Feed

Fuel

Food

Competition and potential impacts
on small-scale crop–livestock–energy farming systems

Feed, food and fuel: Competition and potential impacts on small-scale crop–livestock–energy farming systems

An assessment commissioned by the
CGIAR Systemwide Livestock Programme

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Design and layout—ILRI Editorial and Publishing Services, Addis Ababa, Ethiopia.

Correct citation: Dixon J et al. 2010. *Feed, food and fuel: Competition and potential impacts on small-scale crop–livestock–energy farming systems.* CGIAR Systemwide Livestock Programme, Project Report. SLP, Addis Ababa, Ethiopia. 114 pp.

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Abbreviations and acronyms

APAARI	Asia-Pacific Association of Agricultural Research Institutions
Btoe	billion tonne of oil equivalent
CDD	Complex differentiated dynamic
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CIMMYT	Centro Internacional de Mejoriamento de Maiz y Trigo (International Maize and Wheat Improvement Center)
CIP	Centro Internacional de la Papa (International Potato Center)
CLEFS	Crop–livestock–energy farming system
DDGS	Distillers Dried Grains with Solubles
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GHG	Green house gas
ICARDA	International Center for Agricultural Research in the Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDB	InterAmerican Development Bank
IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
MDG	Millennium Development Goal
Mtoe	Million tons oil equivalent
SAT	Semi-Arid Tropics
SLP	System-wide Livestock Programme
1G	first generation (bioethanol) production, from starch or sugars
2G	second generation (bioethanol) production, from ligno-cellulose

Preface and acknowledgements

The Systemwide Livestock Programme had the foresight to anticipate the potential challenges posed by expanding biofuel production associated with increasing energy prices, and commissioned this study of plausible impacts of biofuel production on crop–livestock farming systems and poverty. As is well known, there is great diversity in the crop–livestock systems which are potentially impacted by changes in fuel prices. Moreover, the period of the study has witnessed substantial volatility in energy and food prices which may well continue, albeit perhaps in a muted form, for the foreseeable future. Thus, the study did not seek to forecast precise impacts; rather, it sought to illuminate the nature of the complex interactions and trends which shape the competition and synergies between feed, food and fuel in the context of sustainable development. The authors chose a novel framework to illuminate the interactions between the various components of crop–livestock–energy systems as well as diversity of potential outcomes in different contexts in developing regions.

On behalf of the SLP, Interim Coordinator Dr William Thorpe, initiated the study, along with the sister study on 'Drivers' and from October 2008 SLP Coordinator Bruno Gerard guided its finalization. In the course of the study 22 authors and their colleagues from nine CGIAR Centres contributed ideas, analysis and text to the report. Draft reports were externally reviewed and considered in SLP meetings.

The report built on a variety of analyses, some of which represent work in progress as this report is being finalized, not least the simulations of impacts using the IMPACT model at IFPRI. The report is closely aligned with the sister study of SLP on the drivers of change to maximize synergy and avoid contradictions in results and conclusions.

The authors appreciate the general support and editorial advice of Betty Rojon and Mike Listman.

Executive summary

Introduction

Across developing regions more than three-quarters of the poor and hungry are found in rural areas; and it is mixed crop and livestock production on which a majority of rural households depend for their core livelihoods. However, their livelihood portfolios have been evolving and may even change radically under new energy and economic development scenarios. Until the collapse of energy prices during 2008, markets and public policies spurred massive investment in biofuel production. While energy prices were high, global renewable energy investment rose from less than USD 20 billion during 2003 to USD 150 billion during 2007. Should energy prices continue to rise, further investment in renewable energy in general and biofuel production in particular can be expected.

Mixed crop–livestock farming systems are a major, often dominant, agricultural production model in much of Africa, Asia and Latin America. These systems are often based on starchy staples (e.g. maize, rice, wheat, cassava and sorghum) and various ruminants (e.g. buffalo, cattle, goats and sheep) and monogastrics (e.g. swine and poultry). Because bioenergy production and use plays such a key role in these systems, they are referred to in this report as crop–livestock–energy farming systems (CLEFS). It would be a mistake to conclude that animal production would escape the impacts of biofuel production: in fact, the demand for biofuels could potentially impact CLEFS in various direct and indirect ways, not least through the supply and demand of biomass—but little is documented. More directly, expansion of biofuel production could promote the intensification of bioenergy crops with potential adverse environmental effects from monoculture and unbalanced input use, and augments incentives to expand cultivation into forests which worsens carbon emissions, threatens biodiversity and may hinder the replenishment of water resources. Again, the evidence is sparse and mixed. Moreover, biofuel facilities could affect local environments.

This study addresses this knowledge gap by illustrating the complex interactions between feed, food and fuel and the probable outcomes for livelihoods and poverty in contrasting CLEFS. For the purposes of this analysis, the following CLEFSs (and associated case study countries) were contrasted: cassava-based (Nigeria); maize-based (Kenya); wheat-based (Turkey), rice–wheat (India); sorghum-based (India); rice-based (China and India); sugar-cane-based (Brazil).

In broad terms, bioenergy produced from biomass provides renewable energy for more than half of world's population. However, viewed from the perspective of industrial economies, primary energy consumption—of approximately 10.3 Mtoe (million tons of oil equivalent) in 2002—is sourced from oil (35%), gas (21%), coal (23%), nuclear (7%) and renewables (14%) respectively. In relation to renewables, most recent interest has centred on two liquid biofuels: bioethanol derived from starch- or sugar-rich crops and biodiesel derived from plant oils and animal fats. Global production of bioethanol in 2007 was about 51.3 billion litres, dominated by USA, Brazil and China compared with about 10.6 billion litres of biodiesel, dominated by Germany and France.

In parallel with past expansion of investment and substantial public support for biofuels R&D which continued even when oil prices bottomed out at less than USD 40 per barrel (around half of current prices), biofuels production technologies are developing rapidly. The progress with bioethanol holds major significance for livestock producers in developing countries. At present about 90 percent of bioethanol is produced through a first generation (1G) technology from starches or sugars, mostly from maize grain or sugar-cane (only modest volumes of wheat, cassava, sugar beet, sorghum and other feedstocks are used). While sugar-cane-based bioethanol production is a mature technology, advances in maize grain processing are improving conversion efficiency, increasing the value of by-products and reducing the capital cost of plants. Further, one major step forward is the generation of bioethanol from cellulose, so called second generation (2G) processing, which, although requiring more expensive facilities, offers the promise of dramatically reducing the average cost of bioethanol production. The implications of this technology for revolutionizing the production of livestock feed are not always recognized: the same process will in theory convert low value cellulose to high quality animal feed suitable not only for ruminants but also for monogastrics. Conversely, the shift to second generation processing is likely to increase competition for crop residues, which are the main source of livestock feed in many of the poorest parts of the world. This could have strong negative impacts on the livelihood of farmers dependent on small-scale mixed crop–livestock systems where competition for use of biomass for food, fuel and soil replenishment is already strong. While the first commercial plants began operations in 2009, it is predicted that most new bioethanol plants established after 2010 will utilize 2G technology. Such a re-orientation of new investment from 1G bioethanol to 2G bioethanol production could have profound effects on the industry and for livestock producers.

The expansion of biofuels production creates both opportunities and risks for livestock industries and smallholders in developing countries which could change dramatically as biofuel production technologies shift from 1G starch and sugar-based first generation to 2G cellulose-based second generation technologies. It is expected that 2G will underpin much new investment in biofuel production from 2010 onwards, and a majority from 2015. Thus, this document compares and contrasts potential effects and impacts in 2015, characterized by starch and sugar-based production technology, with 2030, dominated by cellulose-based production technologies. This shift is expected against a backdrop of continuing investment in other renewable energies including thermo-combustion, e.g. of rice straw, wind and solar.

Global trends and market responses

One set of projections estimates global population growth through 2015 to 2030 from 7.2 billion to 8.2 billion (of which two-thirds will occur in sub-Saharan Africa and South Asia) and an expansion of global income from USD 52 to USD 82 billion which would lead to increased demand for food by 14% over the period, including an additional demand for livestock products (notably meat, eggs and milk) by 19% to 2015 and 40% to 2030. With greater income, the demands for transportation and other energy intensive services and thus energy would be expected to increase by 24% over the period—from around 14.3 Mtoe (million tonne of oil equivalent) in 2015 to 17.8 Mtoe in 2030, with India, China, Middle East and parts of Africa registering the strongest growth.

Based on IFPRI research, three scenarios are depicted in this assessment: baseline as at the turn of the century (S0), 'business-as-usual' biofuel growth (S1) and 'aggressive' expansion (S2) of biofuel production. Significant expansion of demand for feedstocks is projected by 2020 (e.g. maize demand under S0, S1 and S2 of 37 Mt, 152 Mt and 303 Mt respectively; and oilseeds, 2 Mt, 22 Mt and 44 Mt respectively—and under the S2 scenario cassava, wheat and sugar reach 57 Mt, 25 Mt and 28 Mt respectively.

After years of steady decline in international food prices, several factors led to strong price increases on international markets for many crops up to 2008, which have now eased considerably—albeit still higher than the international cereal prices of the early 2000s and substantially higher in many developing countries. It is estimated that by 2020 maize prices would increase by 26% more under S1 scenario than the S0 scenario, compared with 18% for oilseeds, 12% for sugar, 11% for cassava, and 8% for wheat. As would be expected, the S2 aggressive biofuel expansion scenario shows dramatic price increases by 2020 relative to the baseline: maize 72% higher; oilseeds 44% higher; cassava and sugar 27% higher; and wheat 20% higher. With more crop grains/tubers and biomass used for 1G and 2G bioethanol production respectively, livestock feed faces strong competition and feed shortages, high feed prices and high animal product prices can be expected: under S1 scenario, beef prices increase 21%, pork 16%, lamb 14% and poultry 10%. Even greater increases would be expected under the S2 aggressive biofuels expansion scenario. These simulations have not factored in the potential ameliorating effect of greater availability of feed supplements generated from cellulosic biomass through technologies spun off from 2G bioethanol production (see above).

Resources and environment

Land, water and greenhouse gases (GHGs) are the three main environment concerns with aggressive expansion of biofuels. If all national policies and plans for biofuel production were to be implemented, up to 30 million additional hectares of crop land could be needed along with 170 km3 additional evapotranspired water and 180 km3 of additional irrigation water. Although a small fraction of total crop area and water use, the impacts for some countries and areas could be highly significant, including China and India. Biofuel impacts on carbon savings and GHGs emission depend on the feedstock production and processing practices. For example, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages. Converting rainforests, peatlands, savannas, or grasslands to produce food crop–based biofuels may create a substantial biofuel carbon debt. Under the different scenarios of biofuel expansion, crop areas and production practices are expected to change, including grain and residue prices, the consumption basket, crop substitutions, land and water use, cultivars selection and field management. While maize and sugar-cane dominate bioethanol feedstock use at present, some diversification of bioethanol (and biodiesel) feedstocks is expected by 2030. Moreover, while there are strong pressures for intensification because of the strong demand for cereals, water and nutrient use efficiency is expected to rise as water and fertilizer prices rise relative to grain prices.

The differentiation of potential effects and impacts is crucial: crop–livestock–energy systems have evolved in many different depending on the agro-ecologies, population density, producer and consumer demands and local markets, regulations, farmer associations, etc. This study has considered the international market responses, resource and environment dynamics and crop–livestock–energy system adjustments from a ‘business-as-usual’ biofuel expansion compared with aggressive expansion of biofuels. While the global impact would be the sum of system- and crop-specific land, water and livelihood adjustments in different locations, the effects play out in many contrasting ways. Besides the expansion of the existing land area under a particular bio-energy crop through land conversion from forest or pasture to cropping, greater changes are likely to occur from crop substitution on existing crop land.

Agricultural production will also adjust to increased biofuel feedstock demand in other ways, for example, through the intensification of input usage. Water is an increasingly-scarce production input that allows agriculture to adapt along the ‘intensive margin’ of production—one traditional intensification pathway has been the conversion of rainfed areas to irrigation, or the partially irrigated areas (e.g. spate irrigation) to full irrigation. For those land-scarce regions that are unable to adjust along the extensive margin—intensification may be the only option available, and the environmental consequences should be considered. Aggressive biofuel expansion programs cause different pressure points in the systems and different winners and losers in terms of food security, poverty, livelihoods and vulnerability profiles. The campaigners against biofuels have often cited the threats to food security, not least the increase in food prices resulting from expanded biofuel production leading to reduced availability of and access to food.

Analyses suggest that the adverse effects on calorie consumption are particularly severe in Africa, with a reduction of more than 8%, although this obviously varies between countries and systems.

Crop–livestock–energy system impact

Different farming systems may have distinct responses to expanded biofuel production with different implications for smallholder livestock production. If grain-based biofuels expand strongly by 2015 and there is no dramatic breakthrough in crop yield growth in the next few years, a reduction in the amount of grains fed to animals appears unavoidable. Under this storyline, without other feed supplements animal production will decrease. The more intensive the system (i.e. dairy), the more repercussions the increases in the price of grains will have. Systems that consume little grain (more extensive livestock production) will not be affected much, such as Argentina grazing systems, unless land is taken away for grain production.

By 2030 biomass (instead of grain) will become the focus of competition as second generation (cellulose-based) bioethanol production assumes a dominant role in production. There are already many contrasting demands from livestock fodder, domestic energy, construction, etc which lead to the removal of a high proportion of above-ground biomass in smallholder crop–livestock systems and thereby threaten soil health, reducing soil organic matter, nutrient cycling and moisture holding capacity and increasing greenhouse gasses and global warming. One major use of crop residues is as ruminant fodder, principally for maintenance energy rather than the production of saleable milk or meat. While crop residues may account for as much as 60% of ruminant fodder in current systems and high value markets have developed in land scarce systems for stover and straw, e.g. India, it is expected that with the transformation of smallholder livestock production towards market products that the demand for high value fodders and concentrates will increase relative to crop residues of low nutritional value. Moreover, the retention of sufficient crop residues in the field affords protection to the soil surface, improved water holding capacity and yield stability, and ultimately improved soil health. Thus in places with high animal populations there will be greater competition between biofuels, feed availability, and soil quality. The overall effect is likely to be reduction in biomass availability for animals in systems in locations such as China and India which lack alternative feed resources, and a consequent reduction in production. In contrast, livestock production in pasture-based systems may be less affected unless competition for land arises for crop production, e.g. biofuel feedstocks. Thus in places with high animal populations there will be greater competition between biofuels, feed availability, and soil quality. The overall effect is likely to be reduction in biomass availability for animals in systems in locations such as China and India which lack alternative feed resources and depend on cut and carry, further a consequent reduction in production. In contrast, livestock production in pasture-based systems may be less affected unless competition for land arises for crop production, e.g. biofuel feedstocks because improving pastures and intensify might be partly solutions to the demand of ruminant feed.

Poverty effects

Although the poor typically derive their livelihoods from multiple sources, their household food security generally depends significantly on purchased food. Given that food accounts for 50–70% of the expenditure of poor households, food price increases lead inevitably to reduced calorie intake and child malnutrition. Taking into account both rural and urban poor, the S1 and S2 scenarios which result in increased food prices, reduce calorie consumption by 2–4% and 4–8% respectively, depending on the region. In a similar fashion, the population of malnourished preschool children increases, by 1.5 million and 3.3 million under S1 and S2 respectively in sub-Saharan Africa. Livestock producers will be particularly affected in sub-Saharan Africa and South Asia, and in the latter the rural landless poor.

Small CLEFS households are often poor in both livelihoods and resources, and vulnerable to further climatic, health and economic shocks. They often derive half or more of their livelihoods from off-farm sources, depending on the system, labour market and inter-sectoral linkages between agriculture and other sectors. The impacts of biofuel production on small CLEFS households can be framed in terms of the effects on the most common poverty escape pathways, viz. intensification, diversification, growth, increased off-farm income and escape from farming—and of these pathways (further) on-farm diversification and off-farm income are particularly important pathways for CLEFS households. Biofuels impacts on farmer household livelihoods include household income, food consumption and energy consumption, resulting from the effects of local markets for commodities, land and water resources, and labour, as well as environmental elements. Along with changes in livestock production practices, farmers may adjust crop production and labour use patterns. At the farming system level intensification and diversification are expected to be two common strategic responses.

The opportunities and risks of expanded 1G and 2G bioethanol and biodiesel for the viability of the poverty escape pathways differ, as do the impact pathways on the production and consumption sides. On the positive side, local production of biodiesel reinforces on-farm diversification through greater incentives for oil crop production, where technically feasible (there are substantial differences in this respect between palm oil, soya bean, rapeseed, sunflower and other possible oil crops). The current 1G and 2G bioethanol technologies can accelerate intensification through increasing demand and prices for starchy staples, but further research is needed on downscaling processing technologies for local production. All three types of biofuel production generate high value feeds which foster the development of livestock fattening operations. However, these positive outcomes depend on significant downscaling of technology and adaptation by farmers that is not assured. If farmers are unable to adapt and take advantage of new opportunities outcomes will likely be increased degradation of the resource base on which small-scale farmers depend, and decreased production of livestock, with accompanying loss of income and increased risk.

Policy implications

As a modest disclaimer, this assessment was not intended to analyse in depth the complex livestock feed–food–biofuel problems, but rather to identify some key insights in relation to livestock and poverty reduction. Clearly, in the long-term biofuels have both potentially positive and negative effects on the environment, livelihoods and crop–livestock systems. There are great uncertainties in relation to critical parameters, not least of which are the rate economic growth, food prices, trade in renewable energy, the transition from 1G bioethanol technologies to 2G technologies, and a range of public policies. If biofuel demand is driven by regulations and quotas in the absence of cost-effective and sustainable technology, there could be substantial short-run economic and humanitarian costs and even further pressure on food grain and animal feed prices, and threatening, in the long-term, deeper hunger and poverty.

Public subsidies and blending regulations have been strong drivers of biofuels expansion in developed and developing countries, and thus policymakers have a crucial role in determining the rate of expansion and location of bioethanol and biodiesel production, consumption and trade. One key area of policy debate should relate the target rate of expansion of biofuels to the particular agricultural resource base, farming systems and available technologies of each country. To date barriers to biofuels trade have limited the emergence of a broad international market for ethanol and biodiesel which has added to the local distortionary effects of biofuel policies—ideally the barriers to biofuels trade should be reduced. The biofuel–crop–feed–livestock value chain needs systematic assessment. The case has been argued for support policies to encourage small and medium size land owners and to promote biomass production on marginal and fallow lands where competition with food crop production is reduced. In a different vein, policies to support the development and deployment of small-scale, local, bioethanol and other energy technologies could have profound benefits for poor smallholders in remote areas. More generally, it is very important to invest in further research on different aspects of biofuels production and use. Priorities for such research are listed below.

Research priorities

Crop–livestock–energy systems are complex, dynamic and differentiated. Strategic assessment and targeting is required, recognizing that the differentiation of responses and impacts identified across different situations in this study represents only a small portion of the variation across continents. In order to capture and analyse such complexity in a way that results can be extrapolated to wider domains, it is proposed to construct and validate crop–livestock–energy models at the farm-household/community level. These models should be based on integrated production–consumption theory and village economy modelling practice, and incorporate biophysical and socioeconomic processes at the field and community levels, and be produced for 8–10 of the systems described above. Such modelling would also identify priority intervention points for coping with change in different systems. Through careful analysis of responses, effects and impacts, with a particular emphasis on pathways out of poverty, systems could be categorized according to the likelihood of generating strong positive benefits, no net effects and strong negative impacts. The biofuel hotspots with a concentration of negative impacts on poverty and which threaten system collapse should be identified and mapped.

Full life cycle analyses (LCA) of biofuel production-use alternatives is an important extension of current analyses of the environmental effects of biofuels. While it is clear that negative balances arise from land conversion for bioethanol production, the environmental effects from the expansion of feedstock production through intensification or crop substitution on existing crop land are far less clear, although this will be a common expansion pathway. Thus, a systematic set of comparative LCAs should be conducted for contrasting CLEFS (such as identified in this report) which fully incorporate livestock production and differentiate types of land, infrastructure and institutions. This will improve knowledge on the energy balance of different types of biofuel production.

In relation to the technologies for biofuel processing, during the past decade fast progress has been made. The priority will be: first, to accelerate the development and commercialization of 2G bioethanol technologies; and, second, to downsize the technology for use at village or district level in remote areas. For livestock producers a third priority is the adaptation of 2G technology for the production of concentrate feeds from low quality biomass, which has the potential to revolutionize the livestock feed industry.

Crop residue management lies at the heart of the sustainability of smallholder crop–livestock systems. There are many contrasting demands for crop residues, including as livestock fodder, domestic energy, construction, etc, which lead to the removal of a high proportion of above-ground biomass in smallholder crop–livestock systems and thereby threatens soil health, including soil organic matter, nutrient cycling and moisture holding capacity and increasing emissions of greenhouse gasses. In many low-productivity systems the major use of crop residues is as ruminant fodder, principally for maintenance energy rather than the production of saleable milk or meat. While crop residues may account for as much as 60% of ruminant fodder in current systems and high value markets have developed in land scarce systems for stover and straw, e.g. India, it is expected that with the transformation of smallholder livestock production towards market products that the demand for high value fodders and concentrates will increase relative to crop residues of low nutritional value. Moreover, the retention of sufficient crop residues in the field affords protection to the soil surface, improved water holding capacity and yield stability, and ultimately improved soil health. Therefore, a study of farmer and community institutions and decision-making in relation to the valuation and utilization of crop residues in alternative uses is urgently required.

The international food market and trade responses to biofuel expansion need to be much better understood, including but not limited to the recent commodity price increase and subsequent collapse. While tariffs need to be documented, high priority should be assigned to the analysis of biofuel value chains and local markets, with a view to increasing efficiency, improving coordination along the chain, increasing efficiency and identifying technologies which reduce overall cost. Among other benefits, this knowledge would facilitate careful design of biofuel subsidies and blending targets. Moreover, biofuel production is capital intensive which is one reason for barriers to new entrants. Further study is required on how small and medium size enterprises (farmers or businesses) can overcome barriers to entry in a saturated market.

Many local systems and markets are poorly integrated to international market responses and therefore a low cost early warning system in potential hotspots (especially with regard to resource degradation, local food markets, feed/fodder markets and poverty) for monitoring of local resource, system, market and institutional dynamics is essential. This could be focused on 10–20 different systems in major countries/regions. The experience of ILRI with Kenyan pastoral system information systems information is pertinent.

In the search for sustainable local solutions that contribute to the MDGs, technology and adaptation is needed to develop new crop–livestock–energy systems for different resource and economic contexts. It is proposed that integrated crop–livestock–energy systems be developed through multi-stakeholder local innovation and learning systems and tested on-farm, incorporating improved germplasm for crops, pastures, livestock and improved production practices in selected crop–livestock–energy systems.

These complex and dynamic systems are characterized by enormous uncertainty over the underlying science and critical potentially momentous outcomes for ecosystems and humanity. We do not anticipate that the improved knowledge and data from the foregoing research will lead to 'magic bullets': in fact, quite the contrary. Each CLEFS will merit separate consideration; therefore a flexible and adaptive approach by researchers and policymakers is advised.

Chapter 1 Introduction

Agricultural research has been remarkably successful in contributing to food security, poverty alleviation and environmental sustainability. However, half the 15-year planning period for achieving the Millennium Development Goals (MDGs) has passed, with disappointing progress towards most MDGs, notably the first MDG of halving poverty and hunger (World Bank 2007; IAASTD 2008). About 50% of the hungry are smallholders, the majority managing mixed crop and livestock farming systems (Dixon et al. 2001; Hazell et al. 2007; Herrero et al. 2010). Agriculture faces major uncertainty and volatility, as seen in the past decade in energy, food and agri-input prices, and is challenged in different locations by stagnating productivity, increased climate risk, emerging biotic stresses and unfavourable agricultural policies. Whilst many observers opine that agriculture is in crisis, new agricultural opportunities are also merging. In this respect the recent, unprecedented expansion of investment in biofuel R&D creates both threats and opportunities—and is recognized as one of the six great future challenges for agriculture (McCalla et al. 2010).

For decades the most important sources of energy have been crude oil and coal, both finite non-renewable resources. Until the onset of global economic recession in late 2008, the growth of demand for energy stimulated soaring crude oil and coal prices, in parallel with mounting concern about energy security in many nations. Many policymakers responded by initiating public subsidies and R&D programs for renewable energy including biofuels and technologies to improve energy efficiency. Both economic growth and sustainable development are heavily dependent on adequate supplies of low cost energy, especially of liquid fuels for transportation (Argonne National Laboratory 2007). In recent years the demand for transportation fuels grew at a faster rate than Gross Domestic Product (GDP), especially in rapidly growing developing economies such as India and China. Because of the uncertainty surrounding the depletion of existing oil fields and the discovery of new exploitable reserves, the concept of 'peak oil' (the point at which global oil production plateaus and begins to decline) has provoked much debate. In the medium- to long-term, the predicted shortages of oil and tightening of energy markets call for investment in technologies and policies for energy efficiency and alternative sources of energy. The conversion to alternative sources of energy takes time, therefore it is recommended that programs for conversion should be initiated at least two decades before the onset of the shortages in order to avoid major economic disruption (Hirsch 2007).

The environmental effects of biofuels have been the subject of many studies. In general, the substitution of biofuels for gasoline or diesel leads to a reduction of CO_2 emissions (Biofuels Research Advisory Council 2006; OECD 2007). On the other hand, there are concerns over negative impacts of biofuels on global warming, sustainable land use and water. Recent studies have taken a life cycle approach (LCA) incorporating the emissions from feedstock production and/or land conversion, e.g. clearing of tropical forest for oil palm plantations and show reduced benefits for biofuels, particularly for feedstock production on existing crop land (Liska et al. 2007; Searchinger et al. 2008). Although biofuel production may threaten cropland soil degradation through removal of crop residues for second generation bioethanol production (Ortiz et al. 2006; Lal 2008), there is potential for bioenergy production which could enhance agro-ecosystem conservation (Milder et al. 2008). Major aggregate effects are not yet predicted (de Fraiture et al. 2007a). However, the localized environmental effects could be significant and vary distinctly with the type of crop–livestock system. All in all, the direct effects are complex and the indirect effects multifarious which demands an integrated approach to assessment (Langeveld et al. 2010b).

Bioenergy produced from biomass provides renewable energy to more than half of the world's population (FAO 2005, 2008b). Most recent interest focuses on two liquid biofuels: bioethanol from starch- or sugar-rich crops and biodiesel from edible and non-edible plant oils and animal fats (Dixon and Langeveld 2007). Bioethanol, which represents 90% of total biofuels, is currently produced from starch or sugar crops (and 90% of bioethanol is produced from maize or sugar-cane, but cassava and sweet sorghum are also good feedstocks). Global production of bioethanol in 2007 was about 51 billion litres, dominated by USA, Brazil and China, and that of biodiesel was about 10.6 billion litres of biodiesel, dominated by Germany and France. The biofuel boom has driven global renewable energy investment from less than USD 20 billion during 2003 to USD 70 billion during 2006 and around USD 150 billion during 2007, with European Union and United States the largest investors, followed by China and India. The current, first generation of bioethanol production, using starches, from cereal grain or cassava, or sugars, from sugar-cane, sugar-beet or sweet sorghum, has generated vigorous debate on economic and environmental benefits and costs.

The central theme of this volume is the competition between biofuels, food and feed. The demand for cereal grains for biofuel needs to be set in the context of existing consumption patterns of major food crops for food and feed (APAARI 2007; World Bank 2007). Traditionally food grains were used for human food and seed, with small amounts being absorbed in livestock feed, industrial use and waste—and in this context, Engel's Law was formulated which postulates declining marginal aggregate demand for food as incomes rise. The projected regional distribution of population and income is shown in Table 1, which are the principal determinants of the demand for food. Table 2 shows the average global cereal grain consumption between 2001 and 2003. In the case of maize, 20% of grain was used as human food, 76% as animal feed, and 3% as other uses including biofuel. For wheat, 80% of grain is used as food and 19% as feed; while for rice, 97% is used as food, and 2% as feed. Maize and wheat are the main grains used as livestock feed which have, in recent years, begun to be used for bioethanol production. With a high proportion of cereals being used as feed and emergent markets for cereal grain use for biofuels, the growth of demand for both livestock products and energy with increasing disposable income suggests that Engels Law may be less applicable to agriculture in the future (Naylor et al. 2007).

Table 1. *Projected world population and income distribution*

	Population (million)					Income (billion 2000 USD)				
	2000	2015	% change 2000–2015	2030	% change 2015–2030	2000	2015	% change 2000–2015	2030	% change 2015–2030
World	6062	7189	17	8157	13	33,542	51,313	53	82,057	60
Sub-Saharan Africa	381	930	37	1238	33	376	678	80	1334	97
West Asia and North Africa	1409	495	35	601	21	1,033	1727	67	2740	59
South Asia	315	1774	31	2092	18	646	1620	151	3796	134
North America	1978	361	14	400	11	9751	14,888	53	23,005	55
East Asia and the Pacific	513	2205	49	2331	6	8616	13,903	61	22,945	65
Latin America and the Caribbean	799	623	19	711	14	2051	3226	57	6489	101
Europe and Central Asia	667	801	– 8	785	– 2	11,069	15,270	38	21,749	42

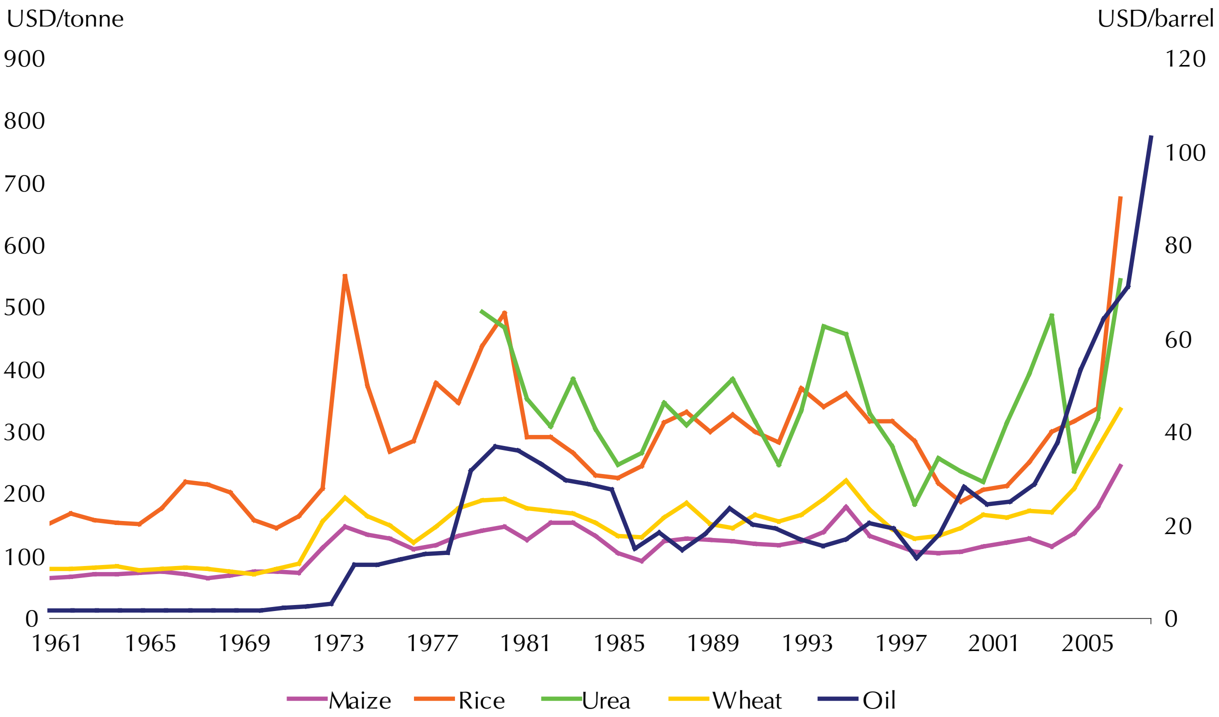
Sources: UN world population prospects (2004); income data is from IFPRI projection.

Table 2. *World cereal grain and cassava consumption*

	Developing (million tonnes)	Developed (million tonnes)	World (million tonnes)
Maize			
Food	16.6	94.1	110.8
Feed	233.6	177.4	411
Other	11.5	5.3	16.8
Rice			
Food	15.1	330.8	345.9
Feed	0.4	6.3	6.6
Other	0.3	1.0	1.3
Wheat			
Food	130.8	288	418.7
Feed	86.5	10.9	97.4
Other	5.7	3.1	8.8
Cassava			
Food	103.3	0.06	103.4
Other	85.0	0.0	85.0

Source: FAO STAT.
Notes: other consumption includes industrial and biofuels uses but excludes use as seed; rice is milled grain equivalent. Cassava other include the amount for feed.

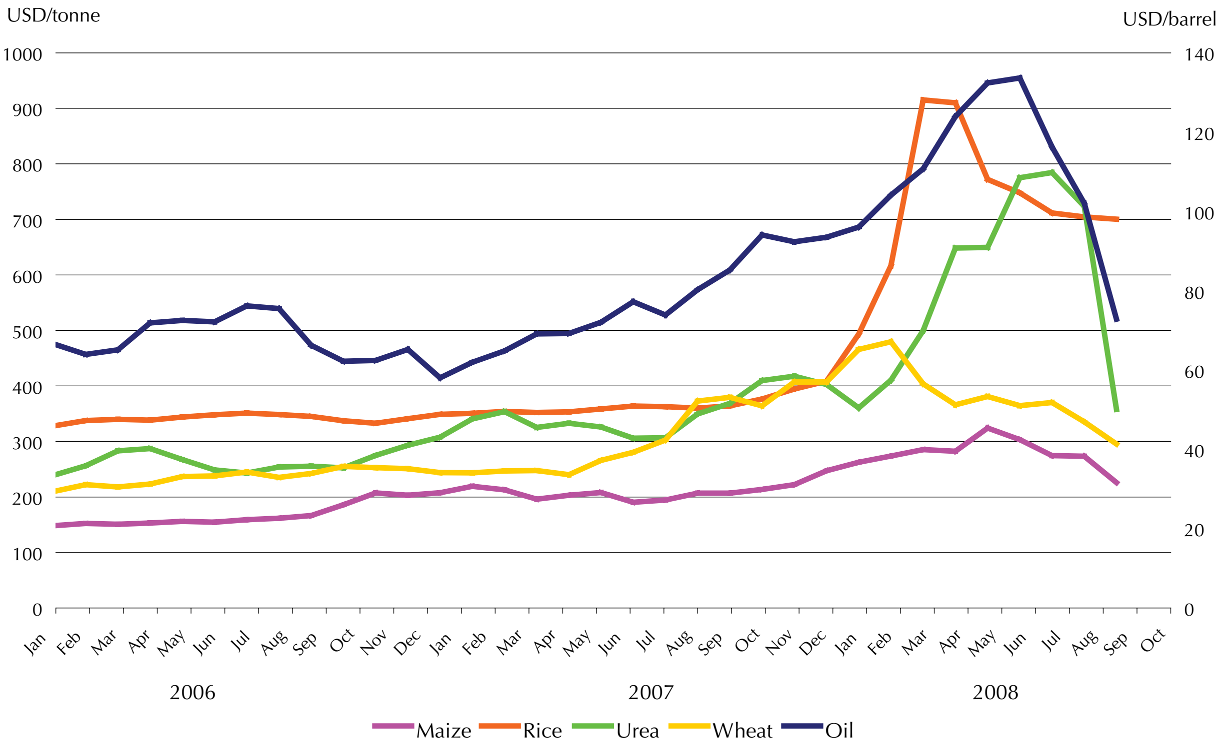
Contrary to assumptions which prevailed during previous decades, there is now strong evidence of the integration of agricultural and energy markets (see Figure 1; also Rosegrant et al. 2008; Tyner and Taheripour 2008). Moreover, these markets have become extremely volatile.



