CHAPTER 1

Towards a sustainable energy technologies based agriculture

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> "*Modern society continues to rely largely on fossil fuels to preserve economic growth and today's standard of living. However, for the first time, physical limits of the Earth are met in our encounter with finite resources of oil and natural gas and its impact of greenhouse gas emissions onto the global climate. Never before has accurate accounting of our energy dependency been more pertinent to developing public policies for a sustainable development of our society, both in the industrial world and the emerging economies.*"
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> Minutes, Debate of Senate (Eerste Kamer), 2009 (in Dutch)[1]

1.1 INTRODUCTION

Agriculture, including associated primary industry such as production of machinery, fertilizers, feed concentrates for livestock, agrochemicals, water and agroprocessing, is an energy intensive activity. To manage the escalating global food demand, agriculture is increasingly becoming energy intensive, and importantly, the agricultural frontiers are expanding into areas that not ideally suited for farming. This further translates to an increase in demand for energy, which is not proportional to the food production increase achieved. In many cases, energy cost may represent up to 20–50% of the total agricultural production inputs cost, including the cost of manufacturing and transportating inputs such as fertilizers. Nutrient-poor soils not only require large quantities of fertilizers but may also require large volumes of irrigation water, which, in some instances, must be pumped from ever-greater depths. The last is caused by increasing limitations on the availability of surface water due to seasonal fluctuations and its continuous quality degradation as a result of anthropogenic contamination, which in many areas makes groundwater the principal source for irrigation and other agricultural purposes. The importance of groundwater for agriculture will undoubtedly further increase in the future with the need to sustain food supplies to an increasing world population. Thermal desalination of seawater or saline or brackish groundwater, which in many areas will be the only available option for regional or national food production, is even more energy demanding.

The sustainable provision of increasingly large amounts of energy and freshwater demanded for agricultural production is crucial in a world facing both population and economic growth. This must be achieved while also avoiding or mitigating greenhouse gas emissions that would occur if the additional energy demand were to be covered by fossil fuels and conventional agricultural technologies. Such a scenario of increasing competition for water and energy resources urgently requires the development and implementation of innovative integrated agricultural approaches. Greatest efforts are required in the developing world to meet their food requirements, with their high population growth rates, rapidly-expanding emerging economies and increases in living standards. This can be clearly demonstrated using the parameter "electricity demand", the world-average of which is predicted in the World Energy Outlook 2012 (IEA, 2012) to increase by 70% in the 2010–2035 period (2.2% per year on average), with an annual average grow rate of 3.3%

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[1] Source: Minutes of the debate of the Senate (Eerste Kamer) of the Dutch Parliament, March 31st, 2009, http://www.eerstekamer.nl/stenogram/stenogram_254/f=x.pdf.

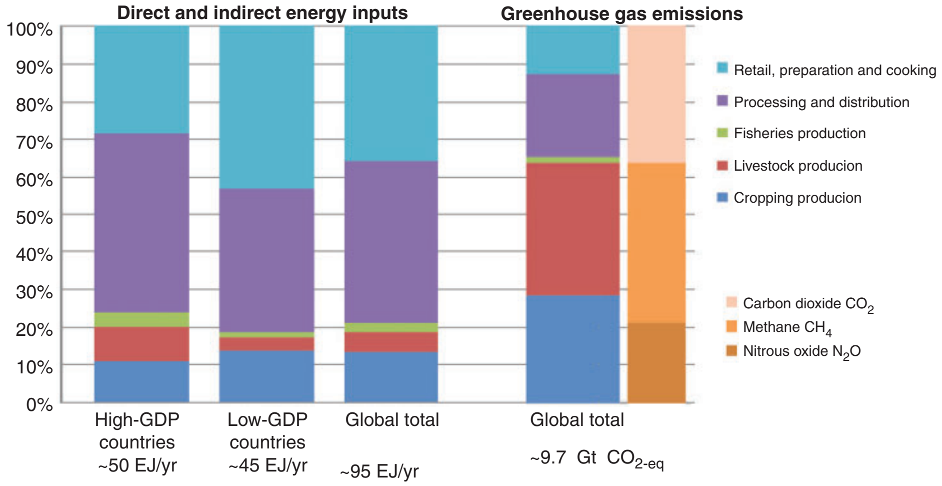

Figure 1.1. Global sectorial shares of the energy consumption of the total food sector and related GHG emissions and distribution to high-GDP and low-GDP countries (source: FAO, 2011).

in developing countries (non-affiliated with OECD: Organization for Economic Cooperation and Development), compared with a growth rate of only 0.9% in industrialized countries (OECD countries) (IEA 2012, New Policies Scenario). For comparison, the Current Policies Scenario and the 450 Scenario result in average annual world electricity demand increases of 2.6% and 1.7%, respectively (IEA, 2012).

