CHAPTER 1 INTRODUCTION

Reducing "Energy Poverty" is increasingly acknowledged as the "Missing Development Goal". This is because access to electricity and modern energy sources is a basic requirement to achieve and sustain higher living standards. It is essential for lighting, heating and cooking, as well as for education, modern health treatment and productive activities, hence food security and rural development.

Yet three billion people – about half of the world's population - rely on unsustainable biomass-based energy sources (UNDP/WHO 2009), to meet their basic energy needs for cooking and heating, and 1.6 billion people lack access to electricity (IEA 2002). National policies and programmes aimed at providing broader access to energy services for the rural poor can significantly contribute to sustainable development and achievement of the Millennium Development Goals (MDGs), including those on poverty reduction and sustainable natural resource management in the face of climate change. This can be significantly supported and partially achieved through the design and implementation of livelihood-oriented, gender-sensitive small-scale bioenergy schemes, adapted to local conditions.

Small-scale farmers are globally the largest farmer group and of key importance to local and national food security in developing countries. According to an analysis by the Consultative Group on International Agricultural Research (CGIAR), the world's one billion poor people (those living on less than one dollar a day), are fed primarily by hundreds of millions of small-holder farmers (most with less than two hectares of land, several crops and perhaps a cow or two) and herders (most with fewer than five large animals) in Africa and Asia (Herrero *et al.* 2009). Therefore, safely integrating, intensifying and thus increasing food and energy production for this large group of producers may have the best prospect to improve both local (rural) and national food and energy security and reduce poverty and environmental impact at the same time.

While biomass is, and has been, the primary energy source for the rural poor in developing countries, it has also been of special interest in the Organization for Economic Co-operation and Development (OECD) countries in recent years, mainly due to the production of liquid biofuels for transport. This has caused strong controversy, mainly regarding the potential risk that the production of biofuels may pose to food security of the rural poor in developing countries, but also regarding issues related to global climate change. While some energy crops provide a positive greenhouse gas emission balance, others are significantly negative. Another unresolved issue is the indirect land use change (ILUC) that might occur when food crop plantations are replaced by energy crops and

BOX 1

THE ECOSYSTEM APPROACH

The Ecosystem Approach is defined as a strategy for the management of land, water and living resources that promotes conservation and sustainable use in an equitable way. While similar to a number of other holistic approaches to conservation, development and natural resource management, it has some key distinguishing features, i.e.:

- it is designed to balance the three CBD objectives (conservation, sustainable use and equitable benefit sharing of genetic resources);
- it puts people at the centre of biodiversity management;
- it extends biodiversity management beyond protected areas while recognizing that they are also vital for delivering CBD objectives; and
- it engages the widest range of sectoral interests.
- The key principles of the Ecosystem Approach are:

Principle 1. The objectives of management of land, water and living resources are a matter of societal choice.

Principle 2. Management should be decentralized to the lowest appropriate level.

Principle 3. Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

Principle 4. Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should: a) reduce those market distortions that adversely affect biological diversity; b) align incentives to promote biodiversity conservation and sustainable use; and c) internalize costs and benefits in the given ecosystem to the extent feasible.

Principle 5. Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

Principle 6. Ecosystems must be managed within the limits of their functioning.

Principle 7. The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

Principle 8. Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.

Principle 9. Management must recognize that change is inevitable.

Principle 10. The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.

Principle 11. The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations & practices.

Principle 12. The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

Source: Smith and Maltsby, 2003

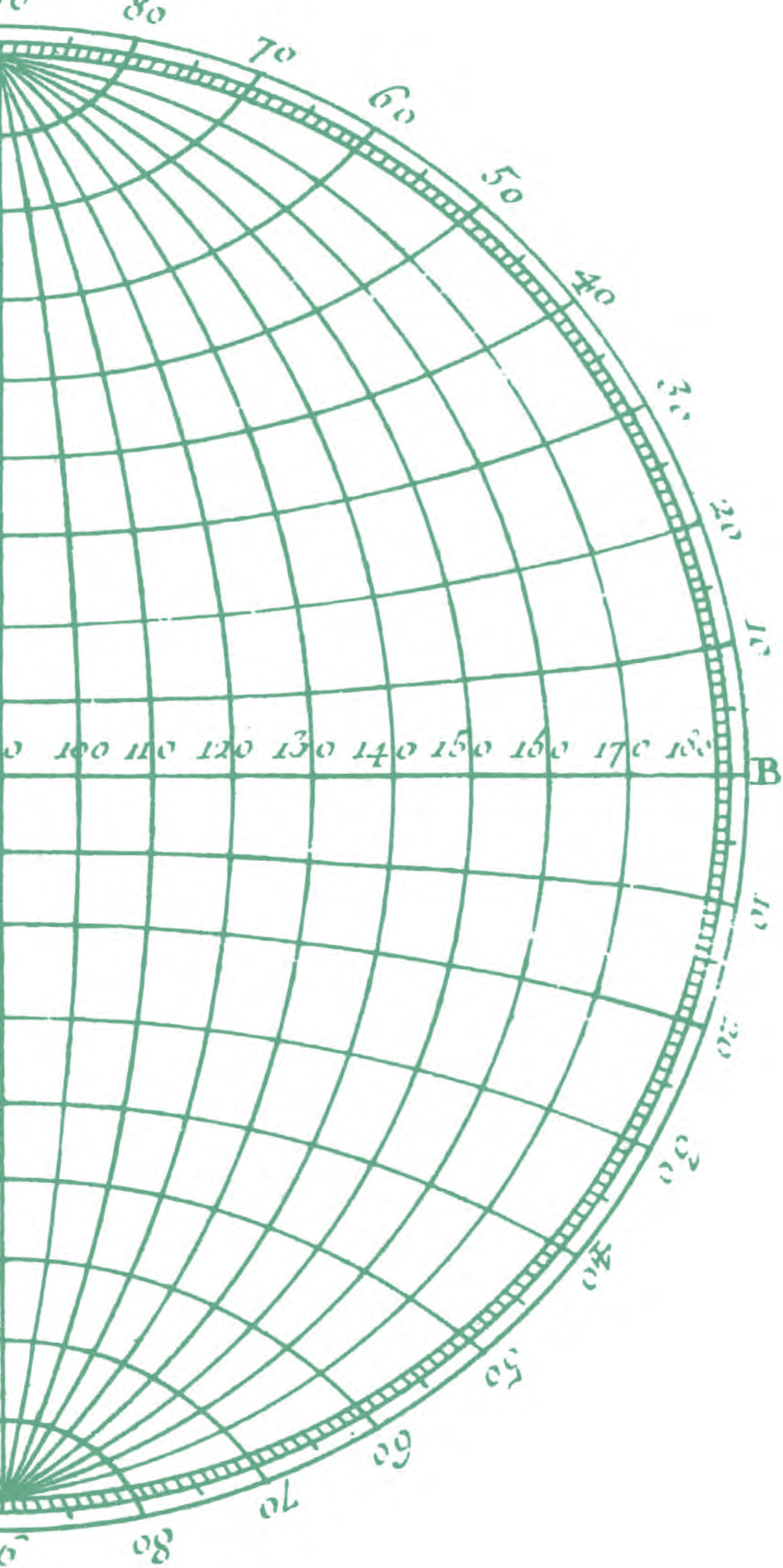
food production is then shifted to other regions, potentially causing the depletion of natural resources (see Box 4 in Chapter 2.4.3.).

