"ENERGY-SMART" FOOD FOR PEOPLE AND CLIMATE

ISSUE PAPER

ENERGY-SMART FOOD FOR PEOPLE AND CLIMATE

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"The General Assembly of the United Nations declared 2012 to be the International Year of Sustainable Energy for All. Initiatives by Member States and international organizations are being undertaken to create an enabling environment at all levels for the promotion of access to energy and energy services and the use of new and renewable energy technologies."

United Nations Secretary-General (UN General Assembly, 2011)

CONTENTS

Acronyms

CFC	Chlorofluorocarbon
CHP	combined heat and power
CO2	carbon dioxide
DECC	Department for Energy and Climate Change, United Kingdom
DEFRA	Department for Environment, Food and Rural Affairs, United Kingdom
DME	Dimethil ether
EJ	petajoule
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
F-gas	Fluorinated gas
GDP	gross domestic product
GHG	greenhouse gas
GJ	giga Joules
GPS	Global Positioning System
IEA	International Energy Agency
IFES	integrated food-energy system
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle analysis
LPG	Liquified petroleum gas
MDGs	Millennium Development Goals
MEPS	minimum energy performance standards
Mha	million hectares
MJ	megajoule
Mt	mega tonne
MW	megawatt
NAMA	Nationally Appropriate Mitigation Action
OECD	Organization for Economic Co-operation and Development
PJ	petajoule
PV	Photovoltaic
RD&D	research, development and demonstration
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention of Climate Change
USA	United States of America
WRAP	Water and Resources Action Programme

EXECUTIVE SUMMARY

The global community is becoming increasingly concerned about the high dependence of the global food sector[1] on fossil fuels. This anxiety is compounded by FAO projections indicating that by 2050 a 70 percent increase in current food production will be necessary to meet the expanding demand for food, primarily through yield increases. The use of fossil fuels by agriculture has made a significant contribution to feeding the world over the last few decades. Energy from fossil fuels has increased farm mechanization, boosted fertilizer production and improved food processing and transportation. However, if an inexpensive supply of fossil fuels becomes unavailable in the future, options for increasing food productivity may become severely limited.

The food sector currently accounts for around 30 percent of the world's total energy consumption. High-GDP countries use a greater portion of this energy for processing and transport. In low-GDP countries, cooking consumes the highest share (Fig. ES1). The food sector contributes over 20 percent of total GHGs emissions (Fig. ES1). Primary farm and fishery production[2] accounts for around one fifth of the total food energy demand, but produces two thirds of the GHGs. The great challenge the world now faces is to develop global food systems that emit fewer GHG emissions, enjoy a secure energy supply and can respond to fluctuating energy prices while at the same time support food security and sustainable development.

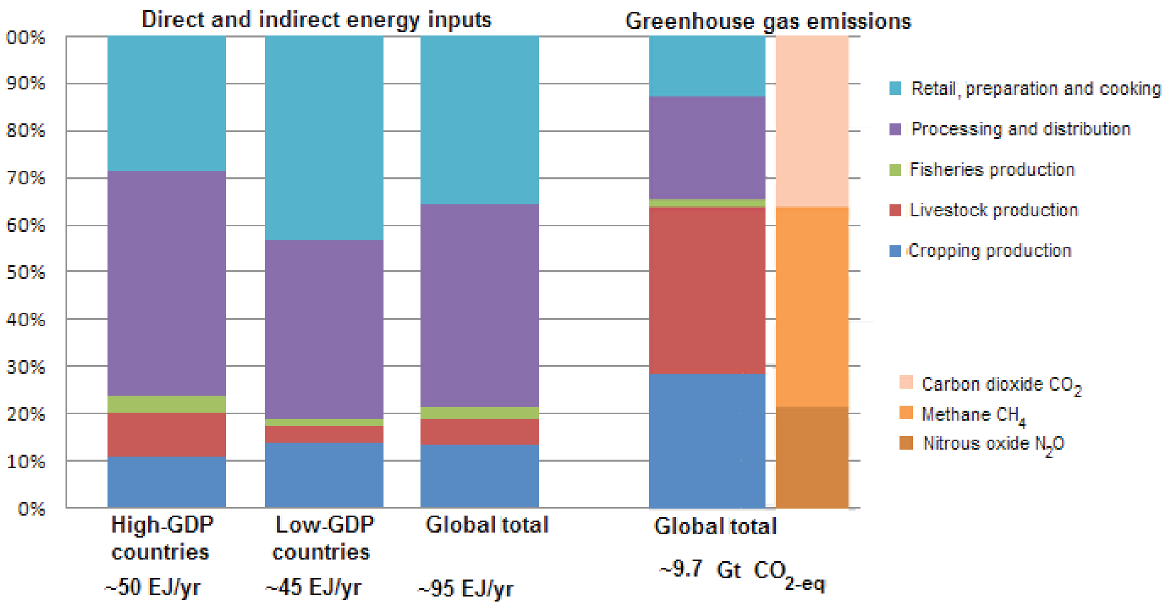

Figure ES 1. Indicative shares of final energy consumption for high- and low-GDP countries, the global total and total associated global GHG emissions for the food sector

NOTE: FAO's analysis is based on the best available data. However, this data is at times unreliable, incomplete and out of date. Results should be treated as indicative only and interpreted with care.

1 In this paper food sector, food systems and food chain are used interchangeably. They refer to all the stages from on-farm production (including input manufacturing) to the consumer's plate.

2 Primary production here includes cropping, pastoral and intensive livestock, aquaculture and fishing

A recent FAO study has shown that around one-third of the food we produce is not consumed. A significant share of total energy inputs are embedded in these losses. In low-GDP countries most food losses occur during harvest and storage. In high-GDP countries, food waste occurs mainly during the retail, preparation, cooking and consumption stages of the food supply chain.

The aim of this paper is to discuss how the entire food sector, from the farmer's field to the consumer's plate, can become more 'energy-smart'. Becoming energy-smart will require a transformation along the food chain that involves:

- relying more on low-carbon energy systems and using energy more efficiently;
- strengthening the role of renewable energy within food systems;
- providing greater access to modern energy services for development, and at the same time supporting the achievement of national food security and sustainable development goals.

This paper provides examples of energy-smart practices for both small-and large-scale enterprises and covers the entire food sector.

Commodity prices tend to be linked with global energy prices. As energy prices fluctuate and trend upwards, so do food prices (Fig ES2).

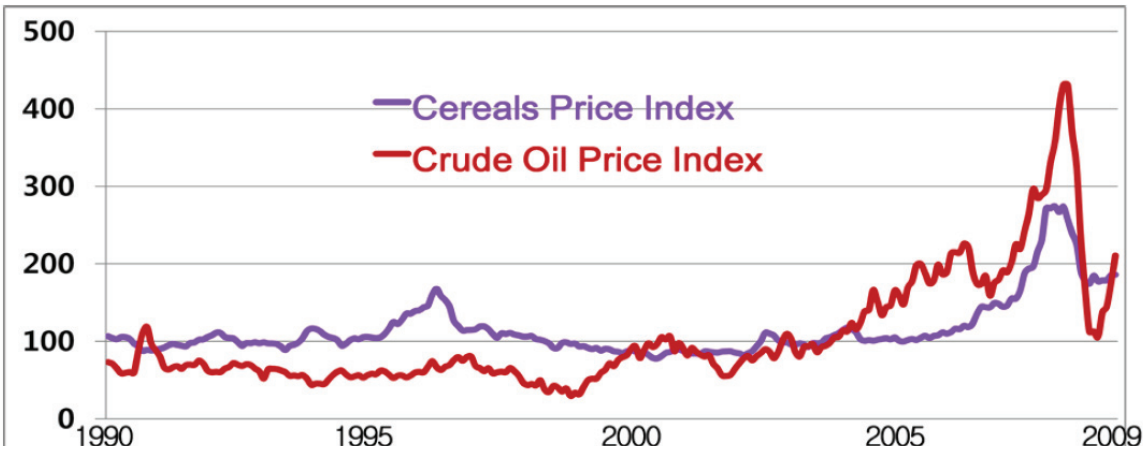

Figure ES2. Comparative trends of crop commodity and oil price indices from 1990 to 2009 (with 2004 as baseline) (Kim, 2010).

Decoupling increase in food production from fossil fuel use will require fundamental changes in global food systems. More analysis is required on how a shift to a less fossil fuel dependent food sector would affect food security, food prices, energy access, climate change resilience, technology uptake and capacity building.

Reducing energy demand. If energy prices continue to rise, the global food sector will face increased risks and lower profits. The efforts from low-GDP countries to emulate high-GDP countries in achieving increases in productivity and efficiencies in both small and large-scale food systems may be constrained by high energy costs. Lowering the energy inputs in essential areas, such as farm mechanization, transport, heat, electricity and fertilizer production, can help the food sector mitigate the risks from its reliance on fossil fuels. Existing production and processing practices behind and beyond the farm gate can be adapted so that they become less energy intensive in terms of energy consumption per unit of food produced, and at the same time deliver food in a safe and environmentally sustainable manner. Methods for improving energy efficiency are reasonably well understood. However, these methods should be applied only when they do not lower productivity, do not restrict energy access and do not threaten rural livelihoods. A simple 10 percent reduction in food losses and a change to diets for example to include the use of more fresh and local foods would help reduce overall demands for energy, water and land. However, implementing these changes would take time as they involve significant behavioral changes and present formidable social challenges.

Renewable energy systems. Increased deployment and use of local renewable energy inputs during the production and processing stages of the food chain can:

- help to improve energy access, particularly in rural areas;
- reduce the food sector's dependence on fossil fuels;
- allay energy security concerns;
- diversify farm and food processing revenues;
- lower GHG emissions and
- help achieve sustainable development goals.

Wind, solar, hydro, geothermal, and biomass resources are often widely available on farms. Potential also exists to produce bioenergy from food processing plants. In the future, it may be possible to harness ocean energy for fisheries. Applying technologies that use renewable energies, including bioenergy sources, for decentralized generation of heat and electricity and for the production of transport fuels is feasible in both low- and high-GDP countries. These technologies offer opportunities for generating usable energy on-site and when excess energy is generated, additional revenue may be earned by exporting and selling it off-site. Combining food production with renewable energy generation is possible at the subsistence, small-scale and large-scale levels and can bring co-benefits to farmers, landowners, businesses and rural communities. Integrated food-energy systems that link food production and natural resource management with poverty reduction in food value chains are potential examples of the landscape approach to sustainable agriculture. Further analysis to assess the contribution of these type of systems to energy-smart food production is needed before firm recommendations can be made.

Improved energy access. The provision of basic energy services is essential for meeting several of the MDGs. It is well accepted that food systems in low-GDP countries will need to use more energy if they are to increase food productivity and improve the livelihoods of subsistence farmers, fishers and their families. Adopting energy-smart food systems would help to ensure that impoverished rural families have access to an affordable and sustainable energy supply, which would improve community health and provide greater opportunities for earning livelihoods through improved refrigeration, communications and transport to markets.

Enabling policies. Strong and long-term supporting policies and innovative multi-stakeholder institutional arrangements are required if the food sector is to become energy-smart for both households and large corporations. Financial mechanisms to support the deployment of energy efficiency and renewable energy will also be necessary to facilitate the development of energy-smart food systems. Examples exist of cost-effective policy instruments and inclusive business schemes that have successfully supported the development of the food sector. These exemplary policy instruments will need to be significantly scaled up if a cross-sectoral landscape approach is to be achieved at the international level. Implementing these policies will require:

- investments in applied research development;
- the deployment of appropriate technologies;
- the introduction, sharing and adaptation of energy-smart technologies;
- fiscal support mechanisms and
- capacity building, support services, and education and training.

A supporting policy environment without the appropriate allocation of financial and human resources is unlikely to succeed in establishing energy-smart food systems.

The way forward. Addressing the energy-water-food-climate nexus is a crucial and complex challenge. It demands significant and sustained efforts at all levels of governance: local, national and international. This paper recommends a major long-term multi-partner programme on "Energy-smart food for people and climate", as a key aspect of 'Climate-Smart Agriculture'[3], based upon three pillars:

- energy access,
- energy efficiency and
- energy substitution through the greater deployment of renewable energy systems.

As part of such a programme, local and national governments may want to consider developing and implementing policies and measures that combine food security with energy security to help meet sustainable development objectives while contributing to 'Climate-Smart Agriculture'.

3 Climate-smart agriculture is defined as agriculture that simultaneously seeks to:
sustainably increase farm productivity and income;
adapt to climate change and improve the resilience of livelihoods and ecosystems; and
reduce emissions of or remove GHGs.

1. Introduction

The global food sector is dependent on energy inputs. The natural energy flows from the sun and the various forms of chemical energy stored biologically in the soils and oceans are essential for plant growth to produce food, fish and fibre. However, these natural flows are not discussed in this paper. In agricultural production, humans use external energy inputs to support natural processes so that a given area of land or water produces more than it would do otherwise. Practices for achieving this increased production vary widely between countries and cultures, but they all involve adding auxiliary energy to the natural system. This auxiliary energy can come in many forms: human labour, animal power, fossil fuels, renewable energy or mechanical energy obtained from the consumption of liquid fuels in engines. Meeting the global food demand of a growing world population over the past century has been achieved, at least in part, by the significant increase in the use of fossil fuels at all stages in the food system. Petroleum products power boats, tractors and other vehicles that transport food. Natural gas is used to manufacture chemical fertilizers and pesticides. Fossil fuels are combusted to generate electricity and heat for processing, refrigeration and packaging. A range of fuels are used for cooking. It is this increased reliance of global food systems on fossil fuels that is now becoming cause for concern.

By 2030 it is expected that population expansion and economic growth will increase the global demand for energy and water by 40 percent (IEA, 2010) (WEF, 2011) and the demand for food will increase by 50 percent, to be met primarily through yield increases (Bruisma, 2009). Meeting these demands is being made even more challenging by climate change, the limited availability of productive land and the fact that the planet's natural resource base is already under significant stress. The magnitude and complexity of this challenge, combined with the need for urgent action, explains the current importance being given to the energy-water-food-climate nexus. This 'perfect storm' of factors will have an impact on land use, land acquisitions and the environment at local, national and global levels. To address these challenges, the global economy will have to make a major transition from the business-as-usual approach. We will have to do more with less. FAO has articulated this new approach in its proposed "*Save and Grow*" paradigm shift (FAO, 2011a). This shift will require that stakeholders involved at all levels in the global food sector adopt fresh approaches to agricultural and fisheries production, develop innovative appropriate technologies and formulate new policies and institutional arrangements.

Making the transition to low-carbon 'climate-smart agriculture' can contribute to 'green economy', will improve human well-being and social equity while significantly reducing environmental risks and ecological scarcities (UNEP, 2011). This transition involves:

- using more ecologically-friendly farming methods that significantly improve yields for subsistence farmers;
- improving access to freshwater and using water more efficiently;
- promoting the efficient management of natural resources and energy;
- substituting fossil fuels with low-carbon resources and clean energy technologies and
- reducing losses and waste along the food chain.

These points are all pertinent to the sustainable development issues covered in this paper. However, it must be noted that the food supply chain, particularly the primary production sector, is a complex system relying on healthy soils, adequate supplies of water and careful management of resources.

The concept of energy intensity is introduced to measure the effective use of energy in the food chain. In this paper energy intensity is defined as the amount of energy used per unit of food produced (MJ per ton of food produced). By addressing the energy status of the whole food sector, the paper highlights options for lowering the energy intensity, reducing food losses and increasing the local use of renewable energy resources. Any attempt to reduce energy inputs to the food sector or to generate energy supplies from this sector that would be detrimental to productivity, processing activities, or food quality should not be promoted.

This paper discusses the challenges mentioned above and offers practical ways to meet them. Emphasis is placed on energy in relation to food systems and rural development. FAO has advocated for the development of national policies to stimulate the integration of energy into the agricultural sector for over a decade (FAO, 2000). This paper expands the case by covering the whole food system and commodity supply chain, including:

- agriculture, fisheries and animal feed production;
- the manufacturing of tractors, machinery, equipment, inorganic fertilizers and agri-chemicals;
- the building of infrastructure;
- post-harvest operations;
- food storage and processing;
- transport and distribution; and
- retail, preparation and consumption.

The food sector uses around 30 percent of total global primary energy consumption. Energy consumption is typically disaggregated into direct or indirect energy. Direct energy is used at the operational level primarily on farms and processing plants, for example for irrigation, land preparation and harvesting. Indirect energy, on the other hand, is not directly consumed to operate farms, in fishing or processing plants. It includes the energy required to manufacture inputs such as machinery, fertilizers and pesticides.

This paper makes a distinction between direct and indirect energy **for** (used in) the food chain and energy **from** (that can be produced by) the food sector. Energy from the food chain includes renewable energy produced on farms or in processing plants. This type of renewable energy includes wind, solar, small-hydro and bioenergy. It can be used either on-site as a substitute for purchased direct energy inputs or sold for use off-site to earn additional revenue for the owner of the farm or processing plant.

Food losses along the whole supply chain are addressed, as avoiding this waste will lead to reductions in demand for land, water, energy and lower GHG emissions[4]. Forestry production and the wood product processing industry are not included, except where woody biomass by-products can be used to provide energy for the food sector or agro-forestry systems in rural landscapes. International trade and 'food miles' will not be discussed in detail, nor will issues relating to the impacts of energy use and management on water quality, soil nutrients, groundwater supplies, biodiversity, or management of a farm enterprise, unless there is a direct relationship with energy supply technologies.

4 This paper focuses on the mitigation of energy-related CO_2 emissions. More detailed analyses of mitigating CH_4, N_2O and HFCs produced from the food sector appear elsewhere, such as in the UK's *Foresight Project on Global Food and Farming Futures* (GoS, 2011) and in the USEPA (2006) report on non-CO_2 gases.

1.1 The key challenges

- The projected future higher costs of oil and natural gas, as well as insecurity regarding the limited reserves of these non-renewable resources (IEA, 2010), coupled with the global consensus on the need to reduce GHG emissions, could hamper global efforts to increase the volume and quality of food supplies to meet the growing demand for food.
- Food systems, from small local to large scales, will be required to produce more food, essentially through increased productivity. Over time, this will require improving access to modern energy services for subsistence farmers and rural communities.
- The global food system will need to provide sufficient, secure and 'climate-smart' food supplies over the coming decades. The losses along the food supply chain, currently around one-third of all food produced, will need to be reduced through appropriate policies, institutional and financial measurements.
- Becoming 'energy-smart' along the food chain by reducing its high dependence on fossil fuels, will require new policies and institutions, increased public awareness and education, behavioural changes and significant investments in clean energy technologies.

1.2 Major related issues

- *Increasing food demand.* The 'green revolution' of the 1960s and 1970s solved the food shortage problem at the time. This revolution was accomplished not only through improved plant breeding, but also by tripling the application of inorganic fertilizers, expanding the land area under irrigation and increasing energy inputs to provide additional services along the food chain. Today, the annual incremental yield increases of major cereal crops are declining and fossil fuels are becoming relatively more scarce and costly. Historical trends indicate an evident link between food prices and energy prices (Fig. 1). Further intensification of crop and animal production will be required to feed the world's population, which is projected to expand to over 9 billion people by 2050. The report, "*How to Feed the World by 2050*" (FAO, 2009a) indicates that a 70 percent increase in food production compared to 2005-2007 production levels will be needed to meet the increased demand. This equates roughly to the additional production of around 1 000 Mt of cereals and around 200 Mt of meat and fish per year by 2050. These production gains are largely expected to come from increases in productivity of crops, livestock and fisheries. However, unlike the 1960's and 1970's green revolution, our ability to reach these targets may be limited in the future by a lack of inexpensive fossil fuels.

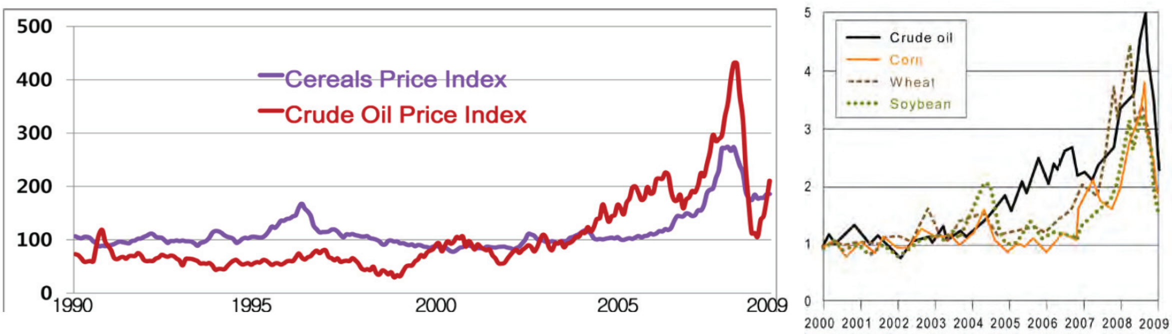

Figure 1. Comparative trends of crop commodity and oil price indices from 2000-2009 (Heinberg and Bomford, 2009) and from 1990 to 2009 (with 2004 as baseline) (Kim, 2010).