According to estimates of the FAO (Food and Agriculture Organization of the United Nations), global food production will need to be increased by 70% to feed the world population, which is forecasted to reach nine billion by the year 2050. Since the global primary energy demand is forecasted to increase by one third in the 2010–2035 period (IEO, 2012) and because the annual global freshwater withdrawal is expected to grow by about 10–12% per decade, corresponding to an increase of 38% from 1995 to 2025 (UNESCO, 1999), the securing of energy and water supply is the key challenge facing modern society. Increasing stress on limited freshwater resources – the largest part used for agriculture – will intensify competition for water for farming and industrial purposes, as well as for consumption in cities. This may require massive production of freshwater from alternative sources, for example from seawater and brackish or saline groundwater.

The FAO (2011) has estimated that about 30% of the global total energy consumption corresponds to the food sector. Figure 1.1 shows energy consumption and GHG emission of different parts of the food sector for developing (low-GDP) countries and developed (high-GDP) countries. Only about 20% of the total food energy is demanded by the primary farm production (i.e. cropping and livestock production) but these activities produce about 65% of the total food sector's GHG emissions (Fig. 1.1).

Figure 1.2 for the example shows the energy demands of the principal energy consuming technologies for crop and livestock production in New Zealand. For some crops, on-farm direct inputs such as chemical and fertilisers can account for up to 70–80% of total energy used in their production (Chen *et al.*, 2013).

Fossil fuel energy resources, which are still the globally dominating energy source in the agricultural sector, are becoming more and more limited. In the case of oil, peak production is already exceeded and production is forecasted to decline by 2030 to half of its 2010 value (Fig. 1.3: EWG, 2007). Decreased availability translates into increasing prices of oil (Fig. 1.4), and other fossil fuels and it can be expected that one day even scarcity prices, i.e. a premium determined by the supply and demand situation must be paid. The same limitation is true for freshwater, the

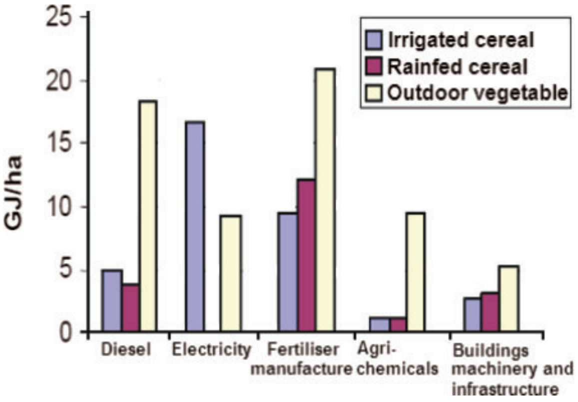

Figure 1.2. Direct and indirect energy inputs into different parts of the crop and livestock production for different agricultural New Zealand enterprises (source: Barber, 2004).

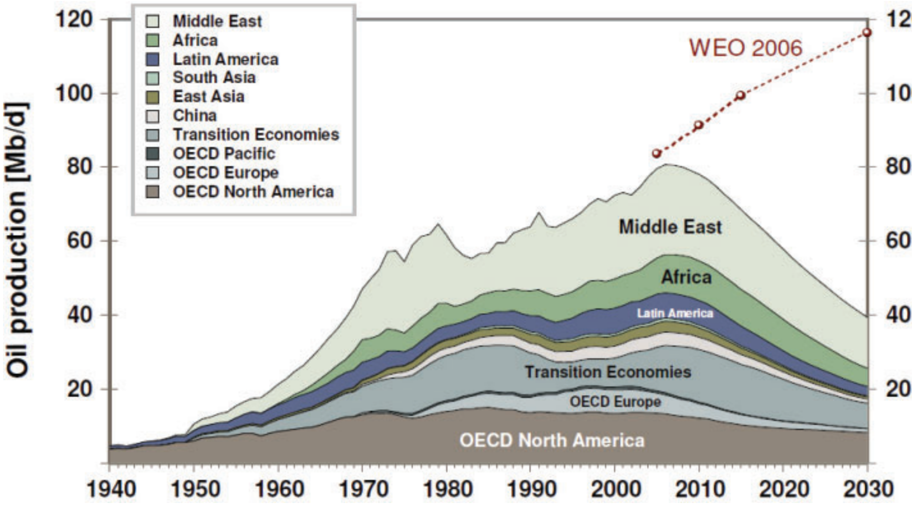

Figure 1.3. Global oil production *versus* World Energy Outlook (WEO) 2006 (source: EWG, 2007).

