Scenarios of energy and agriculture in Africa

Chapter 4 of:

Future Energy Requirements for Africa's Agriculture

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4.1. Introduction

The reliable supply of energy is one of many important requirements for significant growth in Africa's agricultural productivity. For farmers in most African countries, access to fuels or electricity for farm operations or crop processing is limited and costly. If access can be improved, and energy needs for agriculture anticipated and met, then a potential roadblock to agricultural growth can be avoided. Rapid growth in agricultural production could then stimulate rural and overall economic development. The objective of food security could come closer to reality, and exports of agriculturally-based products could improve the regional trade balance. Simply put, the provision of energy for agriculture is essential to Africa's long-term well being.

This chapter looks at just how fast energy needs might grow under conditions of both limited and rapid growth in Africa's agricultural production. It examines the energy-agriculture nexus in several case study countries: Cameroon, Mali, Sudan, Tanzania, and Zimbabwe. Scenarios are then developed for the last three countries, for which sufficient data have been collected. These scenarios depict possible levels of agricultural activity and their energy use implications through the year 2010.

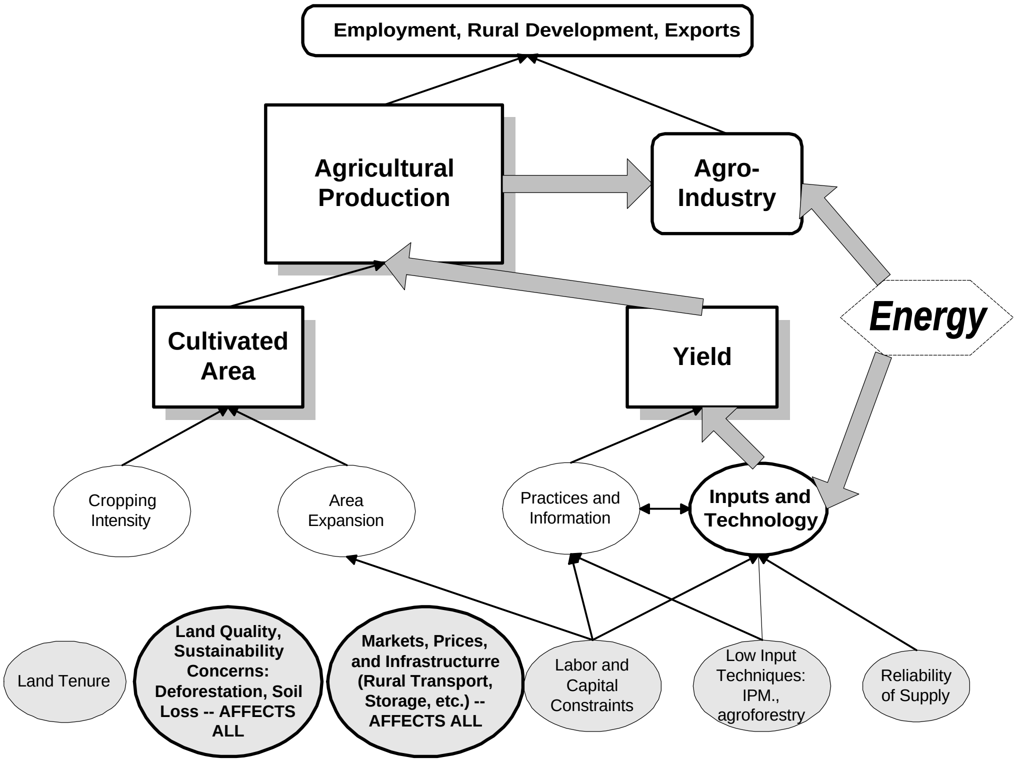
Situated in the largely arid and drought-prone Sahel region, Mali is unique among study countries for its significant nomadic and pastoral populations and for its extensive use of animal traction. In contrast, Cameroon lies within the humid belt of Central Africa, with large potentially arable area; however, increasing cultivated area could require clearing of tropical forests and working with problem soils. Years of civil strife have hampered efforts to increase production in the Sudan, a country with the potential to be a major food exporter -- the potential "bread basket of the Middle East" -- with only 10 percent of its potentially arable land under cultivation and the greatest extent of irrigation in the region. Unlike many African countries, Zimbabwe is a major net exporter of food, characterized by a "dualistic" agricultural sector that includes both highly productive large commercial and traditional communal farming systems. With its diverse geography, climate, diet, and farming systems, Tanzania presents a wide range of characteristics found in many other African countries.