Integrated Food Energy Systems (IFES) aim at addressing these issues by simultaneously producing food and energy as a way to address the energy component of sustainable crop intensification through an ecosystem approach, as defined in Box 1. This can be achieved in two ways: by combining the production of food and biomass for energy generation on the same plot; or by making multiple uses of each agricultural product and its residues.

The concept of Integrated Food and Energy Systems (IFES) as such is not new. Simple integration of food and energy production at both small and large scales has shown many successful results. However, with the increasing complexity of the system, - and hence higher resource use efficiency, the number of successful cases diminishes. Concrete results on wide-scale implementation of more complex IFES are scarce. Few attempts have been made to assess the challenges that true resource-efficient IFES face (Sachs *et al.* 1991; Woods *et al.* 2006), and proper reports that evaluate research and pilot projects years after their implementation are hard to find.

Given this situation, FAO held an international technical consultation in July 2010 on “How to make integrated food-energy systems work for both small-scale farmers[1] and rural communities in a climate-friendly way”. This paper draws on an extensive review of literature and the findings of this technical consultation to identify what hinders IFES, in particular, and some key solutions that could help to realize their benefits on a wide scale. It starts by introducing the IFES concept and potential benefits, as well as some example of IFES in both developed and developing countries. It then briefly discusses the constraints related to IFES implementation, both at the farm level and beyond the farm, before venturing to suggest some possible solutions to overcome these constraints.

1 There is no consistent definition of small-scale farmer, smallholder or small-scale agriculture. The most common approach is to define small-scale farmers by the size of their landholdings, e.g. farmers with less than two hectares of land (CGIAR 2009). Others use these terms often albeit not always appropriately, interchangeably with smallholder, family, subsistence, resource poor, low-income, low-input, or low-technology farming (Heidhues and Brüntrup 2003). Narayanan and Gulati (2002) characterize a small-scale farmer as a “farmer (crop or livestock) practising a mix of commercial and subsistence production or either, where the family provides the majority of labour and the farm provides the principal source of income”. This latter definition allows for the inclusion of local markets, i.e. households and rural communities, but also non-local markets for sale of additional surplus, and outgrower schemes related to large-scale production and processing. It will therefore be the one used for the purpose of this paper.


80
70
60
50
40
30
20
10
100 110 120 130 140 150 160 170
B
10
20
30
40
50
60
70
80

CHAPTER 2 WHAT ARE IFES?

2.1 DEFINING IFES

Integrated Food Energy Systems (IFES) (Sachs *et al.* 1991) refer to farming systems designed to integrate, intensify, and thus increase the simultaneous production of food and energy in two ways:

Type 1 IFES are characterized through the *production of feedstock for food and for energy on the same land, through* multiple-cropping patterns or agroforestry systems.

Type 2 IFES seek to maximize synergies between food crops, livestock, fish production and sources of renewable energy. This is achieved by the *adoption of agro-industrial technology (such as gasification or anaerobic digestion) that allows maximum utilization of all by-products, and encourages recycling and economic utilization of residues.*

2.1.1 Type 1 IFES

Farming systems that are based on diversification of land use and production are either systems combining the growth of different annual crops, such as multiple-cropping, or systems mixing annual and perennial crop species, i.e. agroforestry: either system is sometimes combined with livestock and/or fish production.

Multiple-cropping patterns are described by the number of crops per year and the intensity of crop overlap. *Double cropping or triple cropping* signifies systems with two or three crops planted sequentially with no overlap in growth cycle. *Intercropping* indicates that two or more crops are planted at the same time, or at least planted so that significant parts of their growth cycles overlap. *Relay cropping* describes the planting of a second crop after the first crop has flowered; in this system there still may be some competition for water or nutrients. *Mixed cropping, strip cropping, associated cropping, and alternative cropping* represent variations of these systems (McGraw-Hill 2007).

Agroforestry is a collective name for land-use systems and technologies in which woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately combined in the same management unit with herbaceous crops and/or animals, either in some form of spatial arrangement or temporal sequence (Lundgren 1982). Agroforestry systems fulfil two important roles, providing ecosystem services and productive services. The first role includes practices that ensure food diversity and seasonal nutritional security, and that strengthen resilience to climatic fluctuations. The ecosystem services they provide at landscape level for watershed protection and biodiversity conservation can also be significant. In its second role, agroforestry includes practices that help protect and sustain agricultural production capacity which provides food, fodder, fuelwood, building materials and medicine to the user.

2.1.2 Type 2 IFES

The goal of Type 2 IFES is to maximize synergies between food crops, livestock, fish production and sources of renewable energy. This is achieved by the adoption of agro-industrial technology (such as gasification or anaerobic digestion) that allows maximum utilization of by-products. Type 2 IFES and similar concepts have been described under several different names in the world, e.g. Concept of Circulative Farming System or Biomass Town in Japan, Integrated Three-In-One, Four-In-One or Five-In-One Models in China, or Cascade systems in Germany. However, they all have one core set of characteristics:

- *High productivity:* The cultivation of high-biomass crops should be the first step in establishing IFES, which means basing the production on plants with high photosynthetic efficiencies.
- *Optimal use of biomass, based on the idea that nothing is considered 'waste'*: By-products or leftovers from one process become the starting point for another in cycles that mimic natural ecosystems. This has some practical requirements, i.e. the cultivation of crops that are easily fractionated into food/feed components (the nutritional part of plants) and fuel energy components (the fibrous structural elements of plants); and the means for converting the fibrous elements into usable or saleable energy.
- When appropriate, *crop and livestock integration*: Bioenergy production can reduce the environmental footprint of livestock through the multiple use of animal feed crops. Given that about one third of the existing arable land worldwide is used for growing crops to be fed to livestock rather than humans, there is potential for this to also co-produce bioenergy without significantly reducing the amount of livestock supported.
- *Linking food and energy production:* Anaerobic digestion and pyrolisis are processes that produce both energy and fertilizer, therefore addressing some potential conflicts between food and energy production.

In addition to the characteristics mentioned above, Type 2 IFES sometimes include a microalgae and fish pond component. The nutrient rich slurry from anaerobic digesters can be released into ponds containing microalgae and other aquatic plants that become feed for fish. However, this additional component requires the right climatic conditions which are usually only found in the humid tropics.