Source: World Bank commodity price data.

Figure 1. *Oil and selected cereal prices, 1961–2008.*

Recent years have witnessed an unprecedented rise and crash of oil prices from USD 40 per barrel in 2005 to USD 140 in middle of 2008, falling below USD 40 by the end of 2008 (Figure 2) before rising again through 2009–2010. Moreover, staple food producers and consumers have also experienced strong swings in food prices during 2005–2008: recently the prices of food grains rose substantially but have now fallen back significantly, although not (yet) to the levels of several years ago. For example, yellow maize prices, rose from USD 90/t in 2006 (No. 2 f.o.b. US ports in the Gulf of Mexico) to USD 180/t in June 2007 (Kingsman 2007) before falling back—and wheat and rice prices increased even more steeply before falling back. Intensive livestock production, based largely on grain, is vulnerable to such swings in feed grain prices, where competition for grain for food and feed is unavoidable (Kruska et al. 2003; Coyle 2008).



Source: World Bank commodity price data.

Figure 2. *Oil and selected cereal prices, January 2006–October 2008.*

Mixed crop–livestock farming systems are a dominant production model in developing countries, especially in Africa, Asia and part of Latin America, with maize, rice, wheat and cassava as the staple food and feed crops, and various livestock, buffalo, cattle and goats, sheep, and poultries depend on regional consumption patterns (Sere et al. 1996; Dixon et al. 2001). Research on the characteristics and interaction mechanisms between crop and livestock have been documented (Paris 2002; Thomas et al. 2002; Erenstein et al. 2007). Based on the strong interaction between crops, livestock and bioenergy in the crop–livestock system, an increase in the use of biomass for energy has the potential to impact livestock and small livelihoods of small-scale agricultural households that depend upon crop–livestock systems in beneficial but also negative ways, both through resource-based dynamic crop–livestock production system and through the agricultural market and energy industry effects (Langeveld et al. 2010a). Although the impacts of biofuel on the food, feed and resource competition have been discussed for decades (IFPRI 2006; Peskett et al. 2007), there is little systems research to assess the impacts of bio-energy on the most important farming systems in developing countries. The household activities and livelihoods lie at the heart of the crop–livestock energy interactions. The future productivity of crop–livestock-based farming systems is a critical determinant of local and global food security and the prospects of livelihood improvements for small-scale farmers. Improving our understanding of bio-energy–crop–livestock interactions and their impacts upon rural livelihoods will better position the agricultural R&D community to be more effective in addressing the major challenges of improving livelihoods while ensuring environmental sustainability.

This analysis illuminates the complex interactions and impact pathways between biofuels, crops, livestock and livelihoods within an integrated systems-based perspective of crop–livestock–energy farming systems (CLEFS). The CLEFS is a conceptual framework that allows us to better assess the impacts of biofuels on crop–livestock systems and small-scale household livelihoods (see Figure 4), so that we can draw out the wider range of implications for agricultural R&D and the improvement of policy. This study is carried out by a joint group from CGIAR centres including CIMMYT, ILRI, IWMI, IFPRI, CIAT, ICRISAT, IITA, CIP and IRRI. This report is structured as follows: after introduction and framework, international market effects and resource and environment effects have been considered, which provide a profile for further analysis. Following is the key section of biofuel impacts on crop–livestock farming systems, which include energy crop effects, crop competition for food, feed and energy use, and impact on crop–livestock production. The final section highlights potential impacts on poverty and a closing section discusses the research priorities and policy implication in future.

Chapter 2 Framework and methodology

Framing interactions

The schematic linkages between bio-energy, crops and livestock systems and the pathways that lead to impacts on household-level livelihoods are presented as an integrated system in Figure 3, and serves as a guiding framework for the organization of this document. The three productive components of the system, crops and forages, livestock, and bioenergy all contribute towards the livelihood of the farm household and are interlinked through various flows of materials, resources and revenue (Dixon et al. 2001). Crops, roots and forage systems provide food and income directly to support household livelihood, supply feed—grains, residues, fodder, and crop by-products—for livestock production, and grain, tuber, stem, straw or forages for bio-energy as feedstock depending on the conversion technology; at the same time, crop and forage systems get animal traction and manure to support farm operations and soil quality maintenance from livestock, and may also get fuels from the bio-energy system. Livestock systems get feed, fodder and crop residues from the crop and forage system, and might also get fuels and protein-rich by-products of ethanol production to use as animal feed from the bio-energy system (if and when the technology is available), while supplying animal power to the crop systems and providing animal by-products that help to maintain soil quality. In some cases, animal dung is used in household size biogas technology, such as rice-based intensive farming systems in southeast China.

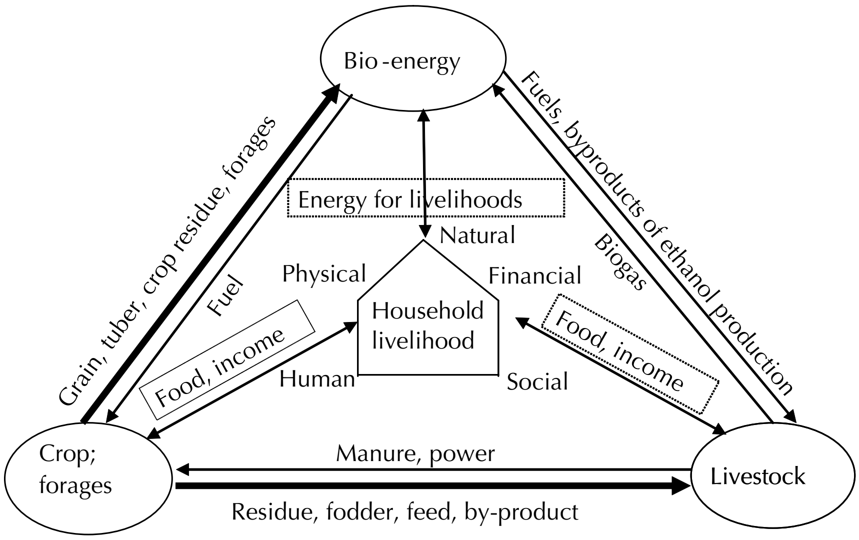


Figure 3. *Schematic frame of crop–livestock–energy interaction.*

This framework represents an idealized, integrated system which takes advantage of the flow patterns between the various components to provide recycling of materials within the system. In reality, all household mixed crop livestock systems interact with their local and larger scale communities by utilizing common property resources such as community grazing lands and irrigation water, and rely on other input and output markets at various scales. Underpinning the system are critical natural resources like land and water, and without secure access to sufficient quantity and quality of these resources the livelihood base of the smallholder farmer within these CLEFS is undermined. Bio-energy, as a rapidly-emerging industry, has the potential to transmit a diversified and uncertain range of positive and negative impacts on almost all sectors, across the wide spectrum of CLEFS that we might consider.

Located in the centre of the conceptual framework is a pentagon-shaped representation of the various livelihood capital resources that are available to the household. The capital which is available to support the livelihood strategy of the household is comprised of five principal asset types: natural resources, physical capital, human capital, financial situation and social resource (Ellis 2000). All of the five types of capital play a role in allowing the household to adjust its resource allocation and livelihood strategy in the face of the impacts that might occur across the range of CLEFS that we consider. The array of natural resources that play a role in supporting the farmers' livelihood range from the characteristics of the immediate landscape, to the farm size, the available water resources, the available livestock and the prevailing climate, which vary in nature and disposition across the various crop–livestock systems. The nature of the various CLEFS are determined by the intrinsic characteristics of the natural resource base, which might present limitations to the adaptation and adjustment of the local farming system to various shocks. Among the physical characteristics that are of importance are irrigation development, mechanization, electricity, phones, and public transport supplies, and market access, which embody the range of infrastructure and public services that are necessary to support farm production and the maximization of added-value. Among the key characteristics of human capital that are of relevance to the maintenance of household-level production are family size, the potential to supply labour, education levels, and the gender composition. Human capital is an 'active' type of resource that has the potential to determine the levels of efficiency in household-level production through providing better access to certain key production factors and productivity-enhancing technology. Among the factors that are important in determining the quality and availability of social capital which exists are population, the share of rural population, household size and poverty status, and the importance of agriculture in social development. These factors are a key to determining the capacity to survive and adjust to economic and environmental shocks at the farm household level and may also be key determinants in deciding how various farming systems achieve important development targets. The key aspects of financial capital that are addressed by most studies are the level of household income and the degree of access to credit, which play an important role in allowing the farm household to adjust its activities and gain access to needed financial support.

By putting the household at the heart of Figure 3, we try to show how the livelihood of the household can be improved by the positive feedback effects that might arise from the various interactions that take place within each type of CLEFS and the ways in which the household can benefit from individual contributions towards its levels of natural, social and financial capital. It is also possible that livelihood of the household can be worsened by the negative effects that can arise from market-level or resource-driven interactions within a particular CLEFS. Therefore, the ultimate effect on livelihoods that will arise from transforming part of the farm household's crop production into biofuels will depend upon the characteristics of the particular CLEFS to which the household belongs, and the amount and disposition of the various types of assets and capital that the household has access to—which might entail different tradeoffs which have their own consequences for their livelihoods (Clancy 2008; PISCES and FAO 2009). Through taking all of these factors into account, one quickly realizes that the link between assets and livelihood outcomes is neither linear nor predictable (Ellis 2000).

Impact pathway from biofuel to livestock and livelihood

PISCES and FAO (2009) conceptualize bioenergy systems as consisting of pathways of energy use that intersect with important biofuel markets and value chains, as shown in Figure 4. Understanding the full impact of bioenergy systems on rural livelihoods requires an improved understanding of the nature of the complete market structure and the value chains that support them, and of the different business models, technologies, institutional arrangements and power dynamics along the chain, which can lead to very different livelihoods outcomes. Not only does the use of the energy result in livelihoods opportunities via energy access and productive uses in enterprises, but each step and substep in the system (as well as wastes, co-products and supporting services) represents a separate livelihoods opportunity and has its own interlinked characteristics in terms of possible technologies, capacities required, financial implications, governance issues, access rights, risk characteristics, environmental impacts, and other factors.

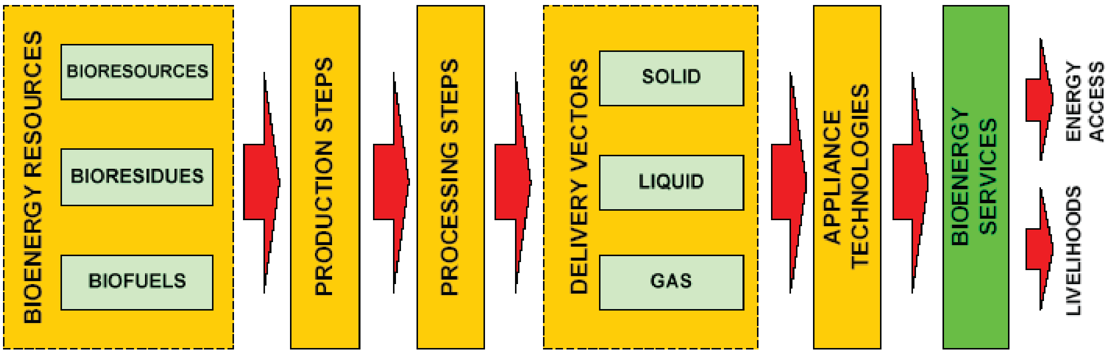


Figure 4. *PISCES and FAO bioenergy pathway.*

This analysis considers the various pathways of impact that act both through the environment as well as through the market (Figure 5). The first set of interactions take place at a fairly aggregate level, and are comprised of movements within international markets for biofuels, food crops and livestock sector products, which have consequent effects on regional markets and environmental conditions. The second level of the impact pathway disaggregates these effects to local communities and farms, and is comprised of an intricate web of interactions that link biofuel feedstock production to the performance of crop–livestock farming systems and ultimately to the livelihoods at the level of the farm household.

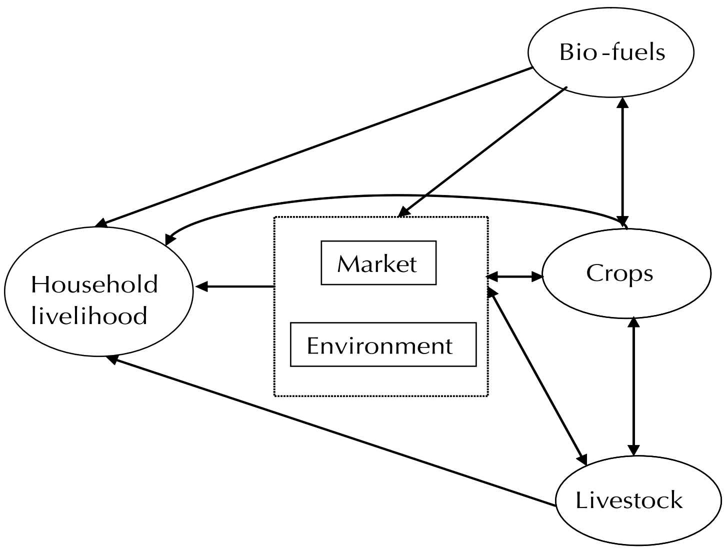


Figure 5. *Schematic pathways from biofuel to livestock and livelihood.*

Biofuel impacts on livestock production and rural livelihoods can be traced along a number of pathways. At a physical level, biofuels create competition for land and water resources between food crops, sources of livestock feed and the actual biofuel feedstock itself. From an economic perspective, the transfer of more food and feed crops and crop residues to biofuel production results in higher prices of feed for livestock, thus adding to the cost of livestock production. The positive contributions of biofuels to the livestock sector also become apparent when one considers the expanded choice of potential energy sources that biofuels can provide to both crop and livestock producers, and the fact that increased resource competition can push the livestock sector to intensify in a way that makes better use of its resource endowments, within a given CLEFS. Rising feed prices are also having a strong effect upon the livestock and poultry industries, causing the returns within these sectors to fall sharply. If the returns continue to drop in these sectors, the levels of production will decline, leading to higher prices for chicken, turkey, pork, milk, and eggs. Whether the balance between the income and the consumption effects from higher prices will be positive or negative depends on the situation and the level of poverty of the households within a particular CLEFS.

For rural livelihood, producers of energy crops could potentially gain from increased crop prices even without expanding or intensifying production. Since these households are net producers of those crops and are poor, there is potential for poverty reduction. Besides increasing crop production and reducing household domestic costs (for heating, lighting, cooking fuels—which has strong gender implications), the biofuel industry could potentially generate additional employment by attracting additional investment for small- and medium-sized enterprises, generating some new technology, new business and new markets, and contribute to local energy security by bringing new energy to agricultural activities and household life (Dufey 2007; Clancy 2008; Raswant et al. 2008). On the other hand, rapidly increasing demand for wheat and maize for biofuel production has particularly affected prices for those commodities. While higher food prices are profitable for the mainly large-scale farmers who grow them, they threaten the economies of food-importing countries as well as the urban poor. Expanded biofuel production could have indirect factor market effects though increased demand for good land, irrigation water, capital and labour—to the disadvantage of other resource-dependent sectors. Moreover, there is major concern regarding the widespread use of second-generation technologies, which could increase the demand for and price of crop residues and therefore cause farmers to remove even more straw from the field—thus threatening soil quality. As well a lot of smallholder monogastric production is done mainly by women, depending on grains as the main feed or the concentrates made from them. Increase grain prices will further increase production cost and if price are not at par (i.e. higher prices less people can purchase) there will be negative impacts on gender.

Scenarios

Global scenarios are used to analyse the effects of biofuel production expansion on international markets, resources, environment and livelihoods and poverty. The baseline for these scenarios is defined by IFPRI projections to 2020 of total population, cereal production, and consumption of livestock products, production, demand, and share of biofuels in total transportation energy demand. Surges in the price of crude oil and policy-driven mandates for renewable energy usage increases biofuel demand, which increased utilization of feedstock crops. Together with the increasing population and income, diet change, variability in water availability and climate effects, biofuel may present a tense situation to the world commodity markets, and resources and the environment.

IFPRI's global scenario work has been applied using a partial-equilibrium modelling framework to capture the interactions between agricultural commodity supply, demand, and trade at the global level. The model used is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which was developed by IFPRI (beginning in the mid-1990s) for projecting global food supply, food demand and food security to year 2020 and beyond (Rosegrant et al. 2001). The IMPACT model is a partial equilibrium agricultural model for crop and livestock commodities, including cereals, soya beans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. It is specified as a set of 115 country and regional submodels, within each of which supply, demand, and prices for agricultural commodities are determined. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth. IMPACT contains four categories of commodity demand—food, feed, biofuel feedstock, and other uses. The model therefore takes into account the growth in demand for the feedstock commodities for biofuel production and determines impact on prices and demand for food and feed for those same agricultural crops. The utilization level of feedstock commodities for biofuels depends on the projected level of biofuel production for the particular commodity, including maize, wheat, cassava, sugar-cane, and oilseeds, as well as commodities such as rice, whose demand and supply is influenced by the price of biofuel feedstock crops. Given the fact that many of the key aspects of large-scale second-generation technologies are still uncertain, and that the IMPACT model does not explicitly consider residues or non-agricultural grass-based or woody feedstocks, we will not treat this scenario explicitly within this study. Rather a rough estimation has been made on the potential impacts of the second-generation biofuel production.

Rosegrant el al. (2006) developed two biofuel scenarios: business-as-usual (S1) and aggressive biofuel production (S2) for global biofuel feedstock projection, for comparison with the baseline scenario. The 'aggressive biofuel growth' scenario assumes the replacement of 10 percent of gasoline consumption with biofuels by 2010, 15 percent by 2015, and 20 percent by 2020. The current first generation (1G) production of bioethanol, seen as dominant before 2015, uses starches, from cereal grain or cassava, or sugars from sugar-cane, sugar-beet, or sweet sorghum. However, the second generation (2G) technologies, which are under development and likely to be commercialized before or by 2030, use cellulose as a feedstock, which could be agro-industrial wastes, forest products and crop residues and perennial grasses. The 2G technologies are expected to be far more efficient than the 1G technologies. This assessment focuses on 1G bioethanol generation before 2015 and thereafter 2G generation

Note for readers

Information presented in this study mostly is based on the knowledge of scientists from different Centres of the Consultative Group for International Agricultural Research. They synthesise and present resource, crop and livestock data related to specific CLEFS (farming systems), and appraise the impact of biofuel production on various aspects of smallholder livestock producers. Global and regional data rely mainly from FAO, World Bank, IEA and IFPRI databases (see Rosegrant et al. 2001, 2006). The basic farming systems data are drawn from Dixon et al. (2001) and follow-on analyses including those for Generation Challenge Program at CIAT.

The report is organized in the following fashion. Following the introduction and framework presented in the first two chapters, some key technical and economic features related to biofuel production are introduced in the next, third, chapter. Fourth, the responses of international markets to the two biofuel scenarios are presented. Fifth, consideration is given to the potential effects on responses, environment and farming systems. Sixth, the potential effects on poverty, especially of selected crop–livestock–energy farming systems, include the indirect effects which become crucial over the longer term. Fourth, the implications for poverty are considered. Finally, implications of the analysis for policies and research priorities are presented in the seventh chapter.

Chapter 3 A biofuel primer

In broad terms, energy produced from biomass provides renewable energy to more than half of world's population, as shown in Box 1. These technologies include combustion, biogas and fermentation. There has been a long history of biofuel production, often stimulated by constraints to import or high oil prices. While biodiesel production from plant-based oils, of which palm, soya bean and rapeseed oils are the most common, is relatively straightforward and relatively scale neutral. In the case of bioethanol production a distinction is made between first generation (1G) production from starches and sugars and second generation (2G) production from chemical (acid, alkaline treatment) and physical (steam and water treatment) hydrolysis and enzymatic breakdown of cellulose and hemi-cellulose found in agro-industrial wastes, stover, straw, pasture and forest products. Bioethanol production from sweets sorghum is somewhat intermediate in that juice is extracted from the sorghum stalks remaining after grain harvest. There are other bioenergy options for agro-industrial wastes and straw, including: biogas or anaerobic digestion, typically of straw mixed with manure, to produce methane; combustion, directly or mixed with coal, to produce steam for generating electricity; gasification, by heating straw with limited O_2 to produce a gas mixture called 'producer gas'; and pyrolysis by anaerobic heating of straw. The emphasis in this report lies on biodiesel and 1G and 2G bioethanol production.

Box 1: World biomass energy

Global biomass consumption (45 EJ)

- Traditional biomass for cooking etc (36 EJ)
- Commercial biomass consumption (9 EJ)
  - Electricity (2.4 EJ)
  - Combustion (4.0 EJ)
  - Miscellaneous, e.g. biogas, syngas
  - Biofuels (2.6 EJ)
    - Biodiesel (0.3 EJ)
    - Bioethanol (2.3 EJ)
      - First generation (starches, sugars)
      - Second generation (cellulose)

Many assessments predict substantial growth in bioenergy production (Fischer and Schrattenholzer 2001; Faaij and Domac 2006; von Braun 2008). The IEA (2007) estimates energy production of the order of 200 EJ per year (1 EJ approximates 1.07×106 Joules). According to WWI (2006), bioenergy processes could potentially generate up to 850 EJ per year of which some 700 EJ would originate from crop land. The additional demand for maize for bioethanol production in the USA has led to significant land use changes (Wescott 2007) and has added pressure to an already tight cereals market situation because of climate-induced production shortfalls during 2005–2007 which drove up food crop prices (Science Council 2008). These circumstances have stimulated investment in biofuels from less than USD 10 billion globally during 2003 to more than USD 25.5 billion during 2007 (Finfacts 2008). The resulting expansion in the production of biofuels has generated concerns over its sustainability (Dixon and Langeveld 2007). Moreover, poor consumers face substantially increased food prices which threaten to increase malnutrition and reverse recent gains in global poverty reduction (von Braun 2008).

In the above circumstances, there are substantial uncertainties related to the volume of future biofuel production, the choice of production technologies (notably starch and sugar-based cf. ligno-cellulosic-based), changes in trade and consumption, and environmental consequences (UN-Energy 2007; Westcott 2007; Edwards et al. 2008). It remains unclear which bioenergy crops and which farming systems will underpin the expected expansion of biofuel production. Many observers fear that increased demand for feedstock biomass may lead to competition with food and/or feed production (Thorne et al. 2002; Fanin 2007). Possible repercussions include food price increases, increased malnutrition, slower economic growth, and possible social unrest; as a consequence, some policymakers have restricted or banned the use of food crops for biofuel production, as recently occurred in China. The economic performance and environmental consequences of biofuel production are to a large extent determined by conditions of bioenergy crop production, transportation, conversion and distribution (Hill et al. 2006; David and Deepak 2007) which vary greatly by farming system as well as scale and efficiency of production and conversion. The resource management considerations include increased water use by biofuel plants, and increased water use in nutrient requirements, leaching and land requirements for bioenergy crops (Raswant et al 2008). The increased demand and use of resources leads to increased resource prices and conversion of land use, e.g. pasture or forest land to annual or perennial cropland (WILMA 2005; de Fraiture et al. 2007b; National Research Council of USA 2007).

However, most recent interest centres on the two liquid biofuels: bioethanol from starch- or sugar-rich crops mostly and biodiesel from edible and non-edible plant oils and animal fats. As shown in Table 3, global production of bioethanol in 2007 was about 50 billion litres (estimates vary), dominated by the outputs of USA, Brazil and China compared with about 9.3 billion litres of biodiesel (other sources suggest up to 10.6 billion litres), dominated by the output of Germany and France.

Table 3. *World biofuel production by region*

	Bioethanol (billion litres)	Percentage (%)	Biodiesel (billion litres)	Percentage (%)
Western Europe	2.1	4	6.6	71
USA, Canada	25.4	51	1.7	18
Brazil, China, India	21.0	42	0.4	4
Other countries	1.0	2	0.6	6
Total	49.6	100	9.3	100

Note: Data for year 2007.
Sources: Bioethanol data is from ethanol industry statistics (Renewable Fuels Agency 2008); biodiesel data is from Coyle (2008). Data vary somewhat across different sources.

The boom in biofuels has driven global renewable energy investment from less than USD 20 billion during 2003 to about USD 70 billion during 2006 and around USD 150 billion in 2007, in which about USD 25.5 billion for biofuel, leading to the construction of a large number of bioethanol plants from maize, sugar-cane and cassava (see Annex Table 1, by way of example, for the actual and planned cassava plants in Asia). In parallel with surging investment and substantial public support for biofuels R&D, processing technologies are developing rapidly. More than 50 countries have enacted legislation or regulations to enforce the blending of biofuels with liquid fossil fuels.

The progress with bioethanol holds major significance for livestock producers in developing countries. At present about 90 percent of bioethanol is produced from starches or sugars (1G technology). While sugar-cane-based bioethanol production is a mature technology, advances in maize grain processing are improving conversion efficiency and reducing the capital cost of plants. However, one giant step forward is the generation of bioethanol from cellulose (2G technology) which, although requiring more expensive facilities, offers the promise of dramatically reduced cost of production (of both feedstock and processing) and decreased CO_2 emissions, a major driver to bioethanol production. While some pilot plants are operational and commercial plants are under construction, the predictions of when a significant number of commercial second generation plants will be on stream vary through the 2010–2015 period. Such a re-orientation of new investment from first generation bioethanol to second generation bioethanol production will have profound effects for livestock producers.

Bioethanol and biodiesel production produce some valuable by-products whose sale partially offsets the cost of production. These include, in the case of bioethanol, Distillers Dried Grains with Solubles (DDGS) which represents a high value feed for ruminants and monogastrics. For example 9 million tons of DDGS was used as feed in the US in 2005; 75–80% for ruminants. In addition DDGS is exported in significant amounts to Vietnam, China and Mexico (Waxenecker 2009). Residual bagasse and leaves from sweet sorghum after juice extraction for bioethanol production were found to be potentially competitive feed ingredients for complete mixed diets in India (Blümmel et al. 2009).

One key point in relation to livestock feed is that the technology to breakdown and digest ligno-cellulose to produce sugars for bioethanol production can also, in principle, be used to produce concentrate feeds for livestock from low quality biomass. In the past livestock nutritionists used ammonia and other alkaline treatments for this purpose which was not widely adopted by small-scale producers. Based on extrapolation from data presented by Orskov et al. (1988), it is estimated that one unit increase in digestibility of cereals straws from hydrolysis through ammoniation increased livestock productivity by almost 11%. In a similar fashion, the development of cost-effective technologies for the conversion of ligno-cellulose to concentrate feed could become a livestock feed revolution. In the case of bioethanol production, economically viable use of ligno-cellulose complexes will depend on: cheap and efficient processes for the hydrolysis of plant cell walls for the release and recovery of a high proportion of and be valuable to allow increased access to cellulose by ruminal microorganisms ugars; the cheap and efficient fermentation of sugars to ethanol as well. The more efficient the hydrolysis processes for bioethanol production become, the closer will straw, stover and woody material become valuable roughages with feeding values which potentially match concentrates. Thus, it might become more attractive to use hydrolysed ligno-cellulose for livestock rather than bioethanol production; and the effect on fodder and feed markets is uncertain.

A final noteworthy feature of biofuel production is scale. Given present technologies, the economies of scale in biodiesel production are modest. Consequently, low cost small-scale units are being utilized at village level in the developing world (and at commercial farm level in developed economies). On the other hand, bioethanol production with present technologies has only been viable in large-scale plants with the attendant requirement for substantial investment, corporate ownership and substantial transportation costs for feedstock and products. However, there are some small-scale pilot bioethanol plants, both 1G and 2G, which indicate the potential for distributed small-scale production which would have implications for smallholder benefits and costs.

Chapter 4 International market responses

Selected projections

Growing population and income in most regions of the world have been strengthening the demand for food and livestock products, as well as augmenting the demand for energy. World population is forecast to expand to 7,295 million by 2015 and 8,318 million by 2030 (UN World Population Prospects 2004), with sub-Saharan Africa, South Asia, and East Asia and the Pacific representing the most densely populated regions (see Table 1). World and regional income levels are also projected to increase substantially, albeit with considerable differences between regions. For example, while world income is forecast to grow 1.6 times from 2015 to 2030, South Asian income is expected to increase by a factor of 2.3 times compared with a doubling in Latin America and the Caribbean, and sub-Saharan Africa. This suggests that these traditionally poor regions can expect substantial improvement in income and human well-being. Moreover, income is a major driver of demand for energy, generally inducing a shift towards more energy-intensive lifestyles. According to reference projections reported in the World Energy Outlook, world energy demand will expand to slightly above 14 Btoe (billion tonne of oil equivalent) by 2015 and almost 18 Btoe by 2030, with India, China, Middle East and Africa generating the heaviest demands for additional energy (IEA 2007).

According to IFPRI's IMPACT model, the demand for food will increase substantially over the medium-term, (see Table 4). Demands for livestock products will also increase during this period, reaching 99, 131, 24 and 123 Mt for beef, pork, lamb and poultry, respectively by 2030, while the demand for eggs and milk will reach 69 Mt and 414 Mt respectively. In aggregate, the total demand for livestock products (meat, eggs and milk) compared to 2005 will increase by 18.6% by 2015, and 40.1% by 2030.

Food and feedstock prices

It is appropriate to consider a wide range of present or potential 2G feedstock crops, including for example cassava, sugar, oilseeds and even wheat alongside sugar-cane and maize. If we were to create a business-as-usual scenario based on projections of national biofuel plans through 2020 (with a declining rate of expansion after 2010 for those countries which show rapid growth early in the projection horizon, such as the United States and Brazil)—then we would expect to see significant increases in biofuel feedstock demand. Under the aggressive biofuels expansion scenario, the 2030 demand for biofuel is projected to be 50% higher than that of the business-as-usual scenario for the year 2010, and twice as large as the business-as-usual scenario for biofuel demand in 2015 and 2020.

In the context of biofuel expansion, grain markets are influenced by diverse supply and demand side factors, including high oil price, climate-induced grain supply volatility, growing demand for feed driven by increasing demand for meat and other livestock products, and of course biofuel production—although it can be seen that only about 7% of global cereal grain is currently used for bioethanol. There have been major increases in cereal prices during 2008. Biofuel competition could be a long-term factor pushing up crop prices, according to the IFPRI projections (Rosegrant et al. 2008)—regardless of short-term prognoses. Given the expectations of 2007, the extra demand from first-generation biofuel would drive the international maize price up by 26% by 2020, compared to the business-as-usual assumptions. Otherwise, a more aggressive expansion for ethanol production could have impacts of up to 72% for maize price by 2020, compared to the business as usual baseline. Food prices for other key commodities associated with ethanol and biodiesel production, such as cassava and sugar, would also see sharp increases over the 2020 baseline levels (Figure 6).

Table 4. *World food crop and animal product demand*

Year	Food crop	Demand (million tonne)	Animal product	Demand (million tonne)
2000	Wheat	417	Beef	59
2015		453		76
2030		532		99
Growth of '00–'15 (%)		8.6		28.8
Growth of '15–'30 (%)		17.4		30.3
2000	Rice	359	Pork	90
2015		381		114
2030		415		131
Growth of '00–'15 (%)		6.1		26.7
Growth of '15–'30 (%)		8.9		14.9
2000	Maize	108	Lamb	11
2015		117		17
2030		133		24
Growth of '00–'15 (%)		8.3		54.5
Growth of '15–'30 (%)		13.7		41.2
2000	Cassava	109	Poultry	68
2015		147		93
2030		177		123
Growth of '00–'15 (%)		34.9		36.8
Growth of '15–'30 (%)		20.4		32.3
2000	Sugar-cane	112	Eggs	49
2015		144		60
2030		174		69
Growth of '00–'15 (%)		28.6		22.4
Growth of '15–'30 (%)		20.8		15.0
2000	Sorghum	24	Milk	275
2015		28		345
2030		36		414
Growth of '00–'15 (%)		16.7		25.5
Growth of '15–'30 (%)		28.6		20.0

As shown in Table 5, by 2020 it is projected that 130 million metric tons (Mt) of maize in the United States will be absorbed in bioethanol production; European countries will use 10.7 Mt of wheat and 14.5 Mt of oil seeds for biofuel production; and Brazil will use 9.0 Mt of sugar equivalent for biofuel production.

Under the business as usual scenario, 2020 world prices are 18% higher for oilseeds, 12% higher for sugar, 11% for cassava, and 8% for wheat compared to the 2020 prices in the conservative baseline scenario. The aggressive scenario shows dramatic increases in 2020 world prices for feedstock crops relative to the baseline, with the price of maize price 72% higher, oilseeds price 44% higher, cassava and sugar price 27% higher, and wheat 20% higher. Given such increases in the prices of important food staples, such as cassava, maize, sugar and wheat, it is not surprising that the levels of child malnutrition would increase significantly, especially in sub-Saharan Africa (SSA) and South Asia (Dixon et al. 2006), as shown in Figure 7.