Patterns of consumption and production of agricultural products also vary widely. The staple food of Zimbabwe is maize; in Sudan, the principal staple is sorghum, and in Mali, Tanzania, and Cameroon, the staples are millet, cassava, maize, sorghum, plantain, or rice, depending on the sub-region. Principal agricultural exports range from coffee, tea, and cocoa in Cameroon and Tanzania to oilseeds and cotton in the Sudan, live animals in Mali, and cereals, tobacco, and meat in Zimbabwe. Cotton is the significant export commodity common to all study countries. Thus, in many ways, these five countries are indicative, if not representative, of the range of conditions and possibilities for the region as a whole.

The purpose of the scenario analyses developed in this chapter is to identify where additional energy may be needed for growth in the agricultural sector and rural economy, to suggest the rough magnitude of this demand growth, to estimate how these needs may differ across regions of the continent, and, ultimately, to spur energy planners to address these needs with appropriate actions and policies. Given the limited scope of these scenario exercises, the projections are designed to be initial and illustrative. For detailed evaluation of specific policy options within each country, more detailed and definitive analyses conducted with a more significant level of effort by local country experts would be needed.

The scenario analyses focus on the elements of the agricultural system that affect energy use, namely, the crops and areas cultivated and the agricultural inputs and technologies that farmers can use to increase yields, such as machinery, irrigation, and fertilization. These elements are illustrated by the shaded arrows in Figure 4.1 below.

Figure 4.1 Energy and Other Factors Affecting Agricultural Development



Increased production can be achieved by increasing yields or increasing cultivated area. Large, shaded arrows indicate focus of present analysis. Other shaded areas at bottom list important underlying factors that are critical to the success of efforts to increase production.

The analyses extend beyond on-farm activity to the energy used for transport and processing of agricultural products. Agricultural growth is the most important contributor to manufacturing and service activity in Africa, not only stimulating agro-industries, but the rest of the economy as well. According to at least two studies, each unit increase in agricultural activity leads to approximately 1.5 units of economic growth. (Haggblade, S. et al., 1989 as cited in

Cleaver, 1993; Stoneman and Robinson, 1987) Thus, the energy consequences for these sectors of the economy are also considered.[1]

This chapter begins with an overview of the methodology used for the scenario analyses and a description of the scenarios considered. To set the stage for national scenarios, a few prominent global and regional agriculture scenarios -- which provide some of the assumptions used in the case study scenarios -- and seminal analyses of energy and agriculture are discussed. The energy end-uses in the agriculture and agro-industry sectors, and key trends in agricultural activity, production methods, and energy use in the case study countries are then examined. A summary of the scenario analyses are presented, highlighting key issues and results. Finally, results from these countries are extrapolated to the region as whole, suggesting the issues that energy specialists and policy makers should consider when looking towards the coming century.

4.2. Methodology

The methodology for preparing the scenario analyses involves several elements. In summary, a bottom-up, end-use approach is applied to develop a set of scenarios for each country where available data were sufficient to warrant the effort. Focal points in each country provided limited, but essential assistance data collection and advice.[2] The energy demand profiles and scenarios were assembled using spreadsheets and a flexible, computerized framework (LEAP) described in Box 4.1, tailored to each national situation.

Overall, the process of developing the scenario analyses involved the following eight steps:

a) Selection of case study countries
b) Establishing boundaries of the analysis
c) Selection of time horizon
d) Collection of available data, local studies, and projections
e) Analysis of past trends
f) Development of base year, end-use breakdowns
g) Establishing agriculture-energy relationships and other assumptions
h) Construction of reference and alternative scenarios

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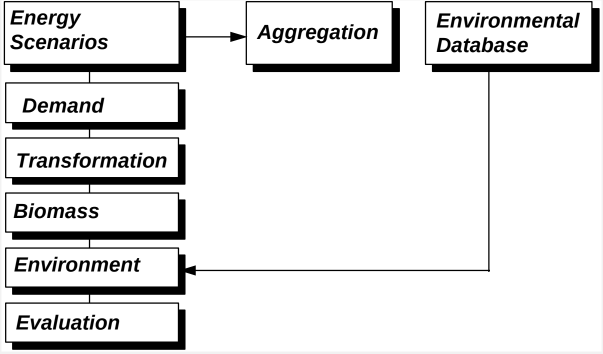
[1] Arguably rapid agricultural growth would affect the entire economy, not simply the closely linked agro-industries and transportation. Increasing rural incomes would affect consumption patterns and migration patterns. Other service and manufacturing activities would also increase. These effects might be estimated using macro-economic tools, such as input-output models. However, this level of analysis is beyond the scope of the limited case studies presented here.