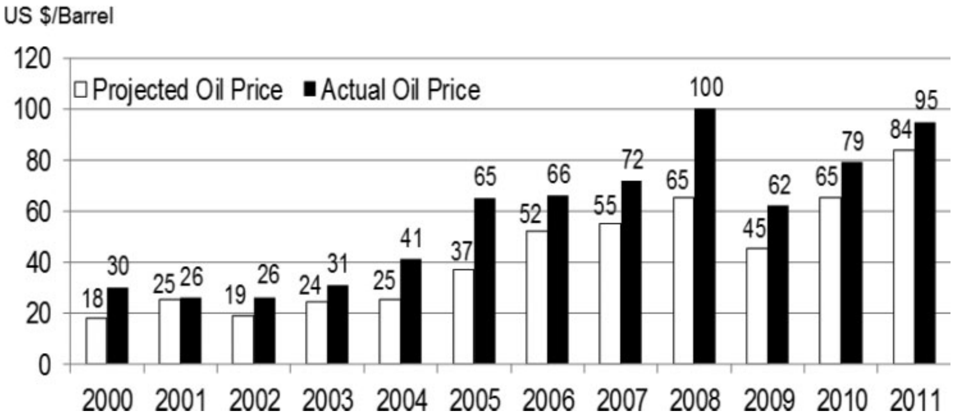

Figure 1.4. Projected and actual price for oil (source: Fell, 2012).

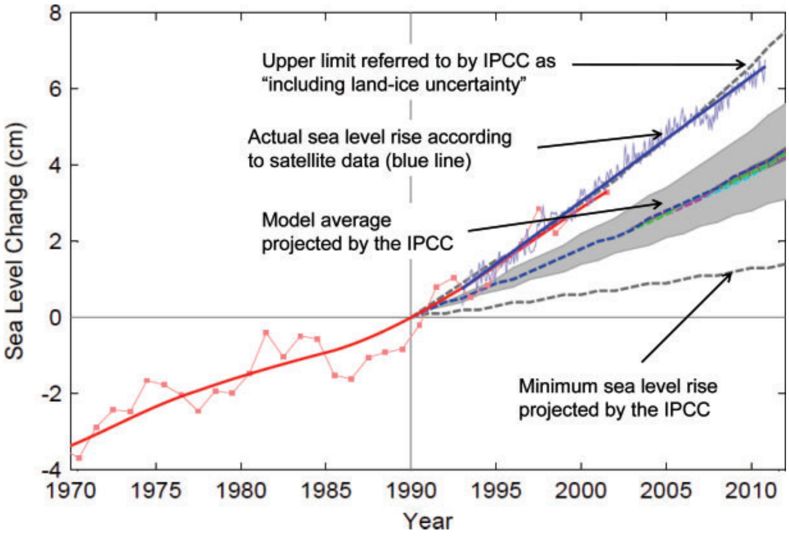

Figure 1.5. Observed sea level rise versus scenarios projected by IPCC projections (source: Rahmstorf *et al.*, 2007; updated by Rahmstorf *et al.* with data from the year 2010).

demand for which is increasing but the availability of which is decreasing due to anthropogenic contamination (UNEP, 2008; UNESCO, 1999).

In addition to the increasing scarcity, fossil fuels have the drawback that they are the principal contributors to global warming. As earlier mentioned, agriculture contributes significantly to global GHG emissions, causing global warming whose consequences advance much faster and more dramatically than formerly thought (Fell, 2012). They comprise melting of the arctic polar ice cap (The Cryosphere Today, 2012) leading to increasing sea levels (Fig. 1.5) (Rahmstorf *et al.*, 2007; updated by Rahmstorf *et al.* with data from the year 2010) contributing to increased risk of flooding of coastal regions worldwide. Global warming is also a cause of an already observed increase in the frequency and severity of weather phenomena, such as major droughts, floods, extremely heavy rainfalls (and related mudslides, etc.), typhoons/hurricanes and forest/bush fires causing severe damage to property and infrastructures, economic loss and increased risk to populations. In addition, global warming results in the thawing of permafrost, which releases large volumes of the greenhouse gas methane.

The above discussion suggests that the future food supply is intrinsically linked with energy, water and climate issues and must therefore be managed in an integrated way. The availability of freshwater and energy are intrinsically linked to human social and economic development. The use of fossil fuels and conventional agricultural technologies to meet the increasing energy demand in agriculture would result in a CO_2 emission increase proportional to the energy demand increase.

Food security requires energy and water security. Hence, securing energy and water supply – fundamental to feeding our global population – while mitigating climate change is the key challenge facing modern society. Implementation of energy- and water-efficient and renewable energy technologies, together with energy conservation methods and greenhouse gas sequestration from atmospheric CO_2 and other greenhouse gases into soil and biomass are therefor essential. Global food security may be compromised if innovative and cost effective technologies and low-cost solutions are not developed. Governments and industries around the world must look into cutting-edge energy-efficient, low-emission technologies and management practices for the agricultural sector.