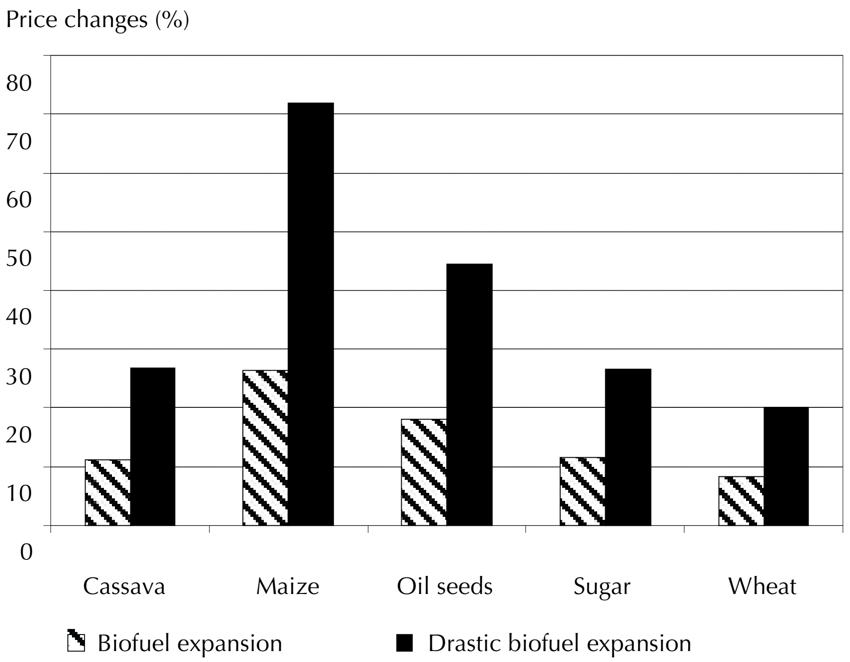


Figure 6. *Percentage changes from baseline world prices of key feedstock crops.*

Table 5. *Projected demands for feedstock commodities for biofuel at 2020 (in thousand tonne)*

Crop	Region	Baseline	Business as usual	Aggressive
Cassava	ROW*	660	6842	13,684
Maize	Europe	97	1086	2173
	ROW	2021	20,511	41,023
	USA	35,000	130,000	260,000
Oil Seeds	Brazil	16	153	306
	Europe	1563	14,572	29,144
	ROW	530	4211	8423
	USA	354	3017	6034
Sugar	Brazil	834	9014	18,029
	ROW	163	1797	3595
	USA	265	3450	6900
Wheat	Europe	1242	10,703	21,407
	ROW	205	2342	4685

Note: Projections to 2020.
* ROW refers to rest of the world.
Biofuel scenarios: 1. ***Baseline scenario.*** Biofuel demand follows historical patterns through 2006, increases by 1% per year between 2006 and 2010, and then for most countries remains constant at 2010 levels. For the United States under this scenario, maize for bioethanol declines after 2010, reflecting either a reduction in subsidies and mandates for biofuels or early adoption of second-generation biofuels that do not require maize as a feedstock. Feedstock commodity demand for biofuel at the year 2000 level are taken as 25% of those in 2005, which are real data. This scenario represents a very conservative plan for biofuel development, in terms of both the magnitude and time span of growing demand for biofuel feedstock commodities. 2. ***Business-as-usual***. This scenario, based on actual national biofuel plans, assumes continued biofuel expansion through 2020, although the rate of expansion declines after 2010 for the early rapid growth countries such as the United States and Brazil. Under this scenario, significant increases of biofuel feedstock demand occur in many countries for commodities such as maize, wheat, cassava, sugar, and oil seeds. As shown in Table 1, by 2020, the United States is projected to put 130 million metric tonnes (mmt) of maize into biofuel production; European countries will use 10.7 mmt of wheat and 14.5 mmt of oil seeds for biofuel production; and Brazil will use 9.0 mmt of sugar equivalent for biofuel production. In this case, we hold the volume of biofuel feedstock demand constant starting in 2025, in order to represent the relaxation in the demand for food-based feedstock crops created by the rise of the new technologies that convert nonfood grasses and forest products. Crop productivity changes are still held to baseline levels. 3. ***Aggressive biofuel expansion.*** This scenario assumes very rapid growth of biofuel demand and is expected to result in drastic impacts on the global food market, food consumption, and malnutrition at the country level. In this scenario, feedstock demand for biofuel from 2000 to 2005 are assumed to be the same as in the 'business-as-usual' scenario; 2010 demand is 50% higher than in 'business-as-usual'; and demand in 2015 and 2020 is double that of 'business-as-usual', as in Table 5.

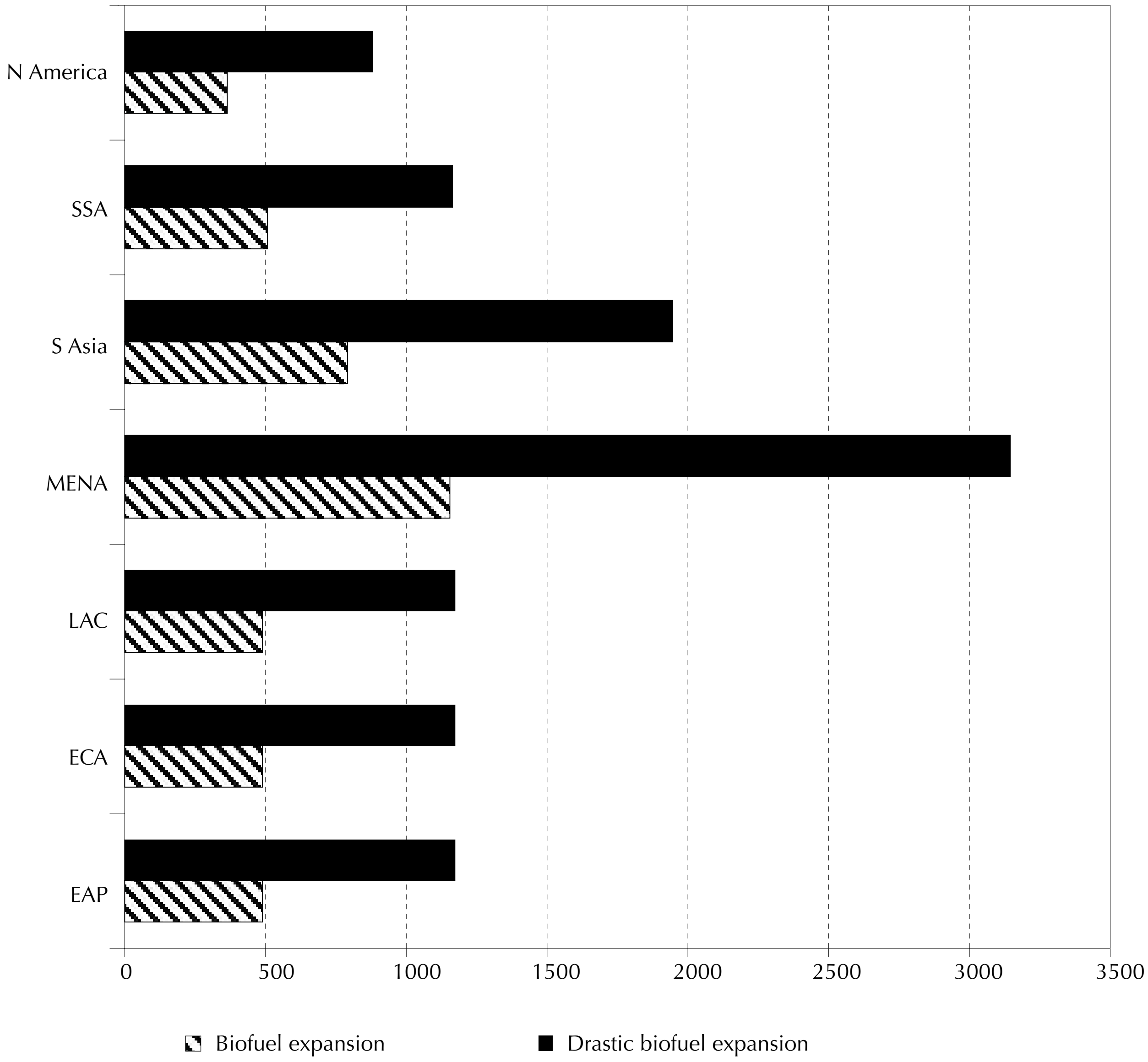


Figure 7. *Changes from baseline levels of pre-school child malnutrition (thousands).*

Aggressive biofuel expansion also has important trade implications for agricultural commodities that can be used as biofuel feedstock. As shown in Table 6, United States is a net exporter of maize in 2020 under the baseline scenario, with a net export of 35 Mt. However, under business as usual and aggressive scenarios, United States becomes a net importing country of maize in 2020, with net imports of 25.8 Mt and 110.1 Mt, respectively. The rest of the world responds to the changed role of United States in world maize market by either increasing their exports (e.g. Latin America and Caribbean and sub-Saharan Africa), or reducing their imports (e.g. Middle East and North Africa), or turning from net importing countries to net exporting countries (e.g. East Asia and Pacific and Europe and Central Asia). The only exception is South Asia which reduces its exports under the two biofuel expansion scenarios due to rapid increase of biofuel feedstock demand for maize within the region itself.

Table 6. *Projected agricultural commodity trade (million metric tonne)*

Region*	Scenario**	Wheat	Maize	Soya bean	Cassava	Meal	Oil seeds	Sugar
East Asia Pacific	Baseline	–23.5	–47.6	–36.1	14.5	–17.1	18.1	7.2
	Business as usual	–18.3	–23.1	–35.6	8.3	–17.3	22.4	9.2
	Aggressive	–11.7	11.4	–34.9	1.4	–17.6	27.1	11.4
East Central Asia	Baseline	26.1	–6.7	–19.8	–10.6	–21.1	–7.7	3.8
	Business as usual	14.8	2.0	–19.5	–10.8	–21.3	–17.7	5.0
	Aggressive	0.5	14.3	–19.2	–11.0	–21.7	–28.7	6.1
Latin America Caribbean	Baseline	–5.2	21.5	34.9	–10.9	32.0	6.7	27.5
	Business as usual	–4.4	36.9	34.3	–11.0	32.4	8.0	22.3
	Aggressive	–3.5	57.6	33.5	–11.3	32.9	9.5	16.9
Middle East North Africa	Baseline	–32.4	–19.2	–2.5	–0.1	–6.3	–5.5	–9.6
	Business as usual	–31.3	–17.5	–2.5	–0.2	–6.3	–4.8	–8.8
	Aggressive	–30.1	–15.5	–2.5	–0.4	–6.3	–4.0	–7.9
North America	Baseline	54.0	31.3	23.5	–0.5	10.1	2.2	–5.1
	Business as usual	53.0	–27.8	23.2	–0.5	10.1	1.8	–7.6
	Aggressive	52.0	–110.0	22.8	–0.5	10.2	1.5	–10.3
South Asia	Baseline	–4.4	3.2	0.6	–1.2	2.2	–11.1	–14.7
	Business as usual	0.2	1.9	0.6	–0.8	2.3	–8.6	–12.2
	Aggressive	6.2	1.2	0.7	–0.3	2.3	–5.8	–9.5
Sub-Saharan Africa	Baseline	–14.6	17.4	–0.6	8.7	0.1	–2.6	–9.0
	Business as usual	–14.0	27.5	–0.5	15.0	0.1	–1.1	–7.9
	Aggressive	–13.3	41.0	–0.5	22.2	0.1	0.5	–6.7
USA	Baseline	34.4	34.9	23.5	–0.4	9.0	1.2	–3.9
	Business as usual	35.4	–25.8	23.2	–0.4	9.1	0.5	–6.4
	Aggressive	36.5	–110.1	22.8	–0.5	9.3	–0.1	–9.1

Note: Projected to 2020.

Likewise, wheat exports of Europe and Central Asia decrease dramatically under the two biofuel expansion scenarios due to increased demand of wheat for biofuel in these regions. As a result, East Asia and Pacific imports far less wheat and South Asia changes from a net importing region to a net exporting region of wheat. For cassava, dramatically decreased export of East Asia and Pacific leads to increased export of sub-Saharan Africa, under the two biofuel expansion scenarios.

Livestock prices

With more grain and biomass used for biofuel production both in booming first generation and foreseen second biofuel technology, livestock feed facing drastic competition, which may encounter feed shortage and high feed price. Under strong growth of starch- and sugar-based biofuel production, if a business-as-usual scenario is adopted, an increase of livestock product prices would be expected (Table 7). Beef would face the highest price leap, with around 21% increase by 2020, compared to 2000, and overall price increase also can be seen for the other three important dietary meats, with increase of 16%, 14% and 10% for pork, lamb, and poultry, respectively. If a more aggressive biofuel scenario were to occur, the prices of these livestock products may increase more intensively over the projection period. Eggs and milk can expect a small increase, or even reduced price, due to increasing per capita levels of production, over time. Increase in egg and milk production will be through improvements in breeding and feeding technology and other adjustments in the livestock sector.

Table 7. *Livestock commodity price under biofuel scenarios (USD per tonne)*

Commodity	Baseline		Business as usual		Aggressive	
	2000	2020	2020	Difference*	2020	Difference*
Beef	1914	2276	2309	20.65%	2320	21.21%
Pork	904	1030	1051	16.26%	1058	17.03%
Lamb	2702	3058	3087	14.25%	3097	14.60%
Poultry	1193	1280	1313	10.05%	1324	10.96%
Eggs	759	778	793	4.44%	798	5.08%
Milk	301	278	282	–6.37%	283	–6.00%

Note: *Difference from 2000.

Price differences between the baseline and biofuel scenarios in 2020 were also considered. For example, beef and poultry price will both increase by USD 33 per tonne under the business-as-usual scenario of biofuel and USD 44 per tonne under the aggressive scenario. In contrast, the change in milk price appears non-significant, approximately USD 4–5 tonne.

Limitations

It should be noted that in this analysis, we have not explicitly modelled the feedbacks between agricultural and energy markets that would allow for changes in feedstock prices to affect projected biofuels production levels, and lessen the impacts that have been shown. In general, the reader should note that the impacts estimated through partial-equilibrium modelling approaches such as the IMPACT and OECD/FAO analyses (OECD/FAO 2008) are often larger than those derived from general-equilibrium models. The full incorporation of biofuel trade into the analysis would moderate some of the effects that are discussed. If an economy wide modelling approach was taken, in which the impacts of biofuels production on wages (and household income) were captured, this might also soften some of the effects on malnutrition that have been presented.

Chapter 5 Potential impacts on resources, environment and crop–livestock systems

Resources, environment and local market

The choice of certain biomass crops and production methods can lead to favourable carbon and energy balances and a net reduction in greenhouse gas emissions. But bioenergy production systems also need to be adapted to local conditions to avoid generating land, water and other environment-related problems (FAO 2008a). With concerns over high energy prices, volatility of oil supply and greenhouse gas emissions, energy derived from biological sources and in particular biofuels have received considerable attention (see for example IEA 2004a, IEA 2004b, Dufey 2006; Dufey et al. 2007).

Land use

Increasing demand for alternatives to petroleum stimulated the production of biofuels from crops, plantations and waste biomass during the current decade. Their production could support the agricultural economy through enhancing productivity per unit of land, water and labour investment; but also imposes costs in some cases. For example, the costs were apparent in growing economies during 2007–2008 where the import of fossil fuels absorbed scarce foreign currency and significantly increased the cost of the food basket, particularly in sub-Saharan Africa and South Asia.

Despite many environmental advantages over petroleum-based fuels, certain types of biofuel production and utilization may result in significant negative consequences on the environment and the availability of livestock fodder and feed. Intensified production of biofuels with mechanization, irrigation and high levels of chemical fertilizer use may decrease soil health, promote mono-cropping and lead to land degradation. It could also lead to the expansion of biofuels onto marginal and fragile lands and systems, thereby accelerating land degradation processes. Its expansion to protected wetlands, grazing areas and agricultural fields and other sensitive and less-developed system niches would reduce ecosystem services and availability of habitats suitable for many species thereby reduce multiple use of land and water resources and damage ecosystem services. This has become evident in the US where expansion of corn ethanol production threatened lands enrolled in the Conservation Reserve Programs (Groom et al. 2008), and expansion of palm oil plantations comes at the expense of natural habitats in Malaysia (Groom et al. 2008). Biofuels, by introducing a new demand, can also put pressure on food production and on biomass availability thereby reducing feed availability, vegetative cover, aggravating land degradation and facilitating climatic risks, and thus a full life cycle analysis is desirable (Liska et al. 2007).

Land degradation, in relation to biofuels, could be understood as the decline in the productive capacity of land over time as a result of nutrient mining and change in biological and chemical properties of soils and landscapes. It is commonly facilitated by inappropriate choice and management of feedstocks, steep slopes, high rainfall intensity, poverty, policy failures and low capacity of communities to respond to environmental and market shocks (Steinfeld et al. 2006). Degradation adversely affects the productive, physiological, cultural and ecological functions of land resources, particularly in crop–livestock systems. This implies a long-term loss of ecosystem functions and services.

Various sources of biofuels are considered in different parts of the world. Biofuels made from ligno-cellulose biomass coming from perennial species, wood or crop residues may prove to be more ecologically friendly than the use of grain and grass feedstocks. For instance feedstocks from poplar and willow have been grown successfully with municipal-waste fertilizers and irrigated with municipal or industrial wastewater, thus decreasing waste streams while achieving inputs needed for high yields (Powlson et al. 2005). On the other hand, the high yielding feedstock from food crops and sugar-cane may require more inputs and could pose environmental and genetic risks unless grown with care. Removal of crop residues for biofuel use from areas were it is currently used to provide organic matter poses increased risks of nutrient mining.

By 2005 the area of land and water resources devoted to biofuel crop production was about 11 to 12 Mha, around 1% of the total area under crops (Table 8, de Fraiture et al. 2007b). In Brazil, the biggest bioethanol producer in past years, 2.4 million ha (5% of the cropped land) is used for biofuel production, with a production rate of 6200 litres of ethanol per hectare from sugar-cane. Under certain assumptions, the global biofuel crop area could increase to around 3% of the total area under crops (Table 9). Increasing the production of feedstocks globally could be feasible under various land use assumptions (Table 10), namely: converting the traditional land allocated for growing food crops to biofuels; increasing the productivity of traditional bioenergy crops such as maize and soya bean, using irrigation, high yielding varieties, chemical fertilizers and other external inputs; converting protected land reserved for wildlife, recreation and wetlands; and reclaiming abandoned land which has been lost to conventional crops.

In relation to expansion of crop land, some countries have abundant agricultural land for growing bioenergy crops, particularly in South America. Brazil alone has 170 million ha of convertible lands that could provide cost-effective feedstock production (Searchinger et al. 2008). A study conducted by the European Environment Agency showed that significant amounts of biomass are available to support ambitious renewable energy targets, even when strict environmental constraints are applied.[1] This potential would exceed the feedstocks required for the European renewable energy target in 2010 (Biofuels Research Advisory Council 2006).

There are concerns, perhaps overstated, that much of the new land for biofuels would be converted from ecologically valuable land systems (Woods Institute 2007). Farmers might search for fertile virgin lands in order to grow bioenergy crops, where biomass production and return per investment of land and labour is relatively high. Such lands include rainforests, grasslands, wetlands and protected landscapes. For instance, in Brazil the direct conversion of forest to cropland totalled more than 540,000 ha during 2001–2004, averaging twice the area of clearing for pasture (Morton et al. 2006). Conversion of these native ecosystems into farm lands for producing feedstocks would change the ecosphere in different ways. Biofuel feedstocks, particularly those for 1G production, increase incentives for mono-cropping with all the associated effects on soil health including the alteration of the biochemical and microbial dynamics of soils. In response to these concerns, some biofuel investments are associated with conservation reserve programs in which farmers receive payments to plant perennial feedstocks—rather than annual crops—on environmentally sensitive lands. These may promote not only sustainable productivity but also soil health, increased availability of feed for cut-and-carry, and other elements of environmental sustainability. It would also drastically reduce the availability of livestock feed by competing for pasture lands and crop residues. The recent policy shift to introduce irrigation schemes into these pastoral and agro-pastoral systems for producing biofuels have potentially negative effects on livestock feed as grazing land shrinks. On the other hand, if irrigation is planned for multiple use of water, whereby part of the water is allocated for livestock drinking and irrigating pasture lands, it could compensate the feed biomass lost by the land allocated for biofuels.

1. http://ec.europa.eu/agriculture/analysis/markets/biofuel.

Table 8. *Biofuels land and water use (2005)*

Country/region	Bio-ethanol (million litres)[a]	Main feedstock crop	Feedstock used (million tonnes)[b]	Area biofuel crop (million ha)	Proportion of total cropped area used for biofuels (%)[c]	Crop water evapotranspiration (km^3)[d]	Proportion of evapotranspiration used for biofuel (%)	Irrigation withdrawals for biofuel crops (km^3)	% of total irrigation withdrawal for biofuel
Brazil	15,098	Sugar-cane	167.8	2.4	5.0%	46.0	10.7%	1.3	3.5%
USA	12,907	Maize	33.1	3.8	3.5%	22.4	4.0%	5.4	2.7%
Canada	231	Wheat	0.6	0.3	1.1%	1.1	1.1%	0.1	1.4%
Germany	269	Wheat	0.7	0.1	1.1%	0.4	1.2%	–	0.0%
France	829	Sugar beet	11.1	0.2	1.2%	0.9	1.8%	–	0.0%
Italy	151	Wheat	0.4	0.1	1.7%	0.6	1.7%	–	0.0%
Spain	299	Wheat	0.8	0.3	2.2%	1.3	2.3%	–	0.0%
Sweden	98	Wheat	0.3	0	1.3%	0.3	1.6%	–	0.0%
UK	401	Sugar beet	5.3	0.1	2.4%	0.4	2.5%	–	0.0%
China	3,649	Maize	9.4	1.9	1.1%	14.4	1.5%	9.4	2.2%
India	1,749	Sugar-cane	19.4	0.3	0.2%	5.3	0.5%	6.5	1.2%
Thailand	280	Sugar-cane	3.1	0	0.3%	1.4	0.8%	1.6	1.9%
Indonesia	167	Sugar-cane	1.9	0	0.1%	0.6	0.3%	0.9	1.2%
S-Africa	416	Sugar-cane	4.6	0.1	1.1%	0.9	2.8%	1.1	9.8%
World ethanol	36,800			10.0	0.8%	98.0	1.4%	30.6	2.0%
Biodiesel	1,980			1.2		4.7			0.0%
Ethanol+diesel	38,780			11.2	0.9%	102.7	1.4%		1.1%

Sources: a. Dufey (2006); b conversion estimates from EIA (2004) Table 3.1 page 53 and Dufey (2006), based on main crop used. The wide range in variation of both feedstock production efficiencies and conversion process efficiencies suggests that more work is needed in this area (IEA 2004a); c total cropped area estimated from WATERSIM model baseline year (see Fraiture 2007a, and Fraiture et al. 2007b); d total ET estimated from WATERSIM model baseline year (ibid); e total irrigation withdrawals estimated from WATERSIM baseline year (ibid).

Table 9. *Biofuels land and water use, projections for 2030*

	Biofuel (billion litres)	Main feedstock crop	Feedstock (million tonnes)	Area biofuel crops (million ha)	Proportion of total cropped area for biofuels (%)	Crop evapotranspiration for biofuels (km3)	Proportion of total crop evapotranspiration for biofuels (%)	Irrigation withdrawals for biofuel crops (km^3)	Proportion of total irrigation withdrawals for biofuels (%)
N-America	51.3	Maize	131	14.1	9.0%	76	11.0%	36.8	20.0%
EU	23	Rapeseed	51	14.6	28.0%	30.1	17.0%	0.5	1.0%
China	17.7	Maize	45	7.8	4.0%	43.6	4.0%	35.1	7.0%
India	9.1	Sugar-cane	101	1.1	1.0%	21.6	3.0%	29.1	5.0%
S-Africa	1.8	Sugar-cane	20	0.2		3.9	12.0%	5.1	30.0%
Brazil	34.5	Sugar-cane	384	4.4	7.0%	86.3	14.0%	2.5	8.0%
Indonesia	0.8	Sugar-cane	9	0.1	0.0%	2.5	1.0%	3.9	7.0%
World	141.2			42.2	3.0%	261.5	3.0%	128.4	4.0%

Source: Projections are based on de Fraiture et al. (2007a).

Table 10. *Biofuel impacts on land resource use and livestock feed availability*

Land use scenarios	Example location	First generation	Second generation
Converting land from wildlife, recreation and wetlands	South America and Europe	Big potential for crop-based biomass under both biofuel scenarios, with little impact on the livestock grazing area	Big potential for biomass under both biofuel scenarios, with major impacts on the soil and livestock feed if aggressive biofuel adopted
Reclaiming abandoned land	Sub-Saharan Africa, Latin America and South Asia	May support livelihood in food aid area, also benefit the environment conservation and livestock feed availability	More sustainable developing and rehabilitating the underutilized pitches may enhance the conversion efficiency, and supply a large amount of feed for small and large ruminants
Converting from traditional cropland	EU, USA, Canada and Brazil	Land use for crops increasing, intensive competition between livestock feed and biofuel	Alleviating competition between livestock feed and biofuel, intensification of crop–livestock systems

If biofuel feedstock production replaces the grass savannah in Sub Saharan Africa and South Asia, there would be a need to monitor the effects of growing biofuels on feed availability, soil nutrient mining and soil erosion. When high yielding sugar-cane is produced for first generation biofuels, the amount of crop residue left in the system could be sufficient to sustain soil organic matter and nutrient cycling, and in some case may even produce more livestock feed than the current biomass produced by the natural vegetation. On the other hand, there could be a risk of aggravating feed scarcity and land degradation if second generation biofuels are adopted, regardless of the amount of chemical fertilizers farmers may use to replenish soil fertility. Removal of crop residues exacerbates soil degradation, increases net emission of CO_2, and aggravates food insecurity (Lal 2008). It will also affect the biochemical and biological characteristics of the soil and reduce land quality in a very short period of time.

An alternative situation entails substantial losses of productive crop, pasture and range land because of land degradation, e.g. 5 to 7 million hectares of crop land alone per year. Much land in Sub Saharan Africa, Latin America and South Asia is moderately to severely degraded. Although particularly apparent in the mountainous landscapes, notably the Himalayas, the Andes and the African highlands, in reality there are larger areas in the foothills and plains which are also severely degraded. These systems are prone to low system productivity, very high soil erosion, high costs of inputs and limited access to institutional supports and market incentives. There are recent attempts in these regions to invest on natural resources management through area enclosure, soil and water conservation, improved in situ water management, strengthened by laws and related activities.

Abandoned or low-productivity lands not suitable for growing conventional crops profitably offer opportunities for the cultivation of biofuel crops without direct competition with food or feed grain supply. There are a variety of perennial biofuel feedstocks which grow on degraded land, e.g. *Ricinus communis*. In conditions of strong local institutions, including linkages to markets, well managed perennial biofuel production could make a positive contribution to environmental rehabilitation in different ways. Firstly, the perennials could act as biological barriers to soil erosion and minimize the removal of soil and nutrients from the system; economically and environmentally benefiting upstream communities and reducing sediment disposal of downstream communities. Secondly, by creating the necessary linkages to corporate and input delivery agencies, there could be spillover benefits to other productive activities in these crop–livestock systems. It will also bring the necessary income for poor farmers to support their livelihoods and protect their environment.

A special case of low productivity or abandoned lands with potential for biofuel feedstock production may be salt-affected 'waste' lands. A variety of bioenergy species have been tested on salt-affected lands (Qadir et al. 2008). Among the biofuel and bioenergy species, jatropha (*Jatropha curcas L.*) is a drought-resistant perennial, which grows well on marginal lands and produces for about 50 years. Relatively little is known about the genetic variation or agronomic management of jatropha grown in pure stands or with other plant species, or under different land conditions, e.g. severely salt-affected soils, or irrigated with saline water. Dagar et al. (2006) evaluated the performance of some multi-purpose bioenergy plant species at different stages of growth under irrigation with waters having variable levels of salinity and sodicity, including *Azadirachta indica A. Juss* and *Jatropha curcas L. Jatropha curcas* can be cultivated successfully up to pH 9.3. However, following the standard auger-hole planting technique developed by the CSSRI, the plants can be raised even in soils having even higher elevated levels of sodicity, i.e. pH1:2 10.2 and ESP 80 (Gurbachan Singh, personal communication 2007; Qadir et al. 2008).

Another opportunity may be associated with irrigation with marginal-quality water resources, e.g. saline water from agricultural drainage systems or pumped from saline aquifers; and wastewater generated from domestic, municipal and industrial sectors (Dagar et al. 2006; Qadir et al. 2008). The use of marginal-quality waters in agriculture through efficient, environmentally acceptable, cost-effective and sustainable strategies, and enabling policies and institutional support can enhance agricultural productivity, thereby contributing to reductions in poverty and hunger and improvement of livelihoods. This particularly implies to those situations where marginal communities rely on irrigated agriculture using marginal-quality waters. Irrigation with marginal-quality waters is an ever-increasing phenomenon, which is expected to intensify in those less-developed, arid and semi-arid countries and regions that are already suffering water, food, sanitation, and health problems (Qadir et al. 2007). Among the multifaceted uses of marginal-quality waters, their use for biomass and biofuel production is promising.

Some companies have opted to integrate biofuel investment with the rehabilitation of degraded lands. In Kenya, a private firm GreenFuels Kenya Ltd. has been pursuing the goal of supplying 14% of Kenya's current diesel requirements using the indigenous tree, *Croton megalocarpus*. If implemented properly, the proposed system will ameliorate land degradation in the vicinity of Masinga Reservoir (WILMA 2005). Understory ground cover of perennial grasses (e.g. *Vetiver zizanioides*) will minimize erosion effects while serving as animal feed. Once the efficiency and effectiveness of the method is demonstrated, the project is planning to expand the approach throughout the river catchments in Kenya, rehabilitating the land while providing sustainable livelihoods. This strategy will also produce more biomass for fodder and improve soil health, e.g. an increase in soil organic matter content, some sequestration of carbon, and long-term improvements in soil quality (Powlson et al. 2005).

Besides the high yielding resource-intensive biofuels there is value in exploring the potential for native, perennial prairie grasses to re-vegetate degraded lands, rehabilitating gullies and underutilized hill tops. In a test project Tillman et al. (2006) grew a diversity of native prairie species on a site with degraded soils, using little or no external inputs, irrigated only in the first year to facilitate plant establishment, and yet obtained fuel yields per hectare comparable to those of corn (Groom et al. 2008). These native species also sequester a comparable amount of carbon and potentially supply a large amount of feed for small and large ruminants.

Farmers could also boost feedstock production through the intensification of the existing crop–livestock systems by application of chemical fertilizers, identifying high yielding plant types and varieties and plant protection methods, which may have their own environmental effects. Reduced crop rotations and greater reliance on monocropping would reduce system resilience and aggravate risks. Moreover, these production systems will be under intense competition for biomass among livestock feed, soil fertility maintenance and biofuels. In mixed crop–livestock systems of Africa where only 22% of the land area supports 57% of the cattle, 50% of the goats and 44% of the sheep (Kruska et al. 2003) and with increasing trend of livestock numbers, converting the crop residue to biofuels could aggravate the current feed deficit and cause a livestock disaster. For instance in East Africa, the number of livestock in mixed systems would increase from 29 to 39 million tropical units (TLU) by 2030, which would increase the feed demand by about 35% (Herrero et al. 2008).

Water use

The expansion of bioenergy crops will require more land and water, notably in fast growing oil importing economies such as China and India which perceive biofuels as one means to curb dependency on oil. While both China and India already suffer from water scarcity problems that will only worsen as their food demand continues to grow with rising populations and incomes. China is implementing a costly transfer project to bring water from the water-abundant South to the water-short North. India is exploring the possible implementation of a controversial multi-billion dollar project of inter-basin water transfers, to meet future demands. In both countries biofuels will add pressure to water resources that already are heavily over-exploited.

Fluctuating energy prices affect agriculture, and thus water management, in different ways. The potential impact of higher energy prices on agricultural water use is fourfold (de Fraiture et al. 2007a). First, the demand for cheaper energy sources, including hydropower and energy from biomass rises, increasing water demand and changing water resource allocation. Second, the cost of pumping groundwater, a major factor in agricultural production around the world, increases. In addition, energy for groundwater use in some parts of the world, most notably India, is subsidized. Rising energy prices thus put additional pressure on government budgets and may lead to rising costs to farmers. Third, when energy prices rise, the viability of desalinization as a source of irrigation and other water supply declines. Finally, fertilizer prices and the unit costs of other oil-based inputs rise with increases in energy prices.

Globally around 7130 km^3 of water is evapotranspired by crops per year, without accounting for biofuel crops (Molden et al. 2007). Biofuel crops currently account for an additional 100 km^3 (or around 1%). In terms of irrigation water, the share is slightly higher because of the relatively large share of irrigated sugar-cane in the biofuel mix (Table 8). Total irrigation withdrawals amount to 2630 km^3 per year globally (de Fraiture et al. 2007b) of which about 2% is used for biofuel crops. It takes on average roughly 2500 litres of crop evapotranspiration and 820 litres of irrigation water withdrawn to produce one litre of biofuel. But regional variation is large. In Europe where rainfed rapeseed is used, the amount of irrigation for biofuel crops is negligible. In the US, where mainly rainfed maize is used, only 3% of all irrigation withdrawals are devoted to biofuel crop production, corresponding to 400 litres of irrigation water withdrawals per liter of ethanol. In Brazil where the main biofuel crop—sugar-cane—is mostly grown under rainfed conditions, very little irrigation water is used for ethanol production. On the other hand China withdraws on average 2400 litres of irrigation water to produce the amount of maize required for one litre of ethanol. Around 2% of total irrigation withdrawals in China are therefore for biofuel crop production. With high sugar-cane yields and conversion efficiency, Brazil yields more than 6200 litres of bioethanol per hectare. In India where conversion efficiencies are lower, one hectare yields 4000 litres. As Indian sugar-cane is fully irrigated, water withdrawals for every litre of ethanol are nearly 3500 litres.

On a global level by 2030 the biofuel scenario requires about 30 million additional hectares of cropped area, 170 km^3 additional evapotranspiration (ET) and 180 km^3 more withdrawals for irrigation. While for individual crops increases may be substantial, compared to the sum of all crops, increases are modest. These figures amount to increases in resource use of only 2 to 5%, levels too small to lead to major changes in agricultural systems at a global level (Table 9). But on country level a different picture emerges. Taking China and India as example: with oil consumption more than doubling, China's oil import dependence will increase dramatically from the current level of 34% to 70% in 2030 (IEA 2004b). Energy consumption in road transport is expected to grow by 5% annually over the coming decades (Schipper et al. no date). To curb oil dependency, air pollution and greenhouse gas emissions and support rural economies, China has set a goal of producing 6 million tons of cleaner-burning substitutes to coal and oil by 2010 and 15 million tons by 2020. In 2020 this is equivalent to 18 billion litres of gasoline energy equivalent, or 9% of projected gasoline demand.

Irrigation plays a dominant role in China's food production. About 70% of wheat and 60% of maize are harvested in the Northern region (i.e. the Yellow, Huaihe and Haihe river basins), where more than 60% of the area is irrigated and groundwater resources are already extensively overexploited (Liao 2005). The water-rich South imports food from the water stressed North and the international food market (Zhou and Wei 2005), for the higher opportunity costs for land and labour. Because of water limitations in the North and land constraints and high opportunity costs to labour in the South, one can foresee limited scope for further improvements in biofuel feedstock, especially maize production.

To meet its stated goals China needs to produce 26% more maize and this means 35.1 km^3 of additional irrigation water is required while this country already faces regional and seasonal water shortages. Under such a scenario it is quite unlikely that the additional maize demand for biofuel can be met without further degrading water resources or major shifts of cropping pattern at the expense of other crops. More likely, under an aggressive biofuel program China will have to import more maize (or other crops to be displaced by maize), which will undermine one of its primary objectives, i.e. curbing import dependency.

Oil demand in India is expected to grow by a factor 2.2, increasing the oil import dependency from 69% now to 91% by 2030. With the number of vehicles doubling between 2002 and 2020 (IEA 2004b), and if 10% of the gasoline demand in 2030 is to be met by sugar-based bioethanol, it will require 9 billion litres of bioethanol, an increase by a factor 4.7 compared to 2002. This is in line with estimates by IEA (2004a) and Rosegrant et al. (2006).

Water withdrawals in India were estimated at 630 km^3 in the year 2000, of which more than 90% was for irrigation. Spatial variation is enormous. The river basins of the Indus, Pennar, Luni and westerly flowing rivers in Kutsch and Gujarat are absolute water scarce, and much of North India suffers from groundwater overdraft (Amarasinghe et al. 2005). A series of large-scale inter-basin transfers to bring water from water-abundant to water-short areas has been implemented to address water scarcity, although these programs are expensive and may have adverse impacts on biodiversity and freshwater ecosystems. Relatively limited scope for further irrigation development can be foreseen.