- *Economic viability.* The volatile prices and possible future supply scarcity of fossil fuels and the heavy reliance of the food industry on these non-renewable energy resources, raises concerns about the availability and affordability of food as well as on the economic viability of some food-related businesses in the years to come. If fossil fuel prices continue to rise and carbon charges are added to cover the externality costs of GHG emissions released during their combustion, the costs of tractor and boat fuel, agri-chemicals and fertilizers, food processing and transportation will all increase. This situation could cast doubt on the premise that, since farm land and fishing stocks are limited, future increases in food production will come mainly from crop yield increases, particularly through the application of higher external energy inputs in less intensive systems. Further intensification in primary agricultural production, together with any land expansion and intensification in activities beyond-farm gate, should ideally be gradually disconnected from additional fossil fuel demands if the world is to move towards a low-carbon, less fossil fuel dependent, food sector.
- *Environmental impacts.* Primary production and the entire food supply chain contribute approximately 22 percent of total annual GHG emissions. An additional 15 percent of GHG emissions results from land use changes, particularly changes linked to deforestation brought about by the expansion of agricultural land (IPCC, 2007). Additional risks from potential impacts of climate change on food supply security requires a careful evaluation of the resilience of the food sector. Analyses of probable climate change impacts on agricultural productivity up to 2050 have shown that negative impacts on the sector are most likely. These impacts may reduce the availability of food and cause declines in human well-being, particularly in developing regions (Spielman and Pandya-Lorch, 2010; Fischer *et al.,* 2009).
- *Competing land uses.* Income growth in developing countries will lead to higher consumption of milk and meat products (FAO, 2011a), which will increase the demand for cereals for livestock feed. In addition, if the demand continues to grow for commodities such as maize as feedstock for liquid biofuels for transport, pressure will increase to boost cereal production. In some areas, urban development and desertification are also placing significant pressures on land. All the above factors are contributing to increasing competition for agricultural land.
- *Energy access.* The poor availability of efficient modern energy services in many regions is a fundamental barrier to sustainable development and to meeting the MDGs. Providing these energy services is a basic necessity that would improve both the health and livelihoods of many people living in rural areas in low-GDP countries (section 3.3).

In summary, fluctuating energy prices, future energy security and concerns on GHG emissions present challenges for the food sector as it seeks to reduce its environmental impact and support sustainable development. A new paradigm of agriculture and food production is needed to respond to the increasing competition for land and water, rising energy costs and the subsequent price increases for inputs produced from fossil fuels and the anticipated impacts of climate change. In this new paradigm, farmers, fishermen and food processors and distributors will need to learn to 'save and grow' (FAO, 2011a).

1.3 The relative scales of food systems

The spectrum of food systems is complex and diverse. These systems range from basic subsistence smallholder farmers growing food for their own consumption to large commercial, corporate farms supplying huge supermarket chains across the world. All of these systems are dependent on energy. Human and animal power, commonly used in small-scale operations, but is being increasingly substituted with fossil fuels in regions where these are relatively inexpensive. In most countries, small-scale farmers provide fresh food not only to local markets, but to processing plants as well. Demand for low-input, chemical free, organic food continues to grow, mainly in OECD countries. Section 4.4 discusses in more detail the relationships between low-input, chemical free and organic agriculture with energy consumption and intensity.

In some developing countries, modern food systems are evolving rapidly. In China, for example, supermarkets are starting to dominate the food supply chain (Vorley B, 2011). Therefore, when discussing the linkages between energy and food, it is no longer practical to classify countries using standard comparisons such as OECD or non-OECD, developed or developing, traditional or conventional, and subsistence or industrialised. It can be helpful for comparison purposes to classify countries according to their major differences in the food chains. For this paper, it was decided to use the terms '*high-GDP*' and '*low-GDP*'. The term high-GDP describes the top 50 or so countries measured in terms of their GDP on a purchasing power parity basis divided by their population. The term 'low-GDP' applies to the remaining 176 or so nations.[5]

To assist the reader to better understand the energy concepts being discussed and their relation to practical primary production enterprises at various scales, this paper will mostly differentiate between 'small' farm and 'large' farm enterprises, even though defining rigidly clear boundaries between these two terms is not possible. Table 1 illustrates the relationship between the concepts discussed throughout this paper. However, there are many exceptions to this typology. For example, small enterprise tea plantations employ many pickers or small family fishing boats have relatively high fossil fuel dependence and related costs.

Scale of producer	Overall input intensity	Human labour units	Animal power use	Fossil fuel dependence	Capital availability	Major food markets	Energy intensity
Subsistence level	Low	1-2	Common	Zero	Micro-finance	Own use	Low
Small family unit	Low	2-3	Possible	Low/medium	Limited	Local fresh/process/ own use	Low to high?
	High	2-3	Rarely	Medium/high	Limited	Local fresh/regional process/own use	Low to high?
Small business	Low	3-10	Rarely	Medium/high	Medium	Local/regional/export	Low to high?
	High	3-10	Never	High	Medium	Local/regional/export	Low to high?
Large corporate	High	10-50	Never	High	Good	Regional process/export	Low to high?

Table 1. Simplified typology of typical 'small' and 'large' scale farms and fisheries based on qualitative assessments of unit scale, levels of production intensity, labour demand, direct and indirect fossil fuel dependence, investment capital availability, food markets supplied and energy intensity. (Notes: 1) Supplying supermarket retailing companies is feasible at all levels other than subsistence. To do so, small or large producers usually have to invest in modern storage facilities that require fossil fuels or electricity. 2) The table shows that no automatic correlation exists between input intensity and fossil fuel dependency).

Subsistence. Households engaged in the most basic forms of small-scale, agricultural and fishing activities produce food solely for their own consumption. Subsistence producers use very low energy inputs, usually deriving from human and animal power. These energy inputs are usually not included in world energy statistics, in part because they are so diffuse. Also, energy balance data is unavailable on the total additional food and feedstuffs needed to offset the energy input required for human and animal power use . Gaining access to energy and securing an adequate livelihoods are the main priorities for subsistence farmers and fishers. However, lack of financial resources limits their ability to meet these priorities. (section 3.3).

5 Index Mundi web site: http://www.indexmundi.com/g/r.aspx?v=67.

Small farms. Depending on the degree of modernization, 'small' family units may engage in a variety of activities, including cultivating small gardens or rice fields, growing organic vegetables, tending orchards, raising livestock, operating privately-owned fishing boats and maintaining dairy herds (from a few up to dozens of cows). Energy efficiency options usually exist for these small enterprises, except for those that depend solely on human and animal power. Small mixed farms may utilize other forms of direct energy such as solar heat for crop drying, on-farm produced biogas for cooking, and electricity generated from a solar photovoltaic (PV) system.(Fig. 2).

Small businesses. They can be family-managed but are usually privately-owned. They operate at a slightly larger scale and employ several staff. These businesses have opportunities to reduce their fossil fuel dependence by improving energy efficiency and generating on-farm renewable energy, which could provide additional benefits for the local community.

Large farms. At the other end of the spectrum, corporate[6] food systems are dependent on high direct external energy inputs throughout the supply chain (Fig. 3). Examples of these systems include fishing trawler fleets, beef feedlots, sugar companies and palm oil plantations. Large farm estates may be owned and managed by a processing mill company. When they are owned by a growers co-operative, some benefits are more likely to flow to the local community. Large corporate organizations usually have access to finance for capital investment for energy efficient equipment and renewable energy technologies. Energy may be used on-farm or sold off-farm for additional revenue.

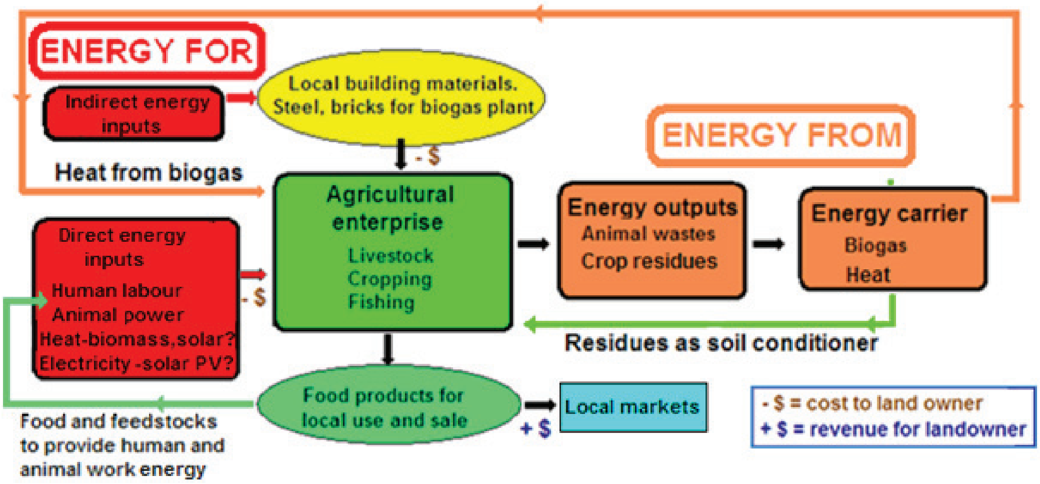

Figure 2. Example of a 'small-scale', low-input, family-managed, farming enterprise showing energy flows through the system. Outputs are primarily fresh food for local consumption, although they may also be delivered to local processing companies. Along with human and animal power, some direct energy inputs can be obtained from other sources, such as solar thermal and solar PV systems and biogas produced using a simple anaerobic digester.

6 'Industrialized', 'market-based', 'commercial' and 'multi-national' are terms used synonymously with "corporate" to describe modern, large-scale, food systems that produce food, fish, feed or fibre.

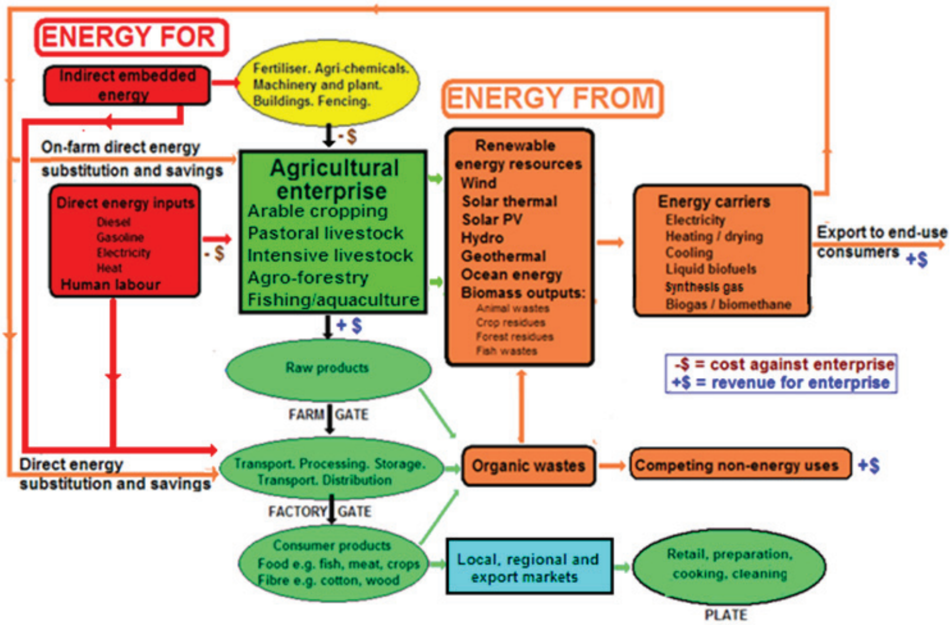

Figure 3. Energy flows through a 'large-scale', high-input, corporate business enterprise with raw food products mainly supplying local and regional processing plants, supermarket chains and exporters. Renewable energy resources, when available from farms and processing plants, can be utilized on-site to substitute for purchased direct energy inputs or exported off-site to earn revenues from both food and energy products.

The transition from subsistence fishing and farming methods to more advanced production enterprises will require investments in machinery, fertilizers, irrigation, transport and infrastructure. All of these investments require energy. Should more low-GDP countries choose to make this transition, both the global demand for energy will increase, as will GHG emissions. For this reason, industrializing agricultural systems by increasing fossil fuel inputs may no longer be a feasible and justifiable option. Leapfrogging to more efficient systems and using renewable energy, which would allow fossil fuels to be reserved for areas where no other affordable energy options exist, could be the most viable solution for the food sector during the coming decades.

1.4 Aim and objectives

The overall aim of this paper is to present the current energy status of the food sector from both the demand and supply perspectives and to identify opportunities where the entire food supply chain could become more 'energy-smart'. Energy-smart food systems use low-carbon energy systems in an efficient manner, provide greater energy access to support productive activities in agricultural and fishing communities, meet their livelihood needs, and enable the achievement of national food security and sustainable development goals. This paper's specific objectives are to:

- outline the current status of the entire spectrum of food supply chains;
- illustrate alternatives means by which small and large-scale farmers and fishers can become less vulnerable to future energy supply interruptions and price fluctuations while reducing GHG emissions;
- discuss how access to modern energy services can be provided to subsistence farmers to increase productivity, reduce food losses and improve livelihoods;
- evaluate how the fossil fuel dependency of the transport and processing components of the food sector can be reduced together with energy costs and GHG emissions;

- consider how renewable energy systems, including bioenergy generated from local biomass resources, can be deployed to benefit the sector by:
  - supplying direct energy inputs for farms and fisheries;
  - selling excess energy off-farm to gain additional farm revenue;
  - supplying energy to the food processing industry;
  - providing liquid biofuels for transport; and
- highlight the link between energy and food losses to strengthen the case for minimizing food losses along the supply chain and during consumption;
- briefly discuss policies that can be employed at various levels to improve knowledge and capacity, and develop the resilience of the sector to adapt to possible future energy supply constraints and climate change impacts; and
- identify gaps in knowledge where further research would be beneficial.

Since having a reliable and affordable energy supply can contribute to sustainable development, this paper will be of value for those policy-makers, businesses, governments and other stakeholders involved with food security and who are:

- negotiating on-going climate change issues through the United Nations Framework Convention on Climate Change (UNFCCC);
- organizing or planning to attend the "Rio+20 Earth Summit" in 2012 which will address major issues related to the green economy in the context of poverty eradication and sustainable development and an Institutional Framework for Sustainable Development;
- responding to the Energy for a Sustainable Future report produced in 2010 by the UN Secretary General's Advisory Group on Energy and Climate Change;
- preparing the 5th Assessment Report of the Intergovernmental Panel on Climate Change, due for release in 2014; and
- undertaking various Sustainable Energy for All initiatives, including the UN 'International Year of Sustainable Energy for All' in 2012.

This paper considers four key elements in relation to energy in food systems and rural development:

- having the right energy mix to meet the goal of producing 70 percent more food by 2050;
- contributing to rural livelihoods in a sustainable way;
- providing affordable and secure energy now and in the future; and
- addressing how the food industry can become more sustainable and energy-smart.

2. Energy inputs for food supply chains and GHG emissions

Once conventional oil and gas flows reach a peak as is predicted, the food sector's continued reliance on these non-renewable resources for production, processing and transportation activities will lead to greater business risks, especially from unpredictable price spikes. Excluding human and animal power, on-farm direct energy demand is around 6 EJ/yr[7] (Fig. 4). Slightly over half of the on-farm energy is consumed in OECD countries. This energy is used mainly for pumping water, housing livestock, cultivating and harvesting crops, heating protected crops, drying and storage (OECD, 2008). In addition, indirect energy demands for operating boats, tractors, and other farm machinery as well as for fertilizer manufacturing is around 9 EJ/yr (GoS, 2011). The synthesis of nitrogenous fertilizers alone consumes approximately 5 percent of the annual natural gas demand (around 5 EJ/yr). For fisheries, global[8] primary production directly consumes around 2 EJ/yr[9] of total final energy (Muir, 2010; FAO, 2009b). Fisheries direct energy consumption is mainly associated with boat propulsion, pond aeration and water pumping. Around 0.4 EJ/yr of indirect energy is embedded in aquaculture feedstuffs (Smil, 2008). These figures illustrate how heavily dependent agriculture is on the energy sector (GoS, 2011).

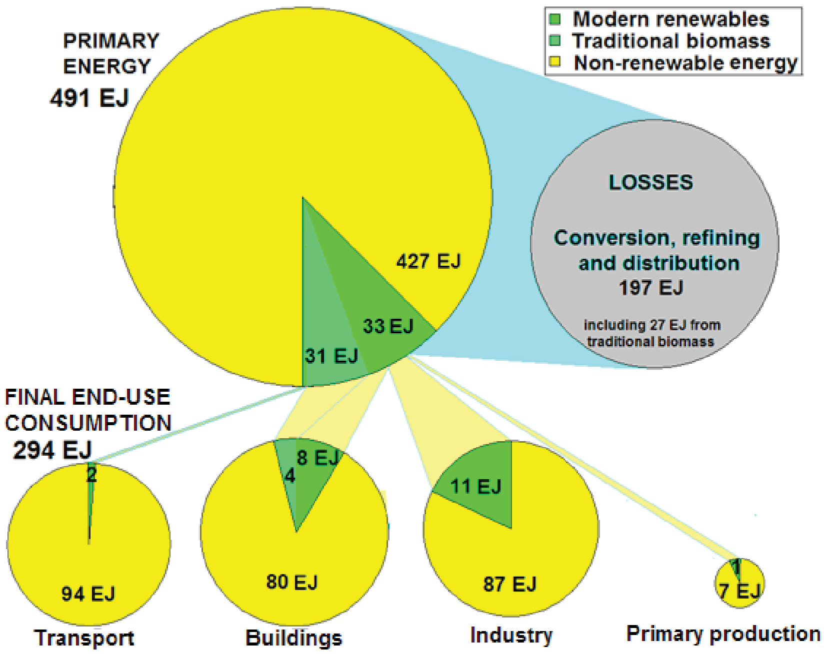

Figure 4. Global final end-use consumption energy in 2008 characterized by primary energy sources from renewable, non-renewable (oil, coal, gas and nuclear) and traditional biomass and presented by major sector. The food sector includes direct energy for primary production (agriculture and fishing) as well as shares of the transport and industry demands for fertilizer manufacturing, food processing etc. (not shown). (Data from IEA, 2010 converted to direct equivalent accounting method. Figures based on IPCC, 2011a).

7 Data is uncertain and varies according to the methodology used to gather and analyze it. For example Schneider and Smith (2009) show global direct energy input for agriculture has stabilized at around 7.1 EJ/yr between 1990 and 2005, whereas Giampietro (2002) gives 5 EJ for 'fuel' plus 1 EJ for irrigation, electricity and heat with an update of this work (Arizpe *et al.*, 2011) indicating over 9 EJ in 2003 for direct plus indirect energy inputs.

8 When global data are quoted they can mask the differences between OECD/high GDP and non-OECD/low GDP food systems, since the latter often have poor data availability, which is therefore not always fairly represented in the totals.

9 Data is uncertain, with estimates in the literature varying by over 50 percent.

Fossil fuel consumption for agriculture is higher in high-GDP countries (around 20.4 GJ/ha) than it is in low-GDP countries (around 11.1 GJ/ha) (Giampietro, 2002). The use of fossil fuels can result in lower energy intensity when crop yields are increased (Table 2). Fossil fuels have also reduced human labour. Typically around 152 MJ of fossil fuel inputs is equivalent to one hour of manual labour in high-GDP countries. In low-GDP countries, one hour of manual labour is equivalent to 4 MJ.

Table 2. Crop yields and energy intensities for US corn production in 1945 compared with 2007 (Smil, 2008).

	1945	2007
Energy inputs (GJ/ha)	6	18
Corn yield (t/ha)	2.2	9.0
Energy intensity (GJ/t)	2.7	2.2

In high-GDP countries, energy used for processing, transport and food preparation is usually around three to four times the amount used for primary production (Smil, 2008). However, these inputs are complex, difficult to assess and vary widely with region[10] (Fig. 5). The dominance of energy for cooking is evident in Africa, which has lower shares of energy used for production and transport compared with USA. In the USA, the overall energy input/food output ratio is around 7 to 1 (Heller and Keoleian, 2000).

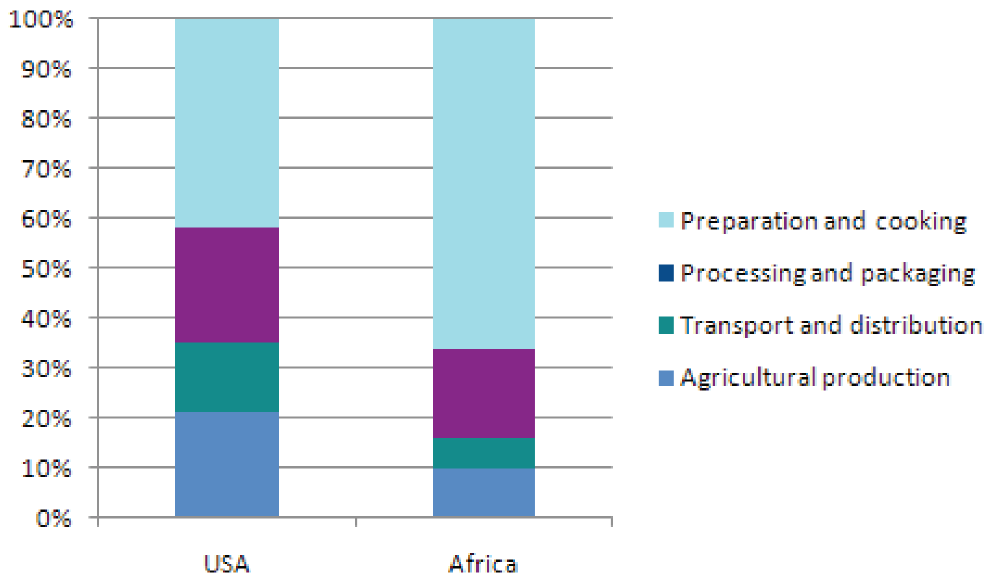

Figure 5. Indicative shares of energy inputs in the food supply chain comparing extreme examples of high-GDP and low-GDP. (Heller and Keoleian, 2000; FAO, 1996).