There is a widespread belief among decision makers that these options are economically unviable. However, the opposite is true: the use of new technologies will contribute to the creation of new jobs and economic growth if these energy-efficient and low-emission technologies are developed and produced in large numbers. This has been successfully demonstrated in Germany where, since 1998, employment in the renewable energy sector increased by more than a factor of 10, from about 66,600 (1998) to 377,800 (2012) with the aim to reach 500,000 in the year 2020, providing the second-highest share of employment in Germany after the automotive industry (Agentur für Erneuerbare Energien, 2013).

In many cases it can be already observed that high and ever increasing fossil fuel prices have increasingly negative financial effects on the agricultural sector and favor the introduction of energy-efficient low-emission technologies in agriculture. Additional benefits include the avoidance of external costs such as those related to human health costs and environmental costs due to consumption of large volumes of fossil fuels, while the use of energy-efficient and low-emission technologies minimizes costs for both the agricultural sector and the consumer of the agricultural products.

Energy-efficient and low-emission technologies in agriculture can grow much faster than generally assumed, similar to the introduction of other technologies such as plasma TVs and mobile phones, which only took few years, have shown (Fell, 2012). A number of sustainable technologies suitable for applications in agriculture already exist in large numbers and at commercial scales, but this does not take away the need to continuously develop new technology. However, the rate at which these technologies are developed and adopted is dependent on favorable political, policy and financial conditions. This requires close cooperation between policy makers and the financial sector; mechanisms, incentive and compensation models and options can be used for the agricultural sector analogous to those described and discussed in detail in the book by Fell (2012).

Adoption of sustainable energy technologies for agriculture requires policies which actively facilitate market entry and wide market penetration as well use as wide application by the farmers. It is essential that the manufacturers recognize markets in the agricultural sector. Therefore, state regulations are required, to allow the diversion of private sector money into sustainable energy technologies investments (both, the manufacturers and the users in the agricultural sector). As investments in sustainable energy technologies start to yield returns, increased scales of production are likely to lead to reduction in the cost of production and wider market penetration. Analogous to the period of 15–20 years estimated by Fell (2012) for the development of self-sustaining renewable energy technologies or measures to become economically mature and self-propelling, given effective state regulation and active political support, we can conclude the same timeframe for the advent of green agricultural technologies.

In many countries the agricultural sector is subsidized by government; this also includes subsidizing non-sustainable energy technologies, such as subsidies or tax exemptions for diesel used on farm. The aim must be to remove such perverse benefits and to instead provide economic incentives for investing in sustainable energy technologies to boost their relative market penetration. Only then, the private sector – who counts on much more capital than governments – will invest in developing and scaling up production of these technologies, leading to cost reduction and wide market penetration as it could be observed for solar panels, for example, which no longer need state subsidization.

Finally, mass production of energy-efficient and low-emission technologies in agriculture is likely to result in a reduction in purchase prices, while more and more people will realize that these technologies will lead to energy savings; adoption of the new technologies will lead to affordable energy costs as the costs of energy from conventional sources (fossil fuels), especially due to the increasing scarcity and the costs of their external damages will further increase. Therefore, it is evident that energy-efficient and low-emission technologies in agriculture will soon become the more economic option.

An overview of technological and other options is given in Section 1.2.

Table 1.1. Growth rates demand projects, per cent p.a. (source: Alexandratos and Bruinsma, 2012).

	1970–2007	1980–2007	1990–2007	2005/ 2007–2030	2030–2050	2005/ 2007–2050
Demand (all commodities – all uses), total						
World	2.2	2.2	2.3	1.4	0.8	1.1
Developing countries	3.6	3.6	3.5	1.7	0.9	1.3
Sub-Saharan Africa	*3.1*	*3.4*	*3.5*	*2.6*	*2.1*	*2.4*
Near East/North Africa	*3.3*	*2.8*	*2.8*	*1.7*	*1.1*	*1.5*
Latin America and the Caribbean	*2.8*	*2.6*	*2.6*	*1.7*	*0.6*	*1.2*
South Asia	*3*	*3*	*2.7*	*2*	*1.3*	*1.7*
East Asia	*4.3*	*4.4*	*4.4*	*1.4*	*0.5*	*1*
Developed countries	0.5	0.3	0.4	0.6	0.2	0.5

1.1.1 *Challenges*

Despite a predicted slowdown in the rate of global demographic growth of -0.75% per year over the next 40 years to 2050 (Alexandratos and Bruinsma, 2012), FAO projections indicate that by 2050 a 70% increase (or 1.1% averaged increase per year) in food production over 2005–2007 levels will be necessary to meet the expanding demand for food (Table 1.1). In the USA, it has been estimated that the operation of current food production systems, including agricultural production, food processing, packaging, and distribution, accounted for approximately 19% of the national fossil fuel energy use (Pimentel, 2006). In another study, Pimentel and Giampietro (1994) found that in the USA about 1500 L of oil equivalents are expended annually to feed each American. It is believed that in many developed countries, fossil fuel consumption by food systems often rivals that of transport systems.