For the production of bioethanol an additional 100 million tonnes of sugar-cane (16% more sugar-cane) is needed, for which 30 km^3 additional irrigation water needs to be withdrawn. This amount will likely come at the expense of the environment or other irrigated crops (cereals and vegetables), which then need to be imported. For many years, the Indian government has focused on achieving national food self-sufficiency in staples. More recently, as the imminent danger of famines has decreased and non-agricultural sectors have expanded, the national perspective regarding production and trade has changed. But it is unclear if India would choose to import food to free up necessary resources to grow biofuel crops.

Above all, at present the role of biofuels in energy supply, and its implications for water and land use, are limited. But there are plans and policies in place around the world to increase biofuel production. If all national policies and plans on biofuels are successfully implemented, 30 million additional hectares of crop land will be needed along with 260 km^3 of additional water available. Although globally this is less than a few percentage points of the total area and water use, the impacts for some individual countries could be highly significant, including China and India, with significant implications for water resources and with feedback into global grain markets. In fact it is unlikely that fast growing economies such as China and India will be able to meet future food, feed and biofuel demand without substantially aggravating already existing water scarcity problems, or importing grain, an outcome which counters some of the primary reasons for producing biofuels in the first place.

Greenhouse gases

Most studies have found that replacing fossil fuel with ethanol can modestly reduce greenhouse gases (GHGs) if these bioethanol are made from corn, cellulose or sugar-cane (Wang et al. 1999; Macedo et al.

2004; Farrell et al. 2006; Argonne National Laboratory 2007). The GHGs emissions for the separate steps of growing or mining the feedstocks (such as corn or crude oil), refining them into fuel, and burning the fuel in the vehicle have been investigated. Because growing biofuel feedstocks removes carbon dioxide from the atmosphere, biofuels can in theory reduce GHGs relative to fossil fuels, although corn and cellulosic ethanol emissions exceed or match those from fossil fuels in the mining and refining stages. Farrell et al. (2006) indicate that GHG emissions from ethanol made from conventionally grown corn can be slightly more or slightly less than from gasoline per unit of energy, but ethanol requires much less petroleum inputs. While ethanol produced from cellulosic material (switchgrass) reduces both GHGs and petroleum inputs substantially after they evaluated six representative analyses of fuel ethanol.

However controversial studies claim that the greenhouse gas emissions resulting from biofuel production and associated agricultural practices would effectively negate or even reverse any reduction in emissions that could be achieved by significantly expanding the use of ethanol as a transportation fuel (Tilman et al. 2006; Searchinger et al. 2008). For example, Searchinger et al. (2008) using a worldwide agricultural model to estimate emissions from land use change, found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Biofuels from switchgrass, if grown on US corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates. Paul Crutzen's research team, who won a Nobel Prize for his work on ozone depletion, recently showed (Crutzen et al. 2008) that the aggressive cultivation of biofuels in the US and Europe produces up to 70% more greenhouse effect than the fossil fuels they displace (nitrous oxide, a by-product of the fertilizers used, has nearly 300 times the heat-trapping properties of carbon dioxide).

Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced. In Indonesia and Malaysia, tropical rainforests have been converted to grow palm biodiesel crop; in Brazil, tropical rainforests and *cerrado* grasslands have been converted to soya bean biodiesel or sugar-cane ethanol use; in US, many of the abandoned cropland, marginal land and grasslands are converted to maize-based ethanol production. Fargione et al. (2008) estimated carbon debt of these kinds of land conversions, and found that converting rainforests, peatlands, savannas, or grasslands to produce food crop–based biofuels in Brazil, Southeast Asia, and the United States creates a 'biofuel carbon debt' by releasing 17 to 420 times more CO2 than the annual GHG reductions that these biofuels would provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages.

Local market effects of biofuels

Other important issue is local market effects of biofuels. Land, labour, water and other factors and market integration are closely related to the household activities, and the scope of biofuel impacts are seen on farmer livelihood. The imperfections of factor markets may have a significant impact on both the efficiency and distributional effects.

The land asset is the most important capital that farmers have. Land markets functioning imperfectly means land sales are constrained or partly constrained, transaction costs may be higher than free market, large farm corporations or government monopolized local or regional land markets, and control the land supply and land price. In China for example, land tenure security has been a focus of rural economic reform. While land ownership belongs to the whole community, farmers have the use and management right with limited terms. This may become an obstacle to land investment and land transfer to the most efficient users; and also may be a barrier for farmers to secure the financial credit (Sonntag and Huang

2005). In these circumstances, the land rental market is not completely developed, and the rent of agricultural land is not based on the market demand and supply. This causes land asset to lose its function on adjusting crop production and farmers' production activities. To meet the more and more demand of biofuel feedstock, land competition and use in efficiently would be very important to realize this goal, considering the scarce land resource. And well-working land market would guarantee farmers' stability in on-farm investment and feasibility in selection of on-farm crops, like biofuel crops, that are crucial for household livelihood security.

The labour resource is extremely uneven through the whole world, with plentiful in South Asia, like India and East Asia, like China, and shortfall in most of the Africa. Population policy, disease, and regional war contribute to this labour situation. Crop production in broad developing world is frequently labour intensive, and usually the young and adult are the on-farm workers. Biofuel crop production in developing CLEFS is also a labour intensive industry, labour migrants are needed in the crop harvest season, such as the sugar-cane harvest in Brazil, thirty-five percent of these harvest jobs were temporary employing many poor migrant labourers from the north east of the country. Labour amount in Africa is pessimistic, as prevalence of diseases, like HIV and inherent poverty, reduce life expectancy significantly in this region. This could constrain a biofuel boom, and poverty reduction in Africa.

Limited water resource and water use efficiency have been attracting more and more attention both from the view of international research also the view national developing. Effective water market function is essential to improving water use efficiency between social-economic sectors and the agricultural production. Water cost can be a key part for farmers' total production cost and this create more uncertainties in water use, especially for the dried and dry rainfed CLEFS. National governments may hope to improve local water use efficiency through enhancing irrigation system and format good water price system. The latter may operate well with immediate reaction from farmers. Risks also exist, if local water market cannot respond to the water based on existing facts, farmers may not use water sustainably and this will ultimately hurt farmer household's livelihood. In addition, impacts such as increase in poverty in local communities may occur because of displacement of smallholders and rise in food prices. However this can be averted if the incomes generated from biomass production for decentralize energy supplies can be invested in local food production on available land.

Crop–livestock–energy farming systems

Introduction

The nine crop–livestock–energy farming systems (CLEFS) provide a framework for examining the different effects of the three biofuel options in contrasting CLEFS. Table 11 summarizes some key characteristics of the CLEFS in relation to livestock and crop production, as well as some indicators of the approximate level of energy consumption. The effects of biofuel production are examined in this section for seven of the nine systems. For the location of the CLEFS, and their relative poverty levels, see Figure 8.

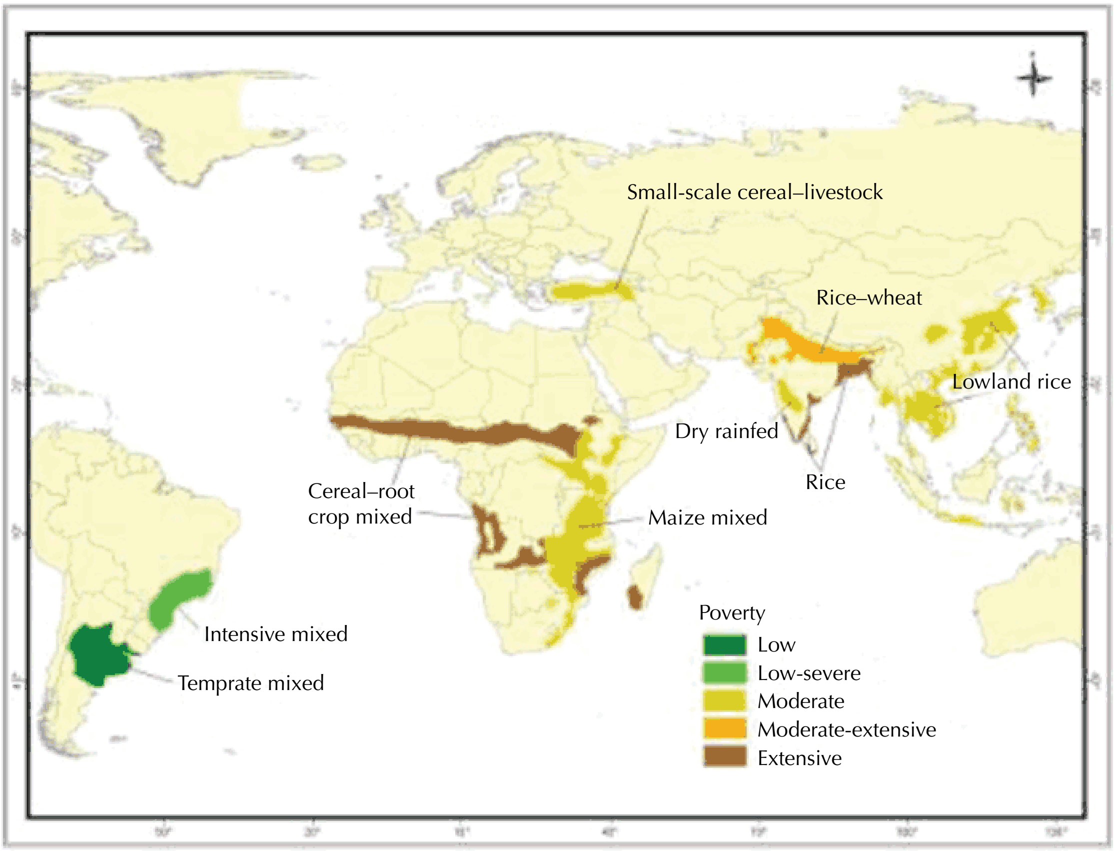


Figure 8. *Location and poverty levels of example farming systems.*

Energy use efficiency in developing countries is relatively lower than that in the developed world. SSA has high energy consumption; Kenya and Nigeria have the highest, namely, 468 and 777 tonne of oil equivalent (toe) USD million GDP, respectively, compared with other countries shown in Table 11. LAC has relatively high energy use efficiency in the developing world, with an average 144 toe per USD million GDP. The energy use efficiency of Asia is intermediate. Energy use efficiency has close relationship to the major energy types. In SSA, solid biomass is still the main energy source, fossil fuel is just 15–20% of the total energy use, and this largely results to a low value of energy use efficiency. While many LAC countries are experiencing an energy revolution, even Brazil with only 58% fossil fuel use, reducing dependency on crude oil and promoting renewable energy use, including bioethanol.

Table 11. *Energy and crop–livestock production by farming system*

CLEFS	Region	Example system	Example country	Energy consumption (Toe per GDP)[a]	Fossil fuels % to total energy use	Livestock density (head/100 ha)		Main crop production		Total calorie consumption (Kilocalories/ person/day)	Cereal food consumption (% to total calories)	Animal food consumption (% to total calories)
						TLU[b]	Poultry[c]	Main crop yield (tonne per ha)	% to total food crop area			
Maize mixed	SSA	Maize mixed	Kenya	468	16	25	79	1.4	50.2	2107	48	12
Wheat-based	EECA	Small-scale cereal–livestock	Turkey	167	87	30	174	2.2	63.7	3358	50	10
Cassava-based	SSA	Cereal–root crop mixed	Nigeria	777	20	20	35	70.9	1.5	2705	45	3
Sugar-cane	LAC	intensive mixed system	Brazil	146	58	35	75	71.2	17.2	3010	31	22
Sorghum-based	SA	Dry rainfed	India	190	59	20	100	0.8	19.2	2420	59	8
Cereal–livestock	LAC	Cereal–livestock	Brazil	146	58	35	300	2.6	24.0	3010	31	22
Rice-based	EAP	Lowland rice	China	231	82	30	1066	6.3	29.9	2958	49	20
Rice-based	SA	Rice	India	190	59	35	338	2.2	62.2	2420	59	8
Rice–wheat-based	SA	Rice wheat	India	190	59	25	202	2.0 (R); 3.2 (W)	29.7	2420	59	8

Sources: Energy and calorie consumption data are from Earthtrend, the Environmental Information Portal, World Resource Institute; livestock density is estimated from ILRI, Density and poverty map.
Notes: most crop data refer to the regional CLEFS; other data refer to the example country.
a. Tonnes of oil equivalent (toe) per million constant 2000 international USD.
b. TLU tropical livestock unit, head/100 ha.
c. Poultry head/100 ha.

The greatest density of livestock production is found in LAC (e.g. Brazil and Argentina) with about 35–40 TLU or more per 100 ha, followed by East and South Asia (e.g. China and India) with 20–30 TLU per 100 ha. Livestock density is relatively lower in central and West Africa, but at middle level for east Africa, like Kenya. Although absolute numbers of livestock are not high, they play an important role for farm household livelihoods over all Africa, with 20% of household income from livestock in SSA, compared about 15% in EAP and SA. Human dietary calorie consumption from animal food is large in LAC, and relatively less in Africa and South Asia. In reverse, calorie consumption from cereal food is greater in Asia and Africa than in LAC. With the energy demand surging, about 69% of total energy consumption will be consumed in the developing world by 2030, which is around 12,142 million tonne of oil equivalent. If 5–10% of this demand is met by biofuel, the pressure on food consumption and livestock production would be limited.

Drawing on the framework presented in Chapter 2, some key aspects of illustrative CLEFS are considered in the following subsections. The discussion of each CLEFS is based on both regional and national data related to the selected CLEFS, the latter from a country where the CLEFS is a typical system. At the end of this section a summary is presented which contrasts the broad effects of biofuels across the selected CLEFS.

Maize mixed CLEFS, sub-Saharan Africa

There is extensive poverty in this CLEFS. Although this CLEFS extends from Ethiopia to southern Africa, the following discussion is focused on that part of the CLEFS which lies in Kenya. Maize is the dominant staple food crop and accounts for 37% of total crop area, followed by cassava 7.3%, and sorghum 6% (see Table 12).

Table 12. *Maize mixed CLEFS in sub-Saharan Africa*

Regional scenario			Example of Kenya		
Agro-ecological zone	Dry subhumid		Agricultural population (million)	28	
Agro-Population percentage (%)	63		Rural population percentage (%)	79	
Cultivated land per capita (ha/person)	0.5		Irrigated land (%)	0.4	
Irrigated land (%)	2.1		Maize area (%)	50	
Market access (hour)	8.4		2006 ethanol production (million litres)	19	
Resource constraints (Index)*	0.5		Energy consumption per GDP (toe per million)	468	
Prevalence of poverty	Moderate		Energy consumption per capita (Kgoe)	481	
Livestock density estimation (head/100 ha)	15		Grain fed to livestock (%)	2	
Farmers' income resource (%)	From crops	25	Energy resource (%)	Fossil fuels	16
	From livestock	15		Nuclear	0
	Off-farm income	40		Solid biomass	78
	Other cash	20		Other renewable	6
Major crop area percentage (%)	Maize	37	Livestock production per capita (kg)	Egg	5
	Cassava	7.3		Meat	11
	Sorghum	6		Milk	4

Notes: Energy consumption per GDP: tonnes of oil equivalent (toe) per million USD (year 2000); kgoe: kilograms of oil equivalent; * see note under Table 28.

Livestock density is estimated at 15 head per 100 ha. Alongside other biomass, maize leaf and stover are an important source of ruminant fodder, and some maize grain (approx 2%) is fed to animals. Livestock production per capita is relatively low: in Kenya for example, per capita production of eggs, meat and milk are 5, 11, 4 kg per year respectively. Resource constraints and market access are moderate in this CLEFS—an average of 8.4 hours from farm to local market centre. Crop productions contribute 25% to farm household income, second to off-farm income (40% of household income) and livestock production which is the lowest income source at 15%.

The major source of energy is solid biomass, around 78% to the total energy consumption in Kenya. Firewood and crop residues are still the staple heat energy, which results in low energy use efficiency. Africa consumes a high level of energy per unit GDP—approximately 300 toe per USD million GDP in the region and 468 300 toe per USD million GDP in Kenya. The second source of energy is fossil fuels, which account for 16% of total consumption.

Due to the important role of maize in this system, international research pays much attention to maize improvement, targeting regional food security, poverty reduction and malnutrition alleviation in children. One of CIMMYT's main priorities, maize breeding is currently targeted to tolerance of drought, low nitrogen and biotic stresses. Residue management is an important question in the conservation agriculture (CA) research.

In Africa bioethanol production grew from 100 million gallons in 2006 to over 160 million gallons in 2007. In the republic of South Africa, strategists target a market penetration of 4.5% of liquid road transport fuels by 2013 (Sorbara 2007). Some other African countries have initiated programs for cogeneration of electricity, heat and production of biofuels from biomass, for example, Malawi, South Africa, Ghana, Kenya, Nigeria, Benin and Mauritius (Makenete et al. 2007). Rainfed maize has potential as a bioenergy crop given the large tracks of arable land, suitable climate, and relatively low cost conversion technology.

Under the biofuel production scenario of business-as-usual (in this case with approximately 4.5% of biofuels in total transport fuels), increasing the use of maize for bioethanol feedstock would significantly increase the international maize food grain price and, subject to relatively free trade, domestically as well. Maize consumption patterns would change greatly between food, feed, and biofuel feedstock. Over time total maize production will increase, but consumption per capita will decline as incomes rise in contrast to growing use for animal feed alongside increased use for 1G bioethanol. This CLEFS, as elsewhere in Africa, has scope for increase in use of water and land for maize production. With improved crop varieties, especially those with improved water use efficiency, maize is likely to substitute sorghum and millet. Irregular rainfall creates periodic drought, which may be a constraint to maize production in the absence of irrigation. Diversification of livelihood patterns, both on-farm and off-farm, is expected, with legumes and forage entering the cropping patterns in many areas.

Under the scenario of aggressive biofuel production level, large volumes of maize used for bioethanol feedstock may push the maize price to an unexpected levels putting maize beyond the reach of sub-Saharan Africa's poor. Without 2G (cellulose-based) production technology, maize stover still can be widely used as fodder for livestock and soil cover.

Table 13. *Biofuel scenarios and possible impacts for maize mixed CLEFS*

Impacts	First generation		Second generation	
	Business-as-usual	Aggressive	Business-as-usual	Aggressive
Maize price	Increase	Great increase	Less increase	Significant impact for maize stover
Maize grain consumption				
For food	Decline	Dramatic decline	Even	Even
For feed	No change	No change	Even	Even
For biofuel feedstock	Increase	Dramatic increase	Even	Even
Maize stover use	Fodder, soil fertilizer	Fodder, soil fertilizer	Competition for biofuel	Competition for biofuel
Crop substitutions	Other crops to maize	Dramatic conversion	No change	Use marginal land
Crop system change	May change	Change	No change	No change
Land and water provision	Tense	More tense	Alleviate	Alleviate
Cultivars selection	Yield, nutrition, drought and disease tolerance	High yield and nutrition, drought and disease tolerance	High biomass, nutrition, drought and disease tolerance	High biomass, nutrition, drought and disease tolerance
Field management	Fertilizer use, and residue management	Fertilizer use, and residue management	Fertilizer use, and residue management	Fertilizer use, and residue management

As 1G biofuel has rarely been economically competitive with petroleum fuels,[2] production is expected to be promoted through subsidies and blending regulations. Conversely, 2G bioethanol would highly improve conversion efficiency, with about 322 litres of ethanol per tonne of maize biomass, which can include maize stover, leaf, and residues. Hopefully, 2G biofuel may reduce the pressure on land and water for additional maize area, and soften the effect on food prices. However, effects also depend on the intensity of biofuel production. Under the scenario of business-as-usual biofuel production, maize biomass and other existing crops may provide enough for biofuel feedstock, so this scenario has less impact on total maize grain production.

Under the scenario of aggressive biofuel production, more biomass, derived both from stem, stover, leaf and residue of crops, as well as from other plants with high biomass production. If this happens, although some biomass can be grown in marginal land, competition for water is unavoidable. Impacts on livestock feed and soil fertility, and with more aggressive biofuel production, and greater pressure on maize stover as fodder and as organic matter for soil conservation would be expected. High biomass production should be included to the priorities of maize breeding and crop management, together with grain yield, nutrition, and drought and disease tolerance. Improving livestock feeding technology, intensifying fodder and forage industry would be part solutions to this problem.

Biofuel impacts on livelihood and poverty in this system has been summarized in Table 14. In areas with low population density, the majority of households are able to produce enough grain to feed themselves, but households with less than 0.5 ha have a food deficit. The main causes of poverty are; very small farm size or landlessness, lack of oxen, low off-farm income and deteriorating terms of trade for maize producers. Maize and other cereals would account for 80 percent of total food production. The household would be food self-sufficient in average to good years and in deficit during drought years. Under 1st biofuel decline of grain consumption and increased food insecurity might happen within the most vulnerable poor families, who can not compensate price increase with increased income. Then

2. http://www.biofuels.ru/bioethanol/What_bioethanol/, 3461 litres per ha.

malnutrition in children is likely to increase under these circumstances, given the vulnerability of that particular demographic group. Large and middle households benefit from the increasing income of maize sales, for the smallholders there is trade-off with more expensive staple food, and energy. Food security improves with the shift towards 2nd generation technology. But maize stover is an important source of soil conservation, and its removal may undermine the soil health, affecting future food security. Income might increase within the whole system as maize grain can be kept as the staple food, some of maize stover can be sale to biofuel factories and farmers can benefit from cellulose-crop planting in marginal land.

Table 14. *Biofuel impacts on poverty for maize mixed CLEFS*

Biofuel generation	Cash income	Household food security	Energy poverty
1st generation technologies	Smallholders benefit from the increasing income of maize sales, but there is trade-off with more expensive staple food, and energy. Meat price is not likely to be affected, due to the extensive livestock system. Deforestation can reduce petty income (collecting firewood) for the poorest. There is a probable increase in poverty in the poorest farmers	Decline of consumption and increased food insecurity within the most vulnerable poor families, who can not compensate price increase with increased income. Increased malnutrition in children	If biofuel projects lead to large-scale deforestation, it removes fire wood as a potential energy source. Small-scale biofuel might provide an option for electricity generation in rural areas. It would increase significantly the energy consumption
2nd generation technologies	There is general reduction of costs (on food expenditure), since cellulosic conversion reduces the food fuel competition and alleviate price pressure	Food security improves with the shift towards 2nd generation technology. But maize stover is an important source of soil conservation, and its removal may undermine the soil health, affecting future food security	Maize stover is an important source of energy for smallholders, but with low domestic energy efficiency. If maize stovers can be sold for biofuel, other more efficient energy source could replace the biomass

Wheat-based CLEFS, Eastern Europe and central Asia

The small-scale family farm CLEFS of EECA is located in the semi-arid and dry subhumid and mountainous zones of Turkey with a growing period of less than 180 days. There is little irrigated land. Agricultural population is around 44% of the total rural population, with poverty currently moderate. Wheat is the most important crop, followed by barley, with 64% and 22% of total crop area in this system, respectively (Table 15). Resource constraints are considered to be medium. Market access is relatively good, with average 2.9 hours from farm to local market centre. Crop income contributes 30% to farmer household income, and off farm income contributes 40%. Livestock density is estimated at 30 head per 100 ha. Livestock production per capita is also relatively high. In Turkey, for example, per capita egg, meat, and milk production are 10, 22, 152 kg per year respectively, and 36% of total grain production is fed to livestock.

Major regional energy source is fossil fuel, around 87% of the total energy consumption in Turkey, which has an energy consumption of about 167 toe per USD million GDP cf. 205 toe in Eastern Europe and Central Asia. Solid biomass and other energy consumption is a lower proportion, around 13% of total energy consumption.

Table 15. *Small-scale CLEFS in East Europe and Central Asia*

Regional scenario			Example of Turkey		
Agro-ecological zone	Dry subhumid		Agricultural population (million)	32	
Agro-Population percentage (%)	15		Rural population percentage (%)	44	
Cultivated land per capita (ha/ person)	2		Irrigated land (%)	5	
Irrigated land (%)	4.9		Wheat area (%)	64	
Market access (hour)	2.9		2006 Ethanol Production (million litres)		
Resource constraints (Index*)	0.5		Energy consumption per GDP (toe per million)	167	
Prevalence of poverty	Moderate		Energy consumption per capita (Kgoe)	1106	
Livestock density estimation (head/100 ha)	30		Grain fed to livestock (%)	36	
Farmers' income resource (%)	From crops	30	Energy resource (%)	Fossil fuels	87
	From livestock	15		Nuclear	0
	Off-farm income	40		Solid biomass	7.3
	Other cash	15		Other renewable	5.4
Major crop area percentage (%)	Wheat	64	Livestock production per capita (kg)	Egg	10
	Barley	22		Meat	22
				Milk	152

Note: Energy consumption per GDP: tonnes of oil equivalent (toe) per million USD (year 2000); kgoe: kilograms of oil equivalent.

The potential implications of the use of wheat grain for 1G bioethanol production or wheat straw for 2G bioethanol production are considered below. Wheat is the most popular crop in EECA and is the staple food and a significant source of feed in this system. Although globally not more than 15% of wheat production is consumed by livestock, Europe feeds 40% of wheat to livestock, accounting for over half of the global wheat feed consumption.

As a bioenergy crop, wheat grain has a relatively lower conversion efficiency than maize grain; one estimate of the bioethanol yield of wheat is 2591 litres per ha.[3] Nevertheless, western European countries are the major producers of wheat bioenergy. According to average Chicago ethanol spot price, USD 2.25 per gallon in 2007 (Caldwell 2007), wheat-based biofuel has a value of approximately USD 1540 per ha, while at the wheat price of 2007, USD 255.2 per tonne wheat value is around USD 766 per ha (estimated at 3 t/ha wheat yield). When oil prices are high, the use of wheat as feedstock becomes viable, and wheat is expected to play an increasingly role as a future biofuel feedstock (Biofuels Research Advisory Council 2006).

Given the close trade links between Eastern Europe and the EU, an expansion of biofuel in East Europe is probable if oil prices remain volatile or increase again, given that up to one-fourth of the EU's transport fuel needs are targeted from biofuels. It is estimated that between 4 and 13% of the total agricultural land in the EU would be needed to produce the amount of biofuels to reach the level of this vision. Biofuel development also has been seen as a contributor to the EU's objectives of securing the EU fuel supply while improving the greenhouse gas balance and fostering the development of a competitive European (biofuels and other) industry. Turkey as a potential EU country would be affected significantly by the EU biofuel policy. As it exports wheat, wheat is a possible feedstock for 1G bioethanol production in Turkey; it is a relatively cheap source of starch.

3. http://www.biofuels.ru/bioethanol/What_bioethanol/, 2591 litres per ha.

As projected by IFPRI for 2020, under the two biofuel expansion scenarios, wheat exports of Eastern Europe and Central Asia decrease dramatically due to increased demand of wheat for biofuel in these countries. Under the more aggressive biofuel production scenario, there would be more reduction on the wheat export and further increase in wheat price (Figure 6). Increasing use of wheat grain for bioethanol feedstock would definitely increase the wheat price as the staple food, together with the effects from maize price increase, which may put wheat beyond the reach of many poor people.

Table 16. *Biofuel scenarios and possible impacts in small-scale CLEFS*

Impacts	First generation		Second generation	
	Business-as-usual	Aggressive	Business-as-usual	Aggressive
Wheat price	Increase	Great increase	Less increase	Significant impact for maize stover
Grain consumption				
For food	Decline	Dramatic decline	Even	Even
For feed	No change	No change	Even	Even
For biofuel feedstock	Increase	Dramatic increase	Even	Even
Wheat straw use	Fodder, soil fertilizer	Fodder, soil fertilizer	Competition for biofuel	Competition for biofuel
Crop substitutions	Other crops to maize	Dramatic conversion	No change	Use marginal land
Crop system change	May change	Reduced rotation	No change	No change
Livestock numbers and management	No change	No change in numbers; reduced grain-based finishing operations	No change	Reduced numbers in high potential zones with biomass production potential; increased grain-based finishing operations (cf. pasture)
Land and water provision	Competitive	More competitive	Competitive	Intense competition
Cultivars selection	Yield, nutrition, drought and disease tolerance	High yield and nutrition, drought and disease tolerance	High biomass, nutrition, drought and disease tolerance	High biomass, nutrition, drought and disease tolerance
Field management	No change to fertilizer use, and residue management	Some increase in fertilizer use	No change to fertilizer use; increased residue use for biofuels in major maize areas	No change to fertilizer use; substantially increased residue use for biofuels in many areas

Based on the current large proportion of wheat in this CLEFS, and other crops' importance like oil crops for biodiesel, there should be less area left for wheat expansion, so major substitutions of wheat for other crops are unlikely. While more intensive on-farm practices could increase wheat yields, this may increase competition for limited land and water resource in this rainfed system. Wheat consumption pattern is likely to change greatly between food, feed, and biofuel feedstock. Percentages of wheat used as food and feed may decline and biofuel feedstock would increase as the wheat-based ethanol industry grows. An increase in demand of wheat suggests that wheat breeding should focus more on the wheat yield potential, drought and disease resistance.

The expected 2G biofuel technology would highly improve the conversion efficiency, with wheat biomass, including straw and residues for the biofuel feedstock. Hopefully, second generation biofuel may reduce the pressure on wheat price as food. However, effects also depend on the intensity of biofuel production. Under the scenario of business-as-usual biofuel production, the wheat straw and other existing crops may provide enough biofuel feedstock, so this situation has less impact on wheat grain production and consumption. Under the scenario of aggressive biofuel production, more biomass, which can be derived both wheat and from other plants with high biomass productivity, like willow etc. If this happens, although some of these plants can be grown in marginal land, competition for water is unavoidable, and it may be more severe especially for this dry rainfed small-scale family farm CLEFS. The impacts for livestock feed of more aggressive biofuel production, more deep impacts on wheat grain as feed for livestock production as with more wheat straw is used for biofuel, the residues left for soil conservation are less, which may affect the wheat yield. High biomass production should be included to the priorities of wheat breeding and field management, together with grain yield, drought and disease resistance.

Biofuel impacts on livelihood and poverty in this system has been summarized in Table 17, with the most significant implications centring on the role of wheat as a food staple for households that are net buyers.

Table 17. *Biofuel impacts on poverty for small-scale CLEFS in East Europe and Central Asia*

Biofuel generation	Cash income	Household food security	Energy poverty
1st generation technologies	Smallholders would benefit the increasing biofuel demand and price increase, but there is a trade-off with more expensive staple food, meat products, and energy	Wheat is a staple food for a large proportion of poor farmers, its overuse as biofuel source affects the food security of many	No significant impact, since the majority of the energy source is fossil fuel
2nd generation technologies	Wheat biomass (including straw and residues) are likely to become potential biofuel sources, which can supplement the farmer´s income	The shift to cellulose conversion would improve food security	The system is using mostly fossil fuel as energy source. Energy efficiency improves; not only conversion efficiency, but energy use for production, due to new technologies

Sugar-cane/crop–livestock CLEFS, Brazil

Centred on Eastern and Central Brazil, these intensive mixed agricultural system represent a heartland of ‘established’ Brazilian agriculture. The inland subsystem occupies an estimated 81 million ha with an agricultural population of almost 10 million using 13 million ha of cultivated land, of which about eight percent is irrigated. Along with sugar-cane, coffee, horticulture and fruit are important products. Because there are substantial areas of pasture land, livestock production is significant—although not to the same degree as in other Brazilian farming systems. This subsystem merges into the coastal mixed farming and plantation system with an additional agricultural population of 20 million cultivating some 20 million ha of land. In both cases productivity can be high. There are two major management types: (a) small-scale family farms with mixed agriculture or in-shore fishing and frequent off-farm employment; and (b) large-scale farms and plantations, the latter typically export-oriented, with intensive production and significant poverty among labourers. Otherwise, poverty is not prevalent across these systems.

In the intensive mixed system of LAC, sugar-cane is the third important crop in the all food and cash crops, with 17% of the total crop area, following maize and soya bean, which are 29% and 24% of the total crop area (Table 18). Resource constraints lay at a middle level with the index of 0.5, compared to the 63 farming systems of the world, and market access is pretty good, with just 3.2 hours from farm to local market centre. Poverty levels are relatively low. Food crop and cash income contributes around 30% to farmer household income, while livestock density estimated at 30 head per 100 ha. Livestock production per capita is also relatively high. For example, in Brazil, per capita egg, meat, and milk production are 8, 44, and 62 kg per year respectively.

Table 18. *Intensive mixed CLEFS in Latin America and Caribbean*

Regional scenario			Example of Brazil		
Agro-ecological zone	Humid		Agricultural population (million)	21	
Agro-Population percentage (%)	13		Rural population percentage (%)	15.8	
Cultivated land per capita (ha/person)	1.3		Irrigated land (%)	1.1	
Irrigated land (%)	8		Sugar-cane area (%)	13	
Market access (hour)	3.2		2006 Ethanol Production (million litres)	17000	
Resource constraints (Index*)	0.5		Energy consumption per GDP (toe per million)	146	
Prevalence of poverty	Low		Energy consumption per capita (Kgoe)	1608	
Livestock density estimation (head/100ha)	30		Grain fed to livestock (%)	58	
Farmers' income resource (%)	From crops	20	Energy resource (%)	Fossil fuels	58
	From livestock	40		Nuclear	2
	Off-farm income	30		Solid biomass	23
	Other cash	10		Other renewable	17
Major crop area percentage (%)	Maize	29	Livestock production per capita (kg)	Egg	8
	Soya bean	24		Meat	44
	Sugar-cane	17		Milk	62

Note: Energy consumption per GDP: tonnes of oil equivalent (toe) per million USD (year 2000); kgoe: kilograms of oil equivalent.

The biofuel program of Brazil targets to 25 percent blending ratio of ethanol with gasoline (E25) in 2007. Major energy is fossil fuel, accounting for 58%, solid biomass accounting for 23%, and biofuel and other renewable energy accounting for 17% to total energy consumption. Energy use efficiency is relatively high, with 146 tonne of oil equivalent per million US dollars of GDP. Energy consumption per capita is around 1608 kgoe.

Brazil has the largest sugar-cane and sugar production and almost the largest bioethanol production, surpassed by U.S. in 2006. Currently, Centre-South region of Brazil produces approximately 85% of the Brazilian cane. Within the region, the state of São Paulo is the leader, producing 60% of the national cane, and 60% of the nation's sugar and ethanol. This region is also one of the densest sugar-cane areas of the world. Sugar-cane cultivation in Brazil is based on a ratoon-system, which means that after the first cut the same plant is cut several times on a yearly basis. Leaves have no purpose in the industry yet, so leaves are left on the field as organic fertilizer.

Although the use of sugar in the human diet is controversial, sucrose supplies about 13 percent of all energy that is derived from foods. With the jump of world oil price, sugar-based biofuel has been booming. Brazil uses sugar-cane as a primary feedstock, and produced around 16 billion litres ethanol in 2005, accounting for 36% of world ethanol production. In Brazil, India and Cuba, the sugar-based ethanol industry has been expanding.