Sometimes, both the food and energy component come from the same plant, e.g. sweet sorghum where the grain is used as food or fodder, and the stems are used to produce ethanol. This is a *multiple product crop*, which does classify under Type 2 IFES, since different parts of the plant are used for different purposes. Food security is not threatened since the energy use does not interfere with the food use. However, there are other crops that can supply both food and energy, which do not necessarily classify under IFES schemes. These are plants that can be used as food or as energy feedstock. Since both applications come from the *same* part of the plants, there is competition between the different uses, hence potentially having a negative impact on food security. The production of oil palm or sugar cane in monocultures would fall under this category, when the oil produced goes entirely into bioethanol or biodiesel production. These systems can become IFES when the by-products such as the molasses of the sugar cane processing are used for animal feed. Furthermore, the right policies would need to be in place to ensure the exclusive production of vegetable oil from oil palm, or sugar from sugar cane, in times of food crises. This is the case for sugar cane processing in Brazil, for example.

Type 2 IFES can be fairly simple, such as the production of biogas at farm level described in the Vietnamese case study in Box 2, or rather sophisticated, with recycling of waste as both energy feedstock and animal food, as shown in the Colombian case study (Box 8).

BOX 2

NATIONAL BIOGAS PROGRAMME, VIET NAM

Viet Nam embarked on an integrated land management scheme, following land rights being given to individual farmers. This is supported by the Vietnamese Gardeners' Association (VACVINA), which works at all levels, and has national responsibility to promote this concept – called the VAC integrated system. It involves gardening, fish rearing and animal husbandry, to make optimal use of the land. Traditional fuels such as wood and coal for cooking, are becoming increasingly scarce and expensive, and can contribute to deforestation. Increasing livestock production in rural communities with high population density leads to health and environmental issues from the quantity of animal dung being produced. Biogas digesters are part of the solution offered by this initiative, using the waste to generate energy, and the resultant slurry as a fertilizer to improve soil quality. A market-based approach has been adopted to disseminate the plants. The service provided to those buying the digesters is comprehensive. The customer must have at least four to six pigs or two to three cattle that provide all the inputs (animal dung). Households use the biogas as fuel and slurry as fertilizer. They pay the total installation cost for the digesters to local service providers, and operate the biodigester using instructions provided by local service providers. A biodigester produces enough daily fuel for cooking and lighting. It improves the surrounding environment, whilst livestock produces meat, milk and fish products for local consumption and subsistence farming. Vegetable production is enhanced through use of biogas slurry. Latrines can be added to the system to enable human waste to be used for energy.

Source: FAO / Practical Action, 2009

A recent review of algae-based IFES shows some of the opportunities such systems present, but also the many challenges they would face to be developed on a large scale (FAO, 2010a).

2.2 IFES SCALES AND CONFIGURATIONS

IFES can function at various scales and configurations, from small-scale systems that operate on the village or household level, to large-scale systems adjusted for industrial operations:

- *small- or community-scale,* are mainly for the purpose of self-sufficiency of the rural population;
- *large-scale*, are mostly owned by a large-scale farmer or the corporate sector, and based on commercial activities, but involving and benefiting small-scale farmers.

It is important to know that large-scale IFES can benefit small-scale farmers when they fulfil *two characteristics*:

- adequate involvement of small-scale farmers in decisions and benefits along the value chain; and
- positive impacts on rural communities.

The involvement of small-scale farmers in large-scale schemes can be achieved through *outgrower schemes.* An outgrower scheme is a contractual partnership between growers or landholders and a company for the production of commercial products, in this case feedstock that will be processed into bioenergy by a large-scale unit. This is further discussed in the Section on "Potential solutions" (6.), and also in FAO (2001b); FAO (2007a) and Vermeulen & Goad (2006).

Be it small- or large-scale, the fundamental distinction lies in the ultimate purpose of the system (Sachs *et al.* 1991):

- One is *"farm-centred",* such as the Vietnamese biogas farm described in Box 2, or in the case of agribusiness, *enterprise-centred*, where the production of energy is a spin-off of agricultural production.
- Another system is the *"energy farm"* unit designed for the production of energy, usually for distribution via conventional means to distant urban markets. One example of this is the Itaipu biogas project in Brazil (FAO 2009), where biogas produced in small to medium farms is transformed into electricity, and part of this electricity is fed into the local grid. This type of system could be expanded into a kind of "public utility" system that provides a social service other than food production, for example, waste water treatment in a manner that simultaneously produces food and energy and reduces the environmental load. Examples of this include urban latrine systems in India, which, coupled with a biogas generator, produce both hot water and street lighting while reducing the sewage treatment problem.
- A third type of IFES is the "*community focused*" system. It seeks to energize daily life in a variety of ways that answer domestic and community needs, such as

cooking and sanitation, as well as individual and community productive needs in agriculture and industry.

2.3 COMBINING DIFFERENT RENEWABLES IN IFES

In many situations, the production of renewable energy can feasibly go well beyond bioenergy alone. Other locally available (non-biological) renewables can be incorporated, such as solar thermal, photovoltaic (PV), geothermal, wind and water power. Technologies for small-scale renewable applications are mature and may often have synergies with agricultural production. For example, small wind pumps can provide water for irrigation to increase productivity. Wind turbines can provide electricity without competing for cropland: by siting them in or around fields, they can harness the wind whilst the crops harness the solar energy, making double use of land.

Technological diversity combined with reasonable simplification can provide more reliable and more flexible solutions that allow IFES to also provide energy needs for modern communities, i.e. electricity, heat and transport energy. Bioenergy combined with other renewables can give greater reliability than if they were separated, as in the case of wind power or solar heating with biomass back-up. Use of other renewables can reduce wood fuel needs, which can reduce the size of a wood lot needed, or create the opportunity to use wood fuel for other things, such as in agricultural processes.

The balance between food and energy production and between self-consumption and excess for markets, needs to be adapted to local needs, farmer capacities (knowledge and economic), physical and environmental conditions. It will change over time and possibly quickly, particularly if economically successful. Thus, it also needs to be able to adapt and change. A lock-in to very high investment technologies, unless economically remunerable in a relatively short time span, may need to be avoided under most conditions.

An example of such an IFES based on different renewable energy systems, combining the use of PVs and biodigesters, is the Tosoly farm presented in Box 8, where solar panels have been recently acquired as a backup and complementary energy source to the anaerobic digester and gasifier. Another such system has been proposed for the Brazilian Northeast Region. It builds on experiences taken from different combined renewable energy systems (RES) in Brazil, and stresses the need to adopt a strong and long-term energy policy towards small size RES, in order to avoid their discrimination by rural and regional communities. Moreover, it emphasizes the importance of acquiring consumer confidence first; people must be invited to participate in the process of decision-making (Borges Neto *et al.* 2010).

2.4 POTENTIAL IFES BENEFITS

2.4.1 Food and energy security

The main driver of implementing IFES in developing countries is the need for food and energy security - the basic requirement for poverty reduction and rural development.

According to the 1996 World Food Summit, food security represents "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."