Population growth, increases in per capita consumption and changes in diets leading to the consumption of more livestock products are the suggested drivers of such expected changes (Alexandratos and Bruinsma, 2012; FAO, 2012). These production gains are largely expected to come from increases in the productivity of crops, livestock and fisheries (FAO, 2009). However, and more importantly, as populations expand and economies grow, the global demand for energy and water is also expected to increase as discussed earlier.

In low-carbon-water starved future, realizing such production improvements will not be a simple task for several reasons:

- Land and water resources are now much more stressed than in the past and are becoming scarcer, both in quantitative terms (per capita) and qualitative ones, following soil degradation, salinization of irrigated areas and competition from uses other than for food production (Figs. 1.6 and 1.7).
- There has been a decline in the development of arable land in developing countries, particularly since the 1980s (Fig. 1.6). However, according to Fischer *et al.* (2011), at the global level there is a significant amount of land with potential for rainfed production, although with various degrees of suitability. However, not all land is suitable for cultivation. After allowing for forest, non-agricultural uses such as human settlement, and marginal and poor quality soil, it is estimated that there are about 1.4 billion ha of prime/good land that could be brought into cultivation (Alexandratos and Bruinsma, 2012).
- Water is another critical resource. Historically, irrigated agriculture has contributed significantly to food security. World irrigated areas have increased more than twofold (by 300 million ha) since 1960 (Alexandratos and Bruinsma, 2012); however, irrigated agriculture is under

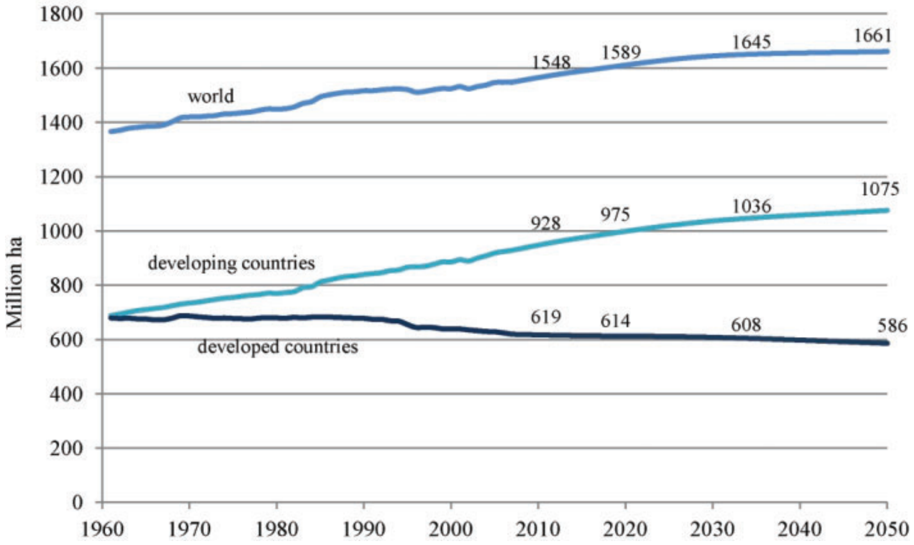

Figure 1.6. Arable land and land under permanent crops: past and future (source: Alexandratos and Bruinsma, 2012).

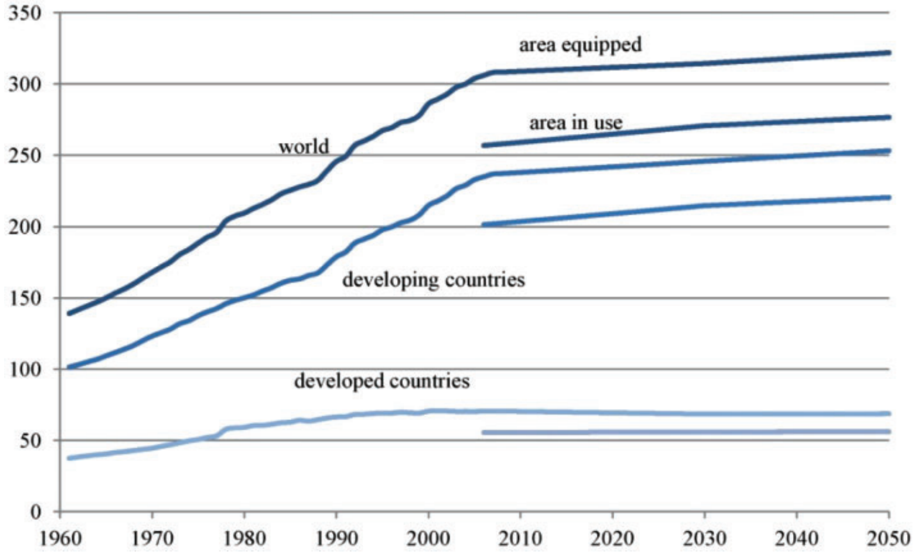

Figure 1.7. Arable irrigated land: equipped and in use (million ha) (source: Alexandratos and Bruinsma, 2012).