The end-use energy demand of the global food sector is around 32 percent of current total global final energy demand (Fig. 6). The food sectors in high-GDP countries consume over half of the global energy demand for the sector. However, high-GDP countries have a much higher rate of energy use per capita rate than low-GDP countries. High-GDP countries also have a higher share of energy inputs in processing and distribution (as also shown in Figure 5, split into two categories).

10 The uncertainty is mainly due to lack of accurate data from many developing countries and differences in calculation methods.

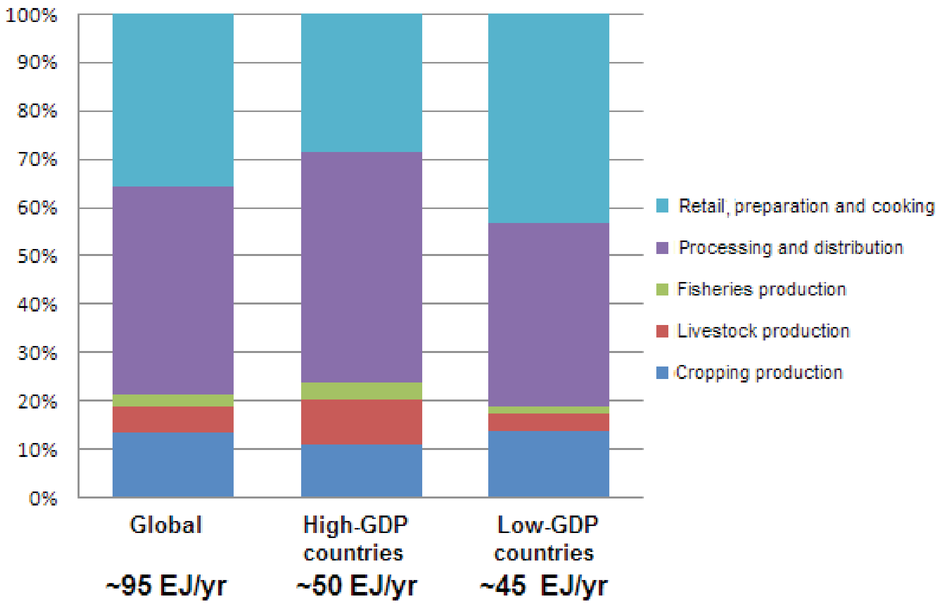

Figure 6. Indication of global, shares of end-use energy demands throughout the food supply chain showing total final energy for the sector and a breakdown between high-GDP and low-GDP countries. (Based on Giampietro, 2002; Smil, 2008; IEA, 2010; Woods et al., 2010; GoS, 2011 and others)

Caveat. It should be noted that Figures 6 and 7 are *indicative only* and should be interpreted with care. FAO analyses were based on the range of data available, but these data were at times unreliable, incomplete and out of date since related energy and GHG data as presented in the literature.

GHG emissions from the entire food chain, including landfill gas produced from food wastes, account for around 22 percent of total emissions (Fig. 7). Globally, energy-related CO_2 emissions throughout the food sector have a lower impact than methane from rice paddies and ruminant livestock (goats, sheep, cattle, deer) combined with nitrous oxides from nitrogenous fertilizers, soil and animal wastes. Primary production accounts for around 14 percent of the total global GHG emissions (Annex 1). This is mainly from methane emissions, which in low-GDP countries are twice as high as those from high-GDP countries. However, when calculated on a per capita basis, these emissions are considerably lower in low-GDP countries (IPCC, 2007a). A greater share of CO_2 emissions arises in high-GDP countries. These emissions are produced from the combustion of fossil fuels to generate heat and electricity for food storage and processing, and from the use of petroleum fuels for food transport and distribution.

Literature is starting to appear with life cycle analyses (LCAs) of the energy demand by the transport, distribution and retail components of the food supply chain.[11] LCA comparisons can provide useful indicators of the impacts of current food production options and the potential impacts from changing demand, but care is needed in interpreting the results[12]. Numerous LCAs have been undertaken to calculate total GHG emissions associated with individual food products. Williams *et al.*, (2007) examined seven products for the UK market. Their report concluded that food imports from countries where productivity is greater or where refrigerated storage requirements are lower could have a smaller carbon footprint than locally produced food. This key point is discussed further in section 2.3.

11 For example, a set of LCA publications is available from http://www.fcrn.org.uk/research-library/lca

12 LCA methodology varies widely in terms of attribution of GHGs to co-products and the boundaries assumed for accounting inputs. Some analyses include GHG emissions from land use change, others do not.

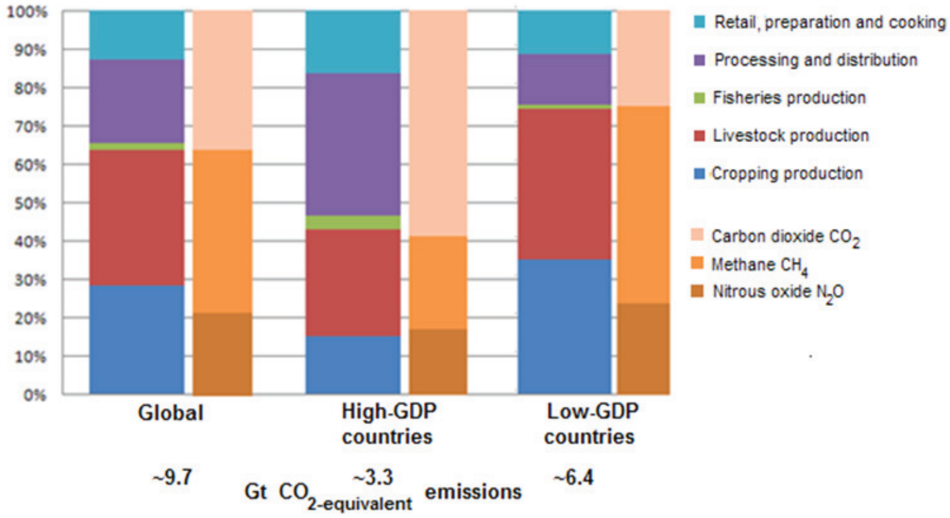

Figure 7. Global shares of GHG emissions along the food supply chain with breakdown by gas and also for high-GDP and low-GDP countries. (Based on Giampietro, 2002; USEPA, 2006; Smil, 2008; IEA, 2010; Woods et al., 2010; GoS, 2011 and others)

Typical breakdowns of GHG emissions from food supply chains and consumption patterns vary. Changes in total GHG emissions from the food sector over time can be useful indicators of system efficiency, particularly when linked with production and supply costs. Garnett (2008) showed that 18 percent of UK's total GHG emissions came from the food sector. Around half of these emissions came from agricultural production and the other half came from food processing, packaging, transport, retail, commercial food services, home preparation and food waste disposal. At the household level, Weber and Matthews (2008) calculated that the average household in the USA emitted a total of 8.1 t $CO_{2\text{-eq}}$, including 44 percent CO_2, 32 percent nitrous oxide, 23 percent methane and 1 percent CFCs and other industrial F-gases.

The following are the estimates of global GHG contributions from the fishery sector based on current total energy requirements:

- 40-90 Mt CO_{2eq}/yr from fuelling fishing vessels;
- 35-40 Mt CO_{2eq}/yr from aquaculture;
- 10-15 Mt CO_{2eq}/yr from post-harvest and processing.

Other global estimates include 3-4 Mt CO_{2eq}/yr from the air freighting of 435 000 t of fresh fish and up to 340 Mt CO_{2eq}/yr for non-air transport (GoS, 2011; FAO, 2009b).

A number of measures for changing agricultural processes and practices to reduce GHGs (Garnett, 2008) are being promoted. These include:

- stimulating carbon sequestration by increasing the use of conservation agriculture systems (no-till cropping);
- incorporating organic matter into soils;
- optimizing nutrient use through more precise dosages and better timing of applications;
- integrating aquatic systems with agricultural systems;
- improving productivity outputs per unit of GHG generated;
- anaerobic digestion of manure, slurry, fish and animal wastes; and
- reducing the carbon intensity of fuel and raw material inputs through improvements in energy efficiency, a better selection of materials and the use of renewable energy.

2.1 Energy for primary production

The major energy consuming technologies for crop and livestock production and fishing are outlined below. Major variations exist depending on the scale of enterprise and on the type of food produced (Fig. 8). The energy demand for the production of similar food products under different production systems can be use to compare fossil fuel dependency. For example, the direct energy inputs of an extensive, unsubsidised, grazing enterprise in Australia (2-3 GJ/ha) can be compared with intensive, subsidised, dairy farming systems in the Netherlands (70-80 GJ/ha) (Smil, 2008).

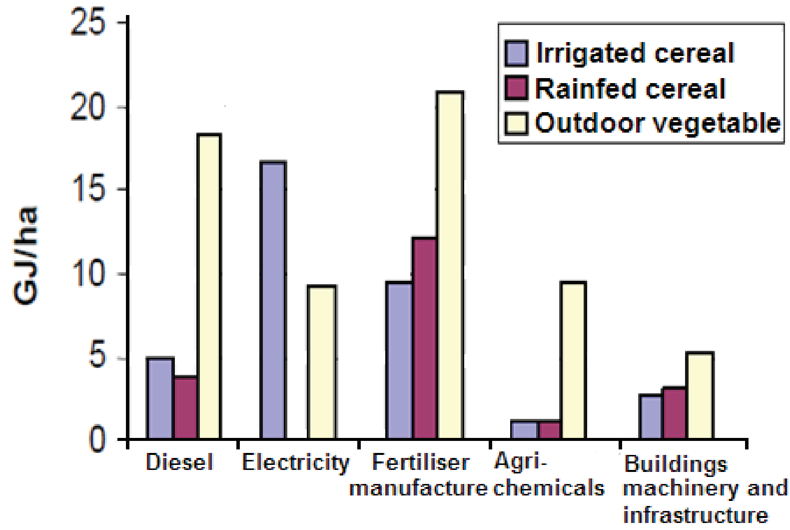

Figure 8. Shares of direct and indirect energy inputs vary with the type of primary production system, as illustrated here for different agricultural enterprises in New Zealand. (Barber, 2004)

Tractors and machinery. In 2005, the 27 million tractors operating in the world (around one-third in low-GDP countries) consumed around 5 EJ of diesel fuel for land development, transport and field operations (Smil, 2008). A further 1.5 EJ/yr was used for to manufacture and maintain tractors and farm implements. The additional fuel demands for the numerous two-wheel designs used mainly by smallholder farmers is not known. Increasing the level of agricultural mechanization, particularly in Africa where approximately 80 percent of farm cultivation is done using hand-tools and animal-powered technologies, will require:

- access to affordable and reliable fuel supplies;
- suitable financing arrangements;
- ownership agreements;
- hiring opportunities for tractors off-farm;
- availability of spare parts, maintenance and repair services; and
- skill upgrading and education (Ashburner and Kienzle, 2011).

In Bangladesh, the deployment of small, mobile, diesel engines, which could be used for a variety of purposes, including powering irrigation pumps, has revolutionized food production (Box 1). This example illustrates the benefits that inexpensive fossil fuels, often made available and affordable through government subsidies, have been able to deliver to smallholder farmers over recent decades.

Box 1. Low-cost machinery systems for small farms.

The introduction into Bangladesh of small, mobile, diesel engines that are demountable and can be used for a range of applications, including powering small boats, tractors or trucks, generating electricity, operating processing equipment and water pumps, has increased food production (Steele, 2011). Public policy changes enabled the import of innovative, Chinese-made, farm equipment. The diesel engines could be easily repaired by local mechanics and were less expensive compared with more sophisticated and more fuel-efficient machinery manufactured in India. The introduction of inexpensive Chinese technology led to the 'agro-tractorization' of Bangladesh. Seeing these results, Nepalese and Indian farm machinery manufacturers have recognized a new business opportunity. Small engines are now being sold mainly into low-cost, farm machinery markets in rural communities. Farm services have expanded as a result of the versatility and transportability of this equipment (Biggs and Justice, 2011).

Irrigation. The mechanical pumping of water on approximately 10 percent of the world arable land area (around 300 Mha) consumes around 0.225 EJ/yr to power the pumps. In addition, another 0.05 EJ/yr of indirect energy is required to manufacture and deliver irrigation equipment (Smil, 2008). Because irrigated lands produce higher yields than rainfed systems and allow for double and triple cropping, these lands provide around 40 percent of global cereal supply (FAO, 2011a). In Africa only 4 percent of cropland is irrigated, mainly due to a lack of available financial investment. In India, irrigation practices have increased yields but have contributed around 3.7 percent (58.7 Mt CO_{2-eq}) of the country's total GHG emissions in 2000 (Nelson *et al.*, 2009). Around two-thirds of global water supplies used for irrigation are drawn from underground aquifers. Energy intensive electricity pumping in deep wells accounted for two-thirds of the total, and projections suggest it will rise to 87 percent in 2050, as the shallower water reserves become depleted. Currently extraction rates exceed the rate of recharge. The threat of potential shortages of fresh water and the high cost of water desalination has led some countries to consider reducing their irrigated crop production and relying more on imported grain.

Fertilizers. Inorganic fertilizer use has contributed significantly to increasing crop yield in recent decades. This demand for inorganic fertilizers will probably continue to expand, mainly in low-GDP countries. In 2000, energy embedded in the production of inorganic fertilizer was around 7 EJ globally (Smil, 2008; Giampietro, 2002; GoS, 2011). Nitrogen fertilizer production alone accounts for about half of the fossil fuels used in primary production. Significant amounts of nitrous oxide can be emitted during the production of nitrate (GoS, 2011). The average annual application of nitrogen, phosphorus and potassium macro-nutrients range from zero in sub-Saharan Africa to 500, 50, 100 kg/ha respectively in double-cropped Chinese rice fields (Smil, 2008). Nitrogen uptake by crops tends to be inefficient. In some regions of China, for instance, uptake is around 28 percent for cereals and only 20 percent for vegetables (Miao *et al.*, 2011).

Livestock. Intensive livestock enterprises usually rely on feed delivered to the farm. This can constitute a significant component of total energy inputs (Table 3). Extensive pastoral systems for sheep, goats, deer and cattle tend to have lower energy inputs than intensive livestock systems. However, these extensive systems also often rely on some energy embedded in purchased feed or for forage crop production and hay and silage conserved on-farm. Regional differences are evident, with low-GDP countries consuming around 1 MJ of fossil fuel per MJ of animal product while high-GDP countries consuming around 4.3 of MJ fossil fuel per MJ of animal product (Giampietro, 2002).

Table 3. Total on-farm energy inputs (including indirect energy for feed, buildings and equipment) per unit of animal food product (Smil, 2008).

Food product	Animal feed conversion	Direct and indirect energy inputs
Chicken	4.2 kg/ kg edible meat	25 - 35 MJ/ kg meat
Pork	10.7 kg/ kg edible meat	25 - 70 MJ/ kg meat
Beef (feedlots)	31.7 kg/ kg edible meat	80 - 100 MJ/ kg meat
Laying hens	4.2 kg/ kg eggs	450 - 500 MJ/ year
Dairy milk	0.7 kg/ litre milk	5 - 7 MJ/ litre of fresh milk
Fish (trawler capture)		5 - 50 MJ/ kg (mainly liquid fuel inputs)
Shrimps		107 - 121 MJ/ kg

Protected cropping. Greenhouse designs are used for fruit, vegetable and flower production in peri-urban areas. These production systems use a closed cycle system or hydroponic or aeroponic systems to deliver water and nutrients without soil. They rely on relatively high direct energy inputs, particularly for artificial lighting and heating. Energy inputs can be around 40MJ/kg for fresh produce, such as tomatoes or peppers (FAO, 2011a). In countries such as China and South Korea, the area used for simple shade houses is increasing, but their energy inputs are low compared with energy-intensive heated greenhouses used in other parts of the world. In general, crops grown in greenhouse can have energy intensity demands around 10 to 20 times that of the same crops grown in open fields (Saunders and Hayes, 2009).

Fishing. The global fishing fleet captures around 80-90 Mt of fish and invertebrates each year and consumes around 620 liters of fuel per tonne of catch (Tyedmers *et al.*, 2011). Capture fishing is one of the most energy-intensive methods of food production. Small-scale enterprises produce around half of the total fish catch using a fleet consisting of about 4.3 million small vessels. Two-thirds of these vessels are powered by internal combustion engines powered by fossil fuels. The rest of the fleet, mainly located in Asia and Africa, use sails and oars (SOFIA, 2010). Aquaculture produces an additional 55 Mt of product per year. In 2008, 44.9 million people, more than double the number in 1980, were directly engaged, full time or part time, in capture fisheries and aquaculture. This represented 3.5 percent of the 1.3 billion people economically active in the broad primary agricultural production sector worldwide (SOFIA, 2010).

Boats are relatively high fuel consumers. Most boat owners are working to reduce energy demand since fuel costs, typically represent about 15 percent of total costs (Muir, 2010) and about 50 percent of catch revenue for some enterprises (FAO, 2009b). Small boats mostly have inefficient engines with high rates of fuel consumption that cannot be easily improved. There is, however, little data on their use. Indirect energy inputs for boat building and maintenance accounts for around 10 percent of fuel energy consumption (Smil, 2008).

Aquaculture enterprises (fish farming and mariculture) are expanding. Some of these enterprises, such as shrimp farming, rely on direct energy for pumping and aerating water, as well as on indirect energy for producing and delivering feed. Muir (2010) calculated that the total demand was around 0.05 EJ/yr of direct energy and approximately another 0.3 EJ/yr for indirect energy. This equates to around 100-200 MJ per kg of fish protein (Smil, 2008). However, energy input estimates vary widely in the literature.

Forestry. Energy inputs per hectare over the life of a plantation forest are relatively low. Energy is mainly used to operate machinery for harvesting and replanting and possibly for the application of fertilizer. Energy demands of forestry and timber production and processing are not included in this paper.

2.2 Drying, cooling and storage

To maintain their quality, cereals are normally dried artificially after harvest and before storage and transport. Electricity, natural gas or liquified petroleum gas (LPG) can be used to provide heat at around 0.5 - 0.75 GJ/t to dry wet grain down to an acceptable moisture content for storage. Crop drying and curing can be one of the more energy-intensive on-farm operations. For example, in Zimbabwe, tobacco curing accounted for over half the total on-farm energy demand (FAO, 1995). Solar heat can also be used for drying grain or fruit, either in the open air or in solar-heated facilities.

Smil (2008) calculated that food storage involves between 1-3 MJ/kg of retail food product. Refrigeration can have significant GHG contributions when electricity inputs, manufacture of cooling equipment, and GHG emissions from lost refrigerants are taken into account. Refrigerated storage, including during transport, can account for up to 10 percent of the total food supply carbon footprint for some products (Cleland, 2010). The refrigeration component of the carbon footprint for the UK food supply chain showed that 40 percents is attributed to domestic refrigeration, 31 percent for retail, 24 percent in the transport sector and 5 percent comes from energy embedded in equipment manufacturing.

Drying and cooling are not always practiced in low-GDP countries where post-harvest losses can be high (see section 3.4).

2.3 Transport and distribution

Given the fluctuating prices for fossil fuel prices, transport and distribution are particularly vulnerable components of the food chain. In 2000, global food shipments totaled over 800 Mt (Smil, 2008). This amounts to over 130 kg per person. Transport, under certain circumstances, can account for between 50 to 70 percent of the total carbon footprint of some food products, as is the case when fresh fruit or fish are delivered by road to markets several hundred kilometres away. However where poor roads restrict long-distance travel to markets, as in low-GDP countries, energy used for transport may be negligible.

Locating production and handling of food closer to areas of high population density can help to reduce transport energy inputs (Heller and Keoleian, 2000). However, since long distance transport by ship or rail can be done at relatively low ratios of energy per ton per km (Table 4), producing specific crops and animal products in locations where productivity is naturally high can provide energy savings that compensate for the relatively little extra energy required for their transport to distant markets. The trend towards buying food at 'farmers markets' that sell only local produce may in some cases save relatively little energy on transport. However, since the food at farmers markets is usually sold fresh or minimally processed, the buying local approach can be more energy-efficient than purchasing heavily processed and packaged supermarket goods (Bomford, 2011). For the average household in the USA, 'buying local' would reduce GHG emissions at the most by around 4-5 percent (Weber and Matthews, 2008).