This implies that energy is available and accessible. Without energy security, there is no food security. Energy is required for cooking most foods, and for boiling (and purifying) water. Energy is needed to make most food eatable and digestible. If energy is scarce, women may be forced to ration cooking time. This can lead to decreases in food consumption or meal frequency. In turn, the nutritional well-being of household members may suffer. Additionally, lack of energy may increase the incidence of illness through bacterial or parasitical contamination resulting from contaminated water or improperly prepared food. Improved access to modern bioenergy such as biogas, wood pellets, or bioethanol or other sources of renewable energy, significantly improves the health condition of rural people in developing countries, especially women and children, and IFES can contribute to this improvement.

IFES can directly improve the farmer's livelihood when the farmer or local community becomes self-sufficient in terms of food and energy production, or when the food and/or energy generated provides income to the farmer or community. Access to sufficient energy for basic services and productive uses therefore represents the key to improve livelihoods in the poorest countries and drives local economic development on a sustainable basis. Basic services comprehend the provision of electricity for lighting, health, education, communication and community services (50-100 kWh per person per year) and modern fuels and technologies for cooking and heating (50-100 kgoe of modern fuel or improved biomass cooking stove). Energy for productive use is given when electricity, modern fuels and other energy services are in place to improve productivity, e.g. water pumping for irrigation, fertilizer production, agricultural processing, and transport fuels (AGECC 2010).

Finally, by reducing the use of fossil fuels in agriculture, IFES also reduce the risk that inputs, which are necessary to increase productivity, become unaffordable due to the high price of fossil fuels. This is an important consideration, given that the necessary significant increase in food production in the decades to come will be achieved mainly through yield increase (FAO, 2010d).

2.4.2 Maximizing resource efficiency

Although food and local energy security are usually taken for granted in *developed countries*, there is still an increased interest in combining food and energy production. This is mainly based on the fact that land is anything but an abundant resource in most industrialized nations. In densely-populated regions such as the Netherlands, energy crop introduction is strongly hampered by lack of available land (Londo 2002), and improving resource efficiency is therefore among the top priorities in today's world, as governments, businesses and civil society are increasingly concerned about natural resource use, environmental impacts, material prices and supply security (OECD 2008).

Resource efficiency, at its most basic, means the efficiency with which resources such as land, water, biomass and workforce are used in simple processes and turned into valuable products (AGECC, 2010). This is achieved when the same level of a given output or service is produced with a lower total amount of inputs and resources e.g. reducing the amount of land cultivated by intercropping food feed and fuel crops. Alternatively, resource use becomes more efficient when more goods or services are produced with the same amount of resource inputs, e.g. producing food, feed and fuel production from one crop, by making full use of all by-products.

2.4.3 Addressing climate change

While the main drivers behind IFES are often safeguarding food, feed and energy security and improving resource efficiency, IFES also addresses several challenges posed by climate change and climate variability. These are among the most important challenges facing developing countries due to their strong economic reliance on natural resources and rain-fed agriculture. Adaptation should enable agricultural systems to be more resilient to the consequences of climate change. Mitigation addresses its root causes, thereby limiting, over time, the extent and cost of adaptation, as well as the onset of catastrophic changes (FAO 2009).

Agriculture accounts for roughly 14 percent of global greenhouse gas emissions (GHGs) or about 6.8 Gt of CO_2 equivalents (e) per year (IPCC 2007). When combined with related land use changes, including deforestation (for which agriculture is a major driver), this share becomes more than one-third of total GHG emissions. About 74 percent of total agricultural emissions originate in developing countries (IPCC 2007) where food, feed and fuel for the consumption of both developing and developed countries are produced. With regards to emissions from energy use, it is necessary to distinguish between basic energy needs and productive uses. While universal access only to the most "basic human needs" levels of energy services will have a limited impact on GHGs, as basic universal electricity access would add around 1.3 percent of total global emissions in 2030 (IEA 2009). Increasing the level of energy provision and consumption for productive uses could increase emissions substantially (AGECC 2010).

2.4.3.1 Adaptation to Climate Change

In order to minimize the risks of climate change and climate variability, it is important to diversify farming systems through the integration of cropping, livestock, forestry and fisheries systems, the conservation of ecosystems, their biodiversity, and resilience and ecosystem services. It is also necessary to link climate change adaptation processes to technologies for promoting carbon sequestration, substitution of fossil fuels, and promote the use of bioenergy (FAO 2007).

This is closely related to the "Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change" of the United Nations Framework Convention on Climate Change (UNFCCC).

As of October 2008, the UNFCCC Secretariat had received National Adaptation Programmes of Action[2] (NAPAs) from 38 Least Developed Countries (LDCs), of which 80 percent are falling under the category "Food Security and Agriculture". Among these, IFES are suggested by different countries as a local means of adaptation to climate change, sometimes explicitly, as in the case of São Tomé and Principe – see Box 3, and sometimes indirectly as part of the country's energy strategy, as in the case of Rwanda (UNFCCC 2008a).

BOX 3

INTEGRATED LIVESTOCK DEVELOPMENT IN THE NORTH OF SÃO TOMÉ ISLAND

Climate change enhances the lack of animal foods in the northern part of São Tomé, due to the occurrence of drought. This might lead to the loss of cattle, as happened recently in Kenya. Among livestock, the goat is most adapted to drought conditions, since it can feed on pastures of smaller nutritional value and it needs less drinking water than other livestock, such as poultry and pigs. It produces milk, cheese and local meat - products that are deficient in the country. Goat manure can be used for fertilizer production, and/or energy generation through biodigestion. This pilot project should be implemented by the livestock sector, through the establishment of dynamic partnerships between the Agriculture, Forest, and Environment sectors and international, bilateral or multilateral technical cooperation. The results could be disseminated by local companies and family producers, and be further economically and technically developed.

Adapted from UNFCCC (UNFCCC 2008b)

More specifically, IFES have the potential to contribute to local adaptation to climate change through:

- *Soil conservation* when IFES systems include the incorporation of organic matter in the soil (e.g. compost from crop residues or slurry from biogas production). Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods). A key element to respond to both problems is soil organic matter, which relies primarily on the incorporation of crop, forest and livestock residues in the soil. In addition, residues deliver essential minerals, and constitute an important source for soil carbon and a medium for soil's micro-and macro-organisms.

[2] NAPAs provide a process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage.

- *Increase of biodiversity* when IFES are based on diversified land use and production. Biodiversity increases resilience to changing environmental conditions and stresses. Genetically-diverse populations and species-rich ecosystems have greater potential to adapt to climate change. Through the use of different types of crops in multiple cropping patterns or agroforestry systems in Type 1 IFES, the risk of biodiversity loss decreases, and sometimes local biodiversity even increases.
- *Financial resilience* due to IFES, especially those relying on the use of by-products Type 2 IFES, can lead to more self-sufficiency in some inputs, such as organic fertilizer and/or animal feed and energy; hence reduced debt and easier access to inputs which become more important under uncertain production conditions.