immense pressure due to increased competition with non-agricultural sectors while the potential impacts of climate change may change rainfall distributions (Mushtaq *et al*., 2012; Torriani *et al*., 2007) and further exacerbate competition for increasingly scarce water resources. The potential for further expansion of irrigation, therefore, is limited without investment in water saving irrigation to improve water use efficiency and water reuse technologies (Mushtaq *et al*., 2103). There are significant quantities of renewable water resources globally; but they are extremely scarce in regions such as the Near East/North Africa, or Northern China, where they are most needed (Alexandratos and Bruinsma, 2012). The irrigation expansion project suggested by Alexandratos and Bruinsma (2012) indicates that the area equipped[2] for irrigation could be expanded by 20 million ha (or 6.6%) over the period from 2005/07 to 2050, nearly all of it in the developing countries (Fig. 1.7). There is further potential to increase the production of irrigated areas, which could effectively expand by 34 million ha with an increase in multiple cropping on both existing and newly irrigated areas. However, again, sustainable technologies need to play a major role in achieving such growth.

- Energy: Fossil fuels have been the primary energy source for our world for more than a century. However, because fossil fuels are a limited resource, improvements in farming energy efficiency are essential. Continuous high fuel price, the increasing demand for "green food" and significant reductions in greenhouse gas emissions also make the exploration of new alternative and renewable energy sources essential.

1.2 SUSTAINABLE ENERGY OPTIONS IN AGRICULTURE

> "*Tackling the challenges of food security, economic development and energy security in a context of ongoing population growth will require a renewed and re-imagined focus on agricultural development,*" . . . "*Agriculture can and should become the backbone of tomorrow's green economy,*" . . . "*It's time to stop treating food, water and energy as separate issues and tackle the challenge of intelligently balancing the needs of these three sectors, building on synergies, finding opportunities to reduce waste and identifying ways that water can be shared and reused, rather than competed for,*" . . . "*Climate-smart farming systems that make efficient use of resources like water, land, and energy must become the basis of tomorrow's agricultural economy,*"
>
> Alexander Mueller
> FAO Assistant Director-General for Natural Resources
> Bonn 2011 Nexus Conference

In practice, most of the technologies and other options needed for providing sustainable energy solutions in agriculture already exist. The suggested measures have been described many times, and importantly, components of such systems, such as solar panels, have been available in mass markets. Practical on-farm demonstrations (Chen *et al.*, 2009) have also been undertaken to assess the viability of their use in agriculture and clarify the potential technical issues in their applications.

1.2.1 *Energy efficiency and energy conservation*

Improving energy efficiency and energy conservation in agriculture are essential to reduce energy demand and therefore reduce costs. Improving energy efficiency, and thus reducing reliance on fossil fuels, will further reduce greenhouse gas emissions. In addition, it must be taken into consideration that a reduced energy demand will also proportionally reduce investment costs for farm expansions or for shifting from fossil fuels to on-site renewable energy sources.

Everywhere in agriculture where energy is used, its demand can be reduced. For example, it has been shown that fossil energy use in the current food system could be significantly reduced by appropriate technology changes. In the USA, it is estimated (Pimentel, *et al.*, 2008) that the total energy in corn production could be reduced by more than 50% with the following changes of practices: (i) using smaller machinery and less fuel; (ii) replacing commercial nitrogen

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[2] Data reported in FAOSTAT on arable irrigated land refer to 'area equipped for irrigation'.

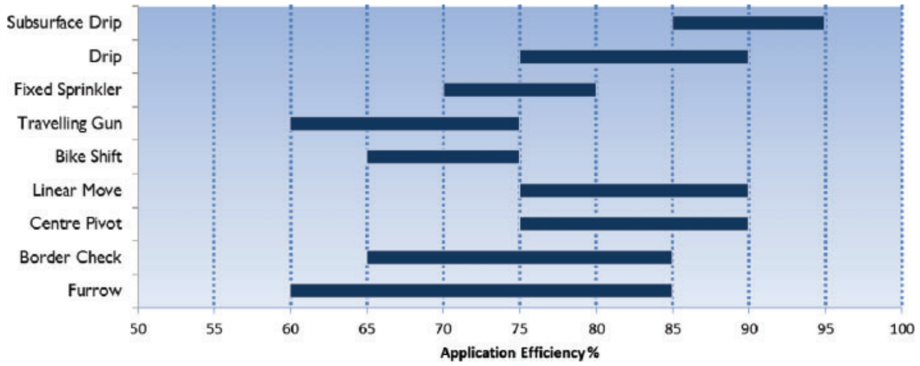

Figure 1.8. Application efficiencies for various irrigation systems (source: Mushtaq and Maraseni, 2011).

applications with legume cover crops and livestock manure; and (iii) adopting alternative tillage and conservation techniques.