Table 19. *Biofuel scenarios and possible impacts in intensive mixed CLEFS*

Impacts	First generation		Second generation	
	Business-as-usual	Aggressive	Business-as-usual	Aggressive
Sugar-cane price	Increase	Great increase	Less increase	Significant impact for maize stover
Sugar-cane area	Some increase	Major increase	No change	Modest decline
For sugar	No change	Some reduction	Slight increase	Modest increase
For biofuel feedstock	Increase	Major increase	No change	Modest decline
Crop substitutions	Some expansion into pasture land	Substitution of pasture and food crops	Addition of biomass crops, mostly permanent pastures	Some substitution of cane with biomass pastures
Crop system change	No change	Intensification	No change	No change
Livestock numbers and management	No change	Reduced livestock numbers	No change	Reduced numbers in high potential zones with biomass production potential
Land and water provision	No change	No change	No change	No change
Cultivars selection	No change (yield, sugar content)	Add drought tolerance to expand into drier rainfed areas	No change	Growing emphasis on sugar content
Field management	No change	Increased fertilizer use	No change	No change

Sugar-cane has the highest conversion efficiency of current feedstock for biofuel, with 75 litres ethanol produced per tonne sugar-cane stalk, which translates to 6000–6500 litres ethanol per ha sugar-cane.[4] Furthermore, sugar-cane bagasse is also a renewable resource. Using second-generation conversion technologies, bagasse would be an additional biomass source for biofuel, although this would undermine bagasse-based paper production such as in South America, India, and China, where it represents 20% of all paper production. The biggest constraint for sugar-cane is water: the requirement varies from 1500 to 2500 mm evenly distributed over the growing season.[5] Under rainfed conditions it will not be able to expand sufficiently to satisfy demands for biofuel blending level.

Based on important role of sugar-cane as cash crop in this system, international tropical researchers maintained breeding and selection program to identify sugar-cane cultivars with high yield potential and resistance to sugar-cane diseases and test them for site adaptability. In the coming year, approximately USD 50 million will be allotted for research and projects focused on advancing technologies to obtain ethanol from sugar-cane in Sao Paulo, through a joint venture between the State of Sao Paulo Research Foundation (FAPESP) and Dedini S/A Industrias de Base.

Under the first generation technology, sugar-based biofuel expansion is expected to push the sugar price up at least by 12% before 2020 (Figure 6). This may stimulate the expansion of sugar-cane planting area in Brazil, the biggest sugar exporter. Under the more aggressive biofuel scenario, more land will be used for sugar-cane planting if suitable land and water are available. Under the second generation, bagasse also could be used to produce ethanol, and the sugar-cane use efficiency would be improved greatly.

Nevertheless this kind of biofuel technology makes crops competition and substitution unavoidable. Sugar-cane production replaces mainly pastures and other food crops in Brazil. The amount of harvesting

4. http://www.biofuels.ru/bioethanol/What_bioethanol/.
5. FAO (2008a) Crop water management, available at: http://www.fao.org/ag/agl/aglw/cropwater/sugar-cane.stm#requirements.

area in the Centre-South region is expected to increase from 2.8 Mha in 1993 to 4.2 Mha in 2003 and by some 50% to 2010 (Goldemberg 2006). As a result, livestock production (and potentially also food crop production) is moving particularly to the central part of Brazil, particularly at the borders of the present crop land, into cerrados, more than into forest areas. Thus, the direct impact of cane production on biodiversity and carbon sequestration is limited, but the indirect impacts could be substantial.

Overall, first generation biofuel production has led to a major expansion of sugar-cane production in these systems, typically from the conversion of native pasture (not forest) land. Given the favourable ecological conditions and the functioning market and infrastructure, these systems will have a competitive advantage in the production of biomass feedstock for 2G bioethanol production as well.

Biofuel impacts on livelihood and poverty in this system has been summarized in Table 20, with no serious implications for staple food consumption at the household level.

Table 20. *Biofuel impacts on poverty for intensive mixed CLEFS in Latin America and Caribbean*

Biofuel generation	Cash income	Household food security	Energy poverty
1st generation technologies	Sugar-cane has high conversion efficiency, but it requires high input. Although sugar is mostly rain fed, some small-scale farmers have to finance diesel cost of supplemental irrigation, to achieve acceptable yield for being part of the biofuel supply network	Sugar is not a staple food, and its impact on food security is much less emphasized, then of maize and wheat	Rural people can benefit small-scale generation of electricity for light and heat
2nd generation technologies	Major reduction of sugar-cane primary income, as a result of substitution of cellulose crop, but bagasse and residues supplement the farm income. The trade-off depends on the technology availability	Reduced purchasing power. The impact of sugar price (+/–) change on food security is less severe then of maize or wheat	Reduced energy price and increased availability of rural energy

Sorghum-based CLEFS, India

Sorghum fodder is the major source of dry matter for milk as well as draught animals that are indispensable components of mixed crop–livestock farming system that prevail in dryland India. Sweet sorghum, compared to grain sorghum, may bring average USD 79 additional income per year (of two seasons) per hectare (Reddy et al. 2008). Therefore sweet sorghum is an attractive biofuel crop for some countries. In this case the mixed crop–livestock farming system in dry rainfed SAT in India is taken as an example CLEFS.

In this CLEFS sorghum, one third to half of the total population, near 30 million, are classified as agricultural. Cultivated land account for 53% of the total system area, 36% of the cultivated area is irrigated. The per capita cultivated land of 0.33 ha is relatively low. Because of the prevalence of irrigation, vulnerability is somewhat lower than other systems. Thus the level of poverty is moderate, and seasonal. Resource constraints index (0.25) is at a lower level compared to the average world 63 farming systems. Market access is relatively good, with average 2.2 hours from farm to local market centre. Sorghum, millet, and rice are the major 'livelihood' crops, accounting for 19%, 20% and 8.5% respectively of crop area (Table 21). Most of the grain is consumed as food, and about 4% of the sorghum grain and most of straw are used as feed for livestock. Crop income contributes 45% and off farm income contributes 35% to household income. Livestock density is high and livestock production per capita is also relatively high.

Table 21. *Dry rainfed CLEFS in SA*

Regional scenario			Example of India		
Agro-ecological zone	Humid		Agricultural population (million)	808	
Agro-Population percentage (%)	70		Rural population percentage (%)	71	
Cultivated land per capita (ha/ person)	0.33		Irrigated land (%)	30	
Irrigated land (%)	36				
Market access (hour)	2.2				
Resource constraints (Index*)	0.25		Energy consumption per GDP (toe per million)	190	
Prevalence of poverty	Moderate		Energy consumption per capita (Kgoe)	512	
Livestock density estimation (head/100 ha)	>20		Grain fed to livestock (%)	4.3	
Farmers' income resource (%)	From crops	45	Energy resource (%)	Fossil fuels	59
	From livestock	12		Nuclear	1
	Off-farm income	35		Solid biomass	39
	Other cash	8		Other renewable	1
Major crop area percentage (%)	Sorghum	19	Livestock production per capita (kg)	Egg	23
	Millet	20		Meat	62
	Rice	8		Milk	28

Notes: Energy consumption per GDP: tonnes of oil equivalent (toe) per million USD constant 2000 international USD; kgoe: kilograms of oil equivalent.

The major energy source in India is still fossil fuels, around 59% to the total energy consumption, followed by solid biomass, around 39%. Energy consumption per million USD GDP is 190 toe (tonnes of oil equivalent). In this mixed crop–livestock CLEFS in SAT India, the sweet sorghum-based ethanol industry is booming and gets support from the government and private companies. That has been seen as a way to integrate thousands of poor small-scale farmers with a few large-scale biofuel processing facilities and further to reduce poverty in this region.

India has set a 10% ethanol blend fuel target, seeking to reduce environmental pollution and fuel import costs. This target will require 1 billion litres of ethanol per year, on top of the 4 billion litres needed for other purposes, representing a total national demand projection of 5 billion litres per annum as the blending target is approached. Currently, 95% of the bioethanol produced in the country is based on molasses, a by-product of sugar extraction from sugar-cane (Dayakar et al. 2004; Deurwaarder et al. 2007). In the long run, the increased demand for fuel-grade ethanol cannot be met through the use of sugar-cane molasses alone. Some scientists believe that sweet sorghum can contribute to filling this fuel gap. Excellent sweet sorghum varieties and hybrids have been developed by the India's National Research Centre for Sorghum (NRCS) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The yield of sweet sorghum ethanol in India is relatively high, with 40 litres per tonne millable stalk. If the yield of sweet stalk sorghum is 70 tonne per ha, then ethanol yield would reach 5600 litres per hectare per year over two crops. Based on this perspective, sweet sorghum area in India would be expected to undergo sizable expansion, and crop substitution is avoidable. Indian farmers know well the cultivation of sweet sorghum as grain sorghum. Sweet sorghum can be grown in the rainy season without irrigation and in other regions with slightly favourable moisture regime. Nearly, 60% of the rainy season grain sorghum area is suitable for sweet sorghum cultivation. Also, the areas with supplemental irrigation facilities, like rice fallows, in post rainy and summer seasons are also suitable for sweet sorghum cultivation. Small-scale farmers with government support have created facilities for supplemental irrigation to take up the sweet sorghum cultivation.

Grain sorghum as the major food crop in this area plays an important role in regional food security. However, if the sweet sorghum crop is harvested at grain milk stage farmer can get higher (20%) stalk/juice yield at the cost of grain. The choice between the harvest with and without mature grain will depend on the farmer choice and need for mature grain (for food). With more land and water used for sweet sorghum, the supply of grain sorghum and other food crops, like millet, would be affected. The price of the food at this area may increase if no food supplements are brought into from other regions. Fortunately, the farmers and urban poor may benefit from the new ethanol industry through planting sweet sorghum or employment opportunities. The economic tradeoffs need to be worked out through more in-depth research, given the complex inter-play between positive benefits that might come from wage markets, versus the implications that arise for net buyers of grain who will see higher market prices due to increased demand for feedstock, among other effects.

Table 22. *Biofuel scenarios and possible impacts in dry rainfed CLEFS*

Impacts	First generation		Second generation	
	Business-as-usual	Aggressive	Business-as-usual	Aggressive
Sorghum grain price	No change	Some increase	No change	No change
Sorghum grain consumption				
For food	Decline	Dramatic decline	No change	No change
For feed	No change	Some reduction	No change	No change
For biofuel feedstock	Increase	Dramatic increase	Increase	Increase
Sorghum stover use	Fodder, potential for soil cover	Competition livestock/biofuel	Competition livestock/biofuel	Strong competition livestock/biofuel
Crop substitutions	Other crops to sorghum	Dramatic conversion to sorghum	No change	Use marginal land for biomass
Crop system change	No change	Intensification	No change	No change
Livestock numbers and management	No change	Reduced availability of sorghum fodder and some shift to high quality fodders	No change	Reduced availability of sorghum fodder and some shift to more grain-based feeding
Land and water provision	Competitive	Competitive	Competitive	Competitive
Cultivars selection	Yield, sugar content, and disease tolerance	Stover yield, sugar content, drought and disease tolerance	Grain and stover yield, sugar content, and disease tolerance	Stover yield, sugar content, drought resistance and disease tolerance
Field management	No change	Intensification	No change	Intensification

Biofuel impacts on livelihood and poverty in this system have been summarized in Table 23.

Table 23. *Biofuel impacts on poverty for dry rainfed CLEFS in SA*

Biofuel generation	Cash income	Household food security	Energy poverty
1st generation technologies	Well suited crop to hot and dry systems, and marginal areas. Increasing market for sorghum can provide opportunity to farmers of marginal lands, and decrease poverty	Sorghum plays an important role in food security in the system	Rural people can benefit small-scale generation of electricity for light and heat
2nd generation technologies	Major reduction of primary income, as a result of substitution of cellulose crop, but sales of residues supplements the farm income. The trade-off depends on the technology	N/a	Reduced energy price and increased availability of rural energy

Cassava-based CLEFS, sub-Saharan Africa

This CLEFS extends from Guinea through Northern Côte d'Ivoire to Ghana, Togo, Benin and the mid-belt states of Nigeria to Northern Cameroon (and there is a similar zone in Central and Southern Africa). Located in the dry subhumid zone, it accounts for 31 million ha of cultivated land and supports an agricultural population of 59 million. Cattle are numerous—some 42 million head. Although the system shares a number of climatic characteristics with the Maize Mixed System of East Africa (described above), it differs in terms of lower altitude, higher temperatures, lower population density, abundant cultivated land with more root crops including cassava, higher livestock numbers per household, and poorer transport and communications infrastructure. Although cereals (such as maize, sorghum, and millet) are widespread, wherever animal traction is absent root crops (such as yams and cassava) are more important than cereals. Intercropping is common, and a wide range of crops is grown and marketed.
A number of factors explain the rapid expansion of cassava-based CLEFS in West Africa. Cassava has the advantage of being relatively undemanding and thrives on poor soil. In places where land is scarce, farmers are confident of having low cost, plentiful supply of calories by growing cassava than they would have obtained from the cultivation of cereals. For peri-urban farmers, cassava is a valuable cash crop, with a flourishing market. The main sources of vulnerability are drought and diseases. However, the International Institute of Tropical Agriculture has made significant strides in developing varieties that are resistant to key pests and viruses, e.g. mosaic. Therefore cassava continues to be well recognized as a food security crop of vulnerable communities in drought prone environments in Africa. Cassava production in the middle belt of Nigeria is dominated by smallholders. However, a commercialization drive has encouraged industries that use cassava as raw material including starch. Some processors who depend on roots from smallholder farmers for production push up food prices.

While IITA and African NARS have produced many high yielding varieties with good levels of multiple disease and pest resistance as well as acceptable quality for food, feed, and industrial uses, the dissemination of these varieties has often suffered from the lack of a reliable system for the distribution of planting material and thus limiting the potential of cassava to meet the food needs and reduce poverty in the rural communities. Poverty incidence is limited, numbers of poor people are modest and the potential for poverty reduction is moderate. Agricultural growth prospects are excellent and, as described in the relevant section below, this system could become the bread basket of Africa and an important source of export earnings.

Notwithstanding the other crops and livestock in the system, it is instructive to consider the implications for the system of new opportunities for cassava use as biofuels. The development of a bioethanol industry-based on cassava will have a positive effect on the livelihood of cassava farmers by further strengthening markets for cassava-based products. Moreover, it is expected that the bioethanol industry will promote the adjustment of the CLEFS. For example, focus in agricultural research will have to be shifted towards breeding for high starch yield and improved storage traits. In addition, the cassava biomass will have to be produced with the highest possible productivity, at the minimum possible cost, without interfering with current food production systems and without adversely affecting soil management and environmental conservation systems. These will offer more potential for developing the cassava-based CLEFS. However, the cultivation of cassava as an energy crop could cause or exacerbate environmental problems. A major concern is the potential impact that the expansion of the agricultural frontier could have on tropical forests, savannas, and biodiversity. Moreover, the growth of cassava on ecologically fragile lands could accelerate soil erosion and aquifer depletion processes.

On the social side, there are also important issues involved. The creation of uncompetitive market structures and the impact that these may have on the distribution of benefits along the crop-to-biofuel chain is a key concern. The increasing demand for energy and the apparent potential of biofuels to promote agricultural development are no guarantee that small-scale farmers and poor people in developing countries would have their lives and livelihoods improved. Given the many uses of cassava (direct human consumption, starch and starch derivatives, roots and foliage for animal feed, processed food and, more recently, bio-ethanol) it will be interesting to see how the different demands for cassava, as raw material, evolve to satisfy these demands. Moreover, there is likely to be an interaction between different processing end uses of cassava. For example, bioethanol operations based on different crops will produce protein-rich by-products that could, perhaps, promote the use of cassava in animal feed because they may complement the low protein content of cassava roots. Other relevant aspects of the crop-to-biofuel value chain would need to be considered.

Lowland rice-based CLEFS, China and India

The lowland rice CLEFS is the single most important CLEFS in Asia in economic and demographic terms, containing over one quarter of the region's agricultural population. It covers both humid (270 to 365 growing days) and moist subhumid (180 to 269 growing days) tropical environment in mainly flat landscapes. Average household incomes are low and poverty is extensive and severe in many areas. Land ownership is often traditional. The system is generally well serviced by roads, communications, community, goods and support services.

The CLEFS is predominantly rice-based, with from one to three harvests per annum depending on rainfall distribution, length of growing season and the availability of supplementary irrigation. The second most important crop is wheat. Other crops, in descending order of importance by area, are vegetables, oilseeds, maize, root crops, soya beans, sugar-cane, cotton and fruits. Large and small ruminants, pigs and poultry are a minor but important source of income generation. More intensive production systems are found in areas with higher population density and smaller farm size, for example in China. While cultivated area per farm household can reach as much as several hectares in central Thailand, in the Red River Delta farm households average only 0.24 ha. Other locations tend to have farm sizes between 0.5 and 1 ha.

Most of the rice production goes to food consumption (about 88% of total production), and its use as feed is just about 1–2%. China and India grow more than half the total crop. Rice calorie supplies as percentage of total calorie supply are 29% across Asia (cf. 8% in Africa) (IRRI 2008). The international price of rice is rebounding since 2000 and spiking in the past year. Rice is mostly grown on puddled lowland soils which are heavy and inherently more fertile than other cropped soils, but natural fertility is declining under conditions of continuous cropping with inadequate or unbalanced nutrient inputs. High-yielding varieties are used in all countries, but some still have significant areas of lower yielding, traditional varieties because of their perceived higher grain quality and acceptability. Fertilizer use varies from limited to high, including the use of both inorganic and organic types. Triple cropping only occurs where transplanting is used and there is a continuous supply of water during the year.

Livestock are important for draught power, meat, income and savings purposes, and a major proportion of the cattle, buffalo and pigs of the region are found in this CLEFS. Ruminant livestock graze under extensive conditions and animal health services are generally poorly developed. Pigs and poultry are important for household consumption and sale. In the more extensive areas within the system, animals mostly scavenge during the day with some supplementary feeding. Buffalo will probably decline in importance and numbers in the future, as mechanization increases. More intensive production systems for pigs and poultry are found in China where a more intensive CLEFS is generally practiced. Animals are usually housed, and productivity levels are higher as a result of better feeding, husbandry and animal health practices. On-farm fish production is an important source of food and income in this CLEFS. Fish are cultivated in association with wetland rice fields and in ponds. Rice cultivation has been further diversified in coastal areas in China where rice culture has been combined with other fisheries products, such as crabs, shrimps and pearls. This type of farm diversification has numerous benefits; including improved pest control, nutrient cycling and a higher cash income that can be used to purchase crop production inputs.

The majorities of farm households in this system are food secure and sell surplus rice, cash crops, livestock and fish. However, at a national level, most countries are barely able to meet domestic demand; only Thailand and Vietnam are significant exporters of rice. Until the present time, livestock and fish have only been marketed domestically, however, small quantities of some other crops are traded internationally.

Rice, as the staple food for most Asian, plays a key role for this region's food security. If rice price continues going up, it will definitely threaten the food security for net rice importing countries, such as Nepal, Bangladesh, India, and Indonesia. Under the first generation biofuel technology, rice-based ethanol production destines to be limited only to a small-scale production. Several reasons attribute to this conclusion: firstly, economically, the cost of rice grain-based biofuel is much higher than any other crop-based biofuel. Scientists from Japan estimated that ethanol made from food-quality rice would cost around USD 2.93 per litre, whereas retail gasoline prices are around USD 1.27 per litre. Moreover, importing ethanol from Brazil, the world's largest exporter, now just costs about USD 0.68 per litre (Reuters 2007). Secondly, the introduction and expansion of other biofuel crops have already caused major land-use changes, and that many feedstock crops (although originally targeted at marginal lands) will compete with rice in productive ecoregions. Maize area expansion in such lands is an example. Such an expansion may impose additional pressure on food security and will dim the rice-based biofuel industry.

Second generation biofuel technology, which makes use of crop residues, such as rice straw, can be considered as an optimistic scenario for some Asian countries, where straw is largely being burned. This is a priority area for R&D, particularly with regard to thermal conversion technologies for different scales (APAARI 2007). Nevertheless, the level of residue retention, which may be needed for sustainable land use under different cropping system, and use of rice straw as livestock feed, should not be overlooked. A balance must be achieved amongst the various uses of rice straw as livestock feed, retention in soil for sustainability, and biofuel. Biodiesel from rice bran may be a choice as rice bran oil is a non-conventional, inexpensive and low-grade vegetable oil. Crude rice bran oil is also a source of high value added by-products. Thus, if the by-products are derived from the crude rice bran oil and the resultant oil is used as a feedstock for biodiesel, the resulting biodiesel could be quite economical and affordable.

Biofuel pressure on feed crop, pasture, and livestock production

Crop straw, stem and residue, like maize stem, wheat straw and their by-products usually are used as animal feed supplement and a means for soil conservation. With 2G biofuel generation, these types of biomass can be used to produce bioethanol, which may present opportunities for increasing farmers' income by selling these mass, although this activities may undermine the soil indigenous nutrient levels in some fertilizer-deficit area and the importance and value placed on maintaining soil organic matter.

Producing a continual supply of quality feed ingredients is difficult in many tropical regions, particularly those areas with long dry seasons. In response, producers accept lower animal productivity or seek alternative feed supplies such as drought tolerant improved forages, hays or silages (Reiber et al. 2007).

Smallholder farmers can produce protein-rich forages for use in feed rations to partially replace feed grains. Both grains and foliage of forages can be processed for use in feed rations. Such fresh feed or meals are able to provide the essential protein, energy, minerals, vitamins and pigments required by monogastric animals. There must be also quite some potential for using forages for feeding monogastrics (i.e. removing the pressure from higher cost of grain). The most widely adopted example may be *Stylosanthes guanensis* for pork production tropical China. There may be negative effects on fodder production when 2G biofuel is introduced.

Under 1G biofuel generation, the competition of fodder for biofuel and livestock is focused on land and water competition. The biggest concern is that increased demand for land for biofuel production may increase pressure on resources, and expansion of agricultural land (Askew 2005). Under the second biofuel generation, besides fighting for land and water resource, fodder is an alternative good biomass for cellulose biofuel. Grasslands are among the largest biomass in the world, covering about 40.5% of terrestrial area excluding Greenland and Antarctica (White et al. 2000, Mannetje et al. 2007). They provide the livelihoods of over 800 million people including many poor smallholders, with livestock production a means out of poverty (Horne et al. 2005; Reynolds et al. 2005).

Competition from biofuel will impact the poor and the livestock revolution, but the overall impacts are not yet fully understood given the complexity of the impact pathways involving land, water, soil, air pollution and climate change. However, some preliminary conclusions are presented in terms of pressure points of expanded biofuel production on CLEFS in Table 24. For example, in SSA, maize and cassava are staple food, and residue of these crops are main livestock feed resources, biofuel competition may give high pressure to the availability of these two crops for food and feed, with major effects on maize grain by 2015 and on crops residue by 2030. For wheat-based system example from Turkey, with relatively high yield in wheat, the pressure for wheat grain is not so severe, and hence may have minor impacts on wheat residues. In EAP and SA, normal sorghum is not considered as biofuel feedstock, and sweet sorghum is a primary potential crop for biofuel. Their competition depends on the production in this region. With more aggressive biofuel scenario by 2030, the crop needs to be expanded. Rice-based CLEFS with intensive livestock systems appear in some places of China and India. These are the most populated countries, and food grain demand is sizeable. Rice straw usually is used as animal food, so the impact of biofuel may be quite severe both in the grain-based technology and cellulose-based technology. For sugar-cane-based biofuel production in LAC, impacts may be minor, except for the minor effects on sugar supply and bagasse as feed for animal. For the pasture and grazing system, the livestock feed supply is supported by land and water availability, competition may come from land requirement for biofuel crops and possible impact on grass biomass.

Table 24. *Biofuel pressure on livestock feed*

Farming system	Example countries	Feed and fodder biofuel pressure point							
		Maize grain		Roots or stems		Crop residues		Pasture	
		2015	2030	2015	2030	2015	2030	2015	2030
Maize mixed crop–livestock	Kenya	Major	Medium	x	x	Minor	Major	x	x
Wheat-based crop–livestock	Turkey	Medium	Minor	x	x	Minor	Minor	x	x
Sorghum-based crop–livestock	India	Minor	Minor	Major	Major	Minor	Minor	x	x
Cassava/crop–livestock	Nigeria	x	x	Major	Minor	Major	Major	x	x
Sugar-cane/crop–livestock	Brazil	x	x	Minor	Minor	Minor	Major	x	Major
Cereal–livestock	Brazil	x	x	x	x	x	Major	x	Major
Rice-based crop–livestock	China	Major	Minor	x	x	Minor	Major	x	x
Rice-based crop–livestock	India	Major	Minor	x	x	Minor	Major	x	x
Rice–wheat-based crop–livestock	India	Major	Minor	x	x	Minor	Major	x	x

Note: Major denotes possibly large shortage, minor means enough, or almost enough, production.

Biofuel implications on livestock production may be quite different among different CLEFS, as shown in Table 25. If grain-based biofuels have a more intensive output by 2015, without crop yield breakthrough in next few years, reducing the amount of grains in the diet to animal feed will be unavoidable in the grain-based livestock systems especially in China and India. Under this storyline, if no other feed sources are available and farmers do not feed their livestock with anything else, the productivity and intake will decrease. With the higher feed grain price resulting from by biofuel production, all farmers will do is to reduce the margin. The more intensive the system (i.e. dairy) the more repercussions the increases in the price of grains will have. Systems that use little grain (more extensive) will not be affected much, like grazing system in Argentina.

Table 25. *Biofuel impact on ruminant and monogastrics productivity*

CLEFS	Effect on ruminant productivity	Effects on monogastric productivity
Maize mixed CLEFS, Kenya	2015: limited effects on productivity apart from reductions in the margins obtained from the sale of milk in intensive systems. 2030: systems based on crop residues may suffer significant reductions in feed availability as competition increases for second generation biofuels	Changes in diet composition to coarser grains by 2015. Increases cost of the ration will decrease profitability. This could lead to reductions in animal numbers per operation in the semi-intensive systems. Magnitude of the effect dependent on livestock densities (moderate)
Wheat-based CLEFS, Turkey	2015: not many apart from reductions in the margins obtained from the sale of milk in intensive systems. By 2030 these systems may continue to suffer form price increases of concentrates but not from lack of feed availability as animal densities are relatively low	High, lots of animals
Sorghum-based CLEFS, India	This relatively low input system will start suffering reductions in biomass availability due to increased competition for second generation biofuels by 2030. This will lead to reductions in productivity	High, lots of animals
Cassava-based CLEFS, Nigeria	Little effects to 2030	Moderate
Sugar-cane-based CLEFS, Brazil	Little effects to 2015 but availability of sugar-cane tops for dry season feeding may be compromised by second generation biofuels in 2030	Moderate
Rice-based CLEFS, China	Little effects but from 2015 onwards crop residues may decrease and reduce productivity if there is no access to other feed resources	The poor will need too rely on lower quality rations that will have an effect in productivity if they cannot afford the high process of grain feeds
Rice-based CLEFS, India	Substantial pressure for feed resources by 2030 will increase the prices of diets or will reduce productivity, specially for the poorest livestock keepers	The poor will need too rely on lower quality rations that will have an effect in productivity if they cannot afford the high process of grain feeds
Cereal-based CLEFS, Brazil	Little effects to 2015 but by 2030 these system may experience significant changes in feed composition and productivity	Size of operation will dictate the magnitude of the effect. Large operations will see reductions in profit but not productivity while smaller ones will disappear
Rice–wheat-based CLEFS, India	Substantial pressure for feed resources by 2030 both for 1G and 2G Biofuel	Moderate; Increases cost of grain feed will decrease profitability and affect the operation scale. Effects in the small-scale livestock farmers might be more serious than large-scale farmers or commercial producers

By 2030 competition will focus on biomass rather than grain. In places with high animal density, there is greater cellulose-based competition between biofuels and feed availability. If animal diets contain a high proportion of stover or straw, the biofuels impact is stronger. The overall effect is likely reductions in biomass availability for the animals (like China, India) which do not have too many alternative feed resources. This will lead to reductions in livestock productivity. Pasture-based systems such as in Argentina may be affected less, unless crop production spreads into grazing lands.

Specifically, in SSA, grain is the main human food, so there are few effects of biofuel impacts on livestock production by 2015. But maize mixed system in Kenya may suffer biomass reduction for feed availability by 2030. For the monogastric animals impacts would be moderate. For the wheat-based small-scale crop–livestock CLEFS in EECA, Turkey has relatively low densities of ruminants, and the biofuel impact may be moderate except for intensive milk production. But impacts for monogastric animals may be high as there is high density for this, about 125 head per 100 ha. For EAP and SA, impacts on livestock include reduced feed availability for monogastric animals (high densities) derived from first biofuel generation and biomass resource reduction for ruminant derived from second biofuel generation. Both may undermine livestock production in this region. For the LAC, most livestock production is based on pasture or grazing system, and thus will have little effects from first biofuel generation. While it may face competition from the second one if more land is developed to plant biofuel crops or the conversion technology can use grass as biofuel feedstock.

Biofuel impact on poverty

Biofuel production can potentially catalyse rural development, by generating new employment, providing renewable energy options in energy deficient rural areas, and greening and restoring wastelands. Although biofuel production has clear benefit to the agricultural sector, the net impact on poverty and food insecurity in developing countries is less clear. Higher food prices would be beneficial to farmers who produce a net surplus of food, but detrimental to poor consumers and food-deficit farmers, who would have to balance more expensive food against less costly energy (Hazell and Pachauri 2006). The potential socio-economic impacts of biofuel development are analysed within the context of a sustainable livelihood framework (DFID 2000). Within the framework of the IMPACT model, outlined in previous chapters, we attempt to identify the impacts of business as usual and aggressive biofuel expansion scenarios on livelihoods and poverty.

If biofuel development starts, some landless labourers will have more opportunities to find work in the extended agriculture or processing plants, but employment opportunities are likely to be relatively local. Small-scale farmers would gain from the growing demand for crops, which might also increase crop prices. But second generation maize technologies (using residues for biofuel) could also undermine conservation agriculture practices, unless alternatives such as green manures or cover crops are deployed, so that farmers would lose on land quality. High input farmers with high yield products most likely benefit more than low input farmers. They can penetrate the market of the biofuel development program. Livestock producers face potential competition for fodder with the biofuel industry. Fodder prices are expected to go up, unless the biofuel industry is able to efficiently commercialize bio-fuel by-products on the fodder market. Consumers, in general, will be affected by changes in feedstock prices, price of meat products could be affected by increasing fodder prices, and changes in fuel prices. Until biofuel becomes more competitive with fossil fuel, the price of fuel is also expected to increase with the mandatory blending of biofuel, unless subsidies support the development process. The future competitiveness depends on the future fuel price, and the cost improvement of the biofuel industry. Success of a domestic biofuel industry will also depend on being cost-effective and competitive against imports from abroad. A biofuel impact matrix summarizing the potential effects on different livelihood typologies under the IMPACT scenarios is illustrated in Tables 26 and 27.

Table 26. *General impacts of business as usual (BaU) scenario—biofuel development impact matrix on livelihood and poverty*

	Small-scale mixed CLEFS farmers	Large mixed CLEFS farmers	Large-scale commercial livestock producers	Landless rural poor	Urban poor
I. BaU with 1st generation technologies	Small-scale farmers likely to benefit from expanding crop market and price increase, but probably only high input (high yield) irrigated crop farmers benefit from direct contracts. The development of micro finance is essential to support small-scale farmers lacking sufficient cash flow to finance, e.g. diesel cost for irrigation	Large farmers likely to benefit from the increasing crop demand and prices or direct contracts with ethanol plants	Biofuel from crop competes for fodder, increasing feed price. This can cause spiral inflation in the prices of meat and milk products, but without significant profit loss for the producers, because they build in the additional cost in the final price of the products	Localized job opportunities on plantations and biofuel processing plants may increase, but the overall livelihoods effect will depend on trade-offs between higher off-farm income and inflation of food and fuel prices. Excessive deforestation can have deteriorating effect of livelihood especially of African women, who made their petty income before from wood collection	Urban poor perceive negative impacts—change in livelihoods depends on consumer prices of fuel and staple food (crops and meat)
II. BaU with 2nd generation technologies	Even rainfed lower yield producers in dry areas likely to benefit the growing demand for residues Conservation agricultural practices are essential, also after introducing the 2nd generation technologies, turning residues into biofuels	There is a new combination of competition: fuel, feed, and conservation agriculture. Selling most of the residues for biofuel can also undermine the long-term productivity of the land and depreciate the productive capital	Decreasing food fuel competition lowers crop prices; but pressure on animal feed prices remains. It increases residues prices, which affects the price of meat and milk products. Large-scale livestock producers would not be negatively affected as the increasing cost would be built in the consumer price	Localized job opportunities on plantations and biofuel processing plants may increase, but the overall livelihoods effect will depend on trade-offs between more off-farm income and the possible (+/–) change of crop, meat, milk and fuel prices. Though 2nd generation technology lowers crop prices, the price of meat would probably be negatively effected	Assuming that 2nd generation technology would highly improve conversion efficiency and contributes to lower prices of staple food; there is less or no negative impact. In case of inflated prices, this is the most vulnerable group. Hence biofuel supply should not be driven by unrealistic quotas, but the realization of highly efficient new technology

Table 27. *General impacts of an aggressive biofuel expansion scenario—biofuel development impact matrix on livelihood and poverty*

	Small-scale mixed CLEFS farmers	Large mixed CLEFS farmers	Large-scale commercial livestock producers	Landless rural poor	Urban poor
III Aggressive biofuel expansion with 1st generation technologies	Even rainfed lower yield producers likely to benefit the rapidly expanding crop market and price increase, but the net impact is unclear… they need to produce enough to compensate spiralling inflation. Some alternative crops, like sorghum may open opportunities to small-scale farmers in drier areas. Small-scale livestock dominant farmers might lose on the higher feed prices, but it is probably compensated by higher meat prices	Large farmers likely to benefit from the increasing crop demand and prices. They do not lose on increasing crop and meat prices, because it is compensated by the consumer. Aggressive biofuel expansion and high inflation however can create riots, and political instability	Food/feed/fuel competition generates high inflation of crops, which increases the input prices for livestock producers	Localized job opportunities on plantations and biofuel processing plants may increase, but the overall net livelihoods effect will be negative. The high inflation of food and fuel prices is hardly compensated by higher off-farm income Excessive deforestation can have deteriorating effect of livelihood on local communities in Africa	Very high inflation of staple food prices fuelled by crop competition for food, feed and fuel could lead to food insecurity, upheavals and political instability
IV Aggressive biofuel expansion with 2nd generation technologies	Even if 2nd generation conversion energy efficiency would increase significantly, transporting residues to plants are highly energy inefficient. Hence only producers close to biofuel plants would gain supplier contract. Selling most residues for biofuel would undermine the long-term productivity of the land and depreciate productive capital	Large mixed farmers likely to benefit aggressive biofuel expansion, growing demand and increasing prices	Large-scale commercial livestock producers will face with increasing feed prices, but compensated by increasing meat prices	Localized job opportunities on plantations and biofuel processing plants may increase, but the overall net livelihoods effect will be negative, unless 2nd generation technology contribute to significant drop in prices of food and fuel products	High inflation of food prices may be reversed by new technologies, and might contribute to lower fuel prices, which has general anti-inflationary effect

Farm household income in CLEFS derives principally from food and cash crop income, livestock income and off-farm income. Under first generation biofuel, feedstocks coincide largely with food crops like maize, wheat, cassava and sorghum; or with existing cash crops like sugar-cane, rapeseed, peanut, soya bean or oil palm. In second generation (cellulosic) biofuels, crop residues and grass from pasture may be used but also some new crops may be introduced, e.g. willow, switch grass, etc., which can be grown on the marginal land with less water. For farmers who have adequate land, biofuel could bring additional cash income. But for smallholders and rural landless, these effects are minimal, at least directly.