2.4.3.2 Mitigation of Greenhouse Gas Emissions

Mitigation of GHGs in agriculture and other land use sectors includes measures that: (i) reduce emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Cole *et al.* 1997; IPCC 2001; Paustian *et al.* 2004); (ii) sequester carbon in soils or biomass; and (iii) avoid emissions from fossil fuels or displace them with biomass energy. IFES have the potential to contribute to the global mitigation of climate change through GHG emission reduction, carbon sequestration and the avoidance of emissions.

i. Reduction of GHG emissions

Emissions of CO_2, CH_4 and N_2O can be controlled through sustainable agricultural practices. For instance, practices that deliver added N more efficiently to crops often suppress the emission of N_2O (Bouwman 2001). Improved manure management in the livestock sector can reduce CH_4 emissions by capturing the gas in covered manure-storage facilities (biogas collectors). Captured CH_4 can be flared or used to provide a source of energy for electric generators, heating or lighting (which can offset CO_2 emissions from fossil fuels) (FAO 2009b).

Furthermore, IFES reduce pressure on land use through intercropping of food and energy feedstocks and/or the use of residues such as food, feed or fuel. As a consequence, GHG emissions that would have occurred from new land conversion for food, feed and fuel production are reduced or avoided. A recent study found that the more systematic use of by-products could amount to a reduction of ten to 25 percent of land needed to produce liquid biofuels, depending on the GHG reduction targets and use of second generation biofuels (Croetzen *et al.* 2008).

By-products used in Type 2 IFES also affect indirect land-use change (ILUC). When bioenergy crops generate feed as by-products and feed production elsewhere can be avoided, the indirect land-use change is smaller. For instance, using the example of animal feed products from rapeseed and wheat as a substitute for imported soybean in Europe, Ros *et al* (2010) contend that, based on the protein content of the by-product and soybean, the land use for soy cultivation can be reduced by 50 to 100 percent compared to the land used for the cultivation of the rapeseed and/or wheat depending on the yields of the concerned crops and by-product characteristics (see Box 4 for how IFES can mitigate the risk of indirect land use change).

BOX 4

HOW IFES CAN MITIGATE THE RISK OF INDIRECT LAND USE CHANGE

Approaches to address indirect land use change (iLUC) through expansion of biofuel crops have intensively been discussed between different stakeholder, particularly for the purpose of biofuel certification, e.g. under the GBEP and RSB. Most efforts have been undertaken to quantify potential iLUC effects through modeling. This exercise has shown many different results to-date, mainly due to different assumptions underlying the given models, and an agreement between different stakeholders is not to be expected in the near future. However, a necessary complement to risk quantification, has hardly been taken into account so far – i.e. the prevention and/or mitigation of unwanted effects related to iLUC.

There are several mitigation options available that can address this issue, but the current debate lacks concrete information on **how to make mitigation options work in practical terms**: How do farming practices look like in technical and agronomical terms? How should intuitions be structured to support the implementation of the options available? Which policies need to be in place to incentivize certain models and best practices? Which would be the best option for reducing greenhouse gas emissions and environmental impact in general? How can small-scale farmers and private companies benefit alike?

Integrating food and energy production through *physical integration* of different crops (Type 1 IFES) and, mainly, through the *use of by-products* in one production system or across regions (Type 2 IFES) is suggested to be an effective approach of mitigating iLUC (e.g Ecofys 2010, Tilman *et al.* 2009). Implementing IFES leads to increased land and water productivity, therefore reducing greenhouse gas emissions and increasing food security. Moreover by combining food and energy production, IFES reduce the need to convert land to produce energy, in addition to land already used to agriculture. This further reduces the risks associated with land conversion – hence additional GHG emissions Several recent scientific studies substantiate the mitigation of iLUC through IFES options, particularly Type 2 IFES, with concrete data. A report commissioned the Netherlands Environmental Assessment Agency (Ros *et al.* 2010) comes to the conclusion that if by-products from rapeseed and wheat are used for feed substituting soy meal, the land use for soy cultivation can be reduced by 50 to 100% compared to the land used for the cultivation of the rapeseed and/or wheat depending on the protein content. Therefore, by-products used for feed may substantially change indirect effects of land-use change and overall greenhouse gas emission reductions from biofuel production. An in-house literature review conducted for DG Energy as part of the European Commission's analytical work on iLUC (EC 2010) finds that taking into account of co-products reduces the estimated land requirement significantly - between 23% and 94%.

The significant GHG reduction potential of (mainly type 2) IFES makes these systems good candidates for carbon finance, as illustrated in Box 5.

BOX 5. CARBON FINANCE FOR SMALL-SCALE FARMERS

Only ten percent of Nepalese households are connected to the power grid, and most energy comes from traditional fuels. The dependence on fuelwood has contributed to deforestation, resulting in fuelwood scarcity and widespread erosion. Fossil fuel is expensive for many rural people. The villagers often spend hours collecting fuelwood in order to cook a proper meal each day. The project aims to develop biogas use as a commercially viable, market-oriented industry in Nepal. Between 2004 and 2009 the project planned to install 162 000 quality-controlled, small-sized biogas plants in Nepal. The provision of subsidies has been a key element in making these biogas plants accessible to poor households. The biogas plants displace traditional fuel sources for cooking-fuel wood, kerosene, and agricultural waste and introduce the proper treatment of animal and human wastes, as well as produce a high-quality organic fertilizer. Each biogas plant can reduce 4.6 tCO_2e annually. The project will generate a total of approximately 6.5 million t CO_2e during the crediting period of ten years.

Source: World Bank, no date

ii. Carbon sequestration

Agricultural ecosystems hold large reserves of carbon (IPCC 2001), mostly in soil organic matter. Any practice that increases the photosynthetic input of C or slows the return of stored C via respiration or fire will increase stored C, thereby 'sequestering' C or building C 'sinks' (Smith *et al.* 2008). This can be achieved by avoiding burning and soil movement during land clearing, avoiding deforestation, afforestation, increasing soil organic matter levels, and by crop and grazing land management, in particular, by avoiding soil tillage. Soil carbon sequestration is estimated to be nearly 90 percent of the technical mitigation potential of agriculture (IPCC 2007).

IFES contribute to carbon sequestration though the inclusion of perennial crops in farming systems, which characterize Type 1 IFES, such as agroforestry systems which are explicitly recommended as mitigation strategy by the IPCC (Smith *et al.* 2007); and through Type 2 IFES ('zero-waste' systems) which provide alternative sources of energy to traditional fuelwood. Such use often leads to forest depletion, and even deforestation in areas under severe population pressure (e.g. refugee camps, peri-urban areas).The significant climate change mitigation potential of IFES implies that such systems should be considered as important ways to achieve objectives under REDD[3] in developing countries.

However, the use of primary biomass residue for energy can compete with its use to directly sequester carbon in soils. Only in cold and moist climates is the quantity of biomass produced higher than the carbon storage potential for organic matter in soils. In those cases, removing biomass for bioenergy production can work. In tropical conditions this might not be feasible for at least the next 30 to 50 years, until the carbon gap in the soils is closed [Friedrich, personal communication].

