions and how any type of intervention might affect these. In this way the HNDS can guide mitigating actions that may be taken by households to address particular nutrient deficiencies through better food production and purchasing decisions or other actions.

The HNDS was also developed as a response to some of the problems with existing measures such as the lack of quantity measurement in dietary diversity scores, the lack of micronutrient information in calorie intakes, the difficulty in identifying causal factors from perception-based measures, as well as confounding issues with anthropometric and other indicators.

The following sections summarise the conclusions of the other research questions posed, with the first section covering the impact of biofuel operations and different models of feedstock production on food security, the second reviewing the impact of biofuels on land and food availability and the third summarising the impacts on food prices.

7.1 Conclusions on the Impact of Biofuel Operations on Household Incomes

The study found that biofuel feedstock operations can help alleviate food insecurity at the local level. The survey results from the selected biofuel sites in Mozambique and Tanzania support the findings of a number of other recent studies that biofuel feedstock operations in developing countries can have a positive relationship with both income and food security.

The analysis of the five different biofuel feedstock operations, show that those households that were involved with the biofuel operations, either through selling feedstock as outgrowers, or acting as employees, recorded lower nutrient deficit scores than other households in the same locality. The nutrient deficits were substantially lower for those households that had employees earning wages on jatropha and sugar cane estates. Indeed, the average score for such households was negative, indicating that the mean nutrient intake met the calculated requirement for those households with employees, whereas the average deficit for non-involved households was 31.5 per cent.

Using a regression analysis that controlled for geographical location and other independent variables such as household size and area farmed, it was found that the average nutrient deficit score for households with employees was 27 percentage points lower than that for non-involved households ($p<0.001$). When controlling for the source of income, the average score was 22 percentage points lower ($p<0.001$).

Whilst the number of sites and households included in the survey is too small to be able to generalise in any way, the analysis suggests that greater food security benefits may sometimes be achieved in operations offering waged employment compared to some outgrower models where the impact on income from feedstock sales can be too small to make a noticeable difference.

The qualitative results, meanwhile, indicated that a large proportion of households involved with biofuel operations perceived an improvement in their food security status after the biofuel operations were established, whilst most households, whether involved or not, expressed contentment with the establishment of the biofuel company in their locality, mainly due to envisaged benefits for the community as a whole.

The key factor in the better food security status of households with biofuel employees was the improvement in household income. This, together with the ability to maintain some own food production in many cases, led to much lower macro and micronutrient deficits than other households in the same locality. The importance of income in improving access to food corresponds to Sen's work on entitlements in the 1980s.

These findings suggest that biofuel operations could help to improve food security in developing countries where there is less pressure on land and other resources, and where higher-yielding feedstocks can be grown without taking land from communities, damaging the environment or displacing food production. Biofuel initiatives could also help to replace fossil fuel energy imports, whilst providing employment and market opportunities in disadvantaged rural areas.

However, this study also noted the poor economic sustainability of biofuel projects in Africa. Two of the five projects studied closed down, partly due to poor choice of feedstock in the case of jatropha, but also the inadequate infrastructural and agribusiness environment and the inability of companies to secure sufficient funding as the financial recession took hold and food versus fuel concerns were increasingly voiced. In such cases, where many households had previously enjoyed the benefits of salaried employment, most would have returned to semi-subsistence farming, and probably greater food insecurity.

In conclusion, this study, together with other recent research in this field, suggests that involvement with biofuel operations under the right conditions can lead to better household food security in areas that are currently food insecure. Notwithstanding the economic viability issues for biofuel operations in Africa, the right to food should be given priority by policymakers and policies should be developed to support sustainable biofuel investments that can help improve food security in rural areas where hunger remains most prevalent.

7.2 Conclusions on the Impact of Biofuels on Land Use

The macro analysis found that global biofuel production has so far used much less land than is generally reported in the literature, with little increase in land use over recent years due to the increasing proportion of waste feedstocks used, such as used cooking oil and animal fats, and land-neutral co-products, such as molasses, as well as higher feedstock yields.

The increase in land use that has occurred over the past decade has been mainly for maize-based ethanol in the US, soyabean and rapeseed based biodiesel in Europe and South America, and sugar-cane based ethanol in Brazil, with very little land currently being used for biofuel feedstock production in the most food-insecure countries, and particularly in Africa.

Co-products have accounted for a significant proportion of the increase in land use. Of the 33 million hectare rise in global land use for biofuel feedstocks between 2005 and 2015, it is calculated that 14 million hectares should be allocated to co-products on the basis of revenue earned. Most of the co-products have entered the food supply as animal feed. This suggests that global biofuel policies have accounted for an additional 19 million hectares of feedstock in the decade since 2005.

Estimates of suitable additional land for rain-fed crop production are wide-ranging, but some of the more conservative figures from the literature converge around 200-250 million hectares globally, but concentrated within specific regions, mostly in sub-Saharan Africa and South America. The lower end of this range is also half the estimated 400 million hectares of additional land that Rockstrom et al calculated could be cultivated yet still remain within their estimated planetary boundary for global land use.

Projections of additional land requirements for food production over the coming decades are also wide-ranging, with different views on potential yield improvements and particularly regarding climate change impacts. The FAO has estimated that an additional 70 million hectares could be needed to meet food needs by 2050. But the generally accepted view that we already produce more than enough food to meet the needs of the global population, even given the fact that one-third of all food production is lost as waste, suggests there is considerable scope for improving the efficiency of the food supply chain and improving the means of access to sufficient food for everyone. Rising levels of obesity and the associated health and environmental impacts of excessive meat and processed food consumption, also suggest that improvements are possible in the way food is produced and land is used.

Given the concerns regarding climate change impacts on crop yields and pasture over the coming decades, and the greenhouse gas emissions associated with bringing new land into cultivation, some commentators have called for a moratorium on the use of land for biofuel feedstocks. But this would prevent the development of initiatives that could improve employment, income and food security within low-income rural areas, as well as bringing much needed investment in infrastructure and renewable energy supplies to improve water pumping, irrigation, storage, and cultivation. Also, estimates of potential land use are largest in sub-Saharan Africa where rural employment and energy supplies are most needed and where the most land-efficient feedstocks can be grown.

At the micro level, a number of studies have found that land has been unfairly transferred from local communities to biofuel projects. Within the fieldwork for this study, there was little evidence of land grabbing, but a number of households had agreed to transfer land to biofuel companies on the basis of compensation that appeared to be less than adequate, whilst four households were identified in one locality that had not received any compensation for land transfers at the time of the survey. It was also notable that relatively few of the randomly selected households lost land to biofuel operations and that of those that did, most received what they deemed to be fair compensation.

There was also little evidence that the biofuel feedstock operations had affected food availability in the locality. For the outgrower-based operations, most farmers grew jatropha as a dual-purpose crop, for harvesting the seed and as a hedge to protect fields from wildlife damage. Since this was a traditional practice in many parts of Tanzania, there was little impact on land use, and, indeed, it could be argued that the jatropha hedge had an overall positive benefit on food availability through protecting fields of food crops. For those households that grew jatropha on a larger-scale, most fields were inter-cropped with maize or used as a shade boundary for other crops such as coffee.