Table 4. Shares and relative energy inputs by different mode of freight transport (Bernatz, 2010; Smil, 2008; Heinberg & Bomford, 2009)

Mode	Share of global transport (% of total t km)	Global shares of local distribution transport (% of total t km)	Energy intensity of travel mode (MJ /t km)
Rail	29%	16%	8-10
Marine shipping	29%	Not applicable	10-20
Inland waterway	13%	19%	20-30
Road trucks	28%	62%	70-80
Trolley, cycle, tractor	Data not available	3%	Variable
Aviation	1%	0 (domestic only)	100-200

When fresh fruit is exported, international shipping constitutes an important component of the total energy used. For example, shipping can account for up to 45 percent of the energy consumed to export fresh fruit from New Zealand to Europe[13] (Cleland, 2010). Air transport is costly in terms of energy intensity and economic costs, therefore rarely used. For example, only 0.5 percent of the fresh fruit imported to the USA is shipped by air (Bernatz, 2010). Globalization in the past two decades appears to have increased the average distance travelled by food products by 25 percent. In the USA, taking an extreme case, the average household consumes around 5 kg per day of food with the average transport distance per kg totalling 8 240 km[14]. However, total global GHG emissions from transport of food remain far smaller than emissions from primary production (Weber and Matthews, 2008). Trips by consumers to purchase food can account for an additional 1 to 4 MJ of vehicle energy inputs per kg of food purchased.

2.4 Food and beverage processing

The total amount of energy needed for processing and packaging is estimated to be between 50-100 MJ per kg of total retail food product (Smil, 2008). The food processing industry requires energy for heating, cooling, and electricity. The total energy demand for food processing is around three times the direct energy consumed behind the farm gate (White, 2007). In addition, energy is embedded in the packaging, which can be relatively energy-intensive due to the use of plastics and aluminium. For processing fish, the direct energy demand for ice, canning, freezing, drying or curing and producing fish meal and fish oil by-products is around 0.5 PJ per yr (Muir, 2010).

13 Frater (2011) undertook detailed surveys of various stakeholders and calculated that 7.67 MJ of energy were consumed per kilogram of apples produced in New Zealand and delivered to Europe (1.45 MJ in the orchard; 0.51 MJ during post harvest; 1.46 from packaging; and 4.24 MJ for shipping).

14 The total freight transport distance to meet food demand from farm to retail (including transport of seeds, fertilizers and feed for livestock), was approximately 1 200 billion t-km, or around 15 000 t-km/ household/yr. 1997 data updated to 2004, including imported food that is likely to have increased the average distance to markets since 1997.

2.5 Food retailing, preparation and cooking

Household food storage and preparation, an important part of any food system, consumes energy. Electricity and heat are used for essential activities. Heller and Keoleian, 2000 estimated that operating refrigerators and freezers requires around 40 percent of total household food-related energy; cooking meals in stoves, ranges and microwave ovens is around 20 percent; and heating water and operating dishwashers (around 20 percent).

Cooking consumes on average globally 5-7 MJ per kg of food but in low-GDP countries it can be much higher. For example when cooking rice using woody biomass on open fires that are only 10-15 percent efficient it can be as high as 10-40 MJ per kg. Using improved biomass stoves of between 20 to 40 percent efficiency would reduce fuelwood energy demand. Certain products require longer cooking periods thus energy consumption is higher. For example, cooking beans takes around eight times longer and can require more than 200 MJ per kg food (Balmer, 2007). Efficient cooking technologies couple with cleaner energy sources can improve energy consumption, for example in China, home digesters can produce about 24 MJ of biogas per day. This is sufficient to cook three meals and provide lighting for a household of five (Bogdanski et al., 2010a). Washing dishes with hot water consumes around 2-4 MJ per kg of food consumed (Smil, 2008).

The total energy used to put food on the table can represent a significant share of a nation's total consumer energy consumption. For example, it is nearly 16 percent in the USA (Canning *et al.*, 2010), around 20 percent in UK (GoS, 2011) and around 30 percent in New Zealand, a food exporting country (CAE, 1996). In low-GDP countries, in spite of the lower demand for transport and food processing, the food sector's share of national energy consumption can be relatively high. In some African countries, for example, the share of national energy used for the food sector can be as high as 55 percent. Typically, this energy demand for primary production is around 10 percent, for food transport and processing 15 percent, and for cooking and preparation up to 75 percent (FAO, 1995).

The total energy-related cost as share of the production cost varies widely for food products and can be significant for some food systems. For example, in the USA the energy-related costs as a proportion of total crop production ranged from 10 percent for soybean to 31 percent for maize (DEFRA, 2010). In low-GDP countries agricultural development can be limited by the costs of fossil fuel, particularly in countries where imported fossil fuels are a high burden on total GDP. Total energy-related costs as a share of the total purchase price to the consumer also vary widely with the food product and across countries. But it is usually affected differently than production costs. For example in high-GDP countries the proportion is usually relatively low but in low-GDP countries this cost may be significant. In the latter case it is often related to higher transport costs that triggers higher food prices. This negatively impacts on food security since a high proportion of household income is used to purchase food. In both cases energy costs have a significant impact. This is why the correlation between energy prices and food prices is an area of prime concern. Farming costs are more and more dependent on and linked to fossil fuels. Impoverished people, whether they are small-scale producers or staple food consumers, are the most vulnerable to price fluctuations and spikes. Future high and volatile fossil fuel prices, global energy scarcities and the need to reduce GHG emissions are the key reasons why the global food sector needs to become more 'energy-smart'.

3. Improving efficient use of energy by becoming energy-smart

Reducing the energy intensity, that is the amount of energy used per unit of food produced throughout the entire food chain, depends upon:

- behavioural changes,
- the development and deployment of more low-carbon farming and fisheries practices, and
- new technologies with improved energy efficiency specifications.

For several decades, energy efficiency measures behind the farm gate (section 3.1) and beyond the farm gate (section 3.2) have been promoted in high-GDP countries with varying degrees of success. Historically, energy costs have been a small component of the total operating costs for many food businesses. For this reason, incentives to reduce energy demands have not been strongly promoted. However, today as energy costs have increased and more businesses set targets to reduce their carbon footprints, there is renewed interest in improving energy efficiency. In addition, as new energy demands from expanding food sectors in low-GDP and newly industrializing countries are increasing, efforts are being made to minimize their energy intensities (Schneider and Smith, 2009). Opportunities to reduce the energy intensity can come from modifying at no or little cost existing farming and processing practices. These modifications would also require changes in the behaviour of farmers, managers and operators. Introduction of new modern efficient equipment is another option. However, this may require significant capital investment. Producers in low-GDP countries may be faced with financial constraints to adopt improved energy efficient technologies, such as precision farming, irrigation monitoring, improved boat propeller designs, transport logistics using GPS[15] light emitting diodes, heat exchangers and variable speed electric motors among others. Options need to consider the balance between efficiency measures, projected energy costs and the need of improving energy access and affordability (Box 1 in Section 2.4.).

Energy conservation and efficiency measures can be achieved in several ways at all stages along the food chain (Table 5). These measures can either bring direct savings through technological or behavioural changes or indirect savings through co-benefits derived from the adoption of agro-ecological farming practices. For both large and small systems, any means of avoiding food wastage (section 3.4) should be encouraged, since this represents a waste of resources used in their production. Preventing food wastages can usually result in considerable savings of the energy used in producing food that no one consumes. Avoiding food losses can also help reduce the competition for land and water. More details are provided in the following sections.

The applicability of energy efficiency alternatives will need to be carefully assessed based on context specific situations. For large-scale food systems for example there are a number of opportunities including more technological and capital intensive options. For some small-scale systems on the other hand, there may be a case for increasing direct and indirect energy inputs over time in order to improve productivity and water use efficiency. In this case, the efficient use of increased amounts of energy could possibly support agro-ecological farming practices that achieve good yields and benefit livelihoods.

15 Global positioning satellite systems can keep track of truck routes, speeds, road congestion ,etc.

Table 5. Examples of energy efficiency improvements through direct or indirect technical and social interventions along the food sector.

	Directly	Indirectly
Behind farm gate	• Fuel efficient engines / maintenance. • Precise water applications. • Precision farming for fertilizers. • Adopting no-till practices. • Controlled building environments. • Heat management of greenhouses. • Propeller designs of fishing vessels.	• Less input-demanding crop varieties and animal breeds. • Agro-ecological farming practices. • Reducing water demand and losses. • Energy efficient fertilizer and machinery manufacture. • Electronic identification of fish stock locations and markets.
Beyond farm gate	• Truck design and operation. • Variable speed electric motors. • Better lighting and heat processes. • Insulation of cool stores. • Minimizing packaging of food. • Technology transfer and education. • Improve efficiency of cooking devices.	• Improving road infrastructure. • Reducing food losses at all stages. • Matching food supply with demand. • Changing diets away from animal products. • Lowering obesity levels. • Labelling of food products.

Energy reduction strategies across the diverse range of food management options are complex and can involve making trade-offs. Two key points in this regard relating to primary production management practices should be emphasized.

- Methods used to reduce energy inputs that also lower productivity, such as just cutting back rather than optimizing the amount of fertilizer applied, are rarely beneficial and should be avoided.
- High-external input production systems do not necessarily have high energy intensities (MJ per kg product), especially when they result in increased yields (Table 1). Conversely, low-input systems can have relatively high energy intensities when lower yields result.

It should be noted that any improvements in energy efficiency carry the risk of a 'rebound effect'. The rebound effect occurs when reductions in energy demand result in lower energy prices which, in turn, encourage energy purchases in other areas (Barker and Dagoumas, 2009). For example a fisherman saving fuel by a more careful operation of the vessel can use the unspent money to purchase a larger outboard motor. While the scale of rebound effect and its duration are the subject of much debate, there is agreement that the phenomenon is real and should be taken into account when estimating overall energy savings.

3.1 Behind the farm gate

For primary production systems, the aim should be to produce more or similar amounts of food per unit of land or water with less energy. Many detailed assessments undertaken in past decades (see for example Leach, 1976; Stout, 1991; Netting, 1993; Pimentel and Pimentel, 1996) concur that increased intensification and technical progress across primary production systems require greater inputs of energy, but that the energy can and should be used efficiently to maximize the services delivered per unit of energy. More recently, Schneider and Smith (2009) compared agricultural energy intensities in low- and high-GDP countries. Since the 1960s, there has been a global steady increase in fertilizer consumption and machinery. Since the mid 1980s the energy intensities in high-GDP countries, have declined, due to the introduction of energy efficiency practices that have allowed a continued increment in crop yields. While the average energy intensity of agriculture in low-GDP countries can be lower than in high GDP countries, in more recent years, the increased use of fertilizers and mechanization in China and India in particular, has led to rising energy intensities. Taking these opposing trends into account, they concluded that overall global energy intensities started to decline slightly after the 1980s, though the trend varied widely between countries. Raising the national agricultural energy efficiency level of below-average countries to the global average could be achieved by employing a range of different energy efficient options. This has the potential to reduce annual GHG emissions by up to 500 Mt CO_{2eq} (Schneider and Smith, 2009).

Energy demand for primary production can be reduced by either reducing energy intensities or changing the volume and mix of the commodities produced to those that require lower energy inputs, for example, using soybean protein to displace animal products. Since the annual direct energy demand of the primary production sector represents only a small percentage of the total consumer energy in most countries, energy efficiency measures in this area will not make a significant contribution to reducing national energy demands. However, energy saving measures can significantly reduce production costs without affecting productivity, hence increase the profitability of individual enterprises, such as in capture fisheries where boats with rates of high fuel consumption are used. Besides containing costs, energy efficiency can also help to make food production less vulnerable to interruptions in energy supplies and reduce GHG emissions. Some examples are given below.

Tractors and machinery. Many methods of reducing tractor fuel consumption have been well researched and documented (see for example CAE, 1996). These methods include:

- better matching tractor and machinery size to farming needs;
- controlling tractor passes within 'tramlines';
- selecting tractor and harvester engines with higher fuel efficiencies;
- early retirement of high fuel consuming machinery;
- improving engine maintenance;
- correcting tire pressures; and
- implementing training programmes on tractor and machinery operation, repairs and maintenance.

Additional benefits can also result from the implementation of energy efficient options. For example, ensuring correct operation of tractor hydraulics and added ballast to optimize wheel slip can result in 10 percent lower fuel use, 20 percent savings in time and reduced soil damage (CAE, 1996). Some low-GDP countries, such as Kenya, are already well advanced in farm machinery use, so any fuel efficiency initiatives would produce similar results as for farming systems in high-GDP countries. The development of 'precision farming' techniques, such as GPS systems for the accurate application of agri-chemicals and fertilizers and electronic sensors for monitoring soil moisture, can have direct and indirect energy saving benefits (McBratney *et al.,* 2006). Occasionally, improving energy efficiency may be a lower priority for producers than increasing food output and gaining access to energy (section 3.3). For example, farmers in Bangladesh could not afford fuel-efficient tractor designs made in India but were able to gain access to inexpensive Chinese-built multi-application engines that boosted food production. (Box 1 and Biggs and Justice, 2011).

Irrigation. "Knowledge-based precision irrigation that provides reliable and flexible water application, along with deficit irrigation and wastewater reuse, will be a major platform for sustainable crop production intensification" (FAO, 2011a). Mechanical irrigation systems should be designed to use water as efficiently as possible, especially in the many regions where water supplies are scarce. Crops often take up less than half of the irrigation water applied (FAO, 2011a). There is clearly potential to improve water use efficiency by reducing water run-off and water losses due to evaporation and infiltration. This would result in less demand for electricity or diesel fuel for pumping. Energy savings from existing irrigations systems can be derived from improving basic operating conditions, mending leaks and replacing worn or improperly sized pumps. For example, if a pump is working at 20 percent efficiency instead of its design specification of 30 percent, then the energy demand, and subsequent GHG emissions, will be increased by 50 percent above the baseline (Nelson et al., 2009). Both water and energy inputs can be reduced by altering crop sowing dates to avoid anticipated periods of water deficit and by using mulching operations, as well as by adopting sensor-based, demand-led irrigation systems. The use of solar PV and wind–powered irrigation systems needs to be managed carefully and employed in combination with improvements in water use efficiency to ensure that these renewable energies are used sustainably.

Fertilizers. Some mineral fertilizer manufacturers have provided various options for saving energy inputs per unit of fertilizer produced and delivered. In addition, farmers can save indirect energy by reducing the amount of fertilizers applied through more precise applications. This will also serve to lower GHG emissions per unit of output and possibly avoid excess nitrates being discharged into aquifers and surface waters. More precise application can be achieved by improving the accuracy and timing of applications through the use of engineering and computer-aided technologies, such as biosensors for soil fertility monitoring and trace gas detection. In high-GDP countries, since the mid-1980s, a combination of these techniques has achieved significant reduction in fertilizer use (Schneider and Smith, 2009). In the USA for example, between 1979 and 2000, these techniques reduced fertilizer applications by around 30 percent (Heinberg and Bromford, 2008). A shift towards organic fertilizers, including the use of nitrogen-fixing plants, can also reduce indirect energy inputs.

Conservation agriculture. This broad concept seeks to improve farm management by using crop rotations to enhance the soil nutritional status. Also, by avoiding tillage and improving soil quality, conservation agriculture lowers the demand for inorganic nitrogen, reduces pests and minimizes soil disturbance. Reduced energy inputs are usually a co-benefit of conservation agriculture. No-till methods can reduce fuel consumption for cultivation by between 60 to 70 percent. These methods also improve soil water retention, reduce soil erosion by incorporating crop residues into the surface and minimize soil carbon losses (Baker *et al., 2010)*. Historic carbon losses through conventional cultivation are estimated to be between 40–80 Gt C and are increasing by a rate of 1.6±0.8 Gt C per year, mainly in the tropics (GoS, 2011). Increasing soil carbon content over the long term by the addition of biochar is under evaluation. Another option under review is low-labour input perennial crop-based production systems that can be self-regulating in terms of pest and disease management and conserve soil fertility and moisture.

Livestock housing*.* Animal housing can be designed and operated efficiently to conserve the energy needed to maintain optimum temperatures and humidity levels (GoS, 2011). Computer-controlled feeding in intensive livestock systems can help to reduce waste feed and lower overall energy demand. Opportunities also exist to reduce energy inputs needed for water and room heating, drying, feed storage and conveying equipment.

Protected cropping. Intensification of crop production, through such practices as irrigation and fertilization, would probably increase energy demand per hectare. However, this could be compensated for through increased crop yields that would decrease the energy intensity per unit of food produced (Tzilivakis et al., 2005). Energy use in heated greenhouses can be reduced by improving the heat, lighting and ventilation system designs and by using double cladding of glazing or plastic. In China, the heated greenhouse production of fruit and vegetables has been integrated with biogas production using organic household and animal wastes as feedstocks (CNSS, 2011).

Fishing. Fishermen tend to drive their vessels excessively fast and do not maintain them adequately. This reduces the working life of the vessel and wastes large quantities of fuel each year. Costly fuel bills for capture fishing can be reduced by using less energy-intensive fishing methods, improving methods for locating stock, using information and communication technologies to optimize fishing and market decisions and by improving the design of vessels and gear. (World Bank, 2009; Muir, 2010). Changes in technology, such as new propeller designs, are of relevance to vessel operators who are either considering purchasing a new boat or overhauling and re-equipping an existing vessel (Wilson, 1999). Acceptance and understanding of new technologies by boat operators is essential, but so are behavioural changes regarding operation and maintenance. In aquaculture systems, heat recovery may be feasible in intensive hot water systems. Optimizing air and water management can also reduce energy demands.

3.2 Beyond the farm gate

Many successful case studies exist of energy demands being reduced at all stages along the food chain. The examples given below illustrate some potential options. Individual businesses need to decide how best to reduce their specific energy demands and related GHG emissions as these are determined by local circumstances. Cost-effective reductions in energy use could be achievable at all stages of the food supply chain in most countries (CAE, 1996; IPCC, 2007c and 2007d). For example, selection of new equipment should be made on life cycle evaluations that consider not only the initial capital cost but also on-going energy costs. Good knowledge of an entire system rather than taking a demand-side or a supply-side approach can be more effective in identifying the most energy efficient alternative. For example, in order to improve energy efficiency, it may be more effective to minimize the amount of heat that needs to be removed in the processing phase, rather than to improve the energy efficiency of the cooling system (Cleland, 2010).

Improving post-harvest activities in low-GDP countries represents a priority area for helping farmers increase their income, since large amounts of food are lost soon after harvest. This is discussed in Section 3.3. Access to reliable and affordable energy is often the key to ensuring good quality post-harvest operations in those countries.

Transport and distribution. Long-distance transport of food by ship is more energy efficient and therefore emits fewer GHGs (between 10-70 g CO_2/t/km) than rail (20-120 g CO_2/t/km) or road (80-180 g CO_2/t/km) (IMO, 2008). Reducing the energy demand for both long- and short-distance freight travel is possible for existing road, rail, water and air transport using well understood improvements in technologies and changes in operating behaviour (a detailed overview is provided in IPCC, 2007b).

Processing. Food processing facilities that are highly energy inefficient can have a high energy intensity, using more than 50 percent of the energy compared to the best available technologies. This provides a significant opportunity for reducing energy demand and its associated CO2 emissions, if the energy comes from fossil fuels. Over 100 technologies and measures for improving energy efficiency have been identified (Galitsky *et al*., 2003). Food processing plants can be relatively energy-intensive. For example, in the USA, the wet-milling of maize consumes around 15 percent of the total energy used by food industry. Producing heat from the combustion of coal, gas, woody biomass or charcoal for drying, steam-raising and cooking is the main energy demand for processing meat, milk powder, bread and brewery products. In large-scale plants, co-generation of heat and power using biomass available on-site can be a profitable activity (section 4.1).

The low energy efficiency of smaller-scale food processing plants in many low-GDP countries offers the opportunity to introduce improved technologies and practices that can bring about considerable environmental and economic benefits, even though energy bills are typically only 5-15 percent of total factory costs. Simple, general maintenance on older, less-efficient processing plants can often yield energy savings of 10 to 20 percent with little or no capital investment. Medium-cost investment measures, such as optimizing combustion efficiency, recovering the heat from exhaust gases and selecting the optimum size of high efficiency, electric motors, can yield energy savings of between 20 to 30 percent. Higher savings are possible, but they usually require greater capital investment in new equipment (IPCC, 2007c). As with food processing plants, improved energy efficiency in fertilizer and manufacturing industries is often economically feasible (IPCC, 2007c).

Storage. Possible improvements to increase the energy efficiency of food storage include:

- better ventilation;
- the use of high efficiency, variable speed fans; and
- more efficient logistics when transferring food from road containers to rail containers or from shipping containers to refrigerated holds.

As most refrigeration systems use electricity, the local electricity supply system will determine the amount of GHG emissions emitted (Cleland, 2010). Refrigeration during transport powered by on-board diesel generation sets can be inefficient, in part because the surface area to volume ratio of a container is relatively high and insulation levels are low. Because the extra diesel fuel consumption for refrigeration is usually a small portion of the vehicle's total fuel demand, there has been little incentive to improve the efficiency of diesel fuel use for refrigeration. In the retail and domestic sectors, minimum energy performance standards (MEPS) can encourage the use of more efficient compressors and improved designs for heat exchangers, lights, fans and controls. Refrigerants other than F-gases can be used such as CO_2 or hydrocarbons (Cleland, 2010).