Smallholder livestock production is popular in many regions of the developing world. An expected positive consequence from the biofuel boom for small-scale livestock producers is the increase in meat, milk and egg prices. There may be additional benefits from by-products of first generation bioethanol such as DDGS for concentrates, especially if bioethanol production technologies can be down-scaled to village-size or household-scale energy technology. This technology may provide cheaper electricity and power to the farmers. However, surging feed prices will affect small-scale livestock producers. In remote areas the effect may be slight as farmers usually depend on farm-produced feed for their livestock, including self-produced crop residues as the major feed for animals. For the middle and large livestock producers, situation may be quiet different, depend on the trade off between the feed price and production costs.

Biofuel production is as labour intensive as agriculture, and it may be a boon to rural areas with abundant labour, such as China, India, and Brazil. The emergence of biofuel companies obviously creates jobs both in the fuel production factories and in the production of the raw materials, as well as extra employment on farms. Various researches report that biofuel has boosted jobs created among different continents, of the order of one new job for each 20,000 litres production capacity. In Brazil, one study showed that in 1997 the ethanol sector employed about 1 million people, with 65 percent were permanent jobs. The number of jobs in manufacturing and other sectors in Brazil created indirectly by the ethanol sector was estimated at 300,000. Many of the jobs created are unskilled, and this situation offers an opportunity for increased income to poor rural people (Moreira 2006). In developing countries, the potential for employment generation will be among the chief benefits that can be realized by emerging, rural economies, and an important means of improving rural livelihoods.

Biofuel boosts not only the feedstock crops' price, such as maize, wheat, but also the related other food crops, rice, millet, sorghum grain, etc. The middle and large-scale net food producers benefit both from selling food at a surging price and selling feedstock to the biofuel industry. While for the small-scale producer, or food-deficit farmers, food price increases will require that they budget more of their limited income to survive and may reduce the production input at the farm, with an end result of less food in the next harvest season. In fact, increased price of staple foods may drive the production factor price, crowding out the small-scale producers' competing ability. High factor price with high food price make the small-scale farmers, especially landless labours reducing the real income, which may exasperate poverty.

At the CLEFS level, intensification and diversification are the common strategies for system response. As shown in Table 28, resource and market access are the main constraints for system improvement (Dixon et al. 2001). System intensification may be important in temperate mixed livestock system in LAC and cereal-coot crop mixed CLEFS in SSA, which is dominated by livestock production and diversification may be most feasible in sugar-cane/crop–livestock and rice-based crop–livestock systems.

Table 28. *Household response strategies based resource and market*

CLEFS	Example countries	Land resource constraints	Market access	Intensification	Diversification
Maize mixed clefs	Kenya	0.5	8.4	2	3
Wheat-based clefs	Turkey	0.5	2.9	Na	Na
Sorghum-based clefs	India	0.7	9.8	2.5	2
Cassava-based clefs	Nigeria	0.4	7.0	3.5	2
Sugar-cane-based clefs	Brazil	0.5	2.5	2	4
Cereal-based clefs	Brazil	0.3	4.1	0	1
Rice-based CLEFS	China	0.5	3.2	1	4
Rice-based CLEFS	India	0.4	2.3	2	3
Rice–wheat-based CLEFS	India	0.2	2.0	1	3.5

Notes: A normalization process has been used to create index with the range 0 to 1 for land resource constraints (smaller the value, better the resource situation), for which 20 key indicators of soil quality have been used; market is the average hours for the farmers arriving the local central market (Sanchez et al. 2003).

At the level of farmer household, the basic unit of CLEFS can be expected from two aspects of production and energy use. Consistent with the crop and livestock CLEFS change, farmers may spontaneously adjust their crop and livestock production to fit the challenge of biofuel. Comparing the cereal crop and livestock endorsement (see Table 29), Asia has higher value of per capita cereal production than Africa, with rice-based CLEFS in China the highest production per capita, 341 kg per person, followed by Indonesia and India. Cassava is the most important food crop in Nigeria, while the cereal production is relatively low, with just 38 kg per person. The relative ratio of livestock to cereal production can be considered as an index to elaborate the regional productivity of ruminant- or poultry-based on the cereal grain or residue availability. This ratio presents advantages of ruminant production in Africa, with higher value of Ratio of TLU to Crop (more than 0.2 head per tonne cereal production), as well as advantages of poultry production in Asia, with average 2.5 and 1.2 head per tonne cereal production. This implicates that improved crop production might contribute more in ruminant production in Africa, where 60% of crop residues are used as animal feed and more provide benefit for Asian poultry production, where more intensive feeding has been adopting.

Table 29. *Cereal and livestock in Asia and Africa*

CLEFS	Region	Example countries	Cereal production per capita	Livestock–cereal production ratio	Poultry–cereal production
			Kg/cap	TLU/tonnes cereal grain	Number/tonnes cereal grain
Maize mixed CLEFS	SSA	Kenya	105	0.21	0.66
Cassava-based CLEFS	SSA	Nigeria	212	0.19	0.32
Rice-based CLEFS	EAP	China	341	0.07	2.50
Sorghum-based CLEFS	SA	India	184	0.16	0.82
Rice-based CLEFS	SA	India	217	0.13	1.26
Wheat-based CLEFS	EECA	Turkey	745	0.14	0.79

Note: Crop production includes maize, wheat, rice, millet, sorghum and barley.

From the crop effects section, under the two scenarios of biofuel expansion, the changes within the crop CLEFS include crop grain and residue price, crop consumption structure, crop substitutions, land and water use, cultivars selection and field management. Accordingly, farmers' responses to biofuel expansion in the CLEFS can embrace crops and cultivars selection, which target to meet the local biofuel developing feedstock demand, residue management and land and water distribution between crops, and all these responses would be expected to achieve more benefits from crop production.

Under the competition of grain for feedstock for first generation biofuel, and crop residue for feedstock for second generation biofuel, feed for livestock production has been going tough time without big breakthrough for grain and total biomass yield. Under these situations, farmer may select easy-feed and mixed feed livestock, which may save crop feed and production costs. Livestock substitution may happen regarding major regional biofuel feedstock and price of livestock product. If maize feed-based livestock production faces maize-based biofuel expansion, besides looking for feed substitution, change livestock categories may be another choice, even this adoption usually is not easy to perform.

For the feeding technology and management, priority may be different at the stages of biofuel technology. Under the first generation of biofuel, farmer can increase and improve use of crop stover, straw and residues for animal feed, avoiding the loss of high opportunity cost of crop grain for food and feedstock with high price. Look for replaces of fodder crop, improving feeding system may be the better choices for the scenarios of second biofuel generation. Intensification of all production factors, such land, water, fertilizer, labour, power would be necessary for achieving more grain yield and crop biomass.

When regional biofuel has been flourishing, looking for off-farm employment and finding more economic energy access may be a good supplement for household livelihood improvement. Rest of household labours can try to have a full time job in the production and value train of new energy industry, and on-farm farmers can expected to take a part-time work seasonally, such as the biofuel crops' harvest season. With more biofuel product brought to the world, developing village or household size energy technology is really a boon to poor small-scale farmers in most of the remote rural area of developing countries. Plant biomass, crop residues, and animal dung could be good materials for developing renewable and cheaper energy for farmer household. Such as the use of biogas plants in South Asia, especially in India and China, at where many biogas plants have been built in a simple rural household (family size) unit, providing the family cook, heat and 24 hours light energy (Inforse-Asia 2008). Adoption and extend renewable energy technology in small-scale farmer household or village level not only help to reduce poverty in poor area, but also contribute to the saving of biomass, such as forests, which help to maintain a amenable environment.

Other important future drivers for CLEFS

The companion study to this report which focused on important 'drivers' of change for livestock industries into the future, considered an expanded set of alternative scenarios to the biofuel-specific ones that we have focused on in this volume. In addition to the baseline and aggressive biofuel expansion scenarios that we have treated—the 'drivers' study considered the implications of future drop in meat demand (due to changes in consumer preferences) and an optimistic scenario of higher investments in agriculture, knowledge science and technology (AKST), which embodies within it a higher level of investments in irrigation and water use efficiency. Table 30 outlines these additional scenarios, as they were implemented in the IMPACT model of IFPRI. It should be noted that these scenarios do not include the effect on energy security.

These scenarios were derived from those that were used in the International Assessment of Agricultural Science and Technology for Development (IAASTD 2008), which brought together a widely-representative and highly consultative framework for envisioning plausible future policy alternatives and human well-being outcomes arising from enhancing the robustness of knowledge management, science and technology application towards agriculture, specifically. While there were a number of other scenarios that were analysed, in that assessment, we only consider the two that are most relevant for this study.

For the sake of completeness, we will also consider the outcomes that are likely to arise under these additional scenario variants within the specific CLEFS that we have been studying, so as to see the variation in outcomes that we might expect when a combination of consumer driven demand-side effects and policy-driven supply-side effects are played across the various regions and are manifested within regional and global markets as changes in supply, consumption and prices. We discussed about these effects, briefly, within the context of each CLEFS region, and have provided a summary of our discussion in Table 31.

Table 30. *Assumptions for scenario variants with low meat demand and high agricultural investment*

Parameter changes for growth rates	Baseline CASE	Low meat demand	High AKST + irrigation
GDP growth	3.06% per year	3.06% per year	3.31% per year
Livestock numbers growth	Base model output numbers growth 2000–2050 Livestock: 0.74%/year Milk: 0.29%/year	Base model output numbers growth 2000–2050 Livestock: 0.74%/year Milk: 0.29%/year	Increase in numbers growth of animals slaughtered by 30% Increase in animal yield by 30%
Food crop yield growth	Base model output yield growth rates 2000–2050: Cereals: %/year: 1.02 R&T: %/year: 0.35 Soya bean: %/year 0.36 Vegetables: %/year 0.80 Subtropical/tropical fruits: 0.82%/year	Base model output yield growth rates 2000–2050: Cereals: %/year: 1.02 R&T: %/year: 0.35 Soya bean: %/year 0.36 Vegetables: %/year 0.80 Subtropical/tropical fruits: 0.82%/year	Increase yield growth by 60% for cereals, R&T, soya bean, vegetables, ST fruits and sugar-cane, dryland crops, cotton Increase production growth of oils, meals by 60%
Irrigated area growth (apply to all crops)	0.06	0.06	Increase by 25%
Rainfed area growth (apply to all crops)	0.18	0.18	Decrease by 15%
Basin efficiency			Increase by 0.15 by 2050, constant rate of improvement over time
Access to water			Increase annual rate of improvement by 50% relative to baseline level, (subject to 100% maximum)
Female secondary education			Increase overall improvement by 50% relative to 2050 baseline level, constant rate of change over time unless baseline implies greater (subject to 100% maximum)
Biofuel feedstock demand	2000–2005: Historical level 2005–2050: 1%/year expansion	2000–2005: Historical level 2005–2050: 1%/year expansion	2000–2005: Historical level 2005–2050: 1%/year expansion
Rate of decline of income elasticity of demand for meat		Developed regions: 150% of reference case Developing regions: 110% of reference case	
Rate of decline of income elasticity of demand for non-meat products		Developed regions: 50% of reference case Developing regions: 90% of reference regions	

Note: This Table has been adapted from Table 17 of the SLP 'Drivers' study.

Table 31. *Differentiated impacts of IAASTD scenarios on small-scale mixed farmers in CLEFS*

CLEFS	Lower meat demand		High AKST and irrigation expansion	
	HH cash income	HH food security	HH cash income	HH food security
Maize mixed CLEFS (Kenya)	Lower revenue for livestock producers due to lower sales to urban centres and lower regional prices. Less income for feed producers as well. Lower international prices for maize (due to lower feed demand) might affect export price—but regional prices less so	Lower regional and international prices for grains enhances food security for crop producers probably more in aggregate than the modest losses by livestock producers from lower meat prices—but local consumption will expand even as global consumption contracts	Considerable smallholder benefit from increasing farm productivity from improved technology and markets. Some trade-off with lower international (export) prices as production goes up globally	Overall positive effect on food security through increased availability of food, more resilience (more stability) because of improved crop technology against disease and pest, and lower regional and international prices (enhancing access to food)
Wheat-based CLEFS (Turkey)	Lower international prices for maize and feed grains (due to lower feed demand) will have some substitution effects with wheat and lower demand (and price)	Wheat is a staple food for a large proportion of poor farmers, so a lower price (for wheat and other substitutes) will enhance food security. Income effects might dampen it somewhat	Smallholders would see higher wheat yields with improved technology and irrigation—but lower marginal revenue due to the price effect	Food security will be enhanced by greater domestic production and lower international and regional prices—especially for urban poor
Cassava-based CLEFS (Nigeria)	Cassava not as directly used for feed, or linked to feed or feed grains crops. Lower maize prices might cause some substitution, but price and income effects will be small. Income for livestock producers will go down due to lower export prices	Food security is enhanced through lower regional and international prices for grains and alternative starch staples	Cassava output will be greatly enhanced with improved technology and inputs—but will lead to lower prices. Other crops will also be enhanced—especially in drier regions. International prices will be lower for those crops as well	Positive effect on food security and nutrition, due to lower prices for cereal grains and cassava
Sugar-cane-based CLEFS (Brazil)	Livestock and feed grain price effects won't affect sugar-cane producers. Demand for soya likely to also go down somewhat and relax the competition for land with sugar-cane This might lead to lower income for some labourers and revenue for some soya producers	Sugar is not a staple food, so the change in food security comes from lower maize and wheat prices. This will enhance food security for those households	Increased irrigation will further boost yield of sugar-cane above rainfed levels, and increase output. World price may dampen slightly, but overall income effect should be positive—including the wage effects	Lower staple prices due to higher world and regional production and higher sectoral productivity and wages should improve food security—especially for labourers
Sorghum-based CLEFS (India)	Lower demand for feed will reduce world sorghum price, creating less export revenue. Lower maize price also causes substitution away from sorghum in some regions, further lowering prices	Food security enhanced through lower prices of sorghum and other competitor grains	High AKST will sorghum in hot and dry systems, and marginal areas. Might also increase potential for other higher-value crops, increase farm revenue and decrease poverty. Additional irrigation potential will be limited, though, by scarce water in some regions	Greater food security because of lower prices of sorghum, grains and increased farm revenue

Rice-based (China)	Drop in maize price likely pulls down the price of rice as well, causing drop in revenue and cash income. Although strong increase in demand for rice with future increases income and urbanization in Asia—so this could offset this somewhat	Positive food security effects due to lower grain prices	Increased production of rice and other grains means lower prices, which offsets farm-level revenue. Increased resistance to pests and submergence might reduce variability, however, and improve the stability of cash income	Overall positive effect on food security because of increase in production, decrease in price and volatility of supply
Rice-based CLEFS (India)	Reduced meat consumption will reduce demand for feed grains and therefore international rice and wheat prices. But domestic food policies and strong preference for rice consumption will buffer domestic prices so limited effects on farm gate prices and cash income	Lower price of grains represents a boost for farmers. Perhaps some loss in wages if production is affected—but largely offset by employment guarantee schemes	Increased production of rice and other grains means lower prices, which offsets farm-level revenue. Increased resistance to pests and submergence might reduce variability, however, and improve the stability of cash income through shocks. Irrigation potential limited in drier regions of India (especially central-south with hard rock aquifers) and heavily overdrawn groundwater basins	Overall positive effect on food security because of increase in production, decrease in price and volatility of supply
Rice–wheat CLEFS (India)	Domestic food policies and strong preference for rice and wheat consumption will tend to insulate Indian producers from lower international price effects of reduced meat consumption	Limited change because of low integration with international markets. Any local losses largely offset by employment guarantee schemes	Increased diversification crop income with substitution of food crop area. Increased cereal income moderated by lower prices. Increased water use efficiency	Overall positive effect on regional and household food security because of increase in production and decrease in food price
Intensive cereal CLEFS (Brazil)	Lower producer prices for livestock means less revenue—perhaps substitution towards alternative proteins like soya, which, however, could benefit those farmers	Lower cereal prices and meat prices will be a benefit for food-deficit households (urban)	Increased cereal production and lower cereal prices means lower feed prices for livestock producers and higher cash income	Higher food security because of increased income for livestock producers as well as lower cereal and food prices

Note: HH = household.

Maize mixed CLEFS, sub-Saharan Africa

Within the context of a maize-based system, the decreased demand for meat and livestock products will be felt mainly through the reduced price for feed grains in the international market, which includes maize as well as other crops which compete with maize, like sorghum. The producers of maize and sorghum will experience a loss in revenue, because of this effect, while the producers of livestock products will see a lower export price in international markets, as well as reduced demand from the regional urban markets that they supply with animal products. This will likely result in a loss in household revenue and income, which will have some negative poverty effects for net sellers of these products. Given the insulation of many of the markets in sub-Saharan Africa from international effects, the effects might be somewhat muted, and respond more to the local and regional market dynamics. In terms of food security—lower prices for grain and meat products translates into a benefit for the net consuming households, and will also allow for food aid shipments (if they are to continue into the medium to long-term) to be procured more cheaply on both domestic and international markets—providing further benefits for food security.

The 'high AKST' scenario will provide additional crop technologies and extension that smallholders can benefit from, which will provide a needed boost to on-farm productivity and crop yields that will be of immediate benefit for those struggling in adverse and challenging agricultural environments. The higher on-farm yield will be matched elsewhere and will likely result in overall higher production and lower prices—which will offset the increase in farm revenues and household income, for the net sellers of staple and cash crop products. More of the effects are likely to be felt through the improvement in seed technologies and productivity enhancing inputs, rather than through increased irrigation, as the potential for expansion will not be possible for everyone—given a widely diverse set of hydro-geological and environmental conditions. Any increase in irrigation that does occur, however, would have to be accompanied by improvements in drainage, as there are problems with salinity and water-logging in some regions that have irrigation potential. The effect on food security, given these improvements, will be unambiguously positive, due to both the increased production and availability of staple crops for the net consumers, as well as lower prices, that further enhances access for households and increases their ability to procure their nutrition from the market. The improvement in technologies are also likely to reduce the vulnerability of crop yields to pest, disease and fluctuations in environmental conditions, which should also be of considerable benefit to the security of households across the region.

Wheat-based CLEFS, Eastern Europe and central Asia

Within the context of these wheat-based systems, the decreased demand for meat and livestock products is not felt as directly as in the maize-based systems, due to the absence of feed demand for wheat. There will be indirect substitution effects, however, on both the international and regional markets, as the lower maize prices also lead to downward pressure on wheat prices, which will cause some loss of revenue for producers and household income for net sellers of wheat. As in the case of maize, however, lower prices for grain and meat products translates into a benefit for the net consuming households, and should enhance the food security of most households, including the pure net consumers in urban areas. Those households that benefit from the wage labour that larger wheat farms provide, might experience a drop in earnings—but should still get some food security benefit from lower grain prices for consumption.

The 'high AKST' scenario will provide an additional boost to on-farm productivity and crop yields that will raise on-farm production, but which might be combined with a lower international and regional price for wheat that offsets the potential revenue gain. Grain storage behaviour in these regions could offset that effect, by trying to keep the grain prices higher—although we would expect this to be less a government-driven policy and more in the hands of private traders (who are under various degrees of regulation). The susceptibility of certain regions of eastern Europe and central Asia to wheat disease should be reduced through a widespread and accelerated deployment of technologies, which should serve to stabilize fluctuations in production that would otherwise occur and affect both regional and international markets. This—by itself—should bring enhanced food security, in terms of enhancing the stability of food supply, which is an important factor for poorer households—maybe even more so in other less developed regions of the world.

Cassava-based CLEFS, sub-Saharan Africa

We would not expect the cassava-based systems to be affected as much by changes in livestock demand, given their weak linkage to feed uses and feed markets. Given that cassava is an important staple in key regions of this CLEFS, with some limited substitution possibilities with maize in direct food consumption, we only envision a price linkage with livestock product demand changes through this particular pathway. We don't think that it will constitute nearly as important a loss to income as it will for those actually raising livestock and selling their products for export or to local and regional markets. At the same time, rice is also an important consumption crop in parts of this region—therefore we would expect positive food security effects due to lower regional and international prices for maize and its substitutes like rice and wheat.

The 'high AKST' scenario will provide an additional boost to on-farm productivity and crop yields that will benefit cassava growers in this CLEFS region, as much as it will the producers of other staple crops, thereby raising on-farm and regional production. The higher production will likely cause a price drop that offsets the on-farm revenue gains, but the enhanced stability of supply is expected to improve with better resistance to cassava diseases like mosaic. In the drier parts of this CLEFS region, there could also be benefits to expanding irrigation, which is notoriously under-exploited in sub-Saharan Africa—for reasons of both geography, environment and institutional design and implementation of projects. Where expansion is possible, and accompanied by drainage, there could also be enhanced stability in the face of environmental stresses, that improves food security. It is likely, though that larger farmers will benefit from irrigation, while smaller farmers will benefit more from the other kinds of AKST improvements.

Sugar-cane/crop–livestock CLEFS, Brazil

The effect of a change in livestock product demand will not affect sugar-cane producers nearly as much as those, in Brazil, directly involved in the livestock sector—who will see a drop in revenue due to decrease in demand on local and export markets. For others in Brazil who are involved in the cultivation of soya, whose demand is linked to that of both livestock (for feed) as well as with other grains like maize, who's price is likely to go down with decreased livestock demand. A decrease in soya price from these effects could, however, be offset with an increase in food demand for soya—since it is a protein substitute for meat. While the combined effects of these forces make the resulting impact on soya somewhat ambiguous, we expect for there to be both revenue as well as land use implications in Brazil—since maize and soya often compete in land area, and are also implicated by the use of land for livestock activities as well. There could be some changes in wages in agriculture, since these commodities represent large employers of agricultural labour in Brazil—such that a decrease in livestock production (and the processing of its products higher up the value chain) could have implications for household poverty and income. The direct effect on income that comes from sugar-cane, however, would be relatively small.

The 'high AKST' scenario has implications for both sugar-cane as well as other crops in Brazil, like soya, maize—and even livestock itself. We expect an increase in productivity to increase production and lower prices—leading to some loss of on-farm revenue and income, for net sellers—although there could be additional labour demand that has a positive effect on wages. Even though sugar-cane is mostly rainfed in Brazil, an expansion of irrigation for sugar-cane could further enhance its yield, especially in the drier regions, and perhaps allow for expanded cultivation in areas that are not feasible under purely-rainfed conditions. This expansion could provide additional employment, higher wages, and higher income for labour-supplying households. The lower prices of food commodities under higher production will provide a food security-enhancing and poverty-reducing effect on households that are net buyers, even though the incomes of net-selling households will be dampened by lower prices (despite higher on-farm output).

Sorghum-based CLEFS, India

The effect of a change in livestock product demand will have a direct effect on feed markets for both maize and sorghum—which, themselves, are also substitutes in food consumption, in certain regions of the world (like sub-Saharan Africa). So lower feed demand for sorghum, caused by lower livestock production and export demand for feed sorghum abroad, will lead to lower revenue for sorghum producers—which will be further compounded by the effect on food sorghum demand, which is expected to decrease when maize prices decline, due to their substitution in consumption. Therefore, the combined food and feed effect will cause the revenue of sorghum producers to go down, causing a drop in the income of households that are net sellers. From a food security perspective, however, we would expect positive benefits to accrue to the net consumers of sorghum and maize, which will also spill over into rice markets, causing lower prices there to have direct benefits for the many consumers of rice—especially in the south of India.

In terms of boosting on-farm crop productivity through the 'high AKST' scenario, there are positive effects on the production of sorghum, as well as other key staple and non-staple crops in India—leading to higher on-farm production, although revenue increases might be dampened by lower market prices. Given that there are many hot, dry and highly adverse environments that could benefit from the improved productivity that enhancing AKST could bring—we feel that the overall effect on income and welfare has to be positive. Not all areas would benefit as much from irrigation expansion, into the medium- and long-term, given the water scarcity problems that many parts of India face—especially in the central and south regions where the 'hard rock' aquifers have limited potential for expanding their yield, and the key alluvial aquifers in the northern regions are already overdrafted. Certainly, any increase in irrigation would have to come after improvement of management—and some regions may still have limited potential for water supply expansion. Nonetheless, we see an increase in food security resulting from this scenario variant, within this CLEFS region, due to the increased output and lower prices of key food commodities, and the likely increase in labour demand and wages that are likely to occur.

Lowland rice-based CLEFS, China and India

The effect of a change in livestock product demand will have a direct effect on feed markets for both maize and sorghum—but not as much for rice, which will only be affected through the indirect substitution effects on the consumption side. As the prices of rice are pulled down, through this effect, the revenues for rice-producing households would be expected to go down, although there might be some trading and speculation behaviour on the part of rice traders and private operators that could offset some of this price drop. The other factor that might offset the price drop is the steadily increasing demand for rice in key parts of Africa and Asia, as income increases. In some regions, higher income and urbanization means a greater demand for short-grain rice—like in East Asia—whereas for south Asia (and especially south India), the long-grain rices are preferred. So given the indirect nature of the linkage to livestock, and the forces that will tend to keep rice prices elevated—we don't expect much of a price or revenue effect to occur for rice, based on this scenario variant.

The effect of the 'high AKST' scenario on rice is much more direct, however, as it has positive implications for yield and on-farm productivity, both through the improvement of traits under 'normal' environmental conditions, as well as the improvement of tolerance to more adverse environmental conditions. The improved tolerance to submergence, and the expansion of varieties that require less water and who are less resistant to pests and disease, will also have both an output-expanding effect as well as a variance-decreasing effect. The adoption of varieties that use less flooding is likely to increase the demand for labour, due to greater requirements for weeding, which will likely raise wages and incomes for labour-supplying households. The lower prices (and lower variance in supply) will also have positive food security benefits which will be felt both within these countries, as well as elsewhere in the region. If some of the AKST technologies are labour-saving—and result in a decrease in labour demand, the presence of employment guarantee schemes in places like India, which are likely to continue into the future, might help to offset the fall in wage income that would otherwise occur.

Intensive cereal–livestock CLEFS, Brazil

The effect of a change in livestock product demand will have a direct effect on the livestock producers of Brazil, and result in lower regional and world export prices, and a drop in producer revenue, and perhaps even wages within that sector. This would certainly be an income loss for ranchers, and will also entail some revenue loss for those farmers who supply feed products or processors that are higher in the value chain. Whatever benefits that could arise under the low-meat demand scenario will be for households that are net buyers of both meat and grain products.

The effect of the 'high AKST' scenario on livestock will be felt more directly through the effect on feed prices, which will drop as products such as maize, sorghum and soya expand in their productivity and production. This will mean lower feed prices for livestock producers and higher cash incomes. There are also some implications for livestock productivity in the AKST scenario, which involves decrease vulnerability to pests and improved breeding and herd characteristics which lead to higher per-animal output, and lower vulnerability to adverse temperature changes. This will improve output and resilience, but might cause a drop in price due to the price-lowering effect of higher production. The most direct food security benefits are to the net consumers of both livestock and grain commodities, although there could also be some positive income effects for wage earners if demand for labour in the sector goes up.

Summary

By taking account of the scenario-based biofuel- and non-biofuel-related drivers of change on the possible outcomes over the various CLEFS, we have illustrated how the complex interplay between market interactions, environmental conditions and local resource constraints might play out across these various regions. Even though we have treated the effects of these driving forces separately, in order to better explain their effects and pathways of impact, it is more than likely that such drivers of change might coincide and act together to affect outcomes across all of these regions, simultaneously. The demand-side driver of change on consumer preferences is, in practice, much harder to implement than it is within our modelling framework—simply due to the fact that it involves changes in consumption habits of people across a wide spectrum of socio-economic classes and cultural orientations. From a policy perspective, it is more feasible to consider the kind of supply-side intervention that is embodied in the 'high AKST' scenario, where focused investments and policy interventions can be brought to bear to provide the financing, information dissemination and logistical support needed to see through improvements in crop breeding, irrigation investments and extension towards farmers. These kind of investments have been slow in coming, however, and are now the focus of a great deal of concerted policy effort to promote and seek donor support at both the national and international level. The negative effects that were noted in many of the CLEFS regions, due to rapid biofuel growth, could be offset by some of the improvements noted in the 'high AKST' scenario, and some of the positive effects of biofuels could be even further reinforced.

Nonetheless, it will remain for policymakers to carefully examine the implementation of biofuels policy, and decide upon the best timing and manner of implementation, being mindful of the distinctions that we have tried to make, here, between those environments that can be highly favourable to the introduction of biofuels—and those in which the introduction of biofuels would present sharp trade-offs in both environmental quality and human well-being outcomes.

Chapter 6 Research and policy priorities

As shown in this study, differentiation of potential effects and impacts is crucial: crop–livestock–energy systems have evolved in many different ways depending on the agro-ecologies, population density, producer and consumer demands and local institutions. This study has considered the international market responses, resource and environment dynamics and crop–livestock–energy system adjustments from a 'business-as-usual' biofuel expansion compared with aggressive expansion of biofuels. While the global impact would be the sum of system- and crop-specific land, water and livelihood adjustments in different locations, the effects play out in many contrasting ways. Besides the expansion of the existing land area under a particular bio-energy crop through land conversion from forest or pasture to cropping, greater changes are likely to occur from crop substitution on existing crop land. Agricultural production will also adjust to increased biofuel feedstock demand through the intensification of input usage. Water is a key production input that allows agriculture to adapt along the 'intensive margin' of production—one traditional development pathway has been the conversion of rainfed areas to irrigation, or the partially irrigated areas, e.g. spate, to full irrigation. For those land-scarce regions that are unable to adjust along the extensive margin—intensification may be the only option available, and the environmental consequences should be considered. Aggressive biofuel expansion programs cause different pressure points in the systems and different winners and losers in terms of food security, poverty, livelihoods and vulnerability. Food security is on the top of biofuel controversy, and the increase in food prices resulting from expanded biofuel production is also accompanied by a net decrease in the availability of and access to food. The adverse effects on calorie consumption are particularly high in Africa, with a reduction of more than 8%, although this obviously varies between countries and systems.

The expansion of biofuel production has both opportunities and risks for livestock industries and smallholders in developing countries which can change dramatically as biofuel production technologies shift from starch- and sugar-based first generation to cellulose-based second generation technologies. It is expected that second generation technologies will underpin the majority of investment in biofuel production from 2015. Thus, this study compares and contrasts potential effects and impacts in 2015, characterized by starch- and sugar-based production technology, with 2030, dominated by cellulose-based production technologies. This shift is expected against a backdrop of continuing investment in other renewable energies including thermo-combustion, e.g. of rice straw, wind and solar.

This study was not intended to analyse in depth the complex and intensely debated livestock feed–food–biofuel problems, but rather to draw out key dimensions in relation to smallholder livestock producers and poverty reduction. The following sections present some conclusions that emerged from the first stage of research which are relevant to current policy debates and on-going research on livestock:

Policy implications

The recent volatility in food grain prices has strengthened the voices of those against biofuels. In the long term biofuels have both potentially positive and negative effects on the environment, livelihoods and crop–livestock systems. This report presents a balanced view of the advantages and disadvantages, suitably differentiated across CLEFS. There are great uncertainties in relation to critical parameters, not least of which are the rate economic growth, the speed with which the first generation bioethanol technologies are augmented or substituted by second generation technologies, and public subsidies, tariffs and regulations, e.g. blending.

It is important to choose appropriate scales and techniques for producing biomass. The current large-scale development is beneficial for the few, who are in the supply network, but smaller scale rural-based production and processing would be more beneficial for the poor. This development pathway is possible only with strong institutional and financial support. The private sector is likely to invest in large-scale bio-energy production that is economically efficient (with economies of scale). The public sector has an important role to ensure better social and environmental outcomes by (i) developing a credit scheme for covering the initial cost of small-scale energy installation, (ii) enhance market incentives (taxes, subsidies, regulation) for achieving greater environmental and social benefits, (iii) and overcoming the vested interest in existing technologies within the car and oil industry; because most of the environmental and social benefits of bio-energy are not priced in the market.

Public subsidies and blending regulations are strong drivers of biofuels expansion in developed and developing countries, and thus policymakers have a crucial role in determining the rate of expansion and location of bioethanol and biodiesel production, consumption and trade. However, policymakers should not encourage the expansion of biofuels without access to sustainable production technologies, in order to avoid resource depletion and degradation, increased food grain prices and deeper hunger and poverty. One key debate should relate the target rate of expansion of biofuels to the particular agricultural resource base, CLEFS and available technologies of each country.

After comparing the environmental, agronomic, socio-economic aspects of different crop livestock systems providing policy/institutional aspects of alternative (Dubois 2008) is necessary: providing an overall strategic vision for biofuel development; developing a series of policies related to biofuel development, including incentives and removing disincentives; providing guidance in such areas as possible environmental changes, market identification, legal compliance, quality control and information dissemination; providing financial assistance to complement the mobilization of local resources; clarifying territorial rights and providing a legal framework for their recognition; protecting against pressures from other economic sectors; providing and maintaining basic infrastructure to support biofuel product development and marketing; providing formal rules for conflict resolution if local rules are insufficient.

Research priorities

For the above mentioned reasons, it is very important to invest in further research on different aspects of biofuels. Research priorities include the following:

The continuing debates on the environmental effects of biofuels and should be informed by full life cycle analyses (LCA) of biofuel production-use alternatives. While it is clear that negative balances arise from land conversion for bioethanol production, the results from expansion of feedstock production through intensification or crop substitution on existing crop land are less clear, although this will be a common expansion pathway. A systematic set of LCA should be conducted for contrasting CLEFS (such as identified in this report) which fully incorporate livestock and differentiate land types and infrastructural and institutional circumstances. This will improve knowledge on the energy balance of different types of biofuel production and implications for biofuel impacts on livestock-based livelihoods.

Fast progress is being made in processing technology development. The priority has been to accelerate the development and commercialization of 2G bioethanol technologies. An additional priority will be to scaledown the technology for use at village or district level in remote areas. Bioenergy, when produced on a small-scale in local communities, can play a significant role in rural development in poor countries, according to a new report jointly published by FAO and the UK's Department for International

Development (DFID). However, for livestock producers an even higher priority is the adaptation of 2G technology for the production of concentrates from low quality biomass for livestock feeding, which has the potential to revolutionize the feed industry.

One of the keys to the sustainability of many smallholder crop–livestock systems is the management of crop residues. There are many contrasting demands from livestock fodder, domestic energy, construction, etc which lead to the removal of a high proportion of above-ground biomass in smallholder crop–livestock systems and thereby threatening soil health, reducing soil organic matter, nutrient cycling and moisture holding capacity and increasing greenhouse gasses and global warming. One major use of crop residues is as ruminant fodder, principally for maintenance energy rather than the production of saleable milk or meat. While crop residues may account for as much as 60% of ruminant fodder in current systems and high value markets have developed in land scarce systems for stover and straw, e.g. India, it is expected that with the transformation of smallholder livestock production towards market products that the demand for high value fodders and concentrates will increase relative to crop residues of low nutritional value. Moreover, the retention of sufficient crop residues in the field affords protection to the soil surface, improved water holding capacity and yield stability, and ultimately improved soil health. Therefore, a study of farmer and community institutions and decision-making in relation to the valuation and utilization of crop residues in alternative uses is urgently required.