The surveyed biofuel estate operations all provided flexible working hours to allow employees time for their own home food production. Two of the estates also provided some land for community production of food, whilst some of the operations were actively involved with local farmers in improving food production in the locality, including the lending of machinery and expertise in developing irrigation systems. However, it was clear that such households had less time for their own food production and that some additional work burden had transferred from the employee to other members of the household. Nevertheless, the net outcome of better income and reduced home food availability was a significant improvement in food security status.

On the basis of the macro analysis, it can be concluded that the global availability of food is unlikely to have been negatively affected by the relatively small increase in the global biofuel feedstock area, particularly as a large proportion (42.4 per cent) of the increased area was for co-products used as animal feed. The estimated area of biofuel feedstock planted in food-insecure countries, totalled just over 200,000 hectares in 2015 after adjusting for co-products, with Africa accounting for a small proportion of that. This also suggested a very limited impact on land use and food availability in food insecure countries.

Perhaps a more important conclusion that should be drawn, based on the evidence of the household survey, is why there is not more biofuel and feedstock production in food insecure countries where sufficient land is available to meet both food and energy needs? If household food security can be improved through local biofuel operations, as the micro-analysis suggests, then more support should be provided for the establishment of biofuel initiatives in such countries.

7.3 Conclusions on the Impact of Biofuels on Food Prices

The key issue linking biofuels and food prices is the increased demand for biofuel feedstocks, which, it is argued, raises food prices around the world and creates greater food insecurity for households that spend a large proportion of their incomes on food.

A definitive assessment of biofuel impacts on food prices seems impossible to make as it is difficult to accurately apportion influence to the many factors affecting the prices of the many types of foods.

It is clear, however, that maize is the main food-based biofuel feedstock used and is also the main cereal produced globally and an important determinant of staple food prices. The US is the largest producer and exporter of maize so US maize prices have the most influence globally.

It is also clear from the study findings that fundamental supply and demand forces play a significant role in determining the price of US maize. Because there is a close relationship between the US maize price and the stock-to-use ratio of US maize, changes in the components of this ratio can be calculated in order to assess the influence of ethanol demand compared to other supply and demand factors.

The regression model used in this analysis suggests that the maize stocks-to-use ratio explained about three-quarters of US maize price developments over the past decade.

Over the same period, ethanol demand is calculated to have accounted for some 12 per cent of changes to the US stock-to-use ratio. It is therefore plausible to assume that biofuel demand was unlikely to have accounted for little more than 10 per cent of US maize price changes.

Even a 10 per cent share of any price increase, however, may have exacerbated food insecurity in some countries, to the extent that this was transmitted to local food markets in that country. On the other hand, any price increase may also have benefitted net sellers of maize and other food, particularly in rural areas.

However, it seems unlikely that any biofuel-induced increases in US maize prices would significantly affect many food insecure countries due to the poor transmission of US prices to domestic markets. In Mozambique and Tanzania, during the steep rise in global biofuel production from 2008 to 2011, there appeared to be little connection between US maize prices and those on local markets.

At the micro level, there was also little evidence that biofuel feedstock operations had influenced local food prices to any great extent. Local food prices in the biofuel sites in Mozambique were reported to have fallen at the time of the survey in 2009, despite the fact that local incomes had improved. In all of the biofuel operation sites there was a notably high variance in purchasing prices of the same foods by different households. The variance in retail food prices is likely to have had a more significant impact on household food security than any biofuel-induced influence from global markets.

Given the long chain from US yellow maize markets in the Corn Belt to local sub-Saharan white maize retail markets, with so many factors affecting the transmission of prices along that chain, it is somewhat surprising that so many studies have concluded that US biofuel policies have led to greater food insecurity by increasing food prices in developing countries. On the basis of this study there appears to be insufficient evidence on which to make such a claim. Indeed, notwithstanding the relatively small contribution of biofuel demand to US maize price increases and the lack of transmission from US to local maize prices in food-insecure countries, there is some evidence that higher prices may improve food security for many of the world's poorest households in rural areas.

8. Policy Implications

The Sustainable Development Goals agreed in 2015 require the ending of poverty and food insecurity, as well as regular access to clean energy for all. The attainment of these goals will be particularly challenging in rural areas of least-developed countries where poverty and hunger is most rife and access to clean energy is lowest.

Given the limited literature on the impact of biofuel operations on local food security in food insecure countries, it is recommended that more research needs to be conducted in this area.

Nonetheless, this study finds that biofuels can offer a potential source of employment and improved income in rural areas of developing countries, helping to alleviate poverty and food insecurity, as well as providing a source of renewable energy to the more remote areas of the world. It is therefore important that support is provided to those biofuels that can best achieve these goals and that least-developed countries are assisted in establishing biofuel sectors and realising these benefits. However, such benefits will only be garnered under the right conditions.

In order to ensure that biofuels help to end poverty and food insecurity, any larger-scale biofuel initiatives should comply with sustainability criteria that incorporate food security, fair labour, fair-trading and land rights provisions. These issues can be addressed through sustainability certification schemes that require companies to meet criteria relating to these and other sustainability-related issues, and to take mitigating actions if and when negative outcomes arise. All such schemes should include a rigorous food security screening system for food insecure areas. It is notable that most of the existing voluntary sustainability certification schemes relating to biofuels and approved by the EU, do not require a detailed food security assessment.

Also, biofuel operations should only be facilitated by governments where there is clear evidence of available land that is not in existing use or required for local food needs, following detailed land mapping exercises, and where companies can provide evidence of economic and environmental sustainability. Applications to lease land to grow biofuel feedstock should only be authorised for limited periods and where any affected communities are willing to lease land under free, prior and informed consent, with procedures that provide equivalent livelihood compensation and allow for land to be returned to previous owners should the operation fail to meet its commitments to the communities or close down.

Governments should also encourage local ownership of biofuel initiatives wherever possible, including smaller-scale local energy initiatives involving outgrowers. The results of the household survey suggest that larger-scale operations can also provide much needed employment and income stability in rural areas, as well as having positive spillover impacts for local communities.

The socio-economic criteria within voluntary certification schemes are currently insufficient to ensure that biofuels will make a positive contribution to the SDGs. It is therefore recommended that international mandatory standards and methodologies that target these issues are agreed and adopted. These standards should be developed by the relevant UN agencies as part of the commitment to the SDGs.

One of the difficulties faced by organisations providing sustainability certification to operators is identifying indicators and methodologies that can accurately measure whether companies are complying with sustainability criteria. Food security is a particularly complex concept to measure. This study provides a novel alternative to the wide range of food security indicators in the form of a composite score for household nutrient deficiency[88], which encapsulates the four dimensions of food security in its methodology. This can help to provide a more straightforward yet rigorous measure of whether a project or any other intervention has a negative or positive impact on food security in a particular locality, and can also help identify mitigatory actions to redress any negative impact.

It is recommended that the Household Nutrient Deficit Score methodology and indicator be further developed to improve its scope to other nutrients, such as zinc, and the relationships between nutrients, such as the inhibition of zinc absorption by phytate, which is common in staple cereal foods. The weightings used in the overall

[88] It can also be used to measure individual nutrient deficiency where such data can be garnered

nutrient deficit score could also be refined and validated as more detail is included within the score. Given the need for more detailed information to be captured from households for the HNDS indicator, it is also recommended that a tool be developed to speed up the data collection process and enable real-time feedback to households.