Preparation and cooking. Advice on reducing energy demand in the domestic or commercial kitchen is widespread and much of it is common sense. For example, it is not energy efficient to completely fill a kettle to make only one cup of tea or coffee. Based on MEPS, consumers should note the energy requirements of kitchen appliances when making a purchase. In developing countries, inefficient cooking on open fires and the associated health risks from smoke inhalation and energy efficiency options are well documented (see for example IPCC, 2011b and World Bank 2011b). More details are provided in Chapter 5 on energy access.

Changing diets. Diets that are based more on locally-produced, seasonal foods that are grown using energy efficient management systems, require little cooking time, and include relatively low amount of meat and dairy products would result in overall reductions in energy demands (Schneider and Smith, 2009). However, these consumption patterns need to be socially acceptable to take hold. In theory, significant reductions in energy demand for food could be achieved by if people ate fewer animal products. In practice, the reverse is happening, as upper and middle income classes in low-GDP countries are moving to diets that include more meat and dairy products. GHG intensities vary widely with different food groups, with red meat on average being around 150 percent higher (in terms of $CO_{2\text{-eq}}$/kg) than chicken or fish. Changing to a diet low in red meat and milk products can be an effective means of lowering a household's carbon and energy footprint (Weber and Matthews, 2008). For example, a household that substitutes red meat and dairy products consumption for vegetable-based protein for just one day a could achieve the same GHG mitigation benefits as if they had bought all their weekly food from local providers and avoided the energy used for transport.

However, the argument that all meat consumption is bad is simplistic (Godfray et al, 2010). In this regard, three points should be made.

- First, there are significant differences in the production efficiency and consequent energy use in the processing of the major classes of meat. For example, 8 kg of cereal are needed to produce 1 kg of beef meat, whereas 4 kg of cereal are needed to produce 1 kg of pork meat and only 1 kg of cereal is needed to produce 1 kg of chicken meat. Moreover, it may be possible to increase the efficiency of meat production through better rearing or improved breeding.
- Second, a significant proportion of livestock continue to be grass-fed. This practice takes place in land that is often not suitable for crops without major investments. Using this type of land even to indirectly feed people can have possible adverse environmental effects. Pigs and poultry on the other hand are often fed on human food waste.
- Finally, in developing countries, meat represents the most concentrated source of some vitamins and minerals, which are important, particularly for young children. Livestock also are used for ploughing and transport. They can provide a local supply of manure and can be a vital source of income. They are of huge cultural importance for many poorer communities.

Changing dietary habits can reduce energy demand in other ways as well. By eating more whole foods or minimally-processed foods that have little packaging consumers can reduce their carbon foot print. Figure 9 illustrates that in the USA, the food system provides mainly highly-processed, high-calorie foods, with only a small fraction dedicated to grains, fruits, and vegetables.

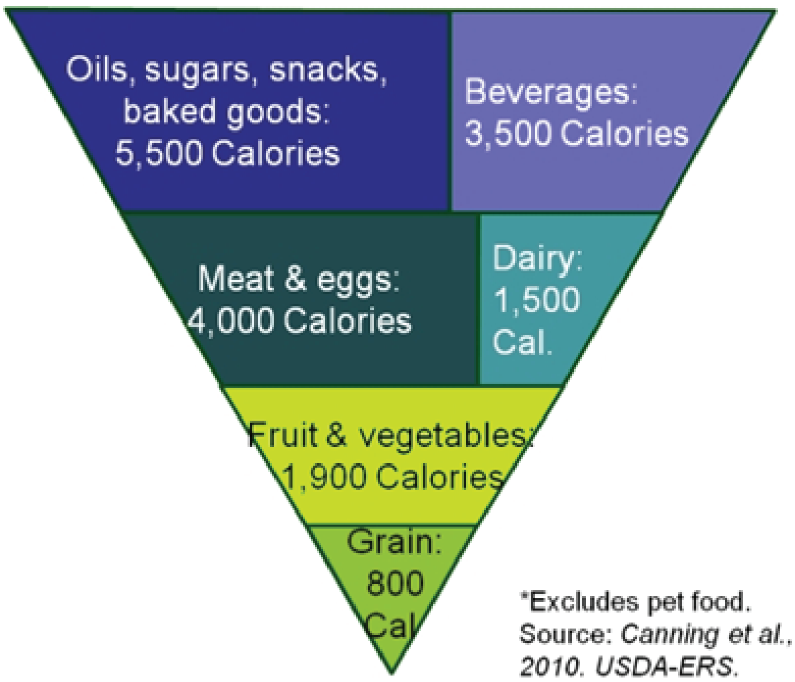

Figure 9: Daily per capita energy input to the US food system (Source: Bomford, 2011)

3.3 Energy in food losses and wastes

About one-third of the food produced is lost or wasted. Food losses occur at all stages of the supply chain, amounting to around 1200 Mt per year (Gustavsson et al., 2011). Every day, the average person needs to consume enough food to provide around 9 MJ of energy. The amount of energy each person requires will vary depending on age, size and level of daily physical activity. Average food availability in sub-Saharan Africa is below 8.5 MJ per day per capita. In high-GDP countries, by contrast, it is around 15.7 MJ per day per capita (Smil, 2008). Hence in high-GDP countries around 50 percent more food is produced than is required. Some of this excess supply of food has resulted in high levels of obesity. However, considerable amounts of food are simply being wasted. Food waste in European and North American countries is between 95 to 115 kg per capita per year (Gustavsson et al., 2011). In sub-Saharan Africa, South Asia and South-East Asia where food is relatively scarce, losses are between 6-11 kg per capita per year (Ibid). Over half of total losses occurring in high-GDP countries are due to the deterioration of fresh produce. Some of the factors that contribute to this waste are:

- a mismatch between supply and demand;
- poor purchase planning;
- careless preparation;
- the rejection of foods that do not meet stringent quality standards or have exceeded the 'use-before' date; and
- leaving prepared food unconsumed.

In low-GDP countries, food arriving at the table is rarely wasted, but considerable food losses occur earlier in the supply chain due to inadequate harvesting techniques, poor storage facilities, limited transportation infrastructure and ineffective packaging and market systems. Raising public awareness to avoid food losses and waste throughout the supply chain could benefit the international goals to reduce energy inputs and GHG emissions (UNEP, 2011), lessen the competition for land and water, cut food costs and alleviate poverty and hunger.

The quantified global data on food losses and waste throughout the food chain compiled in the *Gustavsson et al* study (2011) was used to assess the energy embedded in the food losses. When food is wasted, this embedded energy is also wasted (Fig. 10). The amount of energy embedded in wasted food is significant. For instance, in the US food losses account for about 2 percent of total annual energy consumption (Cuellar and Weber, 2010). Overall, the energy embedded in global annual food losses is thought to be around 38 percent of the total final energy consumed by the whole food chain. As was the case for Figures 6 and 7, this analysis can only provide indicative results since the data are largely uncertain.

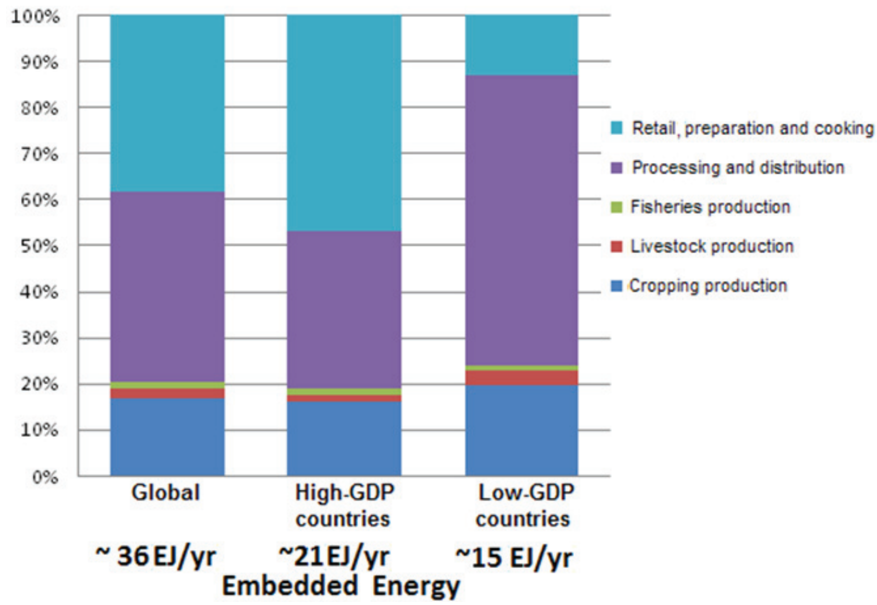

Figure 10. Indicative shares of energy inputs embedded in food products lost along the food supply chain. Around 60 percent of these losses in High-GDP countries are occurring mostly at the retail, preparation and cooking stage. In low-GDP countries most losses occur during post-harvest storage, processing and transport. (FAO elaboration on the basis of food loss data from Gustavsson et al., 2011; global energy data from on Giampietro, 2002; Smil, 2008; IEA, 2010; GoS, 2011 and others. The cumulative energy losses were taken into account).

Public awareness campaigns have begun to draw attention to the problem of food losses and waste. Public and private investments to reduce losses in crop, fish and livestock production systems would reduce risks to the supply chain, improve food quality and reduce GHG emissions per unit of consumption. Avoiding post-harvest losses would lower the costs of food production and reduce GHG emissions arising from waste treatment and disposal of spoiled produce (Box 2). In many low-GDP countries, financial and technical limitations hamper efforts to optimize harvesting techniques and improve the storage, the packaging, and marketing components of the food chain. Educating smallholder farmers on how to reduce food losses could be a relatively cost-effective manner for improving rural livelihoods.

Box 2. Food waste in the United Kingdom.

The UK throws away around 13 M dry tonnes of food and drink wastes a year (NSCA, 2006). The domestic and retail sector accounts for around 80 percent of this total. Potatoes, bread and apples are the most wasted items in terms of quantity. Salads are the most wasted food in terms of the proportion of the total amount produced. Around two-thirds of this wasted food is edible. Half of this wasted food is never even touched, and as such is classified as 'avoidable' waste. The other half is is classified under several terms:

- 'unavoidable' waste, such as coffee grounds or apple cores;
- 'unavoidable due to preference', which includes food waste such as bread crusts removed from sandwiches, fat cut from red meat and left-over meals from social events that have been deliberately over-catered ; and
- 'unavoidable due to cooking method', which includes food waste such as potatoes skins that are peeled before cooking.

The value of food wasted by the UK domestic sector equates to over £10 billion annually, with an estimated cost for the average household being between £250 - £400 a year. Most of the wasted food ends up in landfill sites (section 5.1). However, more anaerobic digesters are being developed to convert this resource to biogas*.

Source: The Environment Agency (UK) http://www.environment-agency.gov.uk/business/sectors/32601.aspx

The food choice expectations of people living in high-GDP countries are made possible by affordable refrigeration systems across the whole food supply chain. Developing similar systems for low-GDP countries will be challenging. Avoiding refrigeration dependence is difficult when economic development depends on exporting food to high-GDP countries. Possible solutions focus on bulk preservation with transport only to local markets and the use of passive evaporative-cooling technologies rather than active cooling that depends on electricity supply. When they become economically viable, stand-alone solar chillers are another option with good potential. To reduce food supply chain losses in developing countries, post-harvest storage and technologies need to be appropriate, simple, prevent pest infestation, and, where possible, use local renewable sources of energy.

Energy efficiency opportunities exist to reduce demand at all stages of the food system for both large- and small-scale systems in high- and low-GDP countries. On-farm improvements in energy efficiency can be deemed successful only if productivity does not decline as a result. For subsistence farmers, energy access can lead to improved livelihoods. However, it is imperative to use energy wisely to ensure that it is affordable. Avoiding food losses along the food chain will help reduce overall demands for energy, water and land.

4. Energy supply from the food sector

Although fossil fuels will continue to be used for many years, the transition to renewable energy systems has begun. Biomass, wind, solar, hydro, geothermal and ocean energy resources are widely available. These resources can be converted into the full range of energy uses and carriers, including electricity, heating, cooling, liquid and gaseous biofuels. This section focuses on the opportunities for renewable energy development in rural areas. This development must be flexible and gradual, to allow for the necessary trade-offs that need to be made between the continued use of fossil fuels, opportunities for renewable energy substitution and implementing measures to improve energy efficiency.

Where good solar, wind, hydro, geothermal, or biomass resources exist, they can be used as a substitute for fossil fuels to generate heat or electricity for use on farms or in aquaculture operations. If excess energy is produced, it can be exported off the property to earn additional revenue for the owners. Such activities can bring benefits for farmers, landowners, small industries and local communities that can contribute to rural development[16]. There are many examples of rural municipalities strengthening local development by attracting new business ventures because of their availability of local renewable energy resources.

"New and renewable sources of energy stand at the centre of global efforts to induce a paradigm shift towards green economies, poverty eradication and ultimately sustainable development" UN Secretary-General, 22 August, 2011

Food processing plants can use biomass by-products for co-generating heat and power; which are usually consumed on-site. In some instances, excess electricity is produced and sold to the electricity grid generating additional revenues for the provider. For example, sugar mills commonly use their bagasse residues (the ligno cellulosic material left after the sugar has been extracted from the cane) for combined heat and power co-generation. Wet processing wastes, such as tomato rejects and skins, and pulp wastes from juice processing can be used as feedstocks in anaerobic digestion plants to produce biogas. The biogas can be used to generate heat or power for use on-site or, after its upgrading to biomethane by removing impurities[17], it can be injected into the gas grid or compressed as a vehicle fuel (NSCA, 2006). The capacity to export electricity or biomethane can be limited if the farm or processing plant is not located near the existing electricity of gas grids and connection costs are high. Also, some food processing plants operations are seasonal and may not be able to provide a steady flow of energy all year. In these situations, specific contractual arrangements are required.

Traditional biomass used for energy (fuelwood, crop residues and animal dung) is often scavenged, which usually demands considerable labour and time. It is widely used in low-GDP countries for domestic uses, particularly cooking and heating. Traditional sources of biomass, however, are not always sustainably produced and smoke and carbon monoxide emissions can lead to health and safety issues.

Millions of small-scale domestic digesters are largely used by subsistence farmers to produce biogas. These

16 A current OECD project assessing the links between renewable energy and rural development is evaluating such opportunities using 15 case studies in 10 OECD countries. The experiences could equally apply to non-OECD countries. The final report is likely to be realised in mid-2012.

17 The impurities removed in the process are carbon dioxide and hydrogen sulphide.

small systems are not discussed in detail in this paper, except when considering access to modern energy services (section 3.3). Large-scale, centralized renewable energy systems such as hydro dams, concentrating solar power installations and geothermal plants are usually not integrated into food systems and consequently are not evaluated in this paper. However, businesses that manufacture farm machinery, fertilizers, pesticides and other agricultural inputs may have opportunities to purchase 'green energy' produced from low-carbon sources to reduce their dependence on fossil fuels and lower their GHG emissions. They can also improve the energy efficiency of their manufacturing processes to lower costs and reduce the embedded energy in their products (section 3.2).

4.1 Renewable energy systems in the food chain

Renewable energy can be used throughout the food sector either directly to provide energy on-site or indirectly by integrating this energy into the existing conventional energy supply system (Fig. 11). Renewable energy sources tend to be widely dispersed throughout rural areas. The availability of a reliable and affordable energy supply can become an essential component for sustainable development.

Reducing the dependence of food systems on fossil fuels by using renewable energy is feasible for farm and aquaculture production. Renewable energy can also be used for transporting raw food feedstocks, processing food, distributing finished products and cooking. In low-GDP countries, renewable energy also presents opportunities to provide much needed basic energy services (section 3.3).

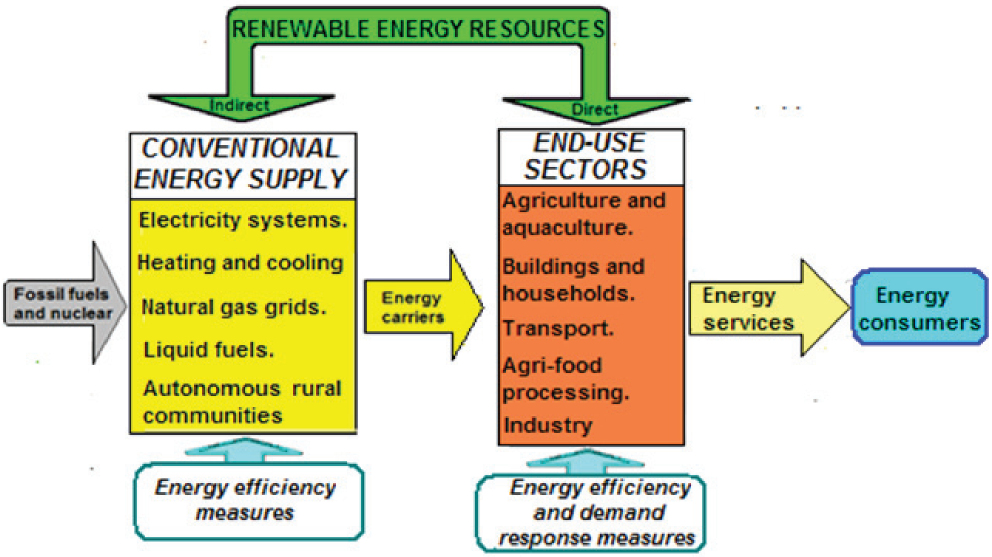

Figure 11. Renewable energy can be used directly on-site by the end-user sectors of the food chain or indirectly through its integration with conventional energy supply systems. Energy services delivered to consumers contain varying shares of renewable energy. (Based on IPCC, 2011c)

Adequate supply of energy in the immediate post-harvest stages is important for reducing food losses in low-GDP countries. Because of this, significant attention has been given to the possibility of using renewable energy in these countries to deal with this issue (see for example GIZ, 2010). Solar energy and biomass have been successfully used for both dry and cold storage. In Sri Lanka, for example, wood biomass is being used to dry spices. This innovation has diversified income streams and increased revenue for a range of local operators in the spice market chain. In addition to selling by-product fuel wood from pepper plants to the dryer operators, small-scale growers are now able to sell mature spices that can be dried and preserved (FAO, 2009c).

In locations where good renewable energy resources exist, farmers, fishermen and food processing businesses have opportunities to install technologies to generate wind power, solar power, micro-hydro-power. In the future, it may also be possible to generate electricity from ocean resources. Solar thermal, biomass and geothermal resources generated from decentralized facilities can be used for both heating and cooling. The recent IPCC report "*Renewable Energy and Climate Change Mitigation*" (IPCC, 2011) contains detailed assessments of each technology and examines the integration of these technologies into existing and future energy supply systems. The report also reviews issues concerning sustainable development, costs and potential revenues and supporting policies.

With the exception of biomass energy crops, the land area required for renewable energy projects is usually relatively small. Wind farms can be physically arranged on the landscape to minimize land use conflicts. Generally wind turbine equipment occupies about 5 percent of the land and the remaining 95 percent can continue to be used for farming or ranching. Large solar PV arrays can occupy several hectares, but are often located on building rooftops. Small hydro run-of-river projects usually need only a small area of land for the turbine house. Bardi (2004) calculated that the fraction of land needed to displace global fossil fuel use with solar and wind energy technologies would use around 1.5 percent of the approximately land area currently used for agriculture. This would have "minimal impact on food and textile agricultural production".

At present, renewable energy meets over 13 percent of global primary energy demand (Fig. 4). Almost half of this energy comes from traditional sources of biomass used for cooking and heating. Many scenarios show there is good potential for the share of modern renewable energy to rise to over 70 percent by 2050 (IPCC, 2011). The costs of producing renewable energy from a number of technologies calculated over their lifetime are typically higher than present average prices for electricity, heat and transport fuels. However, as more knowledge and experience is gained, the costs for renewable energy technologies are likely to continue to decline. In many specific situations, renewable energy can be economically competitive (Fig. 12). For example, in remote rural areas without access to the electricity grid, autonomous renewable energy systems are competitive because they allow users to avoid the high expenses involved in connecting to the grid.