A deeper understanding of the international food market and trade responses to biofuel expansion is necessary (e.g. in the recent commodity price increase followed by collapse). While tariffs need to be documented, a high priority should be assigned to the analysis of biofuel value chains and local markets, with a view to increasing efficiency, improving coordination along the chain, and identifying technologies which reduce overall cost. Among other benefits, this knowledge would facilitate careful design of biofuel subsidies and blending targets. Moreover, biofuel production is capital intensive which is one reason for barriers to new entrants. Further study is required on how small and medium size enterprises (farmers or businesses) can overcome barriers to entry in a saturated market.

Many local systems and markets are poorly integrated to international market responses and therefore a low cost early warning system in potential hotspots (especially with regard to resource degradation, local food markets, feed/fodder markets and poverty) for monitoring of local resource, system, market and institutional dynamics is essential. This could be focused on 10–20 different systems in major countries/regions. The experience of ILRI with Kenyan pastoral system information systems information is pertinent.

Crop–livestock–energy systems are complex, dynamic and differentiated. Strategic assessment and targeting is required, recognizing that the differentiation of responses and impacts identified across different situations in this study represents only a small portion of the variation across continents. In order to capture and analyse such complexity in a way that results can be extrapolated to wider domains, it is proposed to construct and validate crop–livestock–energy models at the farm-household/community level. These models should be based on integrated production–consumption theory and village economy modelling practice, and incorporate biophysical and socioeconomic processes at the field and community levels, and be produced for 8–10 of the systems described above. Such modelling would also identify priority intervention points for coping with change in different systems. Through careful analysis of responses, effects and impacts, with a particular emphasis on pathways out of poverty, systems could be categorized according to the likelihood of generating strong positive benefits, no net effects and strong negative impacts. The biofuel hotspots with a concentration of negative impacts on poverty and which threaten system collapse should be identified and mapped.

In the search for sustainable local solutions that contribute to the MDGs, technology and adaptation is needed to develop new crop–livestock–energy systems for different resource and economic contexts. It is proposed that integrated crop–livestock–energy systems be developed through multi-stakeholder local innovation and learning systems and tested on-farm, incorporating improved germplasm for crops, pastures, livestock and improved production practices in selected crop–livestock–energy systems.

These complex and dynamic systems are characterized by enormous uncertainty over the underlying science and critical potentially momentous outcomes for ecosystems and humanity. There are no 'magic bullets', therefore a flexible adaptive approach by policymakers and scientists is called for, involving sense-act-observe-adjust.

References

Amarasinghe U, Sharma B, Aloysius N, Scott C, Smakthin V, de Fraiture C, Sinha AK and Sukla AK. 2005. *Spatial variation in water supply and demand across river basins of India*. IWMI Research Report 83. IWMI (International Water Management Institute), Colombo, Sri Lanka.

APAARI (Asia-Pacific Association of Agricultural Research Institutions). 2007. Summary of expert consultation in biofuels. APAARI–IRRI–CIMMYT–ICRISAT, Los Banos, the Philippines.

Argonne National Laboratory. 2007. *Greenhouse gases, regulated emissions, and energy use in transportation (GREET) computer model.* (Available from www.transportation.anl.gov/software/GREET/publications.html)

Askew MF. 2005. The potential of grassland and associated forages to produce fibre, biomass, energy or other feed stocks for non-food and other sectors: New uses for a global resource. In: McGilloway DA (ed), *Grassland: A global resource*. Wageningen Academic Publishers, the Netherlands.

Bernardo A, Howard-Hildige R, O'Connell A, Nichol R, Ryan J, Rice B, Roche E and Leahy JJ. 2003. Camelina oil as fuel for diesel transport engines. *Industrial Crops and Products* 17:191–197.

Biofuels Research Advisory Council. 2006. *Biofuels in the European Union: a vision for 2030 and beyond.* Report by European Commission. (Available from http://ec.europa.eu/research/energy)

BIOPACT. 2007. *Sweet potatoes and the carbohydrate economy.* (Available from http://biopact.com/2007/01/sweet-potatoes-and-carbohydrate)

Blümmel M, Rao SS, Palaniswami S, Shah L, Belum VS Reddy. 2009. Evaluation of sweet sorghum (Sorghum bicolor (L) Moench) used for bio-ethanol production in the context of optimizing whole plant utilization. *Animal Nutrition and Feed Technology* (In press).

von Braun J. 2008. Biofuels, international food prices, and the poor. Testimony to the United States Senate Committee on Energy and Natural Resources. IFPRI (International Food Policy Research Institute), Washington, DC, USA.

Caldwell L. 2007. *What is bioethanol?* (Available from http://www.biofuels.ru/bioethanol/What_bioethanol)

Clancy J. 2008. Are biofuels pro-poor? Assessing the evidence. *European Journal of Development Research* 20:416–431.

Coyle W. 2008. The future of biofuels: A global perspective. Report by Economic Research Service/USDA. Amber Waves, USA.

Crutzen PJ, Mosier AR, Smith KA and Winiwarter W. 2008. N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics* 8:389–395.

David Z and Deepak R. 2007. *Review of environmental, economic and policy aspects of biofuels*. Policy Research Working Paper Series. World Bank, Washington, DC, USA.

Dayakar RB, Ratnavathi CV, Karthikeyan K, Biswas PK, Rao SS, Vijay Kumar BS and Seetharama N. 2004. *Sweet sorghum cane for biofuel production: A SWOT analysis in Indian context.* National Research Centre for Sorghum, Rajendranagar, Hyderabad, India.

Deurwaarder EP, Londo HM, Kumar A, Reddy A, Lago Rodriguez C and Vanecek M. 2007. PROBIOS: Promotion of biofuels for sustainable development. ECN-M–07-094. Presented at 15th European Biomass Conference and Exhibition, Berlin, Germany, 7–11 May 2007.

DFID (Department for International Development). 2000. Sustainable livelihoods guidance sheets. DFID, London, UK.

Dixon J and Langeveld H. 2007. *Evaluating biofuel production in cropping systems: Old world, new world and the developing world.* Farming systems design 2007: an international symposium on methodologies for integrated analysis of farm production systems. Catania, Sicily, Italy.

Dixon J, Gulliver A and Gibbon D. 2001. *Farming systems and poverty: Improving livelihoods in a changing world*. World Bank, Rome and Washington, DC, USA.

Dixon J, Rosegrant MW, Msangi S, Sulser T and Szonyi J. 2006. Overview and scenarios: Exploring the potential impacts and implications of maize and wheat derived bioethanol production. Presented for workshop, New Delhi, India.

Dubois O. 2008. *How good enough biofuel governance can help rural livelihoods: Making sure that biofuel development works for small farmers and communities*. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy. (Available from http://www.fao.org/forestry/media/15346/0/0/)

Dufey A. 2006. *Biofuels production, trade and sustainable development: Emerging issues*. IIED (International Institute for Environment and Development), London, UK.

Dufey A. 2007. *International trade in biofuels: Good for development? And good for environment?* IIED (International Institute for Environment and Development), London, UK.

Dufey A, Vermeulen S and Vorley B. 2007. *Biofuels: Strategic choices for commodity dependent countries*. IIED (International Institute for Environment and Development) for Common Fund for Commodities, Amsterdam, the Netherlands.

Ellis F. 2000. *Rural livelihoods and diversity in developing countries*. Oxford University Press, UK.

Enginar JM, Gonzalez JF and Gonzalez J. 2000. Fixed-bed pyrolysis of *Cynara cardunculu L.* product yields and compositions. *Fuel Process. Technol.* 68.

Erenstein O, Hellin J and Chandna P. 2007. *Livelihoods, poverty and targeting in the Indo-Gangetic Plains: a spatial mapping approach*. CIMMYT–RWC, New Delhi, India.

Erenstein O, Thorpe W, Singh J and Varma A. 2008. *Crop–livestock interactions and livelihoods in the Indo-Gangetic Plains, India: A regional synthesis*. CIMMYT–ILRI–RWC, New Delhi, India.

Faaij APC and Domac J. 2006. Emerging international bio-energy markets and opportunities for socio-economic development. *Energy for Susttatinable Development* 10:7–19.

Fanin B. 2007. Ethanol use weigh heavily on livestock. The farmers-stockman.

FAO (Food and Agriculture Organization of the United Nations). 2005. *Bioenergy*. Sustainable Development Department, FAO, Rome, Italy.

FAO (Food and Agriculture Organization of the United Nations). 2008a. *Crop water management*. FAO, Rome, Italy. (Available from http://www.fao.org/ag/agl/aglw/cropwater/sugar-cane.stm#requirements)

FAO (Food and Agriculture Organization of the United Nations). 2008b. *The state of food and agriculture*. FAO, Rome, Italy.

FAO/ICRISAT (Food and Agriculture Organization of the United Nations/International Crops Research Institute for the Semi-Arid Tropics). 1996. *The world sorghum and millet economics, facts, trends and outlook*. FAO, Rome, Italy, and ICRISAT, Patancheru, Andhra Pradesh, India.

FAOSTAT. 2008. (Available from http://faostat.fao.org)

Fargione J, Hill J, Tilman D, Polasky S and Hawthorne P. 2008. Land clearing and the biofuel carbon debt. *Science* 319(5867):1235–1238.

Farrell AE, Plevin RJ, Turner BT, Jones AD, O'Hare M and Kammen DM. 2006. Ethanol can contribute to energy and environmental goals. *Science* 311(5760):506–508.

Fischer G and Schrattenholzer L. 2001. Global bioenergy potentials through 2050. *Biomass and Bioenergy* 20:151–159.

de Fraiture C, Giordano M and Yongsong L. 2007a. *Biofuels and implications for agricultural water use: blue impacts of green energy*. IWMI (International Water Management Institute), Colombo, Sri Lanka.

de Fraiture C, Wichelns D, Kemp Benedict E and Rockstrom J. 2007b. Scenarios on water for food and environment. In: Molden D (ed), *Water for food, water for life: A comprehensive assessment of water management in agriculture*. Earthscan, London, UK, and IWMI (International Water Management Institute), Colombo, Sri Lanka.

Frhölich A and Rice B. 2005. Evaluation of *Camelina sativa* oil as a feedstock for biodiesel production. *Industrial Crops and Products* 21:25–31.

Garcia-Perez M, Chaala CA and Roy C. 2002. Vacuum pyrolysis of sugar-cane bagasse. *J. Anal. Appl. Pyrolysis* 65:111–136.

Giannelos PN, Zannikos F, Stournas S, Lois E and Anaatopoulos G. 2002. Tobacco seed oil as an alternative diesel fuel: Physical and chemical properties. *Industrial Cops and Products* 16:1–9.

Goldemberg J. 2006. Sustainability of sugar cane ethanol in the state of Sao Paulo, Brazil. Personal communication.

Groom M, Gray E and Townsend P. 2008. Biofuels and biodiversity: Principles for creating better policies for biofuel production. Science. Published article online: 11-Mar-2008

Hazell P and Pachauri RK. 2006. *Bioenergy and agriculture—Promises and challenges*. 2020 Focus No. 14. IFPRI (International Food Policy Research Institute), Washington, DC, USA. (Available from http://www.ifpri.org/2020/focus/focus14.asp)

Hazell P, Poulton C, Wiggins S and Doward A. 2007. *The future of small farms for poverty reduction and growth*. 2020 Discussion Paper 42. IFPRI (International Food Policy Research Institute), Washington, DC, USA.

Herrero M, Thornton P, Reid R and Kruska R. 2008. Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. *Agriculture Ecosystems and Environment* 126:122–137.

Herrero M, Thornton PK, Notebaert AM, Wood S, Msangi S, Freeman, Bossio D, Dixon J, Gerard B, van de Steeg J, Parthasarathy Rao P, Lynam J, Peters M, Sere C, McDermott J, Rosegrant M and MacMillan S. 2010. Smart investments in sustainable food production: Revisiting mixed crop–livestock systems. *Science* 327:822–25.

Hill J, Nelson E, Tilman D, Polasky S and Tiffany D. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *PNAS* 103(30):11206–11210.

Hirsch RL. 2007. *Responses to peak oil review*. Department of Energy, Washington, DC, USA.

Horne PM, Stür WW, Phengsavanh P, Gabunada F and Roothaert R. 2005. New forages for smallholder livestock systems in Southeast Asia: recent developments, impacts and opportunities. In: Reynolds SG and Frame J (eds), *Grasslands: Developments, opportunities, perspectives*. FAO Science Publishers, USA. pp. 357–382.

IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2008. (Available from http://www.agassessment.org)

IDB (InterAmerican Development Bank). 2007. IDB fund creates clean energy markets cluster. (Available from http://www.iadb.org/news/articledetail.cfm?artid=3568&language=en)

IEA (International Energy Agency). 2004a. Biofuels for transport. An international perspective. IEA, OECD/IEA, Paris, France.

IEA (International Energy Agency). 2004b. World energy outlook 2004. IEA, OECD/IEA Paris, France.

IEA (International Energy Agency). 2007. World energy outlook 2007. IEA, OECD/IEA Paris, France.

IFPRI (International Food Policy Research Institute). 2006. Global scenarios for biofuels: Impacts and implications. IFPRI, Washington, DC, USA.

IFPRI (International Food Policy Research Institute). 2007. World agricultural outlook staff report. IFPRI, Washington, DC, USA.

Inforse-Asia. 2008. Sustainable energy solutions to reduce poverty in South Asia. (Available from http://www.inforse.dk/asia/M_III_biogas.htm)

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate change 2007: Synthesis report*. An assessment of the Intergovernmental Panel on Climate Change. Valencia, Spain.

IRRI (International Rice Research Institute). 2008. *World rice statistics. (*Available from http://irri.org/science/ricestat/index.asp)

Kingsman. 2007. Energy from nature. Confidential note for premium clients only. Update—USDA Corn Acreage.

Kruska RL, Reid RS, Thornton PK, Henninger N and Kristjanson PM. 2003. Mapping livestock-oriented agricultural production systems for the developing world. *Agricultural systems* 77(1):39–63.

Kukrika N. 2008. *Vegetable oil based biofuels in India: An overview of the value chain and analysis of biofuels' pro-poor potential*. Environment and Natural Resources Program, Belfer Center for Science and International Affairs, John F. Kennedy School of Government, Harvard University, USA.

Lal R. 2008. Crop residues as soil amendments and feedstock for bioethanol production. *Waste Management* 28(4):747–758.

Langeveld JWA, Dixon J and Jaworski JF. 2010a. Development perspectives of the biobased economy: A review. *Crop Sciences* (in press).

Langeveld JWA, Sanders J and Meeusen M. eds. 2010b. *The bio based economy: Biofuels, materials and chemicals in the post-oil era*. Earthscan, London, UK, and IWMI (International Water Management Institute), Colombo, Sri Lanka.

Liao Y. 2005. *China's irrigation for food security*. China Waterpower Press (Chinese), Beijing, China.

Liska AJ, Yang H, Walters DT and Cassman AJ. 2007. A user-friendly simulation tool for estimating carbon credit for corn ethanol systems. Presented on Greenhouse gases: Capitalizing on carbon credits Workshop, June 2007. University of Nebraska-Lincon, Nebraska, USA.

Macedo IC. (ed). 2005. *Sugar cane's energy. Twelve studies on Brazilian sugar cane agribusiness and its sustainability*. UNICA (SPaulo Sugar-cane Agroindustry Union).

Macedo IC, Lea MR and da Silva EAR. 2004. *Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil*. Government of the State of São Paulo, São Paulo, Brazil. (Available from www.unica.com.br/i_pages/files/pdf_ingles.pdf)

Makenete A, Lemmer W and Kupka J. 2007. The impact of biofuel production on food security. A briefing paper with a particular emphasis on maize-to-ethanol production. South Africa Biofuel Associate, 17 September 2007. (Available from http://www.saba.za.org/export/sites/saba/en/resources/Biofuels.pdf)

Mannetje L, Batello C, Suttie J and Brinkman R. 2007. Plant genetic resources of grassland and forage species. Report for Commission on the World Genetics Resource for Food and Agriculture. (Available from ftp://ftp.fao.org/ag/cgrfa/bsp/bsp40e.pdf)

McCalla A, Castle E and Eidman V. 2010. The AAEA: Ever growing and changing research challenges. *Amer J Agr Econ*. 92(2):334–355.

Milder JC, McNeely JA, Shames SA and Scherr SJ. 2008. Biofuels and ecoagriculture: Can bioenergy production enhance landscape-scale ecosystem conservation and rural livelihoods? *International Journal of Agricultural Sustainability* 6(2):105–121.

Molden DK, Frenken R, Barker and de Fraiture C. 2007. *Trends in water and agricultural development*. Chapter 2 in water for food, water for life: A comprehensive assessment of water management in agriculture. Earthscan, London, UK.

Moreira JR. 2006. Brazil's experience with bioenergy. In: *Bioenergy and agriculture: Promises and challenges*. IFPRI (International Food Policy Research Institute), Washington, DC, USA.

Morton D, de Fries RS, Shimabukuro Y, Anderson L, Egidio Arai E and Morisette J. 2006. *Proceeding of the National Academy of Sciences* 103(39):14637–14641.

National Research Council of USA. 2007. *Water implications of biofuels production in the United States*. Committee on water implications of biofuels production in the United States. The National Academies Press, Washington, DC, USA. (Available from www.nap.edu.; http://www.nap.edu/catalog/12039.html)

Naylor RL, Liska AJ, Burke MB, Falcon WP, Gaskell JC, Rozelle SD and Cassman KG. 2007. The ripple effect: Biofuels, food security and the environment. *Environment* 49(9):30–43.

NCSU (North Carolina State University). 2007. NC State University researchers brewing energy from sweet potatoes. (Available from http://news.ncsu.edu/news/sweet%20potato%20release.php)

OECD (Organisation for Economic Co-operation and Development). 2007. *Biofuels: Is the cure worse than the disease?* (Available from http://www.foeeurope.org/publications/2007/OECD_Biofuels_Cure_Worse_Than_Disease_Sept07.pdf). OECD, Paris, France.

OECD–FAO (Organisation for Economic Co-operation and Development/Food and Agriculture Organization of the United Nations). 2008. *Agricultural outlook 2008–2017*. OECD, Paris, France.

Ortiz R, Crouch JH, Iwanaga M, Sayre K, Warburton M, Araus JL, Dixon J, Bohn M, Reddy BVS, Ramesh S and Wani SP. 2006. *Bioenergy and agricultural research for development*. IFPRI 2020 vision for agriculture and environment: Agriculture and energy in developing countries. IFPRI, Washington, DC, USA.

Paris TR. 2002. Crop–animal systems in Asia: Socio-economic benefits and impacts on rural livelihoods. *Agricultural Systems* 71(1–2):147–168.

Peskett L, Slater R, Stevens C and Dufey A. 2007. *Biofuels, agriculture and poverty reduction*. DFID renewable natural resources and agriculture team. ODI, London, UK.

PISCES/FAO. 2009. *Small-scale bioenergy initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Latin America, Asia and Africa*. Report prepared for Pisces and FAO by Practical Action Consulting, Rome, Italy.

Powlson D, Riche AB and Shield I. 2005. Biofuels and other approaches for decreasing fossil fuel emissions from agriculture. *Annals of Applied Biology* 46:193–201

Raswant V, Hart N and Romano M. 2008. Biofuel expansion: Challenges, risks and opportunities for rural poor people. Paper prepared for the round table organized during the thirty-first session of IFAD's governing council, 14 February 2008.

Reddy BVS, Kumar AA, Rao PP, Reddy SR and Chetty MCK. 2008. *Sweet sorghum for ethanol: A successful public–private partnership*. Working paper. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

Reiber C, Schultze-Kraft R, Peters M, Lascano C and Hoffmann V. 2007. Smallholder–forage conservation in Central America—A participatory research project in Honduras. Invited paper. Hare MD and Wongpichet K (eds), *Proceedings of an international forage symposium 'Forages—a pathway to prosperity for smallholder farmers', 5–7 March 2007*. Faculty of Agriculture, Ubon Ratchathani University, Ubon Ratchathani, Thailand. pp. 127–164.

Reuters. 2007. Japan looks to rice-based biofuel. (Available from http://www.reuters.com/article/GlobalBiofuel07/idUST31070020070117)

Reynold MP, Pietragalla J and Braun HJ. 2008. International symposium on wheat yield potential: Challenges to international wheat breeding. CIMMYT (International Maize and Wheat Improvement Center), Mexico.

Reynolds SG, Batello C, Baas S and Mack S. 2005. Grassland and forage to improved livelihoods and reduce poverty. In: McGilloway DA (ed), *Grassland: A global resource*. Wageningen Academic Publishers, Wageningen, the Netherlands. pp. 323–338.

Rosegrant MW, Paisner MS, Meijer S, Witcover J. 2001. Global Food Projection to 2020. Emerging Trends and Alternative Futures, IFPRI (International Food Policy Research Institute), Washington, DC, USA.

Rosegrant MW, Msangi S, Sulser T and Valmonte-Santos R. 2006. Biofuel and the global food balance. Brief in agriculture and energy in developing countries. 2020 Focus 14. IFPRI (International Food Policy Research Institute), Washington, USA.

Rosegrant MW, Zhu T, Msangi S and Sulser T. 2008. Global scenarios for biofuels: Impacts and implications. *Review of Agricultural Economics* 30(3):495–505.

Ryan JG and Spencer DC. 2001. *Future challenges and opportunities for agricultural R&D in the semi-arid tropics*. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, India.

Sanchez P, Palm C and Buol S. 2003. Fertility capability soil classification: A tool to help assess soil quality in the tropics. *Geoderma* 114(3–4):157–85.

Searchinger TR, Heimlich RA, Houghton F, Dong A, Elobeid J, Fabiosa S, Tokgoz D and Hayes Yu T. 2008. Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319(5867):1238–1240.

Seetharama N, Dayakar RB, Ratnavathi CV, Shahid Parwez Md, Binu M and Bharath Kumar KA. 2002. Sorghum as a raw material for alcohol production. Presented at the seminar on current development in alcohol industry organized by Distillers' Association of Maharashtra, 25 August 2002, Sahar, Mumbai, India.

Sere C and Steinfeld H. 1996. *World livestock production systems—Current status, issues and trends.* Animal production and health paper. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

Sonntag HJ and Skerrrit J. 2005. China's agricultural and rural development in the early 21st century. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia.

Sorbara MJ. 2007. Biofuels and Africa. (Available from http://www.pambazuka.org/en/category/comment/43257)

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M and de Haan C. 2006. *Livestock's long shadow: Environmental issues and options*. LEAD (Livestock, Environment and Development). FAO (Food and Agriculture Organization of the United Nations), Rome, Italy.

Sumantri A and Purnomo E. 1997. Sweet sorghum research and development in Indonesia. In: Li Dajue (ed), Proceedings of the first international sweet sorghum conference, 14–19 September 1997, held at the Institute of Botany, Chinese Academy of Sciences, Beijing, China. pp. 49–54.

Thorne PJ, Thornton PK, Kruska RL, Reynolds L, Waddington SR, Rutherford AS and Odero AN. 2002. *Maize as food, feed and fertiliser in intensifying crop–livestock systems in East and southern Africa: An* ex ante *impact assessment of technology interventions to improve smallholder welfare*. ILRI Impact Assessment Series 11. ILRI (International Livestock Research Institute), Nairobi, Kenya. 123 pp.

Tilman D, Hill J and Lehman C. 2006. Carbon negative from low-input–high diversity grassland biomass. *Science* 314(5805):1598–1600.

Tyner W and Taheripour F. 2008. Policy options for integrated energy and agricultural markets. *Review of Agricultural Economics* 30(3):387–96.

UN World Population Prospects. 2004. (Available from www.fao.org/sd/dim_en2/en2_050402_en)

UN-DESA. 2007. *Small-scale production and use of liquid biofuels in sub-Saharan Africa: Perspectives for sustainable development.* DSD background paper 2. United Nations Department of Economic and Social Affairs, New York, USA.

UN-Energy. 2007. Sustainable bioenergy: A framework for decision makers. United Nations. (Available from http://esa.un.org/un-energy/pdf/susdev.Biofuels.FAO.pdf)

US Department of Agriculture, National Agricultural Statistics Service. Statistics of cotton, tobacco, sugar crops, and honey. Chapter II. (Available from http://www.usda.gov/nass/[ubs/agr03_ch2.pdf. 2004)

Usta N. 2005. Use of tobacco seed oil methyl ester in a turbocharged indirect injection diesel engine. *Biomass and Bioenergy* 28:77–86.

Wang M, Saricks C and Santini D. 1999. Effects of fuel ethanol use on fuel-cycle energy and greenhouse gas emissions. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory, Argonne.

Waxenecker F. 2009. *DDGS—A nutritionist's view.* (Available from http://www.aquafeed.com/newsletter_pdfs/nl_000363.pdf)

White R, Murray S and Rohweder M. 2000. *Pilot analysis of global ecosystems: Grassland ecosystems.* WRI (World Resources Institute), Washington, DC, USA.

Williamson AM and Badr O. 1998. Assessing the viability of using rape methyl ester (RME) as an alternative to mineral diesel fuel for powering road vehicles in the UK. *Applied Energy* 59(2–3):187–214.

WILMA (World Institute of Leadership and Management in Africa). 2005. *Land rehabilitation, soil conservation and biofuel production around the Masinge Reservoir in Kenya*. WILMA concept brief. WILMA, Washington, DC, USA.

Woods Institute. 2007. The impact of large-scale biofuel use on landuse and conservation. Workshop on environmental, resource, and trade implications of biofuels, December 2006, Stanford University, Stanford, California, USA. (Available from http://woods.stanford.edu/docs/biofuels)

World Bank. 2007. *World development report 2008. Agriculture for development*. World Bank, Washington, DC, USA.

WWI (Worldwatch Institute). 2006. *Biofuels for transportation. Global potential and implications for sustainable agriculture and energy in the 21st century.* WWI, Washington, DC, USA. (Available from http://www.biofuelstp.eu/downloads/wgreports/070703_WG1_SRASDD_final.pdf)

Zhou ZY and Wei TM. (eds). 2005. *Grains in China*. Ashgate, London, UK.

Annex 1 Potential crop effects

Present biofuel feedstock or bioenergy crops include starch and sugar crops such as maize, wheat, cassava, sugar-cane and sorghum; and plant-oil-based biodiesel feedstocks such as oil palm, rapeseed, soya bean, peanut and other oil crops. Rice and sweet potato are also considered as potential feedstocks. This Annex is intended as a supplement to the discussion in the main report of the effects of a growth of biofuel production on the selected feedstock-based crop–livestock–energy farming systems—in this annex some of the specific effects on crops and crop management are described.

Starch-based bioethanol crops

Maize

Maize is grown in wider range of environment and socioeconomic conditions than other major crops. As well as staple food and feed, green pick, baby cob, sweet maize alone makes maize one of the leading vegetables of the world. For many smallholders maize is an important source of green fodder, and maize stover is a source of energy and a means to prevent soil erosion and keep soil health. Between 2004 and 2006, over 700 million tonnes of maize were annually produced on about 145 million ha. By 2020 maize projection will have increased since 1997 by 45% at global level and by 27% in developing countries, and will have surpassed that of wheat and rice (Rosegrant et al. 2001). Within the developing world, the maize demand for food will be the greatest in sub-Saharan Africa (40 million tonnes), followed by Latin America and then South and Southeast Asia.

Investment in maize-based bioethanol is booming in recent years. The production of bioethanol in the USA has doubled since 2005 and is projected to double again by 2010. About 50 developing countries have established targets for blending ethanol with gasoline. Given the importance of maize for human/ animal consumption and for biofuel production, it is important to analyse the potential tradeoffs around using maize to produce ethanol. With large-scale production of bioethanol using first-generation conversion technologies, maize grain faces intensive competition between demand of food and biofuel feedstock. According to the IFPRI projection, maize as the feedstock for biofuel under the first generation would drive the maize price increase by 26% by 2020, if a business-as-usual path of biofuel adoption is followed. Otherwise, more aggressive trajectory for ethanol production would have impacts of up to 72% for maize by 2020.

Under second-generation conversion technologies, biomass would be the dominant feedstock for biofuel production; maize stover would be a high potential biomass source for biofuel, while this may undermine stover contribution to heat energy and soil conservation. Cellulosic conversion may alleviate the price pressure for maize considerably—perhaps by slightly more than 10 percentage points, as was shown in an earlier IFPRI scenario (Rosegrant, personal communication) also showed that increased productivity growth in maize could bring about a further 6 point decrease in price increases by 2020, which shows the importance of increased investment in yield-enhancing agricultural research and development.

In Africa bioethanol production has increased from 100 million gallons in 2006 to already over 160 million gallons in 2007. South Africa's biofuels strategy hopes to achieve a market penetration of 4.5% of liquid road transport fuels by 2013 (Sorbara 2007). Some African countries, for example, Malawi, South Africa, Ghana, Kenya, Nigeria, Benin and Mauritius have initiated programs for cogeneration of electricity, heat and production of biofuels from biomass. Maize has a great potential for energy crop production because of the large tracks of arable land, suitable climate, and easy conversion technology, but it is not all good news.

How does this maize-based biofuel production happen to maize-dominant production systems? There would be significant differences to different farming systems, which have broad diversities in region natural resource, economic developing levels, crop priorities and energy situation. We select the maize mixed crop–livestock system in sub-Saharan Africa as an example. Maize is the dominant and staple food crop (94% for food) in SSA, as well as main feed for small-scale livestock production both from maize grain (2%) as well as stover and leaf (1–2%). Because of tradition reinforced by the high fertilizer price and extensive poverty in SSA, there is potential to leave a portion of the maize stover on the surface of the field. In the mixed crop–livestock system of SSA, maize harvest area contributes 37% to total crop area, followed by cassava 7.3%, and sorghum 6% (Table 12). Resource constraints and market access are moderate, with extensive poverty compared to the other 63 farming systems of the developing world. Nevertheless, extreme poor condition exists on irrigation. Market access is not so good, with average 8.4 hours from farm to local market centre.

Under the scenario of 1G-business-as-usual (commencing with the current 4.5% of biofuel in total transport fuels), increasing use of maize grain for bioethanol feedstock will definitely increase the maize price as the staple food. This is due to competition between limited maize production, and competition for large land and water resources if more maize area needs to be added. Maize consumption structure would be changed greatly between food, feed, and biofuel feedstock. Maize area for food is expected to decline while that for feed may change little. The latter is because maize grain currently contributes little to feed and that for feedstock would have a huge increase as the maize-based ethanol booming. Certain regions in Africa have scope for increase in use of water and land for maize production. With improved crop varieties and water use efficiency, crop substitution may be driven by crop production and price, such as from sorghum, rice, millets to maize. Irregular rainfall results periodic drought, which may be a constraint to maize production in this poorly irrigated system. Increase in demand of maize enhances the priority in the crop system, may force the crop system adjusted to avoid drought, high season of maize disease and pest occurring. Maize breeding should focus more on the maize yield, nutrition, drought and disease tolerance at the stage of starch and sugar-based first-generation biofuel to face challenge of maize demand increase and to provide enough food nutrition. At the aggressive biofuel of 1G, large number of maize used for ethanol feedstock may push maize price to an unexpected level as suddenly surge of maize demand, putting maize beyond the reach of sub-Saharan Africa's poor. Maize grain used for biofuel would be increased greatly, with less for food. Without the second cellulose-based technology, maize stover still can be mainly used as fodder for livestock and soil conservation safely. More maize area can be conceived by crop substitutions, which further result to crop system changes. High yield, nutrition, drought and disease tolerance still are the top research priorities for maize breeding and crop management. Land and water situation may worse further as more marginal land, and even forests, are used to plant maize.

As first generation biofuels have rarely been economically competitive with petroleum fuels,[6] production in practically all countries is promoted through a complex set of subsidies and regulations. Expected second generation biofuel, based on cellulose and hemi-cellulose conversion technology, would highly improve the conversion efficiency, with about 322 litres of ethanol per tonne of maize biomass, which can include maize stover, leaf, and residues. Hopefully, second generation biofuel may reduce the pressure of land and water competition for more additional maize harvest area, and impose fewer effects on maize price as food. However, effects also depend on the intensity of biofuel production. At the scenario of business-as-usual biofuel production, maize biomass and other existing crops may provide enough for biofuel feedstock, so this scenario has less impact on maize grain production. At the scenario of aggressive biofuel production, more biomass, derived both from stem, stover, leaf and residue of crops, as well as from other plants with high biomass production, such as switchgrass and willow. If this happens, although most of these plants can be grown in marginal land, competition for water is unavoidable. Impacts on livestock feed and soil fertility, and with more aggressive biofuel production, even greater impacts on maize stover as fodder for feed and as organic matter for soil conservation would be expected. High biomass production should be included to the priorities of maize breeding and crop management, together with grain yield, nutrition, and drought and disease tolerance.

Wheat

Wheat is produced in wide range of environment and geographic regions, with demands from different end-uses, including staple food for a large proportion of world's poor farmers and consumers. Overall across the developing world, 16% of total dietary calories come from wheat, with 1400 kcal per capita per day in Iran and Turkey and about 500 kcal per capita per day in China and India. As the most traded food crop internationally, wheat is a single largest food import into developing countries, and also a major portion of emergency food aid. Between 2004 and 2006, over 621 million tonnes of wheat grain were annually produced on about 217 million ha. By 2020 wheat projection will have increased to 760 million tonnes with an annual growth rate of 1.6% (Rosegrant et al. 2001). Based on projections by IFPRI, demand for maize will grow faster than for wheat, particularly because of the strong demand for feed maize and also increasing demand for biofuel maize, in turn the demand for wheat will grow faster than that for rice and follows very closely the growth in global population over this period. Most wheat in the developing countries will continue to be consumed as food, while in the developed countries a significant portion will be used as animal feed.

The boom of maize-based bioethanol and soaring demand for other bioenergy crops has led to a shift of acreage from wheat to maize and other crops. The long-term declining trend of real wheat price over past decades has been halted in 2007, at least temporarily, partly due to poor weather in major wheat producer such as Australia, Canada, China and EU, and also due to the cut down production. Wheat as bioenergy crop is not much popular as maize because of the relatively lower conversion efficiency from wheat grain and straw to bioethanol, and European countries are the major producers of wheat bioenergy. The bioethanol yield of wheat is currently estimated at 2591 litres per ha,[7] lower than maize and other sugar crops. According to average Chicago ethanol spot price, USD 2.25 per gallon in 2007 (Caldwell *2007*), wheat-based biofuel is with a value of approximately USD 1540 per ha, while at the wheat price of 2007, USD 255.2 per tonne, wheat value is around USD 766 per ha (estimated at 3 t/ha

6. http://www.biofuels.ru/bioethanol/What_bioethanol/, 3461 litres per ha.
7. http://www.biofuels.ru/bioethanol/What_bioethanol/, 2591 litres per ha.

for wheat yield in 2007). Economically, as long as oil prices remain high, which are related to the ethanol price, the economical use of wheat as feedstock becomes viable.

Given the importance of wheat as a staple food for world's poor farmers and consumers, even a mini conversion of wheat to biofuel production, it will affect the benefit and welfare of the developing world. As narrated in international market section, increase in the prices of the staple food will threat definitely the food security of the poor and food deficit countries. How does this wheat-based biofuel production affect to wheat production systems? We select the small-scale cereal–livestock in East Europe and Central Asia (EECA) as an example. Wheat is the most popular crop in EECA. Globally not more than 15% of wheat production is consumed by livestock. Europe has the highest percentage of wheat used for feed, with 40% fed to livestock in EU, accounting for over half of the world wheat feed consumption (*USDA 2005*). The small-scale cereal–livestock system of EECA is located in the semi-arid and dry subhumid and mountainous zones of Turkey with a growing period of less than 180 days. There is little irrigated land. Rural population is around 44%, with poverty currently moderate but increasing. Wheat is the most important crop, followed by barley, with 64% and 22% of total crop area in this system, respectively (Table 15). Resource constraints lay at a middle level compared to world's 63 farming systems. Market access is relatively good, with average 2.9 hours from farm to local market centre. Major regional energy is fossil fuels, around 87% to the total energy consumption in Turkey.