This study has identified one way of improving the measurement of food security in order to monitor impact and progress and guide mitigation. It is recommended that an international standard of food security indicators and methodologies be developed and adopted under the auspices of the UN in order to guide researchers and monitoring bodies.

The above recommendations relate mainly to the research questions addressing the impact of biofuel operations on food security at the local level. So far most biofuel operations have been established in the developed world or in relatively food-secure middle-income countries. The slow progress of biofuels in Africa and other low-income countries is due to many complex factors, but one issue that appears to have partly stifled expansion is the food versus fuel debate. Most media attention has focussed on the negative impacts of biofuel operations in developing countries. The work of the media and NGOs in highlighting examples of negative outcomes remains vital to ensure that future biofuel developments remain sustainable and ethical. However, the media and NGOs can also play an important role in highlighting the positive outcomes of biofuel operations on food security.

Regarding the research questions posed at the macro level, this study finds little evidence to suggest that biofuel production-enhancing policies in the developed world have led to greater food insecurity through the reduced availability of food or higher food prices. Given the importance of phasing out fossil fuel use over the coming years, this again begs the question of why there has been so much criticism of biofuels in this regard.

In contrast to the micro level, there has been a lot of research already conducted on estimated macro impacts of biofuel production in developed and middle-income countries on commodity prices. One recommendation, however, would be that more research is conducted on how commodity prices have actually responded to biofuel feedstock production over recent years. This study provides one way of analysing this question for US maize prices, but other more in-depth studies should be conducted, particularly on the question of market-influenced supply responses.

More research also needs to be conducted on whether higher food prices lead to greater food insecurity for rural households in developing countries and the transmission of global commodity prices to national and local prices, particularly in those countries with a high proportion of the population estimated as food-insecure. Related to this is the need for the global community, through UN agencies, to assess what might be considered as an acceptable range of commodity and food prices, above which safety net supports might be triggered for vulnerable households and below which interventions might be triggered to help producers.

One of the problems facing researchers in this area is the reliability of market information, not only on prices, but also on supply and demand volumes. It is therefore recommended that, as part of the wider goal in measuring SDG progress, more resources and guidance be provided to improve agri-food market information services in developing countries. More importantly, better market information services would help to improve market efficiency in local agri-food supply chains, enable farmers to negotiate better selling prices and allow householders to negotiate better food prices given the wide variety of purchase prices reported in the household survey.

In terms of food availability, there are clearly some food-insecure countries, such as Mozambique, that have significant resources of land that could be used for greater crop production, whether for food or energy purposes. Given the uncertainty surrounding land availability and suitability for future food production, a global land plan for food and bioenergy should be developed to assess how existing land resources can be better utilised, including the potential for urban agriculture, and where additional land could be cultivated with the lowest climate change impact to meet future food and energy needs. This should be developed from detailed land mapping exercises conducted at national level. Existing calculations suggest a conservative total of 200 million hectares could be suitable for additional cultivation, mostly based in Sub-Saharan Africa and South America, but more detail is required to identify specific areas.

Where land availability is more abundant and unlikely to encroach on food needs, it would be unethical not to encourage and facilitate biofuel feedstock production that could help to improve rural incomes and food security and increase renewable energy supplies. In such cases, high-yielding feedstocks could be supported whether or not food-based. Indeed, an argument could be made for using food-based feedstocks where these do not displace existing supplies, as they might then provide a buffer stock and be used for food in the event of a production shock.

Africa and other low-income regions have yet to benefit from biofuels, despite the fact that many countries in these areas have the greatest potential to produce the highest-yielding, and lowest carbon-emitting, feedstocks and biofuels. Developed countries should therefore, not only support the development of such biofuels in low-income nations, but also adopt policies that facilitate the import of feedstocks and biofuels that have been produced in a sustainable manner from these countries.

Appendices

Appendix 1 – Examples of how biofuels affect the dimensions of food security

Biofuel operations may affect food security in a number of ways. The following notes provide examples of how each of the four pillars of food security might be affected by a biofuel operation (ie they are illustrative rather than exhaustive lists).

1. Impacts on Food Availability

The physical availability of food could be negatively affected by a biofuel operation in many different ways, including;

- If the biofuel feedstock land was previously used for food production or inputs (eg foodcrops or pasture or hedge/tree shading and protection).
- If the land was previously used for other livelihood activities that would indirectly affect food production (eg local sources of fuelwood or water, the removal of access to which could result in longer distances and hours collecting fuelwood and reduced labour hours for agricultural production)
- If demand for food or inputs by the biofuel project reduced market supplies for other customers (ie market availability was insufficient to meet the new demand from the biofuel project and prevailing local demand; although this should also trigger increased supply from surrounding farms – see below)
- If food yields were negatively affected by the biofuel project (eg through soil erosion, a lowering of the water table or an increased prevalence of pests and disease from the biofuel feedstock, etc)
- If local labour resources were drawn away from food to biofuel production with insufficient inward migration or increased food imports to offset the loss
- If working conditions for employees were such that they had little or no time or energy to spend on home production of food, reducing the amount and variety of home food production

On the other hand food availability could be positively affected by a biofuel operation;

- If the biofuel project provided additional land for food production to the community, which might be cleared or ready-cultivated
- If technical expertise and inputs were made more accessible by the biofuel project, helping to improve food productivity and storage[89]
- If other livelihood supports were made more accessible by the biofuel project (eg affordable clean fuel and safe water supplies, freeing labour resources for agricultural production[90])
- If new demand from the biofuel project stimulated farmers in the locality to produce more foodstuffs for sale relative to subsistence production (ie through effective market demand and higher prices)
- If the biofuel project itself produced more food for sale into local markets (although this might have a negative impact on prices for local farmers)

Measurements could include land area devoted to food production in the baseline against that after the biofuel project has been established, main foodcrop yields and variances pre and post-project, yield levels associated with weather and climate change impacts, market assessments of supply impacts and records of farm sales pre and post project. Such details could be captured in household questionnaires, focus groups and market surveys.

2. Impacts on Food Access

It is generally agreed that access is the most important factor determining food security, as there is often adequate availability of food but many households lack the income to afford access to sufficient nutritious food. Access is not just about purchasing food, but all means of accessing food, including home production, bartering, aid and hunting and gathering of wild foods. Access is also affected by the accessibility and quality of food markets in the vicinity. Hence, there is some overlap between availability and access.

Access to food can be negatively affected by biofuel projects;

[89] Note that technology transfer can also lead to negative impacts if inappropriate for the region and conditions.
[90] Note that improved access to affordable clean fuels would not only save time in fuelwood collection but would also reduce illness associated with smoke inhalation.

- If the land on which biofuel feedstocks are now grown (and providing water access) was previously used for crops, livestock, inputs or other income-generating and income-saving sources (eg hunting and gathering and fishing), the removal of which would reduce incomes or incur increased expenditure for local households
- If the biofuel operation paid low wages to workers, or low prices to outgrowers, which were insufficient to cover household food needs.
- If the new biofuel project generated demand for food, inputs and other essential goods (eg fuel) at local markets which increased the price of such goods, reducing the amount of food and other essentials that could be purchased by other customers

Access to food can be positively influenced by biofuel projects;

- If fair wages are paid to workers which allow them to purchase a sufficient amount and variety of food to meet their nutritional needs
- If local food prices increased following the establishment of a biofuel project, increasing the incomes of those households selling farm products, thereby enabling them to purchase more goods
- If biofuel projects improve the local infrastructure, including roads, making food markets, and more diverse food diets, more accessible
- If storage facilities were improved in the locality encouraging less waste, particularly of foodstuffs containing valuable micronutrients, such as fresh produce.