Therefore, bioenergy generation which produces energy and soil fertilizer and amendments (such as slurry from anaerobic biodigestion, and biochar from gasification) and at the same time, allows for about 50 percent return of carbon to the soil (UNCCD 2008), should be favoured.

iii. Avoidance or displacement of fossil fuel use

Crops and residues from agricultural lands can be used as a source of fuel. This is only sustainable if the feedstocks produced have lower life-cycle GHG emissions than fossil fuels and do not compete with food production for land and water. Biomass can be converted to liquid transport fuels such as bioethanol or biodiesel (Cannell 2003; Schneider *et al.* 2003). After initial enthusiasm for liquid biofuel production, concerns arose around the danger of displacing either food production or natural habitats due to mass production of crops specifically for biofuels. While the issue is still highly controversial, some argue that food production and feedstock cultivation for bioenergy generation are not necessarily mutually exclusive. By combining food and energy production simultaneously, the food-energy dilemma related to biofuels could be significantly mitigated, and impacts regarding elevated GHG emissions could perhaps be solved in a sustainable way.

Tilman *et al.* (2009) sum it up neatly in a recent paper: "*Recent analyses of the energy and greenhouse-gas performance of alternative biofuels have ignited a controversy that may be best resolved by applying two simple principles. In a world seeking solutions to its energy, environmental, and food challenges, society cannot afford to miss out on the global greenhouse-gas emission reductions and the local environmental and societal benefits when biofuels are done right. However, society also cannot accept the undesirable impacts of biofuels done wrong. Biofuels done right can be produced in substantial quantities. However, they must be derived from feedstocks produced with much lower life-cycle*

[3] Reducing Emissions from Deforestation and Degradation, in short REDD, in Developing Countries - is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. For further information, please refer to http://www.un-redd.org.

greenhouse-gas emissions than traditional fossil fuels and with little or no competition with food production".

Combining the production of food and energy crops on the same piece of land, or making full use of all by-products as food, feed, fuel and fertilizer belong to "biofuels done right". Hence, IFES present a potential solution to produce biofuels for transport in a more sustainable way.

Several initiatives support this view. The German Advisory Council on Global Change (WBGU), for instance, suggests to follow an integrated food and energy security strategy to mitigate risks associated with the current bioenergy boom, adding to recommendations given by the German Federal Cabinet in its report on "Global food security through sustainable development and agriculture" (Bundeskabinett 2008). This is further elaborated in WBGU's recent publication "World in Transition – Future Bioenergy and Sustainable Land Use (WBGU 2010), stating that "the strategy would be especially valuable for the least developed countries".

A recent report by FAO, "State of Food and Agriculture 2009", focusing on livestock-related issues (FAO 2009b), further stresses the importance of mixed crop livestock systems, and points to beneficial synergies that might occur when mixed farming systems and bioenergy production for transport, or other energy purposes, are linked in a sustainable way. However, at the same time, the report shows the negative impacts that large-scale biofuel production for transport can have, and has had, on the agricultural sector, when the wrong approach is taken (Box 6).

BOX 6

CROP LIVESTOCK SYSTEMS AND BIOFUEL PRODUCTION

Most traditional livestock production systems are resource driven, in that they make use of locally available resources with limited alternative uses, or, expressed in economic terms, low opportunity costs. Examples of such resources include crop residues and extensive grazing land not suitable for cropping or other uses. At the same time, in mixed production systems, traditionally managed livestock often provide valuable inputs to crop production, ensuring a close integration.

The rising demand for livestock products is changing the relationship between livestock and natural resources. Modern industrial production systems are losing the direct link to the local resource base and are based on bought-in feed. At the same time, some of the resources previously available to livestock at a low cost are becoming increasingly costly, because of growing competition for the resources from other economic sectors and other activities such as production of biofuels.

The separation of industrialized livestock production from the land used to produce feed also results in a large concentration of waste products, which can put pressure on the nutrient absorptive capacity of the surrounding environment. In contrast, grazing and mixed farming systems tend to be rather closed systems, in which waste products of one production activity (manure, crop residues) are used as resources or inputs to the other.

Growing use of cereals and oilseeds to produce fossil fuel substitutes – ethanol and biodiesel – represents a significant challenge for the livestock sector in terms of competition for resources, especially regarding elevated prices and lower availability of crops for feed. However, biofuel production creates valuable by-products, such as distillers' dried grains with solubles (DDGS) and oilseed meals that can be used as animal feed and can substitute grain in animal rations. Biofuel by-products can offset feed costs for the livestock industry. At the same time, biofuel by-products represent an important component of biofuel industry revenues.

Source: FAO 2009b

CHAPTER 3

IFES IN DEVELOPED COUNTRIES

The use of biomass as a renewable source for energy and bio-based chemicals has become of increased global interest in recent times. However, a growing bio-based economy is recognized to pose several challenges to maintaining both food security and natural resources. While the conservation of natural resources, such as the prevention of nitrogen leaching into rivers in highly intensive agricultural settings, has been on the agenda of developed nations for some time, safeguarding food security has been mostly considered a challenge that the developing world is facing.

Nonetheless, with an increasing shift from a petroleum-based to a bio-based economy, and a trend towards increased resource efficiency, especially land use efficiency, integrating food and energy production has become visible on the agenda of industrialized nations too. Academia, industry and governments, have addressed this need and made suggestions as to how to put sustainable farming systems combining food, feed and energy production, into practice.

The nature of IFES will greatly depend on the type of agriculture prevailing in the region. Climate will influence the kind of crops grown; labour costs will have a bearing on the scale of production and degree of mechanization. As a contrast to systems in developing countries, this section will outline some examples of Type 1 and Type 2 IFES in the developed world.

3.1 TYPE 1 IFES

Heggensteller *et al.* (2008), for instance, suggest double-crop systems that have the potential to generate additional feedstocks for bioenergy and livestock utilization, and also to reduce nitrate-nitrogen leaching relative to sole-crop systems. Field studies were conducted near Ames in the United States to evaluate productivity and crop and soil nutrient dynamics in different bioenergy double-crop systems. The results demonstrated that both forage triticale together with corn and forage triticale and sweet sorghum biomass double-cropping systems have the capacity to produce more combined dry matter yields than dry matter production by conventionally managed, sole-crop corn. They further found that the combined biomass and grain output of a triticale and corn double-cropping system could be used to generate greater quantities of ethanol per unit land area than the biomass and grain output of a sole-crop corn system. However, the study also showed that sustained removal of large quantities of nutrient-dense biomass from double-cropping systems would necessitate increased fertilization or integration with nutrient recycling mechanisms.

While multiple cropping systems, including energy and food crops do receive increased attention in industrialized countries, the distribution of agroforestry systems in developed nations is much lower than in developing nations. In Europe, for example, most types of agroforestry practices described around the world existed at different levels of intensity in the past. However, there was a notable decline in the implementation of agroforestry practices in Europe in the 20th century, when agriculture was intensified, specialized and promoted. Most extended agroforestry practices nowadays in Europe are silvopasture and silvoagricultural (Mosquera-Losada *et al.* 2009).