Wheat is the staple food and feed in this system. Agricultural research is targeted at high yield breeding, disease resistance, quality, germplasm improvement (Reynold et al. 2008). Biofuel booming in East Europe makes an ambitious and realistic vision for 2030, which up to one-fourth of the EU's transport fuel needs could be met by clean and efficient biofuels. It is estimated that between 4 and 13% of the total agricultural land in the EU would be needed to produce the amount of biofuels to reach the level of this vision. Biofuel development also has been seen as a contributor to the EU's objectives of securing the EU fuel supply while improving the greenhouse gas balance and fostering the development of a competitive European (biofuels and other) industry. Turkey as an active potential EU country would be affected significantly by the EU biofuel policy and is one of the world's major wheat exporters, with 817,000 tones of net export in year 2000. Therefore, wheat is the most likely feedstock for ethanol production in Turkey. Economically, using wheat for ethanol production makes more sense, as it is the cheapest raw material with higher starch content. Energy crops like wheat, a major crop for this region, are expected to play an increasingly significant role as future biofuel resources (Biofuels Research Advisory Council 2006).

As projection by IFPRI for 2020, under the two biofuel expansion scenarios, wheat exports of Europe and Central Asia decrease dramatically due to increased demand of wheat for biofuel in these countries (Table 6). Under the more aggressive biofuel production scenario, there would be more reduction on the wheat export and further increase in wheat price (figure 6). Increasing use of wheat grain for bioethanol feedstock would definitely increase the wheat price as the staple food, together with the effects from maize price increase, which may put wheat beyond the reach of many poor people.

Based on the current large proportion of wheat in this farming system, and other crops' importance like oil crops for biodiesel, there should be less room left for wheat area expansion. So crop substitutions may be not apparent as imagined. While more aggressive on-farm practices would appear, this may strain competition between limited land and water resource in this rainfed-dominant system. Wheat consumption pattern must be changed greatly between food, feed, and biofuel feedstock. Percentages of wheat used as food and feed may decline and biofuel feedstock would have a huge increase as the wheat-based ethanol industry is booming. Increase in demand of wheat suggests that wheat breeding should focus more on the wheat yield potential, drought and disease resistance.

Expected second generation biofuel would highly improve the conversion efficiency, with wheat biomass, including straw and residues for the biofuel feedstock. Hopefully, second generation biofuel may reduce the pressure on wheat price as food. However, effects also depend on the intensity of biofuel production. At the scenario of business-as-usual biofuel production, the wheat straw and other existing crops may provide enough amounts for biofuel feedstock, so this situation gives less impact to wheat grain production and consumption. At the scenario of aggressive biofuel production, more biomass, which can be derived both wheat and from other plants with high biomass production, like switchgrass, willow etc. If this happens, although most these plants can be grown in marginal land, competition for water is unavoidable, and it may be more severe especially for the rainfed farming system, like this small-scale cereal–livestock in EECA. Impacts for livestock feed, more aggressive of biofuel production, more deep impacts on wheat grain as feed for livestock production as with more wheat straw is used for biofuel, the residues left for soil conservation are less, which may affect the wheat yield. High biomass production should be included to the priorities of wheat breeding and field management, together with grain yield, drought and disease resistance.

Sugar-based bioenergy crops

Sugar-cane

Sugar-cane is a very easy, and profitable plant to grow, but does not naturally reproduce very effectively. Around 1391 million tonnes of sugar-cane have been produced within total 20.4 million ha land in 2006. The countries that produce the largest amounts of sugar-cane are Brazil, India and China, with 455, 281 and 100 million tonnes (FAOSTAT 2008), these three countries count for 60% of world sugar-cane production.

Although the use of sugar in the human diet is controversial, sucrose supplies about 13 percent of all energy that is derived from foods. With the jump of world oil price, sugar-based biofuel has been booming. Sugar-cane and, to a limited degree sweet sorghum, are the main feedstocks for this sugar-based biofuel production. Sugar-cane has been proven to work well in the production of ethanol in Brazil. Brazil uses sugar-cane as a primary feedstock, and produced around 16 billion litters ethanol in 2005, account for 36% of world ethanol production, the same percentage of U.S. maize-based bioethanol production. In Brazil, India and Cuba, the sugar-based ethanol industry has been surging.

Sugar-cane has the highest conversion efficiency in the current feedstock for biofuel, with 75 litters ethanol production per tonne sugar-cane stalk, that means 6000–6500 litters ethanol per ha sugar-cane.[8] Furthermore, sugar-cane bagasse is also a renewable resource. Using second-generation conversion technologies, bagasse would be an additional biomass source for biofuel, although this would undermine bagasse-based paper production such as in South America, India, and China, where it represents 20% of all paper production. The biggest constraint for sugar-cane is water: the requirement varies from 1500

8. http://www.biofuels.ru/bioethanol/What_bioethanol/.

to 2500 mm evenly distributed over the growing season.[9] Under rainfed conditions it will not be able to expand sufficiently to satisfy demands for biofuel blending level.

Brazil has the largest sugar-cane and sugar production and almost largest bioethanol production, surpassed by U.S. in 2006. Sugar-cane cultivation in Brazil is based on a ratoon-system, which means that after the first cut the same plant is cut several times on a yearly basis. Leaves have no purpose in the industry yet, so leaves are left on the field as organic fertilizer. We select the intensive mixed system in Latin America and Caribbean (LAC), mostly in Brazil as an example. In the intensive mixed system of LAC, sugar-cane is the third important crop in the all food and cash crops, with 17% of the total crop area, following maize and soya bean, which are 29% and 24% of the total crop area (Table 18). Resource constraints lay at a middle level with the index of 0.5, compared to world 63 farming systems, and market access is pretty good, with just 3.2 hours from farm to local market centre. Poverty levels are relatively low. Food crop and cash income contributes around 30% to farmer household income.

Based on important role of sugar-cane as cash crop in this system, international tropical research pays attention to related studies, and maintains a breeding and selection program to identify sugar-cane cultivars with high yield potential and resistance to sugar-cane diseases and test them for site adaptability. In the coming year, approximately USD 50 million will be allotted for research and projects focused on advancing the obtain of ethanol from sugar-cane in Sao Paulo, thanks to a joint venture between the State of Sao Paulo Research Foundation (FAPESP) and Dedini S/A Industrias de Base.

How these initiatives of biofuel expansion and agricultural research impact on the regional sugar-cane production? Firstly, under the first generation technology, sugar-based biofuel expansion pushes the sugar price up at least by 12% before 2020 (figure 6). This may stimulate the expansion of sugar-cane planting area by the biggest sugar exporter, Brazil. Under the more aggressive biofuel scenario, more land will be used for sugar-cane planting if suitable land and water are available. Under the second generation, bagasse also could be used to produce ethanol, and the sugar-cane use efficiency would be improved greatly. Nevertheless this kind of biofuel technology makes crops competition and substitution unavoidable. Sugar-cane production replaces mainly pastures and other food crops in Brazil. The amount of harvesting area in the Centre-South region increased from 2.8 Mha in 1993 to 4.2 Mha in 2003 and is expected to increase by some 50% to 2010 (Goldemberg 2006). As a result, livestock production (and potentially also food crop production) is moving particularly to the central part of Brazil, particularly at the borders of the present agricultural land, into cerrados, more than into forest areas. The cerrado is an important biome and biodiversity reserve. Thus, the direct impact from land use for cane production on biodiversity is limited, but the indirect impacts could be substantial.

Water use is a major limitation to sugar-cane planting in all countries. In general there is sufficient water to supply all foreseeable long-term water requirements in the Centre-South region of Brazil as whole, but local water shortages can occur as a result of the occurrence of various water using and water polluting sectors (agriculture, industry) or cities and the uncontrolled use of water and uncontrolled dumping of wastewater. Sugar-cane production is mainly rainfed in Brazil, which is generally not perceived as a problem, but the use of irrigation is increasing. To ensure an efficient use of fresh water resources, legislation is being implemented in some regions. As a result of legislation and technological progress, the amount of water collected for ethanol production has decreased considerably during the previous years in Brazil. It seems possible to reach a 1 m^3/t cane water collection and (close to) zero effluent release rates by further optimizing and reusing and recycling of water (Macedo 2005). Water saving is an important research priority for sugar-cane-biofuel chain. Fertilizer application rates are limited compared to conventional crop production and much lower compared to pastures. The use of mineral fertilizers

9. FAO, Crop water management, available at: http://www.fao.org/ag/agl/aglw/cropwater/sugar-cane.stm#requirements.

could be supplemented by the use of nutrient rich wastes (vinasse) from sugar and ethanol production. Cultivator selection in the present is focused on the sugar-cane yield, weed control, mineral nutrition application, pest and disease control.

Sweet sorghum

Sorghum is fifth most important cereal grain in the world after rice, wheat, maize and barley; and the third important staple food grain after rice and wheat grown in marginal areas in the Semi-Arid Tropics (SAT) in India, and the most important in many concentrated pockets of poverty in both India and Africa. Being a C4 species with high photosynthetic ability, nitrogen and water-use efficiency, sorghum is genetically well-suited to hot and dry agro-ecosystems where it is difficult to grow other food grain crops such as maize. Between 2004 and 2006, around 58 million tonne of sorghum was produced on about 42 million ha. Africa and South Asia are the major producers for sorghum, with 58% and 22% of total world sorghum area. India is the second producer after Nigeria, with 7.24 million ha land for sorghum.

Sorghum grain is used globally both for human consumption (42% of total production) and livestock feed (53% of total production); and sorghum stover contributes to 50% of the total value of the crop in some places, such as SAT India, especially in drought years (FAO and ICRISAT 1996). Sorghum also offers great potential to supplement fodder requirement of the growing dairy industry because of its wide adaptation, rapid growth, high green fodder yields, and good quality. With consumers' preferences and tastes changing, an increasing shift from food to non-food uses of sorghum becomes a blessing-in-disguise for resource-poor sorghum farmers. In fact, the sorghum crop is passing through a transition stage from mere food and fodder crop to an industrially valued raw material such as grain for poultry feed and potable alcohol from grain and fuel-grade ethanol production from sweet stalk sorghum. Recent growth and future projections of aggregated demand patterns suggest that there will be a substantial increase in the demand for animal products (meat, milk and eggs) in the developing countries by 2020 (Ryan and Spencer 2001). Sorghum straw and grain is admirably suited for livestock feed. Enhancing the diversification of sorghum to suit to these value-added uses is a strategic means for increasing dryland smallholder incomes.

Sugar-based bioethanol booming depends largely on the sugar-cane production worldwide. While molasses-based ethanol distilleries currently operate for only half year (during sugar-cane crushing season) usually due to the limited availability of molasses during the rest of the year. Sweet sorghum can contribute to operate facilities at greater efficiency. Sweet sorghum, which stores sugars in its stalk, is an excellent source of feedstock for ethanol production. Sugars can be extracted directly form sweet sorghum stalks and fermented to obtain ethanol. In recent years, there is an increasing interest in the utilization of sweet sorghum for ethanol production as its growing period and water requirement are four times lower than those of sugar-cane, and the cost of cultivation of sweet sorghum is three times lower than that of sugar-cane (Dayakar et al. 2004). The bioethanol yield of sweet sorghum is currently estimated at 8419 litres per ha,[10] higher than sugar-cane, maize, wheat and cassava conversion efficiency. Further, the stillage from sweet sorghum after the extraction of juice has a higher biological value when used as forage for animals, as it is rich in micronutrients and minerals (Seetharama et al. 2002). It could also be processed as a feed for ruminant animals (Sumantri and Purnomo 1997). Therefore sweet sorghum-based biofuel perspective make this crop more attractive for the countries who are seeking renewable energy as a major way to deal with the national energy crisis and energy security. Here takes mixed crop–livestock farming system in dry rainfed SAT in India as an example. In the SAT of India, now the sweet sorghum-based ethanol industry is booming, which gets supported from government and also private companies. This sweet sorghum-based bioethanol approach has been seen as a way to integrate

10. http://www.biofuels.ru/bioethanol/What_bioethanol/.

thousands of poor small-scale farmers with a few large-scale biofuel processing facilities and further to reduce poverty in this region.

In dry rainfed SAT farmers take sorghum, millet, and rice as the major livelihood crops, with the area of 19%, 20% and 8.5% to the total crop area for this farming system (Table 21). Most of the grain is consumed as food, and about 4% of the sorghum grain and most of straw are used as feed for livestock. Cultivated land account for 53% of the total system area, 36% of the cultivated area is irrigated. One third to half of the total population, near 30 million, are classified as agricultural. The per capita cultivated land is relatively low, with 0.33 ha. Because of the prevalence of irrigation, vulnerability is somewhat lower than other systems. Thus the level of poverty is moderate, extensive poverty appears on small farms, and depends partly on the season. Resource constraints index (0.25) is lower than the developing world average across 63 farming systems. Market access is relatively good, with average 2.2 hours from farm to local market centre.

Under the 1G biofuel production there is light impact on sorghum grain price except for the fallout effect by increase of world grain prices. Sorghum grain as animal feed might reduce under the 1G bioful scenario. More intensive cultivate will happen in this sorghum dominant system, and competition for land and water resource between sorghum and other crops becomes intense. More aggressive is biofuel production, more intensive becomes competition. Breeders of sorghum pay more attention to grain and stover yield, sugar content, drought and disease tolerance. Under 2G biofuel technology impact on sorghum grain consumption will be released but more competition of sorghum stover between animal feed and biofuel use comes to true. Use marginal land for sorghum biomass will be a possible solution. As the human diet changes livestock production might turn back to grain-based model (see Table 22).

Cassava

Cassava is grown by resource-limited farmers of Asia, Africa and Latin America and the Caribbean (LAC). Cassava is particularly adapted to marginal environments and can produce competitive yields in spite of the negligible inputs that farmers invest into the crop. FAO's Global Cassava Strategy identified the lack of markets as one of the major constraints for adoption of new technologies in cassava cultivation. This leads to low yields, which result in uncompetitive prices of the root for different processing pathways, perpetuating a vicious cycle. Whenever markets for cassava products develop there is an adoption of technology, investment from the farmer and immediate response from the crop. In Asia cassava fresh root productivity improved greatly, from 8 tonne per ha in 1961 to more than 18 tonne per ha in 2006, driving by the new varieties and cultivation technology, and well-developed market. Cassava is also a major food in Africa, likes in Nigeria, the biggest producer of cassava in the world.

The development of a bioethanol industry-based on cassava will have a positive effect on the livelihood of cassava farmers by further strengthening markets for products based on this crop. Moreover, it is expected that the bio-ethanol industry will promote the introduction of new cropping systems to satisfy its needs where research is necessary. Especially for the first generation of biofuel, starch-based process technology, more aggressive of biofuel production, more potential for cassava-based farming system developing. High starch yield and storage technologies would be the focus of agricultural research for cassava breeding.

Table A1 presents current and planned construction of cassava-based ethanol production facilities in key Asian countries. Other initiatives are currently ongoing, for instance in Colombia. These three potential outputs of a bio-energy development effort are highly related to the poverty reduction targets defined in the Millennium Development Goals.

Table A1. *Actual or planned factories for cassava-based ethanol production in Asia, 2007*

Country	Location	Capacity ('000 l/day)	Status	Fresh root needs ('000 t/year)[a]
China	Qinzhou, Guangxi	400	Built	750
	Beihai, Guangxi	830	Built	1556
	Other	2770	Planned	5194
	Subtotal	4000		7500
Indonesia	East Java	2500	Planned	4688
	SE. Sulawesi	2500	Planned	4688
	S. Sulawesi	600	Planned	1125
	Subtotal	5600		10,501
Thailand	Khon Kaen	130	Built	244
	Rayong	150	Built	281
	Prachinburi	60	Built	112
		1000	Operational in 2009	1875
		7170	Licensed	13,443
	Subtotal	8510		15,955
Vietnam	HCM city	333	Operational in 2009	624
	Binh Dinh	375	Planned	703
	Baria Vungtau	375	Planned	703
	Gia Lai	400	Planned	750
	Other	1480	Planned	2780
	Subtotal	2963		5560
TOTAL		21,073		39,516

Source: CIAT working documents from M Peters.
a. Based on 300 working days per year and a conversion of 160 litres ethanol per tonne of fresh roots.

The cultivation of cassava as an energy crop could cause or exacerbate environmental problems. A major concern is the potential impact that the expansion of the agricultural frontier could have on tropical forests, savannas, and biodiversity. Moreover, the growth of cassava on ecologically fragile lands could accelerate soil erosion and aquifer depletion processes.

On the social side, there are also important issues involved. The creation of uncompetitive market structures and the impact that these may have on the distribution of benefits along the crop-to-biofuel chain is a key concern. The increasing demand for energy and the apparent potential of biofuels to promote agricultural development are no guarantee that small-scale farmers and poor people in developing countries will be benefited and their lives and livelihoods improved.

Given the many uses of cassava (direct human consumption, starch and starch derivatives, roots and foliage for animal feed, processed food and, more recently, bio-ethanol) it will be interesting to see how the different demands for cassava, as raw material, evolve to satisfy these demands. Moreover, there is likely to be an interaction between different processing end uses of cassava. For example, bio-ethanol operations based on different crops will produce protein-rich by-products that could, perhaps, promote the use of cassava in animal feed because they may complement the low protein content of cassava roots.

The cassava biomass shall be produced with the highest possible productivity, at the minimum possible cost, without interfering with current food production systems and without adversely affecting soil management and environmental conservation systems. Relevant aspects of the crop-to-biofuel value chain would need to be considered.

Oil-based biodiesel crops

Oil crops have been expansion in the past decades, with 97% increase from 1961 to 2006 in the world (FAOSTAT 2008). The most comment feedstocks for biofuel are canola in temperate region and oil palm in tropical farming systems. The major part of these two crops is produced on large-scale farms or plantations. There can be some competition with food crops for land; it is considered that the impacts on small-scale crop–livestock holders are relatively low when compared with other bioethanol crops. Therefore, this study describes only one crop–livestock–energy system in Indonesia.

Vegetable oil typically represents 80% of the total costs of biofuels making feedstock development by far the most critical segment of the overall value chain. Given the great importance of edible oils to food preparation and the fact that most developing countries are net importers of such oils, the production of biodiesel will require substantial focus on feed stocks and especially that of nonedible oilseeds.

Biodiesel is produced by the transesterification of vegetable oil or animal fats usually using methanol or basic a basic catalyst, to the monoalkyl methyl esters. Economically important oilseed crops include oil palm, soya bean, sunflower, cotton corn, opium poppy and rape (Bernardo et al. 2003). The oil yields of selected oil seeds crops (litres per hectare) are as follows: oil palm (7144), coconut (3229), jatropha (2273), rapeseed (1429), peanut (1271), sunflower (1148), safflower (934), mustard (686), soya bean (540) and corn (2030). Among the many processes used to solve the high viscosity and low volatility problems such as preheating, blending with other fuels, transesterification, and pyrolysis but pyrolysis and gasification are the most appropriate and the most commercially used (Enginar et al. 2000). Heating temperatures of 400–450ºC is optimum at 50ºC/min has been found to be effective with soya bean oil. Particle size did not seem to cause greater gradients inside the particle so that at given time the core temperature is lower than that of the surface and this possible gives rise to an increase in solid yields (Enginar et al. 2000). The significant production of transport fuels for the decrease in the oxygen content of the bio-oil compared to the original feedstock is favourable, since the high oxygen is not attractive for the production of transport fuels. Viscosity, density, flash point and heating value are known to be typical key properties for combustion applications in boilers, furnaces and engineers. The viscosity of soya bean biodiesel was relatively high compared to values reported for other bio-oils (Garcia-Perez et al. 2002).

Oil palm

Oil palm is the most productive oil seed in the world. A single hectare of oil palm may yield 5,000 kilograms of crude oil, or nearly 6,000 litres of crude oil compared to the 446 and 172 litres per hectare reported for soya beans and corn, respectively. Beyond biofuel, the crop is used for a myriad of purposes from an ingredient in food products to engine lubricants to a base for cosmetics. Palm oil is becoming an increasingly important agricultural product for tropical countries around the world, especially as crude oil prices top USD 100 a barrel. For example, in Indonesia, currently the world's second largest producer of palm oil, oil-palm plantations covered 5.3 million hectares of the country in 2004. These plantations generated 11.4 million metric tonnes of crude palm oil with an export value of USD 4.43 billion and brought in USD 42.4 million (officially) to the Indonesian treasury. Since then, the value of palm oil has only climbed. The price of palm oil in 2006 stood at more than USD 400 per metric tonne, translating to about USD 54 per barrel—quite cost competitive to petroleum.

Palm oil is derived from the plant's fruit, which grows in clusters that may weigh 40–50 kilograms. A hundred kilograms of oil seeds typically produce 20 kilograms of oil. Fruit clusters are harvested by hand, difficult work in the tropical climate where oil palms thrive. The other problem with palm oil as a source of biodiesel lies in the nature of how the crop is produced. In recent years, vast areas of natural forest have been cleared across tropical Asia for oil palm plantations. This conversion has reduced biodiversity, increased vulnerability to catastrophic fires, and affected local communities dependent on services and products provided by forest ecosystems.

Soya bean

Soya bean (*Glycine max*) was domesticated in the north-east of China around the 11th century BC. It reached Europe before 1737, the United States in 1765, Brazil in 1882, and in tropical Africa, speculated to be around 1907. Soya bean has many food and industrial uses; from food (preparation of a variety of fresh, fermented and dried food products like milk, tofu, tempeh, miso, yuba, soya sauce, flour and bean sprouts, vegetable oil) to industrial and fuel oil. According to FAO estimates, the average world production of soya bean seeds is 173 million tonnes/year from 77 million hectare (mean of 1999–2003). The main producing countries are the United States (73.5 million t/year in 1999–2003, from 29.4 million ha), Brazil (39.0 million tonnes/year from 15.1 million ha), Argentina (26.4 million tonnes/year from 10.2 million ha), China (15.4 million tonnes/year from 9.0 million ha), India (5.9 million tonnes/year from 6.3 million ha), Paraguay (3.4 million tonnes/year from 1.3 million ha) and Canada (2.3 million tonnes/year from 1.0 million ha). South Africa produced 188,000 t/year from 121,000 ha. The soya bean production in tropical Africa in 1999–2003 was 790,000 t/year from 895,000 ha, the main producers being Nigeria (439,000 t/year from 601,000 ha), Uganda (139,000 t/year from 124,000 ha) and Zimbabwe (119,000 t/year from 62,000 ha).

Soya beans are the primary biodiesel feedstock in the United States. Although they are a relatively low-yielding oil crop, one advantage of using soya beans is that they derive substantial of N from biological nitrogen fixation and therefore has less fertilizer requirements than many other oil crops

Rapeseed oil

Rapeseed is grown for the production of animal feed, vegetable oil for human consumption, and biodiesel. The leading producers include the European Union, Canada, United States, Australia, China and India. In India, it occupies 13% of the cropped land. The USDA reports that rapeseed was the third leading source of vegetable oil in the world in 2000, after soya bean and oil palm. It was also the world leading source of protein meal although only 20 percent of the production of the leading soya bean meal. The world's rapeseed production is increasing rapidly with FAO reporting that 36 million tonnes was produced in 2003–2004 growing season and 46 million tonnes in 2004–2005. At present in Europe oilseed rape is the main agricultural crop used as raw material for biofuel production, with the methyl ester of rapeseed oil sold as biodiesel (Williamson and Badr 1998). Worldwide, rapeseed is the primary biodiesel feedstock (84 percent of production).

Even though the crop when grown in winter provides a good coverage of the soil and limits nitrogen runoff, ploughed in the soil or used as bedding, some concerns have been expressed relating to the sustainable management practices. Indicators of sustainability that have been identified include: soil health, soil loss, nutrients availability, pest management, biodiversity, value chain, energy, water, social and human capital, and local economy.

Groundnut (*Arachis hypogea*)

The major producers of groundnut are United States, Argentina, Sudan, Senegal, and Brazil accounting for 71% of the total world exports; China and India account for 4% of the world exports.

Groundnut oil was used as a replacement for scarce fossil fuel-based oils and lubricants in the World War II. Groundnut oil produces approximately 1380 litres per hectare compared to the 560 of soya bean oil but groundnut oil is more valuable on the world market than soya bean oil. For example, edible groundnut account for 67% of groundnut use in United States. Popular confections include salted groundnut, groundnut butter, groundnut brittle and shelled nuts. Attempts are currently been made (e.g. at University of Georgia, USA) to develop non-edible groundnut that are high in oil. Geller (http://southwestfarmerspress.com/news/110106) states that biodiesel from groundnut is easy but difficult to get right. It is compatible with fossil fuel-based biodiesel and can be mixed in any combination. It is also less toxic to the atmosphere and has a clearing effect on diesel engines.

Non edible oil-based biodiesel crops

Two such oil sources, jatropha and pongamia are widely recognized as the most economically viable and environmentally neutral feedstock options. Both of these tree-borne oilseeds are adaptable to reasonably harsh climatic and growing conditions, enabling them to be cultivated on so-called 'wastelands' that are not currently employed in agricultural production. These woody plants can grow on barren, marginal land, and so is increasingly popular in countries such as China and India that are keen to boost biofuels output. Of the two, jatropha is considered the feedstock of choice due to its shorter maturation period and its superior adaptability to arid conditions. The growing characteristics and yields of jatropha and pongamia are summarized below and compared to palm and soya bean oil, two edible oil crops are summarized in Table A2.

Table A2. *Comparison of growth characteristics and yield for jatropha, pongamia, palm and soya bean*

Characteristics	Jatropha	Pongamia	Palm	Soya bean
Climate	Arid to semi-arid	Semi-arid to subhumid	Tropical/forest life	Subtropical
Rainfall required	200–1000 mm	500–2500 mm	640–4260 mm	500–4100 mm
Fixes nitrogen	No	Yes	No	Yes
Land type	Waste-land	Waste-lands	Agricultural land	Agricultural land
Plant size	Bush/small tree	Tree	Tree	Vine-like bush
Gestation period	First yields in year 3, maturity in 5th	Starts yielding in year 5, yield growths with canopy	Starts yielding in year 3–4	Annual crop
Oil content	18–38%	20–39%	45–55%	20%
Toxicity of oil	Toxic	Non-toxic	Non-toxic	Non-toxic
Yields (tonnes/ha)	1–5	0.9–9	5.5	0.5

Source: Based on (but revised in part from) GTZ: 'Liquid Biofuels for Transportation' and James A. Duke. Handbook of Energy Crops 1983.

Camelina sativa

Camelina sativa is a spring annual plant of the genus Cruciferae that grows well under temperate conditions. Extensive cultivation began in France and to a lesser extent Holland, Belgium, and Russia in the 19th century but declined by 1947. Renewed interest in low-cost by fuels has led to the re-examination of camelina as an oilseed crop and which has revealed that oil yield from camelina has been similar to that from spring oilseed rape but has the advantage of low requirements of fertilizer and pesticides (Frhölich and Rice 2005).

Tobacco

Tobacco oil was first examined for its potential as biodiesel by Giannelos et al. (2002) but the seed oil methyl or ethyl esters were further examined for their physical–chemical properties by Usta (2005). Tobacco is grown in over 119 countries in the world. The seeds are by product of tobacco leaves production. Since the oil is non-edible, it is not used as a commercial product in food industry and most of it is usually left on the field. Usta (2005) reports that there are no statistical information on potential seed and seed oil production in the literature but contend that these can be estimated from using the harvesting area. The world seed and oil production estimates are given as 2.5m and 950, 000 tonnes, respectively (USDA 2004). Its potential as biodiesel has been confirmed by Usta (2005).

Annex Table A2 giving out a comparison of growth characteristics and yield for Jatropha, Pongamia, Palm and Soya bean. Jatropha seed yields are estimated to be 1 to 5 tonnes per hectare. Empirical studies suggest typical peak yields of 1.0–1.2 tonnes of seed/ha in poor, non-irrigated soil and 3–5 tonnes per ha in irrigated or rain-fed conditions, using germplasm that is available today. These yields assume approximately 1,300 plants per hectare, with each plant typically taking three years to begin bearing fruit and maturity being reached in year five or six.

There is considerably less field trial data available on pongamia cultivation leading to a very wide range of estimated productivity. A review compiled by Kukrika (2008) revealed that pongamia yields are estimated to be 9–90 kg of seeds per tree at maturity of 4–7 years (for a total seed yield of 900–9000 kg assuming 100 trees per hectare). In addition significant and large quantities of wasteland (low productivity) must be identified and agronomic or silvicultural practices improved to achieve peak yield values of at least five tonnes per hectare.

Jatropha nuts and leaves are toxic, requiring careful handling by farmers. In addition, it is a labour-intensive crop as each fruit ripens at a different time and needs to be harvested separately. Its productivity is also low and has yet to be stabilized. The oil yield of the plant, originating in Africa and still largely a wild species, is less than 2 tonnes per hectare with large swings from year to year; it requires intensive research before Jatropha could achieve productivity that would make its cultivation economically viable.

Other potential crops

Rice

World rice production in 2007 was approximately 645 million tonnes. At least 114 countries grow rice and more than 50 have an annual production of 100,000 t or more. Asian farmers produce about 90% of the total, with two countries, China and India, growing more than half the total crop. Overall the world, most of the rice production has been supporting for food consumption, with about 88% of total production, and its use as feed is just about 1–2%. Rice calorie supplies as percentage of total calorie supply are 29% and 8% in Asia and Africa respectively (World rice statistics IRRI 2008). International price of rice is rebounding since 2000, partly due to the world food price increase in the recent years. In Asia, where most of the rice is produced, poverty is still widespread. Rice, as the staple food for most Asian, plays a key role for this region's food security. If rice price continues going up, it will definitely threat the food security for net rice importing countries, such as Nepal, Bangladesh, India, and Indonesia.

Under the first generation of biofuel, rice-based ethanol production destines to be limited only to a small-scale production. Several reasons attribute to this conclusion: firstly, economically, cost of rice grain-based biofuel is much higher than any other crop-based biofuel. Scientists from Japan estimated that ethanol made from food-quality rice would cost around USD 2.93 per liter, whereas retail gasoline prices are around USD 1.27 per liter. Moreover, importing ethanol from Brazil, the world's largest exporter, now just costs about USD 0.68 per liter (Reuters 2007). Secondly, the introduction and expansion of other biofuel crops have already caused major land-use changes, and that many feedstock crops (although originally targeted at marginal lands) will compete with rice in productive eco-regions. Maize area expansion in such lands is an example. Such an expansion may impose additional pressure on food security and will dim the rice-based biofuel industry.

The second generation of biofuel, which makes use of crop residues, such as rice straw, can be considered as an optimistic scenario for some Asian countries because straw is largely being burned in many countries. This is a priority area for R&D, particularly with regard to thermal conversion technologies for different scales. Nevertheless, the level of residue retention, which may be needed for sustainable land use under different cropping system, and use of rice straw as livestock feed, should not be overlooked. A balance must be achieved amongst the various uses of rice straw as livestock feed, retention in soil for sustainability, and biofuel. Also biodiesel from rice bran may be a choice as rice bran oil is a non-conventional, inexpensive and low-grade vegetable oil. Crude rice bran oil is also a source of high value added by-products. Thus, if the by-products are derived from the crude rice bran oil and the resultant oil is used as a feedstock for biodiesel, the resulting biodiesel could be quite economical and affordable.

Sweet potatoes

Sweet potato (*Ipomoea batatas*) is cultivated throughout more than 100 countries with moist tropical and warm temperate climates. Over 95 percent of the global sweet potato crop is produced in developing countries. It can be grown in poor soils with little fertilizer and is highly tolerant to pest and diseases, which makes it a major smallholder's staple crop. Sweet potato produces more than 133 million tonnes globally per year, ranking as the world's seventh most important food crop. China, producing 117 million tonnes, accounts for 90 percent of global production. In the past, most of China's sweet potatoes were grown for human consumption, but now more than 60% are grown to feed pigs in smallholder's farming systems. The rest are grown for processed human food such as noodles and for other products. In contrast with Asia, African farmers produce only about 7 million tonnes of sweet potatoes annually and most of the crop is cultivated for direct human consumption. In eastern Africa, sweet potato is called cilera abana, 'protector of the children' a name that points out to the very important role it fulfils in a region where food security is a critical issue. Average yields of sweet potato in Africa are about a third of Asian yields.

Further to its importance as a food crop of high nutritional value and feedstuff for livestock, sweet potato has a high potential to be used as a feedstock for bio-ethanol. A recent report (BIOPACT 2007) mentions that sweet potato is a prime candidate to be utilized as a source of biomass for the production of first generation biofuels, particularly ethanol. The report indicates that per kilogram, sweet potato yields 40 to 50% more starch than corn while its starch productivity per hectare is 3 to 4 times higher than corn and twice that of cassava. In terms of ethanol yield per hectare, sweet potato could outyield corn 3 to 1, producing up to 10,000 litres of ethanol/ha, with less energy input than corn ethanol. Several countries in Asia and Latin America are interested in producing ethanol from sweet potato. For instance, the National Research Council of Taiwan has announced that their laboratories will begin R&D on the production of fuel ethanol from sweet potato, a common crop in the country. The USA and Canada are also interested in the utilization of sweet potato for producing ethanol. In Canada, sweet potatoes were chosen as the primary feedstock source in addition to millet and sorghum. Since 50 per cent of the edible sweet potato Canadian crop never reaches the market due to its substandard grade, ethanol production proved to be a beneficial opportunity for the 11,000 kg/ha of leftover crop waste in creating an additional stream of revenue. However, the main constraint under the USA conditions is the cost of production of the crop, which requires intensive manpower (NCSU 2007), a factor that is advantageous in developing regions. As to developing regions, a very interesting case is the recent implementation of a rural development program based on the production of ethanol from sweet potato grown by smallholders in the State of Tocantins, Brazil. The program, funded by IDB (IDB 2007), will include two small processing facilities to produce ethanol and animal feed and is oriented to poverty reduction.

Notwithstanding the potential of sweet potato as a feedstock for ethanol production, the fact is that the use of food crops as feedstock for biofuels remains a highly controversial issue. In the specific case of sweet potato, any diversion of the crop to the bioenergy economy might negatively influence its current increasing and vital utilization as a micronutrient rich food crop in Africa and as an animal feed crop in smallholder's farming systems in Asia. Orange-fleshed sweet potato (OFSP) is the cornerstone of the Vitamin A Partnership for Africa (VITAA), which is promoting its increased production, use and consumption. This dichotomy between the alternative uses of sweet potato poses two major researchable themes for related research institution, with mission of reduce poverty and achieve food security on a sustained basis in developing countries. The first one is related to the environmental, economic and social implications of the competing utilization of sweet potato for human and animal nutrition in developing regions via its utilization for ethanol production. The second, complementary question is about the potential of sweet potato to effectively contribute to poverty reduction through its utilization as feedstock for ethanol production without compromising the long-term food security and livelihoods of rural communities and environmental quality.

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