Access measures generally focus on price and income levels. A key measure would therefore be the minimum cost of a healthy diet for the locality for various age and gender groups which could then be applied at household level and compared with wages paid by biofuel operations and prices of feedstocks paid to outgrowers. Diversity of diet could also be measured, and, again, household surveys could provide much of the data needed for these calculations.

3. Impacts on Food Utilisation

Utilisation of food refers to how food is actually used by people in order to meet their nutritional needs. Thus foodstuffs have to be stored, prepared and cooked to make them utilisable, and the way in which food is prepared can affect the nutritional status of the food. Food utilisation is also affected by the health status of different people as this can affect their ability to absorb nutrients. Adequate diets also rely on a balance of different foodstuffs as some nutrients can influence the absorption of others.

Utilisation of food can be negatively influenced;

- If poor health and illness reduces the absorption of essential nutrients (indeed poor access to food and low utilisation can lead to poor health and illness)
- If households lack access to cooking essentials , such as fuelwood and clean water
- If poor education prevents households from purchasing a well-balanced diet to meet nutritional needs
- If the diversity of food production is reduced in the locality of the project (eg if outgrowers use land previously devoted to crops and livestock that provide valuable micronutrients such as fruit and vegetables)
- If poor storage reduces the quality of food and hence, utilisation.

Utilisation can be positively affected by a biofuel project;

- If traditional wood stoves are replaced by improved cooking stoves using biofuels or processed biofuel feedstocks (eg ethanol gel or straight vegetable oil), reducing smoke-related respiratory illness and improving cooking efficiency
- If biofuel projects provide improved access to clean water for drinking and cooking and improved storage.
- If biofuel projects help to improve local education and health and sanitation facilities
- If biofuel projects improve the diversity of food availability in the locality

Measurements could include anthropometric indicators to assess malnutrition rates, time and distances for collecting water and fuelwood and travelling to schools and health centres, cost and quality of fuel and water where purchased, and the prevalence of acute-respiratory and other diseases and the amount of time sick or spent caring. Most of this data could be captured by household surveys and focus groups.

4. Impacts on Food Stability

Stability of food security entails households and individuals having access to a sufficient quantity and quality of food at all times. In many food insecure regions people face seasonal shortfalls in food access during the year, particularly as stocks run low in the period leading up to the next harvest. Many food insecure regions are also in predominantly rural areas, where farmers suffer weather-related shocks from year to year. So it is important to measure such gaps at the household level in order to identify nutritional gaps both during and between years.

Stability can be negatively affected;

- If the biofuel project accentuates any seasonal shortfall in availability and access of particular foods (eg if seasonal work is the main form of employment by a biofuel project, which can leave households short of income at certain times of the year or disrupt local food production).
- If the biofuel project accentuates the variability in food production between years (eg by reducing the water table in the locality and making crops and livestock more vulnerable to drought)

Stability can be positively affected;

- If the biofuel project provides access to additional food supplies or inputs, or temporary income measures (eg food vouchers) in times of shortage
- If there are technical transfers of knowledge in reducing the size and duration of food shortfalls through the introduction of new crops and livestock or better varieties and breeds, or a better application of inputs, such as irrigation
- If storage and transport facilities are improved to reduce wastage and improve the length of food conservation

Measurements could include seasonal patterns of household food consumption, including shortage periods and depth of hunger. Again this could be largely captured by household surveys and focus group methods.

Drawn from the Roundtable on Sustainable Biofuels Food Security Guidelines (Thornhill et al., 2012)

Appendix 2 – Household Survey Questionnaire

Household Survey Questionnaire

Biofuel Company		HH Location	
Site Location		HH GPS Ref	
Region/Country		Interviewer	
Date		HH Code	

Section I – Household Characteristics

1. **Who are the members of the household?** *Complete columns 3 to 5 of the table below*

Table 1 – Household Composition

Column 1 Name *(Not essential - for reference only)*	2 Household Member ID Number	3 Relationship to Household Head *See key below table*	4 Sex *Male = 1 Female = 2*	5 Age *(estimate if not known)*
	1	Head of Household		
	2			
	3			
	4			
	5			
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			

Key for Relationship to Household Head (column 3) is; 1=Spouse, 2=Son, 3=Daughter, 4=Father, 5=Mother, 6=Grandmother, 7=Grandfather, 8=Other (specify in table)

2. **How many years education has the household head?** ______ years

Notes

1

Section II – Food Consumption (Access and Stability)

3. **How many meals do the household members usually have each day?** .... *Number* ☐
(Note this is for normal periods during the year not for unusual circumstances)

Note if the number of meals differs between different members of the household, briefly describe below

....

4. **Is there a period in the year when you usually have a shortage of food?** .... *No=0 Yes=1* ☐
If No go to Q12, if Yes go to Q5

5. **When is the shortfall period in the year?**
(ie what season or which months?)

6. **How many meals would you have each day during that shortfall period?** .... *Number* ☐

7. **Are meal sizes reduced** .... *No=0 Yes=1* ☐
during the shortfall period? *(If No go to Q9)*

8. **If so by what amount?** *per cent (%)* ______ %
(eg estimate by dividing circle)

Questions 9, 10 and 11 enable a household hunger score (HHS) to be calculated in areas where food insecurity is greatest. If using this section answer the following questions using the key below
Key - 0=never, 1=rarely (1-2 times), 2=sometimes (3-10 times) and 3=often (more than 10 times)

9. **In the past month how often was there no food to eat because of lack of resources to get food?** ☐
10. **In the past month how often did any HH member go to sleep hungry due to lack of food?** ☐
11. **In the past month how often did any HH member go a full day and night without eating?** ☐

12. **What are the main foods consumed in the household?** *Enter into column 1 of table 2 below*

13. **What are the normal amounts of each food usually consumed in the household per day?**
Enter into column 2 of table 2 the approximate amounts if these are known. Base answer on normal consumption over past year.

Table 2 - Main Foods and Amounts Consumed by the Household Per Day

Column1 Main foods consumed	2 Amount normally consumed by household per day
(eg maize, beans)	*Amount (show units - eg bags, cups, kg)*
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Notes

2

14. What other foods are normally consumed less regularly; each week or each month? *Enter into columns 1 and then 2 OR 3 of table 3 below (include meat, fish, snacks, vegetables and cooking ingredients)*

Table 3 - Other Foods Consumed and Amounts Consumed by the Household Each Week/Month

Column1 Other foods consumed (not listed in table 2)	2 Amount normally consumed by household each week	3 Amount normally consumed by household each month
	Amount (show units - eg bags, kg)	*Amount (show units - eg bags, kg)*
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
Notes		

15. What are the main foods usually purchased each week by the household? *Enter in column 1 of table 4 below. If none, go to question 14.*

16. What are the amounts of these foods usually purchased each week by the household? *Enter in column 2 of table 4 below.*

17. How much does the household usually spend on each of these foods each week? *Enter in column 3 of table 4 below.*

18. What are the main foods and amounts purchased in shortage periods (if different)? *Enter in column 4 of table 4 below*

Table 4 - Main Foods Purchased by Household and Household Food Expenditure Each Week

1 Main foods usually purchased *(include cooking oils, sugar, salt, flour, etc)*	2 Amount usually purchased each week *(specify unit – eg cups, kg)*	3 Amount usually spent each week *(specify currency)*	4 Amount purchased in shortage periods *(specify unit)*
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
Notes			

3

Section III – Fuel, Water and Health (Utilisation)

19. What type of cooking facilities does the household have? *Yes =1 (*=wood or charcoal stove)*

Open fire - indoor ☐ Wood/Charcoal stove ☐ Ethanolgel stove ☐ Gas/electric oven ☐

Open fire – outdoor ☐ Vegetable oil stove ☐ Other ☐ specify...