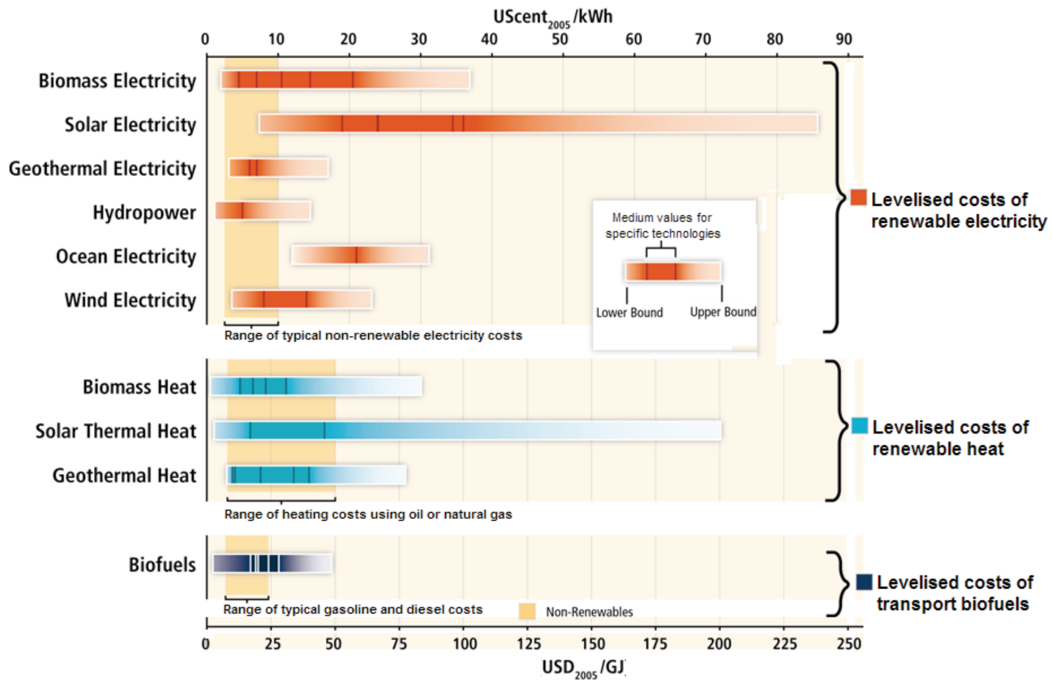

Figure 12. The costs of electricity, heat and liquid biofuels produced from renewable energy sources can be higher than when produced from conventional fossil fuels, but under specific circumstances, some renewable technologies are already competitive (shown where they overlap with the vertical range bars of conventional wholesale electricity, heat and gasoline/diesel costs). (Based on IPCC, 2011).

Animal wastes, crop and forest residues, by-products from food processing , food wastes from retailers, households and restaurants are examples of biomass originating from different stages of the food supply chain. These biomass resources are flexible energy resources. They can be:

- used on-site if and when needed to provide direct energy inputs;
- processed on-site into energy carriers for sale elsewhere;
- sold off-site for collection and use at community heating or anaerobic digestion CHP plants; and
- sold off-site and collected on a wider scale and in greater volumes to supply larger commercial liquid biofuel production plants.

It should be noted that there is also competition for this biomass from uses outside of the energy sector, as they can be used to produce bio-materials and bio-chemicals.

The potential for bioenergy systems to reduce GHG emissions is the subject of much debate. Will bioenergy, and more particularly liquid biofuels, development compete with food for land and water resources? Will it change the way land is used? Will these changes affect GHG emissions? There are no easy answers to these questions. Some are concerned that increasing carbon prices will make biomass production so attractive that agricultural communities will be evicted from their lands, that rainforests and other sensitive ecosystems will be destroyed to allow for biomass plantations and that food prices will increase significantly (Azar, 2011). Others argue that bioenergy production will diversify agricultural markets. Corn and wheat, for example, could be sold for milling, animal feed or biofuel feedstock. This diversification could provide economic incentives for much needed investments in capital and skills in agricultural sector, particularly in developing countries. The mitigation of saline soils in Australia though agro-forestry biomass production linked with food production is an example of the potential benefits of bioenergy development. Energy crop management can also help maintain, and in some cases, enhance soil fertility for future food production.

With careful management, biomass can be produced sustainably in ways that do not compete with food for land or water and do not contribute to GHG emissions. There are opportunities to develop bioenergy production systems that can help achieve both food and fuel production, for instance through integrated food energy systems (section 4.3). A market analysis of 15 case studies in 12 countries in Latin America, Africa and Asia (FAO, 2009c) confirmed that bioenergy from small-scale, on-farm projects can be used to produce heat, power and biofuels for local use, contribute to rural livelihoods, reduce imported fossil fuel dependence, and offer new opportunities for rural communities with no impact on local food security. The project 'Cogen for Africa', funded by the Global Environment Facility, is supporting African countries implement efficient bioenergy CHP systems. There is great potential in this type of work for supplying renewable energy while also contributing to GHG emissions reduction. Mauritius is already obtaining close to 40 percent of its total electricity supply from CHP systems using sugarcane bagasse (Karekezi and Kithyoma, 2006).

Energy crops, such as corn, sugarcane and oilseed rape, are being purposely cultivated in some countries to provide biomass for conversion to liquid biofuels for transport and CHP. Concerns on competition for land and water resources between food and biofuel production are the drivers for research in the development of new and improved commercial crop varieties. These improvements will help reduce crop water requirements, increased yields making biofuel crop production in the future more energy efficient.

Residues generated along the food chain are another potential option to produce energy. The costs of collecting and delivering this biomass supplies to an energy conversion plant (measured in terms of money per GJ delivered) are site specific (IPCC, 2011d). They vary widely depending on the scale of production, the average distance required for transport and the type of biomass produced. In food processing plants where biomass, such as kernels and bunches from palm oil production, is already collected on-site as part of processing activities, costs can be relatively low (approximately USD 0-2/GJ). Their use as a source of energy can even save money in cases where it eliminates waste disposal costs. On farms, the collection and storage of animal wastes and crop residues, such as baled cereal straw, add to the costs of delivering biomass (approximately USD 2-4/GJ). Crops grown specifically to produce bioenergy have higher delivery costs since production, harvesting, transport and storage costs all need to be included (around USD 5-10/GJ or higher).

Even though improvements in performance and conversion efficiencies are continually being sought, modern thermo chemical conversion technologies such as combustion, gasification and pyrolysis are largely mature. This is also true for some bio-chemical conversion processes such as anaerobic digestion. Considerable analyses in this area from demonstration and commercial plants show costs vary widely and are site-specific (Fig. 12).

Recently, interest in using aquatic plants, macro algae and micro algae as feedstocks for liquid biofuel production has grown because of the potential these organisms to sequestrate carbon. In lakes and coastal waters, harvesting aquatic plants can help reduce excessive nitrogen and phosphorus levels caused by nutrients coming from urban centres or agricultural lands. Oil yields per hectare can be several times higher than those for vegetable oil crops. However, numerous demonstration projects have confirmed that separation of cell mass and usable substrate is still costly and the systems require relatively high energy inputs. In the future, algae-based biorefinery systems and seaweed production to assimilate dissolved nutrients combined with intensive fish or shrimp culture in integrated multi-trophic aquaculture systems may be a viable option (Soto, 2009; Van Iersel et al. 2010; Thomas, 2011).

The interaction between biomass production and food prices is a controversial issue. The volatility of energy markets can have a potentially significant impact on food prices, and this would have serious implications for food security and sustainable development (IPCC, 2011b). There are also concerns that by linking carbon to bioenergy production, the carbon will not be returned to the soil and that the removal of biomass from the land will further contribute to soil nutrient depletion. This can limit the volumes of biomass available for energy production from a given site. This is of particular importance for conservation agriculture and organic farming systems that avoid the use of inorganic fertilizers. Integration of energy and food production from biomass crops is technically feasible under many situations, but it needs to be managed carefully and in a sustainable manner. Detailed analysis on the sustainability of biomass production and use is being undertaken by several organizations, including FAO, IEA Bioenergy, the Roundtable on Sustainable Biofuels and the Global Bioenergy Partnership.

4.2 Climate change impacts on renewable energy

It is well documented that climate change will most likely affect food production, that the food sector will need to adapt, and that investments aimed at improving agricultural adaptation will inevitably favour some crops and regions above others. South Asia and Southern Africa are the regions that, unless sufficient adaptation measures are put in place, will likely suffer greater adverse impacts of climate change, as several of the staple crops that their populations depend upon for food security may see reduced yields (Lobell *et al.,* 2008).

Climate change will also likely have an impact on the technical potential of renewable energy resources and their geographic distribution (IPCC, 2011). Examples of these impacts include:

- increased cloud cover that could reduce, but probably not significantly, solar radiation levels;
- a slight increase, but with substantial variations across regions and countries, in the technical potential of hydropower due to changes in precipitation;
- expected changes in the regional distribution of wind energy resources; and
- changes, probably not significant at the global level but with considerable regional differences that will be difficult to assess, in energy crop productivity brought about through changes in precipitation, soil conditions, and atmospheric CO_2 concentration levels.

4.3 Promising approaches for energy-smart agricultural systems

(i) A landscape approach

A ‘landscape approach’ links agricultural production and natural resource management with poverty reduction through improved product supply chains. This approach provide opportunities for rural development that meet the needs of local communities. To date the landscape approach has tended to lack an energy component. However, the multi-agency ‘Landscape for People, Food and Nature’ programme is planning a discussion paper on ‘energy in landscapes’.

(ii) Farming systems and practices

Integrated food-energy systems (IFES), in which food and energy are produced concomitantly on farm to achieve sustainable crop intensification, is an energy-smart practice that follows the landscape approach (Fig. 13). For large-scale, high-input farming systems that often involve crop monocultures and isolated specialized enterprises, such as intensive pig production, IFES can improve energy efficiency in primary production. In certain cases, this can be done without costly capital investment (Bogdanski *et al.,* 2010a). Several successful examples of IFES exist at both large- and small-scales (see for example Bogdanski *et al.*, 2010b).

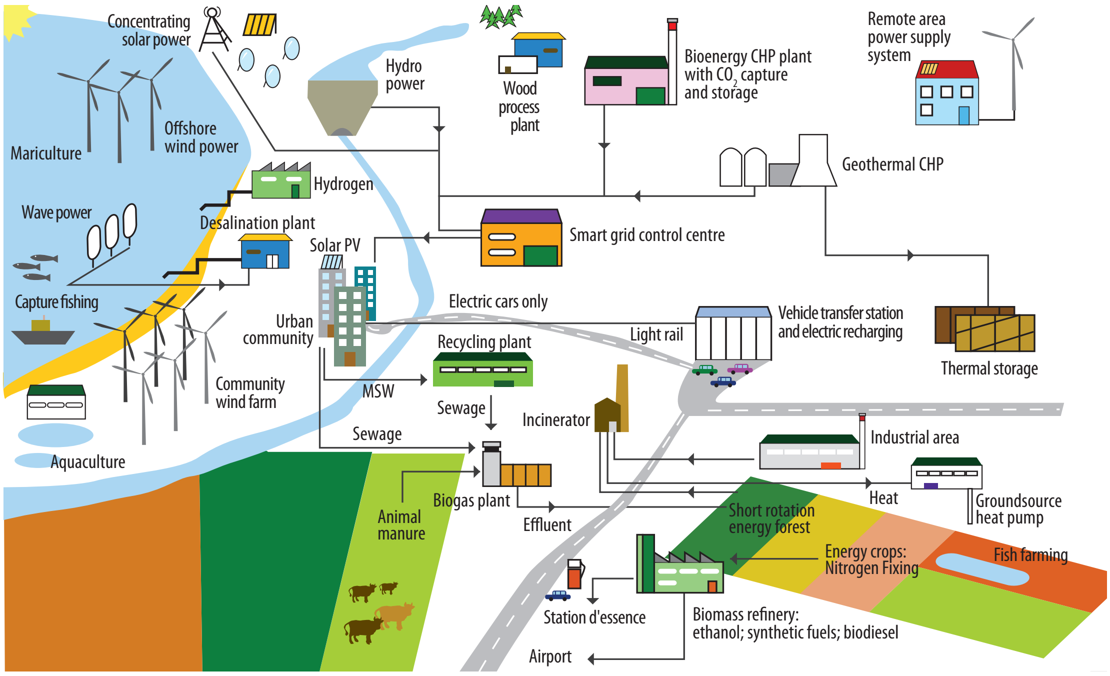

Figure 13. A conceptual IFES, shown in a landscape/seascape perspective that envisages a future sustainable and secure food supply system in both high-GDP and low-GDP countries (Based on IEA, 2009).

On small farms, IFES can provide the household or village with a certain degree of energy self-sufficiency. IFES can also be applied to large-scale farming operations. One IFES approach combines food and energy production on the same parcel of land using multiple cropping or agro-forestry systems, possibly linked with livestock and fish production. The other approach is to maximize the on-farm synergies between food production and the generation of renewable energy by using by-products, such as crop residues and animal wastes, to generate bioenergy. Where locally available, other sources of renewable energy are also integrated into this system (Bogdanski *et al.,* 2010a).

The farm machinery manufacturer, New Holland, has advocated the concept of an 'Energy Independent Farm', where renewable electricity is generated on-site and used in part for electrolysis to produce hydrogen fuel for tractors and trucks (Rodriguez, 2011). At a smaller scale, Ho (2011) has outlined an integrated food and energy 'Dream Farm', based on traditional family farms in China, that minimizes waste and optimizes the sustainable use of resources. It was calculated that the 'Dream Farm', which is primarily based on organic farming practices and the use of anaerobic digestion, has the potential to reduce China's energy demand by

14 percent, or even higher if other options for energy savings are included. Another concept that has been developed is the 'Integrated Energy Farm', which consists of a central business and living area surrounded by land producing food, biomass and other renewable energy sources (El Bassam, 2010). This concept goes beyond cropping and livestock and includes aquaculture for food, feed and energy (Van Iersel et al. 2010).

IFES can provide a balance between monoculture production, which seeks to maximize profit in the short term, and the older, long established 'mixed farming' systems, which integrate livestock, pasture and crop production on the same property. To gain the benefits from both approaches, IFES could possibly evolve into a large-scale regional system combining integrated food and energy production techniques across several neighbouring farms. This would allow for a more specialized, and perhaps more efficient, division of labour. Such systems could support rural development objectives in both developed and developing countries seeking food and energy security.

Low external input approaches to agricultural and aquacultural management can involve crop rotations, organic farming techniques, crop and livestock integration (FAO, 2011b) and the combination of farming with aquaculture. This approach makes better use of natural resources, uses animal wastes and crop residues as a substitute for inorganic fertilizers and relies more heavily on human and animal inputs (Pretty *et al.*, 2006). Likewise, organic farming techniques typically rely on lower energy inputs per hectare, particularly for poultry and horticultural crops (Williams *et al.*, 2010). However, the more useful indicator of energy per unit of food output (MJ/kg), which is a measure of energy intensity, depends on the productivity achieved, which is extremely variable. Results from comparative studies on low external input and organic farming techniques tend to vary and long-term trends remain. For example, in the UK an integrated cropping system monitored over 5 years used 8 percent less energy than conventional cropping mainly due to reduced cultivations. However, since crop yields had declined, energy inputs per unit of output (MJ/kg) were similar (Bailey *et al.*, 2003). On the other hand, a 12 year assessment of a low input, crop rotation system in Italy showed approximately 30 percent lower energy inputs compared with conventional cropping due to less fertilizers (Nassi o di Nasso *et al.*, 2011). Crop and energy yields were not significantly affected by management intensities.

Energy intensity analysis of primary production systems and methods of reducing their energy consumption should be considered in parallel with other long term sustainability factors such as biodiversity, soil quality, improved livelihoods and health. It is particularly important to consider increases in productivity, since any yield reduction will tend to increase the energy intensity. Some analyses of organic farms have shown lower energy demands, but this may be partly offset by increased human labour inputs (Ziesemer, 2007).

(iii) Institutional arrangements – Innovative business models

Addressing the immense and complex challenges related to the food-energy-climate nexus demands inclusive, multi-stakeholder institutional arrangements. Such arrangements need to address a variety of issues, including the division of labour, financial schemes, technical support services and business models.

Division of labour and clear financial arrangements between farmers and energy operators are required to ensure the quality and the expansion of energy-smart farming systems. For IFES, the division of labour is determined by different types of outgrower schemes. Under these schemes, farmers take responsibility for what they do best, which is farming, while others deal with the specialized needs of energy production. Below are some examples of different arrangements:

- In England, farmers produce wheat and a bioenergy plant buys the straw (Bogdanski et al, 2010a).
- At the district model biogas farm in China, farmers cultivate other crops and are not responsible for raising pigs and producing the biogas themselves. Instead the farmers contribute money to the district pig farm for purchasing the pigs. The district farm is responsible for raising the pigs and generating the energy. The farmers in return get yearly dividends from any sales of pigs, cheap biogas and cheap liquid fertiliser from the district farm.
- In Bangladesh, two innovative business schemes are tapping into the private sector's needs for biofertilizer to drive the development of household biomass production for energy (ISD, 2010). One scheme seeks to create a steady supply of bioenergy through a cattle leasing programme. Mainly women participate in this programme. They receive funding to purchase a cow and a calf from an organic tea farm, the women then repay the loan from the sale of milk and dung back to the farm. In the second scheme, still in its pilot phase, households receive loans from the organic tea farm to pay for setting up a biogas system. The households repay the loan by selling dung and/or the slurry to the farm. Once the biogas installation has been completely paid for, the households have the option to continue selling the slurry and dung to the tea farm.
- 'Fee for service' schemes such as energy service companies (ESCO), leasing or concession arrangements schemes.

The World Bank (2008) provides a review of renewable energy business arrangements. Many of these schemes are still in their infancy, so their performance is difficult to assess. Preliminary experiences shows that no institutional scheme significantly provides better success rates than others (GIZ, 2011). Preliminary experience shows that complex arrangements or schemes with many partners are especially prone to politically or commercially motivated actions that question the rules of the game in an environment that is still developing in legal terms. To ease such risk, these approaches for the renewable energy promotion could benefit substantially if they would include some forms of Partial Risk Guarantees (World Bank, 2008).

Renewable energy systems are well understood, and the sector is growing rapidly. Where renewable energy resources are available, it is feasible to use agricultural land to both produce food and generate energy. Food processing plants often have biomass co-products suitable for generating bioenergy. Renewable energy systems in rural areas can provide several co-benefits for landowners, businesses and rural communities. These systems can play a key role for improving energy access to alleviate energy poverty in low-GDP countries. Although further studies are needed, IFES are workable examples of energy-smart food systems that follow the landscape approach. Innovative institutional arrangements and financing mechanisms that involve several types of partners are required to support the development of the renewable energy sector.

5. Energy access for livelihoods in food systems

The poor availability of efficient modern energy services in many regions is a fundamental barrier to economic and social development. Providing energy services can do much to improve food production and consumption, and to ultimately safeguard food security. The increase in global food prices in 2008, in part due to increased world energy prices, hit low-GDP countries the hardest. In the most impoverished households in low-GDP countries, the food bill can account for between 50 to 80 percent of total expenditures. In high-GDP countries, by comparison, the average household spends only 7 to 15 percent of its budget on food. Access to energy services is needed to facilitate economic activities and improved livelihoods. A significant segment of the population in low-GDP countries live in households depending primarily on agriculture and the food-based economy for their livelihoods. Improved agricultural practices in agricultural production, agro-processing, post-harvest and storage facilities, and distribution and retail can contribute to poverty alleviation. All this requires the local availability of modern energy services. Furthermore, considering that today almost 3 billion people have limited access to modern energy services for heating and cooking at the household level, and 1.4 billion have zero or limited access to electricity, energy services provision linked to food systems can contribute to meeting basic energy needs, hence improving livelihoods and support local development. A more extensive discussion about the increased revenues for farmers and other co-benefits that would derive from increased energy access for the food sector and in rural areas are discussed in the upcoming Poor People's Energy Outlook (Practical Action, 2012).

"Renewable energy can enhance access to reliable, affordable and clean modern energy services, is particularly well-suited for remote rural populations, and in many instances can provide the lowest cost option for energy access" (IPCC, 2011e).

Relatively high capital investment costs for installing renewable energy technologies, such as small wind turbines, mini-hydro schemes, solar PV systems, anaerobic digesters and small bioenergy heat and power plants may require micro-financing arrangements to be made available by national and local governments, aid agencies and the private sector for small farmers. The affordability of new technologies needs to be carefully considered based on the income levels in the local community. The availability of local resources will determine what sort of trade-offs need to be made to realize these co-benefits in light of the possible higher costs of introducing renewable energy technologies (section 4.1). The potential of renewable energy to reduce GHG emissions and deliver other co-benefits provide an incentive for local, regional, state and national governments to formulate policies that are conducive to the development of renewable energy (chapter 6).

Solar, wind and hydro resources availability vary with location and so does the potential of a specific renewable energy. For example, wind speeds tend to be higher on hills than on flat arable land. When renewable energy resources are available, the introduction of renewable energy technologies can provide basic services such as domestic lighting, cooking, entertainment and communication. The economic, social and environmental co-benefits derived from the introduction of renewable energy technologies include stronger local development, increased employment opportunities, improved livelihoods, greater social cohesion, heightened skills of local trades people, better health due to reduced air pollution, reduced labour and a more equitable gender balance in the division of labour (IPCC, 2011b). For smallholder producers, better access to energy can play an important role in increasing the labour supply needed for adequate food production.

Furthermore, households coping with energy poverty spend a substantial amount of their time collecting fuelwood to meet basic domestic energy needs. Improving access to energy can reduce the time needed for fuelwood collection and allow families to dedicate more time to more productive work. Quantifying the time and labour lost due to energy poverty would determine more clearly the most cost-effective trade-offs involved between increasing access to energy and achieving sustainable food production systems in developing countries.