Pellizzi *et al*. (1988) showed that with improved management and operation, energy saving of around 12–15% of present consumption can be realistically obtained for tractors, 30% for soil tillage, and 10% for harvesting machinery. Brown and Elliot (2005) found that the largest on-farm energy savings are available in motorized systems, especially irrigation pumping. Pathak and Bining (1985) showed that for irrigation, fuel savings of over 50% were feasible through improvements in irrigation equipment and water management practices. In the USA, energy efficiency audits on irrigation systems have on average identified savings of at least 10% of the energy bill – and in many instances up to 40%. Very often, the irrigators who owned these inefficient systems were unaware of any problems.

Irrigated agriculture is a vital part of world agriculture, particularly in semi-arid and arid cropping areas. Potentially twice as productive as rain-fed agriculture (Entry *et al*., 2002), it not only makes a significant contribution to global food production but it also contributes significantly to national economies. With global population growth, global climate change and growing competition for scarce water resources with different sectors including the environment, irrigated agriculture is under considerable pressure to adopt best practice to ensure efficiency in terms of water use and productivity.

Conventional irrigation practices are generally characterized by low water use efficiencies and there is potential in irrigated production systems for significant water savings, resulting in either increased productivity or increased water availability for alternative uses (Clemmens, 1998; Green *et al*., 1996; Mushtaq *et al*., 2013; Robinson, 2004). However, there may be adverse economic and environmental consequences if water savings achieved result in increases in energy consumption and GHG emissions by agriculture. Agriculture currently relies heavily on the use of fossil fuels. Given ‘peak oil’ predictions, adoption of irrigation technologies are likely to be challenged by higher energy costs (Foran, 1998).

1.2.1.1 *Enhancing irrigation and energy efficiency of the irrigated systems*

Pressurized systems have the potential to increase water use efficiency. In terms of maximum possible efficiencies, drip technology outperforms sprinkler systems, and both deliver greater maximum efficiencies than surface irrigation (Fig. 1.8). However, system design and management can have a big impact on water use efficiency. For example, a flood irrigation system using border check, a sprinkler irrigation system using center-pivot or linear move, and a drip system can have the same level of application efficiency depending on the system design and level of management for each system. However, as the percentile bands for sprinkler and drip systems are higher than for flood systems, the benefit of greater financial investment in a pressurized system is that it will be much less susceptible to water losses from poor management.

Surface irrigation systems, which are usually based on gravity-based system, do not require any energy and therefore do not emit GHGs. A study by Mushtaq and Maraseni (2011) estimates that, on average, center-pivot irrigation systems run by an electric pump increases GHG emissions by 906 kgCO_{2-e}/ML when compared with surface irrigation systems. Similarly, drip irrigation systems run by an electric pump increased GHG emissions by 568 kgCO_{2-e}/ML. However, drip irrigation systems required 28% less energy (between 777 MJ/ML and 3262 MJ/ML), depending on the scale and farming system, compared with center-pivot (between 2321 and 4127 MJ/ML) and lateral-move (between 2884 and 4195 MJ/ML) systems. Similarly, drip irrigation produced around 25% less GHGs compared with center-pivot and lateral-move.

Economic efficiency is also a major consideration. While the level of water savings that can be achieved are substantial and the conversions can be proved to be economically feasible, the energy costs associated with these conversions are considerable. This has implications for production costs as well as infrastructure requirements, depending on the spatial distribution of energy demand. Irrigators will also bear increased costs of pumping, particularly in surface water regions where irrigation water would previously have been applied in a relatively energy 'free' way, and therefore with low or no costs for application. Costs could vary from A$ 120-1000 per hectare with drip and sprinkler irrigations systems, depending on, among other factors, crop water use, irrigation method selected and fuel source (Mushtaq and Maraseni, 2011; Mushtaq *et al*., 2013). This is an option that would need to be carefully considered by farmers and policy makers as any significant increase in the operating costs mean that the overall financial position of farmers is compromised.

1.2.1.2 *Cooling and heating*

There is a considerable requirement for heating and cooling in agriculture. For example, greenhouse heating may be essential to the year-round production of vegetables, fruit and flowers. Temperature controlled storage and refrigeration systems also consume large amounts of electricity and thereby contribute greatly to the running costs of businesses which have considerable cooling requirements, particularly in the horticulture and vegetable industry. Improvements to technical elements and operation of modern refrigeration systems have the potential to reduce energy consumption by 15–40%. This will become more important as a price is placed on greenhouse gas emission and as energy prices rise.

Improved thermal insulation of buildings to reduce the costs of heating and cooling would result in reduced demand for energy, while the on-farm production of energy from renewable sources (e.g. solar), can produce more energy than is needed. The energy efficiency of all electrical devices used in agriculture can also be continuously increased. For example, energy consumption in the lighting sector can be reduced by shifting to energy-saving fluorescent lamps, LEDs or OLEDs. There are many agricultural production processes, the energy efficiency of which can further be increased.