20. What are the main fuels used? *Rank 1,2,3 by importance in boxes (*biofuel = ethanol gel, vegetable oils)*

1.Wood ☐ 2.Charcoal ☐ 3.Kerosene ☐ 4.Gas ☐ 5.Electric ☐ 6.Biofuel* ☐ 7. Other ☐

If other specify ....

21. Which of the fuels are purchased? *Enter no (above) and %*

Fuel No	% bought	Fuel No	% bought

22. How much is normally spent on fuel each week? .... *(note currency)* ☐

23. Who collects most of the fuel in the household? .... *Household Member ID Number(s)* ☐

24. How much time is spent by the household collecting fuel each week? *Total hours by all* ☐ hours

25. What is the main drinking water source for the household? *(description – eg spring, well(protected or not), borehole, tap, river)* ☐

26. How far is the main water source located from the household? *(if possible in m or km)* ☐

27. Who collects most of the water in the household? ....*Household Member ID Number(s)* ☐

28. How much time is spent by the household collecting water each day? ....*No of hours* ☐ hours
(include total hours by all persons collecting, so if 2 people spend 30 mins then record 1 hour)

29. How much water is collected per day? ....*Approximate number of litres* ☐ litres

30. What is the quality of the water? *Enter 1 into relevant boxes (describe box 5)*

1. Good Drinking/Cooking ☐ 2.Poor D/C ☐ 3. Salty ☐ 4.Muddy ☐ 5. Other ☐

31. If there are periods in the year when water is not available from the normal source, where do you get the water when this is the case?
Specify the period and source(s)

Period	Source

32. Do any of the household members suffer from long-term illnesses?
Answer - Household Member ID Number(s) and Type of Illness

HH ID	Type of Long-term Illness

33. How many days/month would this prevent work/school (worst sufferers)?
Answer – number of days per month (if zero enter 0) and Household ID No(s)

HH ID	Days per month

34. Which household member(s) looks after them during such illness? *Household ID No(s)* ☐

4

Section IV– Farming Activities (Availability and Access)

35. Do you.. …… a) grow crops? [ ] b) raise livestock? [ ] c) neither [ ] *(Answer Yes=1)*
If c) go to Q40

36. How much land does the household farm? [ ] and own? [ ]

37. How much of the farmland is rented and what is the rent (per unit)? *Area* [ ] *Rent* [ ]

38. Who works on the farm and how many hours per week?

HH ID	Est Hours/Wk	HH ID	Est Hours/Wk	HH ID	Est Hours/Wk

39. How much land is used for crops, grazing and other uses by the household? *Enter in table 5.*

Table 5 – Household Land Use (Area)

	Area		Area
1.Total *(check Q36)*		5. Fallow	
2.Crops		6. House & Kitchen Garden (ie not included in crops)	
2a Irrigated Crops		7. Other (specify)	
3.Grazing/Pasture		**8. Total (check 2+3+4+5+6+7)**	
4.Forest/Woodlot		*Notes*	

40. How many livestock & products do you own, raise, slaughter for own use and normally sell or buy or barter in a year? *Note - if cannot estimate a normal pattern, estimate for past year.*

Table 6 – Livestock and Products Owned, Used, Bought and Sold

Livestock Type	Purpose (work, meat, milk/eggs)	Number Owned	No Sold/Bartered Yearly (average)	Average Price	No Bought/Bartered Yearly (on average)	Average Price
1.						
2.						
3.						
4.						
5.						
Livestock Type	**No young raised (yearly approx)**	**No for own use***	**Products (meat, eggs, milk)**	**Own use (% or kg)**	**Sales/Barter of Products (% or No)**	**Average Price**
1.			1. 2.			
2.						
3.						
4.						
5.						

** - ie total number livestock slaughtered for home meat consumption in a year (not just young)*

Cropping Details

41. **When are the main harvest periods in the year?** ....

42. **Which main food and cash crops did you plant and harvest last year?** *Enter in table 7 below column 1 (all harvests)*

43. **What area of these crops did you plant and what quantity was harvested?** *Enter in table 7 columns 2 and 3*

44. **How much of each crop did you sell or barter?** (or what % compared to own use?) *Enter in table 7, column 4*

45. **What price did you receive for crops sold last year?** (approx average price or equivalent value if bartered) *Enter in table 7, column 5*

Table 7 - Crop Production

1 Crops grown last year (all harvests in the year)	*2* Area of crops grown last year	*3* Production last year	*4* Sales or Barter last year	*5* Prices received last year *(approximate average)*
Crop Name *(eg Maize/Cassava/Jatropha)*	Area and Unit *(eg acres or ha)*	Production and Unit *(eg bags, kg)*	*(eg as % of production or per unit)*	Price and Unit *(eg currency/kg)*
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Any additional comments to table add in this box.
(eg if crops were poor last year state normal area and production)

Section V - Non-Farm Employment, Income and Expenditure (Access and Livelihoods)

46. **What type of non-farm income is earned by household members?** *Answer in table 8, columns 1-3 below*

47. **What are the estimated non-farm incomes earned by household members?** *Answer in columns 4-5 below.* *Note if respondent does not wish to answer Q47, try to answer Q48 and/or Q49*

Table 8 – Household Off-farm Income and Remittances

1 Household ID Number	2 Type of Income *See key below*	3 Description of Income *(ie what is the type of work or remittance?)*	4 Estimated Income *(and currency)*	5 Period *(wk/ mth/ yr)*

Key - *1=Full-time employment, 2=Part-time employment, 3=Seasonal employment 4=Occasional hired labour, 5=Own business (non-farm), 6=Other (specify in box and include remittances)*

42. **What is the estimated % of the total household income generated from off-farm income compared to farm income?** *(estimate by dividing circle)*

% of household income from off-farm [%] % of household income from farm sales [%]

43. **What is the estimated income received by the household each week or month?** [ ]

44. **Are any remittances received by the household?** *No=0 Yes=1* [ ] *If yes ensure entry in table 8 above*

45. **What are the main non-food essential expenses of the household?** *Enter in table 9 below*

Table 9 – Household Non-Food Expenditure on Essential Items

1 Item (eg school fees, health)	*2* Amount spent	*3* Wk/Mth /Yr	*1* Item (eg school fees, health)	*2* Amount spent	*3* Wk/Mth /Yr
1.			7.		
2.			8.		
3.			9.		
4.			10.		
5.			11.		
6.			12.		