Affordability and cultural issues are essential in the deployment of new or improved energy technologies. The dissemination of improved designs of domestic stoves continues, succeeding mainly when micro-finance is available for the necessary capital investments. Traditional biomass cooking stoves may be less energy-efficient, less healthy and more labour-intensive than solar or biogas designs, but they are often more affordable, which is a critical factor for impoverished rural communities (Geoghegan et al, 2008, UNDP, 2009). Other biomass fuel options being developed to provide more efficient and healthy domestic cooking facilities include ethanol gels and DME (dimethyl ether) (IPCC, 2011b). New stove designs also need to be culturally acceptable. Compared with open fires, the use of more efficient biomass cooking stoves can reduce the demand for traditional fuelwood by half (IPCC, 2011b). However, not all programmes to introduce these more efficient stoves have succeeded. This lack of success is often due to the informal nature of the fuelwood supply chain and a poor understanding of local cultures and their cooking habits. For example, users may prefer to cook with fuelwood during the evenings when it is cooler rather than cooking in the heat of the day with a solar oven. Around one quarter of the 2.7 billion people who rely on traditional biomass for cooking and another 0.3 billion who rely on coal now use improved cooking stove designs. Two-thirds of these 166 million households are in China (UNDP, 2009).

Annex 2 provides an indication of direct energy inputs and relative intensities of energy demand needed for a range of primary production activities, and the possible renewable energy resources that are available from each of these activities. Since every region is endowed with specific natural resources that can be used to produce renewable energy, there here are many exceptions to the typical examples provided in the table. Woody biomass residues from forests and small woodlots are not included nor are human labour, animal power, nor traditional biomass used in low-GDP countries.

A balance needs to be sometimes found between improving access to new energy sources and increasing the efficiency of available energy based on local conditions and the economic tradeoff between these two options. By subsidizing the retail price paid for imported fossil fuels or by introducing measures for that support the deployment of renewable energy technologies in rural areas, governments can help improve access to energy for agricultural communities. The latter option can supply energy directly to the local food system (Chapter 4). The small-scale production of biofuels can power agricultural machinery and vehicles to transport food products to the local market. For example, pure vegetable oil[18] can be used directly in diesel engines to generate electricity or to run farming equipment. Ideally, newly introduced systems should enhance crop yields, improve storage and processing activities, minimize future investment and operating costs and make human labour more effective.

18 Pure vegetable refers to oil that is extracted from plant material and use as fuel without further processing. It is also known as pure plant oil.

6. Policy options

Many existing policies encourage businesses and householders to improve their efficiency of energy use (WEC, 2010) and support renewable energy projects (REN21, 2011). Other policies have been specifically targeted to improve access to energy (Practical Action, 2009). In large part, these policies have been successful, but not always cost-effective (IEA, 2008). However, few international organizations or national and local governments have connected energy policies with policies to strengthen the food sector and safeguard food security.

Food and agriculture policies should be implemented in conjunction with energy policies. Where appropriate, these policies should be in line with policies designed to achieve other national development goals in areas such as transportation, health, rural development, immigration, technological innovation and economic growth.

National food production and food security policies can also serve to strengthen energy security. Climate change mitigation policies, of interest for Kyoto Protocol signatories, are also relevant to energy and food sectors, as policies promoting social and economic development, which are priorities for low-GDP countries (IPCC, 2011e). Mechanisms that support improvements in energy efficiency and the use of renewable energy technologies in the food sector could be incorporated into existing policies to promote win-win situations and capitalize on potential co-benefits.

Current policies on energy and agriculture should be assessed to determine if they are conducive to promoting sustainable energy in the food sector. Modifications to existing policy frameworks may be needed to align these policies so that they support the transition towards energy-smart food systems.

This section gives examples of existing policies that could be implemented more widely to support the goals and ambitions described in sections 3 and 4 in order to reduce the present high energy dependence of the food sector, particularly on fossil fuels. Ideally, a cross-sectoral approach should be taken, rather than having specific policies for each separate sub-sector as tends to be the current situation.

6.1. Climate change mitigation

For Annex I Kyoto Protocol signatory countries,[19] energy policies are often linked with meeting mitigation targets. Under the 2009 Copenhagen Accord, many countries have adopted nationally appropriate mitigation actions (NAMAs) to stabilise their GHG emissions (UNFCCC, 2011). This initial collective effort was intended to limit the increase in global temperature rise to 2°C in the future. However, the global temperature is currently on a trajectory to rise by about 3.5°C by 2035 (IEA, 2010). More stringent long-term policy developments are needed to curb further increases in global temperatures. Food security interventions aimed at both reducing energy inputs for the agri-food sector and generating a supply of renewable energy from the sector have the potential to contribute to energy policies aimed at stabilising

19 These comprise mainly OECD and the former Soviet Union but excluding the USA.

GHG emissions. A combined approach that addresses the complex relationships linking food, energy and climate change can result in multiple benefits globally, nationally and locally.

Meeting global GHG emission reduction targets will require significant changes in existing policies. Due to the complexity of the issues, there is no single approach for formulating GHG mitigation policies that have positive impacts on the security of food supplies. This is due in part to the broad differences that exist between current small- and large-scale food supply systems in high- and low-GDP countries. Policies will require different methods of engagement depending upon specific national contexts.

Strong policies based on fiscal incentives, public finance and stringent regulations are needed to reduce GHG emissions. The most successful approaches tend to use a combination of different measures, including investment in research and development, public awareness and education (IEA, 2007). Technological innovations coupled with market-led incentives are a common approach to curbing emissions. However, careful analysis is needed to determine whether these interventions contribute to increases in staple food prices and entail greater hardships for vulnerable groups.

6.2. Agriculture

Agricultural policies that support energy-smart agri-food systems are similar to those needed to promote the 'Save and Grow' paradigm (Chapter 1). These policies support environmentally friendly agricultural practices and strengthen land tenure security.

Agriculture policies should encourage good agricultural practices since they contribute to increasing productivity, reducing energy inputs and curbing GHG emissions. Good agricultural practices include (FAO, 2011a).:

- conservation agriculture;
- maintenance of soil health;
- integrated food-energy systems;
- cultivation of drought-tolerant crop varieties;
- precision farming[20];
- improved management in fertilizer and chemicals application;
- improved water management

Farmers tend to be risk averse and do not like change, so incentives, together with education and capacity building, are usually necessary to encourage the adoption of new agricultural practices. Existing policy incentives that promote conventional cultivation, the wasteful use of fertilizers and excessive water use for irrigation should be discouraged.

Energy inputs can also be reduces through water management policies that promote the introduction of more efficient irrigation, such as: precision irrigation, low-head drip irrigation, waste water recycling and fertigation (using liquid fertilizers).

Fertilizer management practices that avoid the overuse of fertilizer can be promoted by providing training services to farmers on precision application methods and recommended dosages. Advantages and

20 Precision Farming: farming management concept based on observing and responding to intra-field variations. It relies on new technologies like satellite imagery, information technology, and geospatial tools.

drawbacks of policies that offer financial incentives to access fertilizers should be thoroughly assessed, over the short and long term.

In several low-GDP countries, the use of farm machinery has expanded, especially in Asian countries where agricultural pricing policies have made this machinery more widely available and affordable (Ashburner and Kienzle, 2011). Policy makers now need to devise incentives to encourage farmers, who have become more mechanized and have access to fuel supplies, to use energy and natural resources wisely. Example of innovative approaches that could be used include:

- payments for environmental services and
- the use of land tenure related-policies that entitle landowners to benefits resulting from any increases in the value of natural capital.

Since capital investment is critical for sustainable development, any means that governments can devise to provide access to credit with minimal transaction costs should be considered.

Conscious of the challenges of implementing agriculture intensification using an ecosystem approach on a global scale, FAO has recently committed itself to develop a strategy for implementing a long-term programme to assist countries in this endeavour (FAO, 2010a). The programme focuses on four key areas:

- Technical: capturing efficiencies; promoting empowerment of farmers' learning; disseminating knowledge on good agricultural practices; approaches and technologies that can be used to produce high crop yields; all while maintaining or enhancing environmental sustainability;
- Economic: creating tools to assess the economic value of the ecological dimensions;
- Governance: promoting an enabling policy and institutional environment to ensure productivity, while maintaining or improving the natural resource base; and
- Investment: capital formation (physical and human resources including applied knowledge).

In recent years there has been a growing interest for large scale land acquisition for securing future supply of food as well as for investment opportunities including biofuel production. This development raised concerns about land tenure security, particularly since the poorest segment of the population depend on this resource for their livelihood and food security. Therefore, issues related to land tenure security need to be carefully assessed, in particular for bioenergy production. In that respect, recent experience on how to address the challenge of moving beyond land tenure policies has led to the following recommendations (De Witt *et al*., 2009):

- Set economic development policies upon a series of 'higher principles', such as social equity and natural resource sharing, as has been done in Burkina Faso and Mozambique;
- Develop institutionalized formal negotiated partnership mechanisms between private operators and the local population with government authorities acting as 'referees' and guarantors of law enforcement. Based on the 'higher principles', these partnerships are preferable to large-scale rural development governments initiatives aimed at attracting commercial investors with offers of large tracts of land;
- Ensure adequate levels of stakeholder participation throughout the policy process – from design to implementation and monitoring - in order to produce both 'legal' and 'legitimate'[21] policy measures that are feasible and acceptable to all relevant stakeholders; and
- Link institutional reforms to policy changes.

21 The '*legality*' of a policy measure applies to land rights acquired through some form of government involvement – using a specific law and related formal administrative procedures and services. On the other hand, the '*legitimacy*' of a legally acquired right is strongly influenced by a set of power relations that may be legitimized by formal processes, and backed or opposed through pressures from influential stakeholders. Customary rights illustrate the difference between legality and legitimacy. Customary rights are often much weaker from a legal point of view, but have strong 'legitimacy' because they are rooted in long-standing social and cultural consensus.

6.3. Energy efficiency

Over the last several decades, some governments have implemented policies to manage the demand for energy and improve energy efficiency along food systems. These policies tend to be set within a broader constellation of policies designed to reduce energy use in the transportation and industrial sectors and encourage more energy-efficient behaviour at home. These policies include:

- the introduction of freight truck fuel economy standards and payload limits;
- minimum energy performance standards (MEPS) for machinery, such as electric motors, refrigerators, water boilers, that is used in food systems;
- energy performance labels on domestic appliances;
- vehicle speed restrictions;
- packaging recycling regulations; and
- higher charges for landfill disposal of organic wastes.

Some government policies are good examples (see example of New Zealand in Annex 3) and can offer lessons to other national, regional and local governments.

At present, primary producers are likely to adopt energy savings measures only when significant financial benefits are evident. For example, fishermen are highly motivated to reduce fuel consumption for the immediate economic savings it generates. Schneider and Smith (2009) stated: "*Strategies that realize GHG emission mitigation potentials must become cost-efficient at the farm level either through market price changes or policies*". Policies seeking to improve energy efficiency behind the farm gate should consider the synergies and trade-offs with policies addressing such issues as water use, health and food safety. National governments policies could also stimulate investment, such as micro-financing for projects that would improve energy efficiency in the food chain and encourage the generation of renewable energy:

- on available land through solar, wind, and hydro energy technologies;
- in primary production through the use of crop, animal and fish residues and the cultivation of energy crops; and
- during food processing through the use of biomass co-products.

Designing labels on retail food packaging that display the energy used in the production, processing, packaging and distribution of the product could encourage consumers to consider the energy and GHG implications when making their purchases. This is complex undertaking and would require international standards for measuring energy consumption using standardized LCA methodologies to assess each stage of the food chain (Ziesemer, 2007).

Another way of making the food sector more energy-smart is by encouraging changes in consumer habits regarding diets and food preparation. Successfully promoting a shift to a diet with significantly less animal products would be difficult, unless efforts to make this change are linked to achieving national health objectives. For example, establishing financial incentives or taxes that discourage people from eating foods with high levels of animal fat could be part of national efforts to reduce heart disease and obesity. Changing traditional dietary patterns requires powerful and widespread public awareness campaigns. It would not be an easy task. However, it should be kept in mind that, in many countries, similar campaigns have been successful at addressing other health issues, such as nicotine addiction and drunk driving.

Reducing food waste can contribute to meeting global GHG emission reduction targets by the need to disposal in landfills. The European Landfill Directive, which outlines obligations for reducing organic wastes in landfills, is an example of a policy that reduces food waste. In the UK, a number of initiatives have been established to reduce food waste, including:

- The 'Waste Implementation Programme' launched in 2002 by the Department for Environment, Food and Rural Affairs (DEFRA), set a target of reducing by 2020 the amount of food wasted by 35 percent from 1995 levels .
- The 'War on food waste' was announced in 2008 following the global food price crisis. Launched in June 2009, the campaign encourages supermarkets, restaurants, schools, public sector bodies and householders to cut down the amount of food they throw away. It proposes eliminating the 'best-before-date' on food labels, as many consumers confuse it with a 'use-by-date'. It also discourages supermarkets from marketing cheaper food based on larger quantities purchase and suggests marketing food in smaller packages.
- The construction of several community anaerobic digestion plants to produce biogas from food wastes is underway.
- The 'Water and Resources Action Programme' (WRAP[22]) was created in 2000 to help businesses and individuals use resources more efficiently, develop more sustainable products and reduce waste, including food waste. In 2007, WRAP initiated the "Love Food, Hate Waste"[23] public awareness campaign to encourage the use of left-over food with special recipes, the preparation of meals that are not excessively large and planning meals and shopping trips in advance. Claims have been made that between 2 to 3 percent of food losses, with a value of around £300M, have been avoided after 2 years of the campaign.

The European Commission, through its *Integrated Policy Platform,* reported that the food supply chain was responsible for 20 to 30 percent of the environmental impacts resulting from climate change, ozone pollution, acidification and eutrophication (JRC, 2006). After evaluating European Union consumption trends and using various LCAs, the report concluded that meat and dairy production have the largest environmental impacts in EU-27 countries, along with energy use in buildings and light vehicle road transport. The report also highlighted that these impacts could be reduced by 20 percent if agricultural production was improved, household food wastage was avoided and electricity was saved through conservation efforts and improved efficiency (JRC, 2008). A change of diet to reduce consumption of red meat was recommended but it was realized that "because food and nutrition are strongly rooted in traditions and habits, policy measures aiming at stimulating a change towards healthy diets need to include a combination of different instruments ranging from consumer awareness raising to public procurement activities" (JRC, 2009).

There is increasing agreement that the risk of a rebound effect associated with energy efficiency interventions can be reduced if energy efficiency policy instruments, such as standards and regulations, are combined with other instruments, such as carbon taxes that increase the price of some energy products, or GHG caps that contain energy demand (Passey, and MacGill, 2009).

6.4 Renewable energy

Renewable energy policies deal with the supply side of energy to support food systems, mainly by supporting on-farm project developments and at food processing plants. The EU Biomass Action Plan for example contends that lack of policies or bad policies are the most important barrier to overcome renewable energy development since, "i*t is convincingly proven that whenever appropriate policies are implemented, the market reacts positively and develops the necessary structures and operations systems to deliver results.*"

22 www.wrap.org.uk

23 www.lovefoodhatewaste.com/save_time_and_money

(European Commission, 2005). Policies supporting the development of renewable energy projects are abundant and have been adopted in countries all over the world (REN 21, 2011). These policies include the following elements:

- promotion of renewable energy markets;
- financial incentives;
- standards, permits and building codes;
- capacity building, research, education and communication; and
- stakeholder involvement. (Sawin, 2006, IPCC, 2011e)

In Thailand, regulations were adopted in 2002 to simplify grid connection requirements for small electricity generators up to 1 MW (World Bank, 2011). This and other policies led to the development of integrated sugarcane and rice bio-refineries that produce food, ethanol, heat and electricity. In addition, organic residues were returned to the soil, increasing its fertility. By 2008, 73 biomass projects using a variety of residues, including bagasse and rice husks, had been developed with an installed capacity of 1 689 MW. (IPCC, 2011e).

Box 3. Biofuel and renewable energy policies in the UK

- The British Department for Energy and Climate Change (DECC) has recognized that the need to maintain or increase food production is constrained by the target to reduce agricultural GHG emissions. Generation of renewable energy from land-based resources is one solution with the feed-in-tariff introduced in April 2010 resulting in many farmers embracing renewable energy schemes with a potential 10 percent return on investment as commodity prices dropped sharply (SER, 2011).
- For biofuel strategies it was noted that these will need to be carefully designed to avoid a net increase in overall GHG emissions (DECC, 2010). Policies that support liquid biofuels such as excise tax exemptions, financial support for production and processing, mandating blending levels with gasoline or diesel, or establishing a "Renewable Transport Fuels Obligation" as in the UK, need to avoid increasing competition for land use with food production. They should also discourage the use of biofuels produced from non-sustainable sources when their substitution for gasoline or diesel can actually increase GHG emissions due to land use changes linked with energy crop production. Biofuel mandates have also been criticized for inducing global food insecurity (Pimentel *et al.*, 2009). Protection of above- and below-ground biomass stocks and soil degradation are now included in the UK biofuels legislation (GoS, 2011).

A coordinated global energy strategy needs to be adopted in conjunction with consistent and stable national policies to bring down the cost of renewable energy technologies, including off-grid systems, for use by the poorer segments of rural populations (UN General Assembly, 2011). Recent reviews (World Bank, 2011a; IPCC, 2011e; REN21, 2011; IEA 2008) provide many examples of renewable energy policies in both high- and low-GDP countries. Some important lessons can be drawn from these reviews:

- *A flexible approach is necessary and should be tailor-made to suit specific situations*. Some policy elements have been shown to be more effective and efficient than others at rapidly increasing the renewable energy project deployment more (such as feed-in-tariffs for solar PV in many countries (REN21, 2011). However, there is no universal policy recommendation. Having a mix of policy design and implementation approaches flexible enough to be adjusted as technologies, markets and other factors evolve, can help overcome barriers to renewable energy deployment (IPCC, 2011e).
- *Policy sequencing is critical.* Legal and regulatory frameworks regarding the use of land and other resources, the connection and integration to electricity grids, and the allocation of permits and rights, should be in place before introducing renewable energy policies. The process of granting permits for

new project developments should have a rapid response time and not create bottlenecks.

- *Transforming the energy sector to one based on low-carbon fuels and technologies over the next several decades will require considering cost minimization over this entire period, not only in the near term.* Despite the complexity it entails, all the social and environmental costs and benefits should be calculated to clearly demonstrate and maximize the benefits of renewable energy use.
- *Policies that successfully lead to the scale-up of renewable energy may not necessarily be economically efficient.* Some policies will need to include subsidies for biofuels and over-priced feed-in-tariffs.[24]

A significant proportion of public and private investments in renewable energy projects flow to rural areas. For this reason, effective renewable energy policies can support sustainable rural development. The construction and operation of a renewable energy project primarily benefit the landowner or food processing company. However, renewable energy projects, especially larger ones, can also bring benefits to the local community by pumping more income into the economy and creating employment opportunities. Some of the new revenues can be channelled toward improving public services and attracting new businesses to the community. The initial project can generate new jobs, but long-term employment opportunities are also possible through the creation of local companies involved in the further development of renewable energy technologies, the manufacturing of components and the provision of related energy services. These higher wages jobs favour the development of local skills and help rural communities attract skilled workers. For more remote rural communities, policies can support access to locally produced renewable energy when developing infrastructure and importing energy from outside the area is prohibitively expensive.

6.5. Energy access

Providing energy access to impoverished communities (section 3.3) is usually the responsibility of national and regional governments. The free market approach followed by several high-GDP countries is not generally considered optimal for providing access to energy services in rural areas of low-GDP countries (IPCC, 2011e). Several initiatives, such as the multi-partner Poor People's Energy Outlook (Practical Action 2012), are being carried out to provide a baseline and a practical means to measure energy access for the most impoverished areas. The MDGs make no reference to specific objectives or targets for energy access, nor do they take into consideration renewable energy. Consequently, energy has not been a high priority in international and national policy debates, even though multilateral and bilateral agencies, governments, academia and civil society all acknowledge that access to a secure supply of energy is critical for sustainable development (IPCC, 2011b). To address this situation, the UN General Assembly has designated 2012 as the *International Year of Sustainable Energy for All* (UN General Assembly, 2011). This initiative will serve as a platform to raise awareness about the importance of energy to sustainable development. One of its key objectives is to formulate a coordinated global energy strategy consistent with national policies to bring down the cost of renewable energy technologies and increase their access in impoverished rural communities.

Existing policy frameworks and national energy policies in developing countries often do not respond to the energy needs and capacities of impoverished communities. Questions related to energy access - Is the energy affordable? Is the technology adaptable? - need to be addressed when developing new policies. From the social perspective, co-benefits, such as heightened security of water supplies, healthier landscapes and greater biodiversity should be also considered in any policy decisions. The private sector may need to be

24 Feed-in-tariff is a guarantee of payment to project owners for the total amount of renewable electricity they produce when they sell to the national grid.

actively engaged to support energy projects that foster sustainable development. However, private investors seek to maximize returns on their investment. For this reason, investors would need some incentives to engage in business ventures designed to deliver energy services to communities with very limited ability to pay for them. Government subsidies or other financial incentives, for example offering long-term contracts to renewable energy producers, based on the cost of generation of each different technology would need to be clearly defined.