In Spain, for instance, as in the rest of the Mediterranean basin, land use shaped and organized the present landscape for centuries. Agriculture (mainly grazing) and forest management, created an integrated and structured mosaic landscape of agroforestry systems with high cultural and biological values. Nevertheless, as a consequence of the shift from the primary to the tertiary sector which took place throughout Spain during the second half of the last century, traditional and sustainable multifunctional activities were abandoned or substituted with more purely production-oriented ones. As a consequence, traditional uses of agroforestry systems, mainly extensive livestock and multipurpose forestry for timber, wood fuel or charcoal declined (Casals *et al.* 2009). While recent EU Rural Development policy clearly recognizes the economic, ecological, and social advantages of agroforestry systems, to date the (re)implementation of such systems remains poor throughout most of Europe (Rigueiro-Rodríguez *et al.* 2009).

Some traditional agroforestry systems do still exist. The Dehesa and Montados are the largest agro-silvo-pastoral systems in Europe, located in Spain and Portugal, covering about 3 million hectares of widely spaced oak trees, which are used mainly for fodder and shade for livestock, but also for provision of fuelwood. They are mixed with pastures or intercropped with fodder crops or cereals.

Recently, agroforestry systems that focus on wood production for energy purposes have become particularly popular. Short rotation coppice (SRC) plantations, consisting of fast growing trees or shrubs, which are characterized by higher wood productivity than conventional cultivated forests, are mainly grown for producing wood fuel for heat and power production. SRC of willows (*Salix spp.)* operates on a commercial basis in Sweden over some 15–17,000 ha for biomass energy production, but remains experimental elsewhere in Europe (Eichhorn *et al.* 2006). Most SRC plantations are monocultures or do not include a food component. However some studies have looked at the potential to intercrop SRC trees with food producing perennials such as nut and fruit bearing trees, or agricultural annual crop species (CFS 2010; Clinch *et al.* 2009).

Inter-cropping or alley cropping of poplar (*Populus spp.*) with agronomic and horticultural crops, and for silvopastoral systems, is another common approach, practiced in northern countries. According to Isebrands (2007), the duration of inter-cropping opportunities varies with the spacing between the poplar rows in the field. Traditional ten foot rows allow alley cropping for the first two to three years before tree canopy closure which limits the light, water and nutrients available for the companion crop. Longer duration is possible with wider spacing such as 20 to 30 feet between rows. The following crops have been successfully used for inter-cropping with poplars in different parts of the world (Nair, 1993): barley, buckwheat, clover, corn, lespedeza, melons, oats, potatoes, rye, soybeans, sugar beets, sunflowers, vegetables, vetch and wheat. Poplar wood, chips, or pellets can be burned directly for energy purposes or mixed with coal to produce electricity.

There are also opportunities for silvopastoral operations as commonly practiced in Italy and New Zealand (Isebrands 2007) where poplars are grown at wide spacing and on long rotations. Poplars must be protected from livestock in the first five years or more of the rotation. Silvopastures provide mutual benefits for poplars and animals. The animals benefit from the shelter provided by the poplars, and the trees benefit from the animal manure and weed control provided by controlled and managed animal grazing that minimizes compaction. Furthermore, the foliage from poplars is rich in protein and can provide a valuable source of animal feed.

3.2 TYPE 2 IFES

In Europe and North America, agricultural production and processing tends to be large-scale. The starting point for a Type 2 IFES may be an annual biofuel crop such as corn or wheat. Where grains are grown primarily for biofuels, the co-products can be used for animal feed. Where they are grown for food, the crop residues can be used for bioenergy.

In the latter case, much attention has been given, particularly in North America, to cellulosic ethanol from food crop residues such as corn stover, therefore not competing with food production, but this technology still faces obstacles to commercialization. However, there are currently commercial energy uses for biomass: in the UK, a 38 MW power station near Ely in Cambridgeshire (see also Box 10) runs on straw, taking 200 000 tonnes per annum. As fertilizer costs increase, the recycling of nutrients becomes a commercial, as well as environmental imperative and ash from straw combustion can be returned to local farmers' fields. A proportion of biomass needs to be returned to the soil, usually in the form of crop residues or manure, to maintain structure and fertility.

Slurry from pig or dairy farms can be used for anaerobic digestion for biogas production, which is another way of generating bioenergy without competing with food production. A study in the UK (Mistry *et al.* 2007) showed that centralized anaerobic digestion can bring about significant benefits for treating dairy slurry, with the biogas being fed into a combined heat and power (CHP) unit. Payback times for different scenarios varied from three years to never (running at a loss). The economics depended on factors such as transport costs incurred taking the slurry to the digester, which constituted around a third of the operational costs.

The other IFES approach is to grow a crop primarily for biofuels and use the co-products and by-products for food production. Again, wheat or corn may be used, as well as sugar beet for bioethanol, and occasionally oilseed rape for biodiesel. Large volumes of biomass can be processed, with typical world scale ethanol plants taking around 1 million tonnes of grain or more per year. The animal feed co-products are often dried and transported to a feed producer, but may be fed fresh to livestock nearby. Such scales of operation create great challenges for adding correspondingly large livestock units to make use of the feed co-products. One solution may be to feed a portion directly to livestock and export the rest. Some have opted for smaller-scale ethanol plants with livestock integrated from the outset, seeking to add value to all the co-products rather than export them. A good example of this is the Canadian company, 'Poundland,' which has been raising cattle next to an ethanol plant since 1970. The cattle feedlots have benefited from the distillers' grains from the corn ethanol plant, which are high in protein. This saves on costs of drying and transporting the product to feedlots further away, which is the standard practice. More than a third of distillers' grains in the USA are fed wet to livestock (Renewable Fuels Association 2008), which signifies that the animals are kept in the vicinity of the ethanol plants.

Whilst there are many examples of the systems outlined above, a small handful of companies have gone further and brought the two together. Biofuel crops are grown with the co-products used for animal feed. The livestock by-products are themselves used for energy (usually AD of manure). In such integrated systems it can be quite difficult to distinguish a main product, as all the processes are intertwined with multiple outputs and recycling. This approach is sometimes called a 'closed loop' system. The following table (Table 1) provides a summary of 'closed loop' bioethanol plants in North America, which typify this approach. The systems are all broadly similar, resulting in the co-production of ethanol and beef or dairy products.