Notes

Section VI – Impacts of Biofuel Operation

i) Land & Resource Issues

46. **Has your household lost access to land or resources* as a result of the biofuel project?** [ ]
(livelihood resources - eg water, fuelwood, treecrops, wildfoods) No=0 Yes=1(if No go to 54)*

47. **Describe the area and/or resources lost?** [ ]

48. **What was the previous use of that land or those resources?** [ ]

49. **Did (or will) you or your village receive compensation?** *No=0 Yes=1Dont Know=2* [ ]

50. **What type of compensation was (will be) received?** [ ]

51. **Do you think the compensation is adequate?** ………… *No=0 Yes=1Dont Know=2* [ ]

52. **Do you feel you had the ability to say "No" to the transfer of land to the biofuel project or the removal of access to resources?** …………… *No=0 Yes=1 (if yes go to 54)* [ ]

53. **If "No" why not?** [ ]

ii) Employment Issues

54. **Are any household members employed by a biofuel company?** *No=0 Yes=1(If no go to 59)* [ ]

55. **What is the type of work, and days and hours worked?** *Enter into table 9*
(check that salary/income form the biofuel employment is entered in table 7 above)

Table 9 – Employment on Biofuel Feedstock Enterprise

Household Member	Job Title and Description of Work *(ie more detail than entry in table 7 above)*	Days and hours worked	
ID Number		*Days/week*	*Hours/day*

56. **What are the main advantages and disadvantages of the biofuel employment?**

Advantages

Disadvantages

57. **What affect has the biofuel employment had on the household's own food production?**

No change [ ] Down [ ] By % Up [ ] By % *If no change go to 59*

58. What are the reasons for the change in food production?

iii) Biofuel Feedstock Issues

59. Have you planted any crops for biofuel production in the past 3 years? *No=0 Yes=1*
If no go to 65

60. What are the biofuel crops you have planted this and last year and plan for next year?
Enter in table 10. Note - check that last year's areas match those in table 6

Table 10 – Biofuel Crops and Areas

1 Biofuel Crop and Year Planted		2 Area Planted
Biofuel Feedstock Crop	Year	Area (specify unit)
	Last	
	This	
	Next	

61. What was the land planted to biofuel crops previously used for?

62. Do you intercrop and if so which crops and what area? *Enter in table 11*

Table 11 - Intercropping of Biofuel Crop

Biofuel crop	Name of crops intercropped	Area intercropped (specify unit – eg ha)

63. Have you cut your foodcrop area due to the biofuel crop production? *No=0 Yes=1*

63. If so by how much? – in area units or % of total? Down by

64. What were your main reasons for growing biofuel feedstocks?

65. Has the biofuel crop/project affected your foodcrop yields? *Yes=1*

No change Down by % Up by % Don't know

66. How has the biofuel crop/project affected yields?

67. What do you see as the main advantages and disadvantages of growing biofuel crops?

Advantages

Disadvantages

iv) General Biofuel Issues

68. Has the biofuel operation affected any other livelihood activities in the household?
(ie other than employment in the biofuel operation and outgrower sales) *No=0 Yes=1*

69. If so describe the impact?
(eg new income-earning)

70. How has the biofuel operation affected your household's overall food security? *Yes=1*

No change Better Worse Don't Know *(if no change go to 57)*

71. What is (are) the main reason(s) for the change in the household's food security status?

72. What other impact(s) has the biofuel operation had on the household and local community (if any)?

73. Are you happy to have a biofuel operation in your area? *No=0 Yes=1 Don't Know=2*

Notes

Appendix 3 – Estimated World Fuel Ethanol Production

Fuel Ethanol Production (Billion litres)	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
EU-28	800	1,608	1,803	2,816	3,553	4,268	4,392	4,658	5,000	5,250	5,190
Other Europe and FSU	0	38	38	51	51	54	71	139	160	200	250
Africa	10	11	16	16	26	29	36	53	100	120	200
Canada	250	250	615	960	1,340	1,445	1,700	1,695	1,730	1,708	1,650
U.S.A.	14,780	18,489	24,685	35,237	41,404	50,338	52,727	50,036	50,318	54,180	56,046
Central America	0	0	23	35	70	73	75	171	204	233	275
Argentina	0	0	0	0	23	122	170	253	475	670	815
Brazil	13,813	15,773	19,587	23,582	22,201	24,516	20,212	20,739	24,377	25,585	26,850
Colombia	100	269	275	256	325	291	337	370	388	406	425
Paraguay	0	0	65	90	120	130	130	165	180	195	205
Peru	0	0	0	0	59	70	123	235	240	245	245
Other S.America	0	10	10	10	16	20	20	40	50	60	70
China	1,200	1,664	1,731	2,257	2,466	2,479	2,566	2,858	2,934	2,951	3,078
India	100	200	200	280	100	50	365	305	382	350	685
Philippines	0	0	0	2	23	10	4	35	72	115	175
Thailand	70	135	192	336	419	451	486	471	950	1,058	1,265
Other S.Asia	0	0	1	11	107	110	134	158	187	131	83
Australia	27	42	84	149	203	275	319	306	290	265	265
WORLD TOTAL	**31,150**	**38,489**	**49,325**	**66,088**	**72,506**	**84,731**	**83,867**	**82,687**	**88,037**	**93,722**	**97,772**

Sources: National statistical agencies and government departments, including USDA, EIA (Energy Information Administration), MAPA – Ministry of Agriculture, Fisheries and Food in Brazil, Eurostat, as well as trade associations such as ePure, Brazilian Sugar Industry Association - UNICA (Uniao da Industria de Cana de Acucar), Petroleum, Natural Gas and Biofuels Agency of Brazil (ANP), Global Renewable Fuel Alliance and specialist agencies and companies such as FO Lichts, Strategie Grains, Platts and BP plus international organisations such as International Energy Agency (IEA), OECD, FAO and UNEP.

Appendix 4 – Estimated World Biodiesel and HVO Production

Biodiesel & HVO Production (Billion litres)	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
EU-28	3,272	5,360	6,750	6,860	9,857	10,707	11,041	11,082	11,983	13,341	13,535
Other Europe and FSU	10	30	35	70	67	100	146	176	132	185	158
Canada	15	40	70	95	110	115	120	100	140	340	305
U.S.A.	344	948	1,854	2,567	1,953	1,300	3,662	3,750	5,146	4,841	4,780
Argentina	20	100	215	830	1,360	2,070	2,760	2,800	2,260	2,930	2,070
Brazil	0	65	375	1,100	1,608	2,386	2,673	2,717	2,960	3,460	4,000
Colombia	0	0	9	80	201	416	548	605	621	634	636
Other S America	2	3	17	23	23	60	65	70	114	73	92
China	40	273	352	534	591	568	738	909	1,079	1,133	1,141
India	10	20	10	15	75	90	102	115	120	130	135
Indonesia	10	65	270	630	330	740	1,800	2,200	2,800	3,300	1,600
Korea,South	10	40	100	100	260	340	350	400	475	485	500
Malaysia	15	100	109	212	241	103	54	152	358	359	537
Philippines	0	5	49	66	137	124	133	138	155	172	152
Singapore	1	15	40	100	40	0	250	500	1,830	1,000	2,000
Thailand	50	70	68	449	610	660	630	900	1,060	1,170	1,210
Other Asia	0	0	7	13	41	30	77	62	76	76	76
Australia	20	21	54	50	85	85	80	51	62	65	100
WORLD TOTAL	**3,818**	**7,155**	**10,386**	**13,796**	**17,592**	**19,900**	**25,240**	**26,734**	**31,382**	**33,705**	**33,045**

Sources: National statistical agencies and government departments, including USDA, EIA (Energy Information Administration), Eurostat, plus trade associations such as European Biodiesel Board, FEDIOL (European Vegetable Oil and Protein Meal Federation), Malaysian Palm Oil Board, plus specialist agencies such as FO Lichts, Platts, Oil World and Strategie Grains and international organisations such as UNEP, OECD, FAO.