6.6. Knowledge gaps

- Data availability on energy use is relatively scarce for small-scale fishing and farming systems. This lack of information can lead to misrepresentation on existing situations and mislead the policy developments.
- Data on energy use and related GHG emission factors along the food chain are limited, particularly for low-GDP countries.
- Agreed methodologies for more accurate data collection and analysis of energy use and GHG emissions from farming small-scale capture fisheries, aquaculture and their related post-harvest and supply chains should be used to reduce data uncertainties. In particular, standardized metrics for measuring GHG emissions in the food chain are required to help regulators and stakeholders ensure that efforts to reach targets for reducing GHG emissions are appropriately supported. Different sets of assumptions lead to wide variations in LCA outputs and conflicting conclusions.
- Knowledge of the precise nature and magnitude of possible effects of climate change on both food production and the resource base for renewable energy remains limited, and possible impacts on specific regions remain uncertain.
- Synergies between public and private finance to achieve the needed investments for addressing food security and related climate change challenges (FAO, 2010b) are not well evaluated.
- The implications of food losses on the food supply chain (section 3.4) need further quantification. The high uncertainty in the current data has hampered the development of policies and investments to reduce food wastes.
- Biomass sources arising as co-products from food production and processing operations (section 4.1) can be a useful energy resource. However, competition for these resources exist. Methods for assessing the best use of this biomass require greater clarity and a holistic approach.
- Integrated farming systems, including IFES (section 4.3) have potential long-term benefits, such as improving efficiency in water use, maintaining soil quality and reducing energy demands. However, in some situations, measures to improve energy efficiency can lower productivity. However, these declines in productivity may recover and stabilize in the longer term. Further analysis and demonstrations of existing farming practices and IFES projects are needed to make optimal policy recommendations.
- The time needed to develop new energy-smart food systems so that they are competitive with conventional systems in terms of productivity, cost, and energy intensity is often under-estimated. Analysis of the timelines for creating new pathways for delivering these energy-smart systems, establishing appropriate safety nets and adopting effective transition measures would provide policymakers, institutions, financiers and other stakeholders with a better understanding of how to proceed.

To bridge these gaps, public investment in research and development for energy and the food chain will have to be increased significantly, particularly in low-GDP countries. Private sector investments in research and development in the food chain, directed primarily to large-scale systems, have been driven by the need to respond to the globalization of food commodity markets and the desire to maximize profits (FAO, 2011a). Small-scale systems have been neglected.

There is need for an effective policy environment to support the transition of the global food sector to one depending less on fossil fuels and more on renewable energy. There are good examples of range of successful and cost-effective policies and measures that are both energy- and climate-smart. They are ready for replication or implementation on a larger scale. Policy-makers should also consider policies that ensure benefits of being energy-smart will accrue equitably to all members of the local community. These could involve:

- filling up important knowledge gaps;
- investments in technology transfer and adaptation;
- applied research and development;
- accessing energy-smart technologies;
- fiscal support mechanisms;
- capacity building;
- extension services;
- education and training.

Initiatives targeting food consumers, such as mandating labels on retail food packaging that display the energy used in the production, processing, packaging and distribution of the product; mounting campaigns to promote healthier diets with significantly less animal products and raising awareness about how to avoid food losses can also reduce the food sector's demand on energy. However, the getting consumers to become more energy-smart will be difficult and will take some time.

A supporting policy environment without the appropriate allocation of financial and human resources is unlikely to succeed in establishing energy-smart food systems.

7. Conclusions and recommendations

This Issue Paper has attempted to put into context the relationship between food and energy in both high and low-GDP countries. As mentioned earlier, to meet growing food demands, the world needs to produce 70 percent more food by 2050. Achieving this goal would be difficult if prices and supplies and the costs of fossil fuels remain stable and GHG emissions could be avoided. But supplies of fossil fuels are uncertain and their costs are expected to go up. Furthermore, any increase in the use of fossil fuels to boost production will lead to greater GHG emissions, which the global community has pledged to reduce. There is justifiable concern that the current dependence of the food sector on fossil fuels may limit the sector's ability to meet global food demands. The global community has been forced to reassess current methods of producing, delivering and consuming food. The challenge is to decouple food prices from fluctuating energy prices.

As indicated earlier, the food sector accounts for over 30 percent of global consumer energy demand and produces over 20 percent of global GHG emissions. Around one-third of the food we produce, and the energy embedded in it, is lost or wasted. It is clear that continuing under business-as-usual is not an option.

Policy-makers need to adopt a long-term view to make the needed paradigm shift to food systems that are both climate-smart and energy-smart. The fact that this shift will not be accomplished in the short term does not mean that we can afford to wait. The key question at hand is not, 'If or when we should we begin the transition to energy-smart food systems?', but rather 'How can we get started and make gradual but steady progress?'

Once the commitment to move forward toward establishing energy-smart food systems has been made, a series of other questions need to be considered:

- What does energy demand mean for future food supplies?
- Where can energy use be improved?
- To what extent can renewable energy substitute for fossil fuels?
- What knowledge gaps need to be addressed?
- What policy and institutional mechanisms will be needed to ensure wide and sustainable implementation of energy-smart food systems?
- How soon do actions need to be undertaken?

7.1 The roles for energy efficient and renewable energy

As mentioned earlier, the concept of energy-smart food systems involves providing sustainable energy for the food sector and generating sustainable energy from the sector. There are three basic ways of making food systems energy-smart:

- increasing the efficiency of direct and indirect energy use so that the energy intensity (MJ/kg of food produced) of decreases;
- using more renewable energy as a substitute for fossil fuels without reducing food productivity; and
- improving access to modern energy services.

The energy generated though renewable energy resources can be used directly by farms, fisheries and processing plants or be sold off-site to gain additional revenue. Much of the renewable energy could come from local resources. Energy generating facilities using wind, solar and hydro power can be built on rural lands with negligible impact on agriculture. Biomass residues from primary production and food processing can also be used to generate energy. Awareness raising, capacity building and technical field support are essential if renewable energy projects are to be successfully established and operated.

7.2 Future pathways to energy-smart food systems

Various pathways can lead to increased productivity at both the small- and large-scale of primary production. All of these pathways demand energy.

Investments in improving energy efficiency and establishing renewable energy projects are increasing throughout the entire food sector, from primary production to transport and food processing. The Global Environment Facility has invested in a project to establish demonstration projects, strengthen policy and regulatory frameworks, and create a project pipeline for the food sector in the Ukraine (GEF, 2011). This approach could be replicated by governments of both high and low-GDP countries.

A combination of small-scale renewable energy systems and improved use of traditional biomass can provide access to reliable and affordable energy for many rural, forest and fishing communities currently without basic energy services in low-GDP countries. In the short term, fossil fuels may also be required to address energy poverty in rural areas. However, where feasible, it would be preferable to leap-frog directly to renewable energy systems to avoid investments in technologies that will lock users into fossil fuels for the foreseeable future. The potential co-benefits of renewable energy on livelihoods, employment, health, rural development should be considered.

7.3 Policy recommendations on the way forward

Policies can be employed at various levels in order to ensure that the food sector can adapt to future energy supply constraints and to the impacts of climate change. Rapid deployment of energy efficiency and renewable energy technologies in the sector will require regulatory measures, financial incentives and micro-financing to overcome the high up-front capital costs of some technologies.

- Deployment of sustainable energy systems throughout the global food sector is a huge undertaking requiring an approach consisting of many interconnected initiatives at the international level. Because of its urgency, scope and complexity, it will require the participation of a broad constituency of interested parties. An international effort will be essential in order to implement solutions in a coherent and cost-effective way. To advance toward energy-smart food systems, this paper recommends a multi-partner programme. This "Energy-smart food for people and climate" Programme would be based upon three pillars:
- increasing energy access with a focus on rural communities;
- improving energy efficiency at all stages of the food supply chain; and
- substituting fossil fuels with renewable energy systems in the food sector.

In conjunction with such a programme, national and local governments will need to consider policies and measures that support rural development, combine food security with energy security and meet their targets for sustainable development and GHG emission reductions. Technology transfer and the development of climate change adaptation strategies included in the programme's package of interventions.

Recommendations resulting from this initial report are:

- establishing public-private partnerships to promote energy-smart approaches in food production and trade and reduce the food sector's dependency on fossil fuels;
- encouraging international cooperation on climate-smart initiatives and GHG mitigation measures for the food sector;
- coordinating the formulation of energy-smart food policies between ministries responsible for food, agriculture, energy, health, transport, economic development and the environment; and
- promoting a multi-stakeholder dialogue on practical options for energy production and consumption, and the policies and institutional arrangements needed to achieve the desired results.

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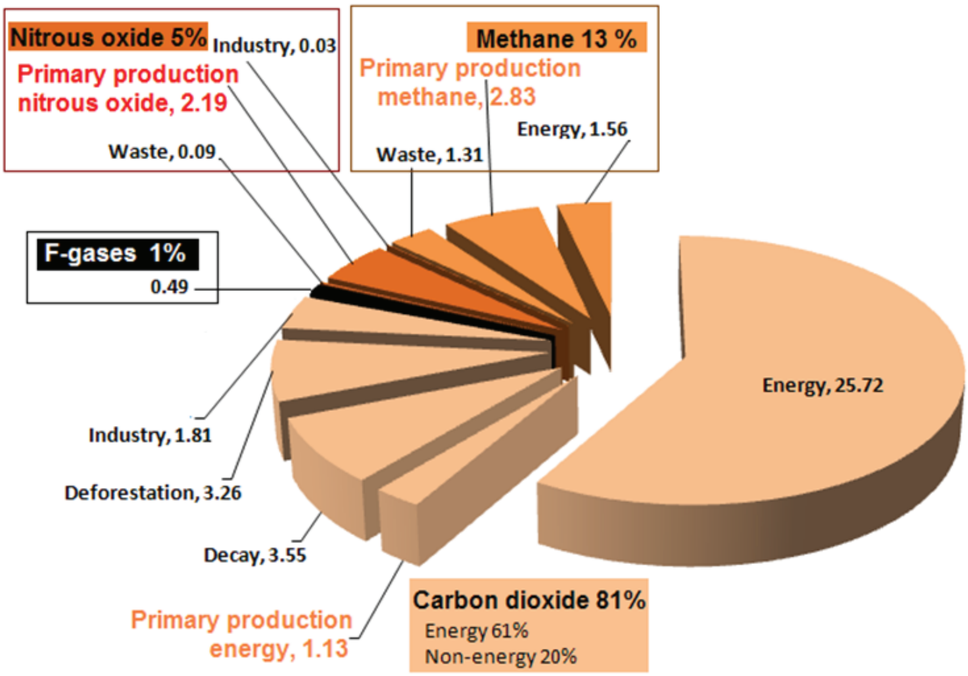
Annex 1. Greenhouse gas emissions

Anthropogenic GHG emissions totalled 44.17 Gt $CO_{2\text{-eq}}$ in 2006.

Emissions from primary production (methane, nitrous oxide and carbon dioxide) were around 14 percent of the total. Land use and land use change accounted for around 15 percent and energy approximately 65 percent (mostly CO_2).



(Based on IPCC, 2007a).

Primary production emissions were made up as follows:

- *Carbon dioxide* from fossil fuel combustion was around 3 percent of total GHG emissions (plus those arising from the oxidation of soil carbon, but noting that carbon released from biomass above or below ground, or from respiration from aquatic organisms, is usually balanced by photosynthetic carbon uptake).
- *Methane* at around 6 percent arose from ruminant digestion, paddy rice cultivation, anaerobic soils and sediments, plus small quantities from some aquaculture sites. Agriculture contributes nearly half of total anthropogenic methane.
- *Nitrous oxide* was approximately 5 percent, most coming from the action of soil bacteria on ammonium and nitrates originating from inorganic fertilizer use, manure and organic wastes, crop residues and nitrogen fixing plants.
- *Fluorocarbons* (or F-gases) give a small contribution, mainly from refrigerant leakages along the cool chain (GoS, 2011).

It should be noted these data are uncertain, particularly for low-GDP countries where possibly over two-thirds of total food-related GHG emissions originate.

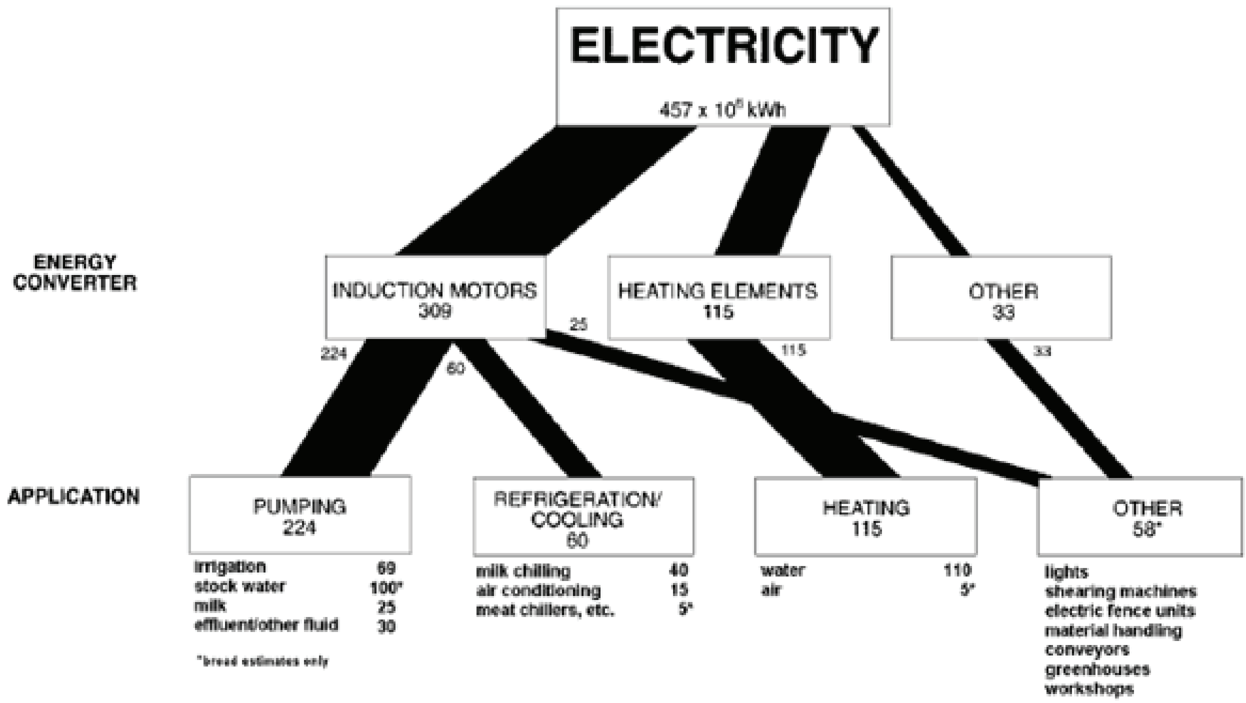
Annex 2. Energy inputs, demand intensities, renewable energy resources and exporting energy potentials for a range of typical primary production enterprises (Table based on IPCC, 2011c)

Enterprise type	Direct energy inputs	Energy demand intensity	Potential renewable energy sources	Energy export potential
Arable (e.g.wheat, maize, cassava, rice, palm oil, sugarcane)	Tractor fuel (diesel). Electricity for irrigation, storage facilities, conveying. Heat for drying (LPG, gas)	High diesel for machinery. High energy demand if irrigated; Low to medium for conservation agriculture. Low heat demand and seasonal.	Crop residues for heat and power generation and possibly biofuels. Biofuels and biogas from energy crops. Solar if good sites.	Biofuels (or feedstocks). Solar power. (Wind and hydro-power less likely on flat to undulating arable land)
Vegetables – large-scale for processing (e.g. potatoes, onions, carrots).	Tractor fuel (diesel). Electricity for irrigation, grading, conveying, cooling, ventilation, storing.	High diesel for machinery. High power demand if irrigated and for post-harvest chillers.	Dry residues for combustion. Wet residues for anaerobic digestion. Solar and wind possible.	Heat and biogas mainly used on-site. Solar power possible.
Market garden vegetables (small-farms).	Gasoline or diesel for 2 or 4 wheel tractors. Electricity for washing, grading.	Medium tractor fuel demand. Low power for post-harvest; medium for cool stores.	Residues and rejects for small biogas plant for use on-site – but small scale and seasonal.	Low.
Protected cropping - greenhouses.	As for market garden, plus heat and power for lighting, irrigation.	Low for machinery. High heat demand in winter.	Some residues for combustion. As for market gardens.	Low.
Fruit orchard (e.g. pip fruit, bananas, pineapples, olives).	Tractor fuel (diesel or gasoline). Electricity for drip irrigation, grading, cool stores.	Medium fuel. Medium electricity if irrigated and on-site post-harvest storage.	Pruning residues for combustion. Reject fruit for biogas.	Low
Dairying (large-scale of more than 50 cows).	Diesel for tractors. Electricity for milking, pumping, cooling, irrigation, lighting. Heat for water, pasteurising.	High electricity, especially if irrigated. Medium fuel for machinery. Low heat.	Manure for biogas. Waste heat from milk cooling. Solar thermal. Solar and wind if good sites.	Heat and power from biogas. Solar or wind power.
Pastoral livestock (e.g. sheep, beef, deer, goat, llama).	Diesel or gasoline for machinery. Electricity for shearing, refrigeration.	Medium if some pasture conserved. Very low power demand.	Wind and small-hydro if hill country. Forest residues. Solar if good sites.	Wind and hydro power.
Intensive livestock (e.g. pigs, poultry, calves).	Electricity for lighting, ventilation, water pumping. Diesel for tractors.	High if mainly housed indoors. Medium to low if partly outdoors. High if feed grown, low if bought-in.	Manure for biogas. Poultry litter for combustion. Solar and wind for water pumping.	Heat and power from biogas and poultry litter at community scale.
Capture fishing -trawlers	Marine diesel or fuel oil. Electricity for refrigeration, ice.	High fuel. Low electricity.	Reject catch. Fish process wastes for biogas, oils.	Low.
Capture fishing – small boats	Diesel, gasoline, 2-stroke fuel. Electricity for refrigeration, ice.	Low/medium fuel. Low power demand.	Fish process wastes for biogas.	None.
Aquaculture – fish farms on-shore or off-shore.	Diesel, gasoline, 2-stroke fuel for service boats. Heat. Electricity for refrigeration, ice, water pumping, aeration.	Low fuel if on-shore; medium if off-shore. Low heat for warm water. Low to medium electricity depending on type of enterprise.	Process wastes for biogas. Geothermal or solar thermal heat. Ocean energy – e.g. wave, tidal, and ocean current systems.	Low. Electricity from ocean energy possible in future.

Annex 3. Government actions to reduce energy demands of the food sector – a New Zealand country case study over four decades.

Since the 1970s, New Zealand has been concerned by the energy demand of its food sector, particularly as food and fibre products contribute around 60 percent of export revenue. In 1987 agricultural subsidies were removed and the industry had to become more efficient to compete. The global 'oil shocks' of 1973 and 1979 resulted in diesel fuel rationing and carless days. As a result, the government established the *NZ Energy Research Development Committee* and the *Liquid Fuels Trust Board* to undertake detailed studies and investments in order to reduce future dependence on imported oil. Energy use across the entire food sector was analysed in detail, as exemplified in Figure A1 for electricity use on-farms, with similar analyses conducted for gasoline and diesel use on-farm, as well as detailed analyses of the entire food processing industry. The aim was to identify the main areas where energy was used and hence enable research activities to focus on reducing energy demand by improving energy efficiency and substituting for imported oil.

Figure A1. Energy flows of electricity demand on New Zealand farms in 1980 - an example of the detailed analysis of energy in the food sector conducted around that time. Source: NZERDC, 1983



The NZ Energy Efficiency and Conservation Authority (www.eeca.govt.nz) was originally established in 1992 to give advice and support to businesses, homeowners and farmers on using energy wisely. Criticisms of New Zealand's exported food products having high 'food-miles' resulted in publication of an updated report on energy efficiency opportunities for all sectors, including primary production, transport and the food processing sector (CAE, 1996). More recently various detailed life-cycle analyses have been undertaken (see for example Saunders *et al.*, 2006; Frater, 2011). Reducing GHG emissions has become an additional driver, the government of this free-market economy aiming to return to 1990 emission levels under its Kyoto Protocol obligation. This has led to: setting a target of raising the present 75 percent of electricity generation coming from renewable energy to reach 90 percent by 2020; state-owned electricity companies advising farmers on reducing electricity demand; and the NZ Emissions Trading Scheme being instigated from 1 January 2008, which presently encompasses plantation forests, transport fuels and the electricity sector. It is planned to include agricultural emissions after 2015[25] (subject to review). These initiatives have resulted in many successes, such as the major milk processing company Fonterra reducing its energy input per tonne of product by 13.9 percent (=0.33 Mt $CO_{2\text{-eq}}$) and its on-farm GHG emissions by 8.5 percent per litre of milk (equivalent to 1.4 Mt $CO_{2\text{-eq}}$) (Ferrier, 2011). In spite of considerable government support and policies, there is still opportunity for the energy intensity of the New Zealand food sector to be reduced considerably more at all levels along the food supply chain. Low energy costs have been a barrier to date.

25 http://www.climatechange.govt.nz/emissions-trading-scheme/participating/agriculture/allocation/

Food and Agriculture Organization of the United Nations (FAO)
www.fao.org/bioenergy