1.2.2 *Use of biomass and biomass waste for carbon-neutral production of biofuel, electricity and bio-coal fertilizers*

Biomass can be produced by cultivating suitable crops and used for production of different types of biofuels. Bio-ethanol can be used to replace gasoline, and biogas to substitute natural gas. Biodiesel and pure plant oils can be produced from oil-rich plants. This biodiesel can substitute for fossil-fuel based diesel used in many agricultural activities and requires only minor changes to the diesel engines. These biofuels can also be used for electricity production, which is a very economic option, in particular in off-grid applications. Compared with biodiesel, pure plant oil can be easily produced without great technical effort. Older diesel engines, which are often used in developing and transitioning countries to supply electricity, can often run without conversion with pure plant oils as fuel. However, modern diesel engines require technical conversions to be fueled with pure plant oils (Fell, 2012).

Therefore, biofuels can reduce the need for agricultural installations to purchase expensive fossil fuels, which must often be transported over long distances, and hence significantly reduce production costs.

Of many crops, only a small part is extracted. The rest is often disposed without any use. An example is given by Fell (2012) from Brazil where annually 100 megatons of sugar is produced from about 1 gigaton of sugar cane. About 90% of the sugar cane crop is burned without any further use. Such biomass waste can be used either for biofuel production and, if needed, electricity. Alternatively, after converting it to bio-coal (e.g. by hydrothermal carbonization) it can be used as fertilizer hence reducing the need to purchase mineral fertilizers. All in all, such measures increase economic benefits and contribute to climate protection.

1.2.3 *Decentralized renewable energy systems (solar, wind, geothermal)*

Many processes and applications in agriculture require energy either in the form of heat, mechanical energy or electricity, which can be provided by solar, wind and/or geothermal energy, depending on the local sources and the specific agricultural application. For example, wind and solar energy can economically produce electricity to power off-grid machinery such as pumps for irrigation; wind energy can also be used as mechanical energy for pumping; solar heat can be used directly for space heating/cooling and warm water production while solar and geothermal heat can economically power thermal water desalination and the treatment of agricultural effluents. Electricity produced from wind and solar energy sources can also be used for water desalination using membrane technologies but at higher cost than thermal methods. Geothermal heat with temperature differences of a few degrees Centigrade to the ambient temperature can be used through heat pumps for space heating/cooling. Depending on the temperature of the available resource, geothermal heat has many applications in agriculture such as for dehydration of agricultural products, and heating for greenhouses, soils and aquaculture. Biomass produced on-site can also provide an energy source as biofuel for machinery, as heat or as electricity produced from it.

1.2.4 *Economic benefit of green food*

That the production of "green food" is also of economic benefit for the farmers can be shown in the case of Germany, where the sales of green food have increased by about 300% in the period from 2000–2011 (BÖLW, 2011; Fell, 2012). Organic food may play an important role in climate protection while contributing also to the population's health and are therefore particularly important in schools, hospitals and retirement homes. Healthy-nourished officials are more efficient than those having consumed unhealthy food for years (Fell, 2012).

1.3 CONCLUSIONS

Agriculture is typically highly reliant on fossil fuels and energy is a significant input cost to production. Production of food and other agricultural products accounts for 70% of global freshwater withdrawals. In addition, in the 2010–2035 period, world primary energy demand is forecasted to rise by one-third and electricity demand by 70% increasing the cost of energy and agricultural production. Some of these demands will be met from bioenergy which will in turn intensify competition for resources, particularly water for food and fiber production and therefore the need to maximize the efficient use of these resources becomes increasingly important.

As fossil fuel costs continue to increase, so does the focus on energy efficiency to help minimize the impacts of rising energy costs on profitability and competitiveness. This includes a growing number of renewable energy sources that could be considered as alternatives to fossil fuels.

Renewable energy sources may include solar, wind, hydropower, biomass, biogas and geothermal power. Where the opportunities are appropriate, integrating renewable energies into the farming operations is likely to save energy, costs, and greenhouse gas emissions. Examples of specific applications include solar crop drying, solar space and water heating, solar irrigation and using biomass for heating purpose and electricity generation. Other applications include off-grid electric fences, lighting, irrigation, livestock water supply, wastewater treatment pond aeration, communication and remote equipment operation and others.

Overall, the long-term future for renewable energy is definitely positive, since the prices of fossil fuels will continue to rise as the resources are depleted while the prices of renewable energy will continue to decrease.

There are already a good number of successful examples of application of alternative energy sources in the agriculture industry. However, it has also been found that practical on-farm demonstrations are essential for the widespread adoption of these technologies and research will be needed to further assess the viability of their use in agriculture and clarify the technical issues raised. Further research is also still required to identify suitable pathways and policy frameworks to encourage future market uptake.

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