Appendix 5 – Mozambique and Tanzanian Crop Areas

Mozambique Area Planted (hectares) – 2009/10 Census				
	Gaza	Inhambane	Manica	Mozambique
Maize	118,310	85,426	213,726	1,430,784
Sorghum	4,985	15,507	57,402	355,732
Rice	14,126	6,129	2,101	281,936
Cassava	50,427	120,094	26,025	1,038,989
Sweet Potatoes	75,498	38,608	104,186	861,312
Butter Beans	3,345	309	9,953	98,695
Jugo Beans	6,541	13,302	7,879	74,492
Pigeon Peas	1,151	223	4,246	262,498
Cow Peas	47,674	68,414	28,194	360,896
Groundnuts	20,970	54,368	20,244	365,856
Sesame	662	357	12,747	97,573
Other	23,666	26,100	45,647	598,423
Total	**343,689**	**402,737**	**486,703**	**5,827,186**

% Breakdown of Mozambique Crop Areas – 2009/10 Census				
	Gaza	Inhambane	Manica	Mozambique
Maize	34.4	21.2	43.9	24.6
Sorghum	1.5	3.9	11.8	6.1
Rice	4.1	1.5	0.4	4.8
Cassava	14.7	29.8	5.3	17.8
Sweet Potatoes	22.0	9.6	21.4	14.8
Butter Beans	1.0	0.1	2.0	1.7
Jugo Beans	1.9	3.3	1.6	1.3
Pigeon Peas	0.3	0.1	0.9	4.5
Cow Peas	13.9	17.0	5.8	6.2
Groundnuts	6.1	13.5	4.2	6.3
Sesame	0.2	0.1	2.6	1.7
Other	6.9	6.5	9.4	10.3
Total	**100.0**	**100.0**	**100.0**	**100.0**

Tanzania Area Planted (hectares) - 2007/8 Census			
	Singida	Arusha	Tanzania
Maize	150,053	123,922	4,082,500
Sorghum	97,513	1,658	566,728
Rice	13,066	887	880,108
Millet	55,721	622	224,539
Cassava	3,235	454	630,472
Sweet Potato	3,591	441	210,327
Beans	6,420	50,726	749,685
Cow Peas	1,264	2,691	88,455
Chick Peas	5,949	2,368	63,207
Groundnuts	15,376	12	470,597
Sesame	5,498	376	139,910
Sunflower	99,154	2,217	347,478
Cotton	2,122	145	574,836
Other	5,622	14,460	346,244
Total	**464,584**	**200,979**	**9,375,086**

% Breakdown of Tanzania Crop Areas – 2007/8 Census			
	Singida	Arusha	Tanzania
Maize	32.3	61.7	43.5
Sorghum	21.0	0.8	6.0
Rice	2.8	0.4	9.4
Millet	12.0	0.3	2.4
Cassava	0.7	0.2	6.7
Sweet Potato	0.8	0.2	2.2
Beans	1.4	25.2	8.0
Cow Peas	0.3	1.3	0.9
Chick Peas	1.3	1.2	0.7
Groundnuts	3.3	0.0	5.0
Sesame	1.2	0.2	1.5
Sunflower	21.3	1.1	3.7
Cotton	0.5	0.1	6.1
Other	1.2	7.2	3.7
Total	**100**	**100**	**100**

Sources : Tanzania - Ministry of Agriculture, Food Security and Cooperatives et al, 2007/8 National Sample Census of Agriculture - Crop Sector National Report.

Appendix 6 – US Maize Supply and Demand - 2004/5 to 2015/16

6a. US maize supply and demand balances – 2004/5 to 2015/16 (Million tonnes)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Change 04-15
Supply	**324.5**	**336.2**	**317.8**	**364.8**	**347.5**	**374.6**	**359.7**	**342.2**	**302.4**	**373.0**	**393.2**	**390.8**	**+66.4**
Opening Stock	24.3	53.7	50.0	33.1	41.3	42.5	43.4	28.6	25.1	20.9	31.3	44.0	+19.6
Imports	0.3	0.2	0.3	0.5	0.3	0.2	0.7	0.7	4.1	0.9	0.8	1.4	+1.1
Production	299.9	282.3	267.5	331.2	305.9	331.9	315.6	312.8	273.2	351.3	361.1	345.5	+45.6
Demand	**270.8**	**286.2**	**284.6**	**323.5**	**305.0**	**331.3**	**331.0**	**317.0**	**281.5**	**341.7**	**349.2**	**345.0**	**+74.3**
Ethanol Use	33.6	40.7	53.8	77.4	94.2	116.6	127.5	127.0	117.9	130.1	132.1	133.4	+99.7
Other H&I Use	35.2	36.0	36.1	35.4	33.5	34.8	35.7	36.1	35.5	34.8	34.5	34.5	-0.6
Animal Feed use	155.8	155.3	140.7	148.8	130.4	129.6	121.3	114.8	109.6	128.0	135.2	133.4	-22.5
Exports	46.2	54.2	54.0	61.9	47.0	50.3	46.5	39.1	18.5	48.8	47.4	43.8	-2.4
End Stocks	**53.7**	**50.0**	**33.1**	**41.3**	**42.5**	**43.4**	**28.6**	**25.1**	**20.9**	**31.3**	**44.0**	**45.8**	**-7.9**
Stock-to-Use Ratio	*19.8*	*17.5*	*11.6*	*12.8*	*13.9*	*13.1*	*8.7*	*7.9*	*7.4*	*9.2*	*12.6*	*13.3*	*-6.6*

6b. US maize supply and demand balance adjusted for protein feed end-use – 2004/5 to 2015/16 (Million tonnes)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Change 04-15
Supply	**324.5**	**336.2**	**317.8**	**364.8**	**347.5**	**374.6**	**359.7**	**342.2**	**302.4**	**373.0**	**393.2**	**390.8**	**+66.4**
Opening Stock	24.3	53.7	50.0	33.1	41.3	42.5	43.4	28.6	25.1	20.9	31.3	44.0	+19.6
Imports	0.3	0.2	0.3	0.5	0.3	0.2	0.7	0.7	4.1	0.9	0.8	1.4	+1.1
Production	299.9	282.3	267.5	331.2	305.9	331.9	315.6	312.8	273.2	351.3	361.1	345.5	+45.6
Demand	**270.8**	**286.2**	**284.6**	**323.5**	**305.0**	**331.3**	**331.0**	**317.0**	**281.5**	**341.7**	**349.2**	**345.0**	**+74.3**
Adjusted Ethanol Use	23.7	28.6	38.1	54.4	64.8	80.7	88.3	88.1	82.1	91.0	92.3	93.7	+70.0
Adjusted Other H&I Use	27.6	28.2	28.3	27.8	26.4	27.5	28.1	28.1	28.0	27.6	27.4	27.4	-0.1
Adjusted Animal Feed Use	169.7	171.5	161.1	174.1	161.5	164.3	159.7	153.7	144.6	162.3	170.5	168.3	-1.4
Adjusted Exports	49.8	58.0	57.2	67.3	52.4	58.8	55.0	47.1	26.9	60.8	59.0	55.6	+5.9
End Stocks	**53.7**	**50.0**	**33.1**	**41.3**	**42.5**	**43.4**	**28.6**	**25.1**	**20.9**	**31.3**	**44.0**	**45.8**	**-7.9**
Stock-to-Use Ratio	*19.8*	*17.5*	*11.6*	*12.8*	*13.9*	*13.1*	*8.7*	*7.9*	*7.4*	*9.2*	*12.6*	*13.3*	*-6.6*