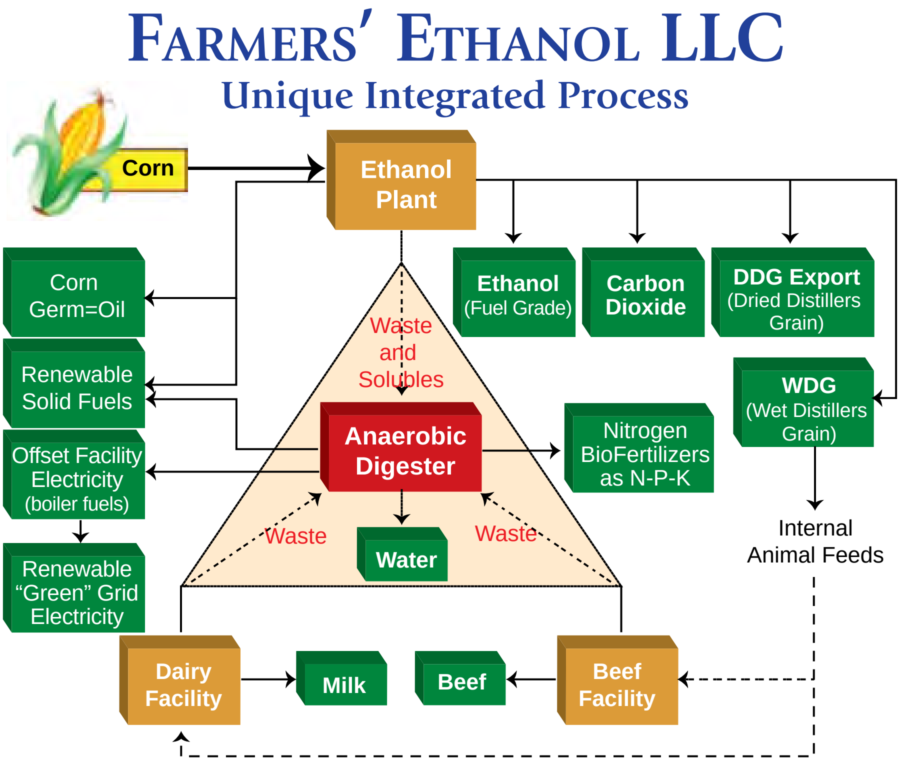
TABLE 1
Summary of 'closed loop' bioethanol plants in North America

Name	Location	Litres Ethanol/yr	Head/Livestock	Status
E3 BioFuels	Mead, Nebraska	114 million	30,000 (dairy)	Closed 2007
Panda Ethanol	Hereford, Texas	435 million	Unspecified (beef)	Closed 2009
Bion	New York State	225 million	70,000 (beef)	Planning
Poundmaker	Saskatchewan, Canada	13 million	28,500 (beef)	Operating since 1970
Farmers' Ethanol	Cadiz, Ohio	Unspecified	10,000 (beef) 2,000 (dairy)	Planning / Construction

Each of the companies above has integrated – or plans to integrate – cattle with ethanol production, to make use of the high protein co-product as livestock feed. The two that closed were reported to have struggled mainly with issues not directly related to the 'closed loop' element, but rather engineering or construction problems with the 'standard' part of the plant. With any system, the manure from the cattle can be used in various ways. Some have opted for anaerobic digestion, which is particularly appropriate for dairy slurry, because of its high moisture content. Panda chose gasification and Bion has developed a proprietary wastewater treatment technology to extract energy and nutrients from the manure. In each case, the energy is used in the ethanol plant to process heat, strengthening the synergies between the two operations. Farmers' Ethanol (Figure 1) is a company planning to open several plants utilizing this principle, starting in Cadiz, Ohio. The schematic below gives an overview of their multi-product approach, with anaerobic digestion making up a key element.

FIGURE 1

Farmers' Ethanol, Ohio



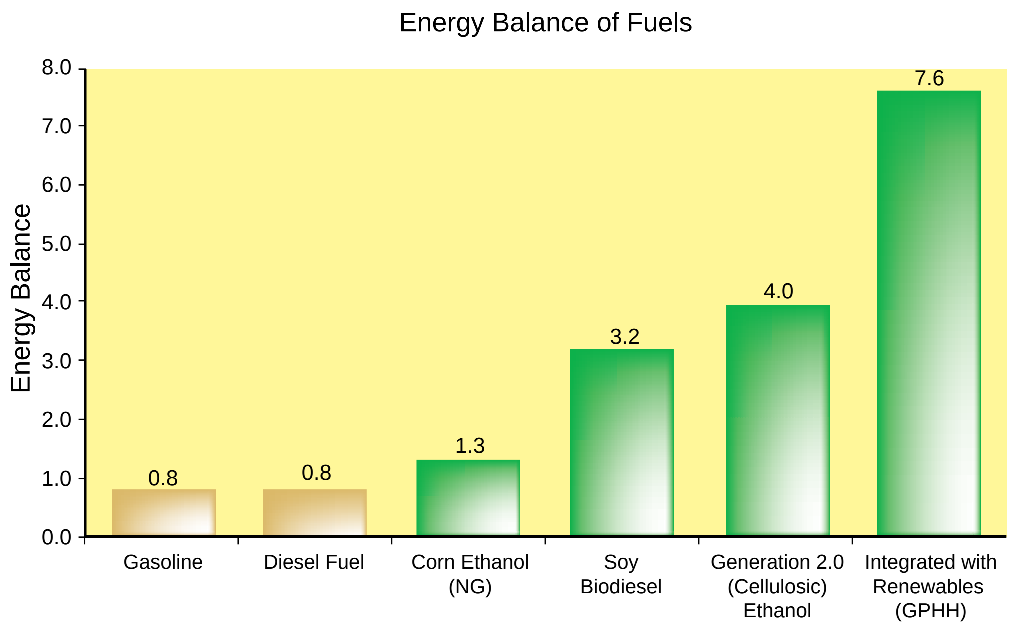
Source: Farmer's Ethanol LLC (no date)

Although most plants seek to extract energy from the livestock manure, the exception among our examples is Poundmaker, who simply return the manure to the local farmers' fields and consider the low-cost animal feed alone as sufficient incentive to co-locate the livestock. Although this may appear to be a missed opportunity, the carbon in the manure is not wasted as it replenishes the soil carbon levels. A recent report from Michigan State University illustrates how livestock manure is more effective in this regard than returning crop residues to the soil. Therefore, by integrating livestock with arable cropping, more crop residues can be harvested for bioenergy if desired, rather than ploughing back into the soil to maintain organic matter (Thelen *et al.* 2010).

Anaerobic digestion of manure can be a stand-alone technology, as can any other element of the 'closed loop' systems described: they do not have to all be integrated in one system. However, there are numerous benefits from doing so, both economically and environmentally. A recent study of the potential for Type 2 IFES in the UK listed some of the economic benefits as economies of scale (in livestock production, AD and biogas use), reduced costs of biomass drying and transport, and lower livestock feed costs (Jamieson *et al.* 2010). Environmentally, the energy balance (energy out compared with energy in) has been estimated to be as high as 7.6 to 1 for corn ethanol in a Type 2 IFES, as illustrated in the right hand bar of Figure 2 below, which is approaching that of sugar cane ethanol at 9 and a drastic improvement on 'conventional' corn ethanol of around 1.3 to 1.7.

FIGURE 2

Energy balance of selected transport fuels[4]



[4] http://highmark.ca/index.php?area_id=1006&page_id=1027&article_id=29