Appendix 7 – US Maize Supply and Demand Balance Changes - 2005 to 2015

7a. US maize supply and demand balance changes – 2005 to 2015 (Million tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Change 04-15
Supply Change	**11.7**	**-18.4**	**47.0**	**-17.3**	**27.1**	**-14.9**	**-17.5**	**-39.8**	**70.7**	**20.1**	**-2.3**	**+66.4**
Opening Stock Change	29.4	-3.7	-16.9	8.1	1.2	0.9	-14.7	-3.5	-4.3	10.4	12.7	+19.6
Import Change	-0.1	0.1	0.2	-0.2	-0.1	0.5	0.0	3.3	-3.2	-0.1	0.6	+1.1
Production Change	-17.6	-14.8	63.7	-25.3	26.0	-16.3	-2.8	-39.6	78.1	9.8	-15.6	+45.6
Demand	**15.4**	**-1.6**	**38.9**	**-18.5**	**26.2**	**-0.3**	**-14.0**	**-35.5**	**60.2**	**7.5**	**-4.2**	**+74.3**
Ethanol Use	7.1	13.1	23.6	16.8	22.4	10.9	-0.5	-9.1	12.3	1.9	1.3	+99.7
Other H&I Use	0.8	0.2	-0.7	-1.9	1.4	0.9	0.4	-0.7	-0.7	-0.2	0.0	-0.6
Animal Feed Use Change	-0.5	-14.6	8.1	-18.4	-0.8	-8.2	-6.6	-5.2	18.4	7.2	-1.9	-22.5
Exports Change	8.0	-0.2	7.9	-14.9	3.3	-3.8	-7.4	-20.6	30.2	-1.4	-3.5	-2.4
End Stocks Change	**-3.7**	**-16.9**	**8.1**	**1.2**	**0.9**	**-14.7**	**-3.5**	**-4.3**	**10.4**	**12.7**	**1.8**	**-7.9**

7b. US maize supply and demand balance changes adjusted for protein feed end-use – 2005 to 2015 (Million tonnes)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Change 04-15
Supply Change	**11.7**	**-18.4**	**47.0**	**-17.3**	**27.1**	**-14.9**	**-17.5**	**-39.8**	**70.7**	**20.1**	**-2.3**	**+66.4**
Opening Stock Change	29.4	-3.7	-16.9	8.1	1.2	0.9	-14.7	-3.5	-4.3	10.4	12.7	+19.6
Import Change	-0.1	0.1	0.2	-0.2	-0.1	0.5	0.0	3.3	-3.2	-0.1	0.6	+1.1
Production Change	-17.6	-14.8	63.7	-25.3	26.0	-16.3	-2.8	-39.6	78.1	9.8	-15.6	+45.6
Disappearance	**15.4**	**-1.6**	**38.9**	**-18.5**	**26.3**	**-0.3**	**-14.0**	**-35.5**	**60.2**	**7.5**	**-4.2**	**+74.3**
Ethanol Use	4.9	9.5	16.3	10.4	15.9	7.6	-0.2	-6.0	8.9	1.3	1.4	+70.0
Other H&I Use	0.6	0.2	-0.5	-1.4	1.2	0.6	0.0	-0.2	-0.4	-0.2	0.0	-0.1
Animal Feed Use Change	1.8	-10.4	13.0	-12.6	2.8	-4.6	-5.9	-9.1	17.7	8.2	-2.2	-1.4
Exports Change	8.2	-0.8	10.1	-14.9	6.4	-3.8	-7.9	-20.2	33.9	-1.8	-3.3	+5.9
End Stocks Change	**-3.7**	**-16.9**	**8.1**	**1.2**	**0.9**	**-14.7**	**-3.5**	**-4.3**	**10.4**	**12.7**	**1.8**	**-7.9**

Source : Using USDA supply and demand estimates as at May 2016 and historical data from USDA statistical yearbooks. Note that Years refer to harvest season (ie 2004 = 2004/5 marketing season).

Appendix 8 – Proportions of Total Supply and Demand Changes in the US Maize Balance from 2005 to 2015

8a. Proportions of total changes in the US maize supply and demand balance from 2005 to 2015 (Percentage points)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Supply	6.3	2.5	10.9	4.5	3.7	2.4	2.4	6.3	11.5	2.7	3.9	**57**
Demand	2.2	3.8	5.4	7.0	3.8	3.2	2.0	4.8	8.3	1.5	0.9	**43**
Demand breakdown												
Ethanol	*1.0*	*1.8*	*3.2*	*2.3*	*3.0*	*1.5*	*0.1*	*1.2*	*1.7*	*0.3*	*0.2*	***16***
Other H&I	*0.1*	*0.0*	*0.1*	*0.3*	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.0*	*0.0*	***1***
Animal Feed	*0.1*	*2.0*	*1.1*	*2.5*	*0.1*	*1.1*	*0.9*	*0.7*	*2.5*	*1.0*	*0.3*	***12***
Export	*1.1*	*0.0*	*1.1*	*2.0*	*0.4*	*0.5*	*1.0*	*2.8*	*4.1*	*0.2*	*0.5*	***14***

8b. Proportions of total changes in the US maize supply and demand balance adjusted for co-products from 2005 to 2015 (Percentage points)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Supply	6.6	2.6	11.4	4.7	3.9	2.5	2.5	6.5	12.0	2.9	4.1	**60**
Demand	2.2	2.9	5.6	5.5	3.7	2.3	2.0	5.0	8.6	1.6	1.0	**40**
Demand breakdown												
Ethanol	*0.7*	*1.3*	*2.3*	*1.5*	*2.2*	*1.1*	*0.0*	*0.8*	*1.3*	*0.2*	*0.2*	***12***
Other H&I	*0.1*	*0.0*	*0.1*	*0.2*	*0.2*	*0.1*	*0.0*	*0.0*	*0.1*	*0.0*	*0.0*	***1***
Animal Feed	*0.2*	*1.5*	*1.8*	*1.8*	*0.4*	*0.6*	*0.8*	*1.3*	*2.5*	*1.2*	*0.3*	***12***
Export	*1.2*	*0.1*	*1.4*	*2.1*	*0.9*	*0.5*	*1.1*	*2.8*	*4.8*	*0.3*	*0.5*	***16***

Source : Using USDA supply and demand estimates as at May 2016 and historical data from USDA statistical yearbooks. Note that Years refer to harvest season (ie 2005 = 2005/6 marketing season).

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