[2] Focal points included: Elamin El Faki Ali Gaafar, Energy Research Institute of Sudan (with Hassan Osman Abdel Nour of the Sudan University for Science and Technology); Mamedy Sacko, Mali Ministry of Industry, Water, and Energy; Patrick Rutabanzibwa, Tanzania Ministry of Water, Energy, and Minerals; Shakespeare Maya, Southern Centre for Energy and Environment in Zimbabwe; and Michel Claude Lokolo of Cameroon. Additional useful materials were provided by Maxwell Mapako, Biomass Users Network in Zimbabwe, Nico van der Linden of ECN Netherlands, and B. Luhanga at TANESCO.

Box 4.1 LEAP: The Long-Range Energy Alternatives Planning System

LEAP represents an easy to use and flexible computer software system for energy-environment analysis developed by the Stockholm Environment Institute - Boston Center at the Tellus Institute. (SEI, 1993a; SEI, 1993b). As a “bottom-up”, end-use modeling system, LEAP's principal elements are the energy and technology characteristics of end-use sectors and supply sources. Its flexible, end-use approach enables the incorporation and simulation of several important factors that can have significant effects on agricultural and agriculture-related energy use. Such factors include changes in land use and farming practices, technological improvements and transitions, and structural shifts among formal and informal economic sectors and subsectors.

LEAP was initially developed as part of the Kenya Fuelwood Project, one of the first major integrated energy planning exercises conducted in a developing country.[3] Since that time, LEAP has been used in over 30 developing and industrialized countries for a wide range of tasks. For example, in the Philippines, LEAP has been applied to decentralized rural energy planning, in Brazil, to evaluation of bioenergy use, and in several African countries, to the development of national energy plans. (van der Werf, 1992; Ackerman and Fernandes de Almeida, 1990) Due to its flexible structure and relationships, LEAP can be applied in different local circumstances, even where data and modeling expertise are limited.



LEAP consists of three blocks of programs: Energy Scenarios, Aggregation, and the Environmental Data Base (EDB). Four of the Energy Scenario programs address the main components of an integrated energy analysis relevant to agricultural development: energy demand analysis (Demand), energy conversion and resource assessment (Transformation), tracking the relationship between land use, biomass energy demands, biomass energy resources (Biomass), and the comparison of scenarios in terms of costs and physical impacts (Evaluation).

Although a general methodology was followed, as a result of wide contrasts in local conditions and data availability, the actual scenario analyses differ significantly among the case study countries. In Sudan and Zimbabwe, for instance, traditional and modern farming systems are distinguished because of data availability and the important, large differences in the use of energy and other inputs. As a result, the Sudan and Zimbabwe scenarios explore the potential consequences of changing farming systems on agricultural output, energy and other input requirements. In Tanzania, the analysis focuses on the considerable energy used for processing of agricultural products, such as tobacco curing, where detailed data enable more in-depth analysis.

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[3] Details of this and other early LEAP studies can be found in volumes 1,2 and 9 of *Energy, Environment and Development.* (Beijer Institute and Scandinavian Institute of African Studies, 1984-1986)

For Mali and Cameroon, disaggregate energy data, even aggregate totals, for the agricultural sector and related industries were inadequate to enable systematic scenario analysis.

a) Selection of case study countries

The five case study countries were selected by the ADB to reflect the wide variation among African sub-regions in climate, geography, economy, and agricultural systems. Arguably, within each African sub-region, no single country is fully representative of all others, and within each country, large disparities in conditions typically exist from province to province. The case studies are illustrative of how conditions and outcomes might vary, but do not presume to represent the full range of agricultural conditions that exist or energy futures that could develop.

b) Establishing boundaries of the analysis

The scenario analyses focus on energy use for on-farm activities, crop processing and other agro-industries, and on the transport of agricultural goods. As illustrated in Figure 4.2, these items are a subset of the entire agriculture-energy system. The reasons for selecting these items -- those of greatest direct relevance to national energy planners -- is discussed in section 4.5a below. Animal and human power were not directly included, nor was the embodied energy in agricultural inputs, such as fertilizers, pesticides and farm machinery.

On-farm activities comprise the typical energy-intensive operations, such as irrigation, traction, drying, and curing. The term “agro-industry” refers to the food, beverage, and tobacco and textile and leather manufacturing industries, as captured in International Standard Industrial Codes (ISIC) 31 and 32, as well as other informal agro-processing industries, such as local beer brewing, which are often unrepresented in official economic statistics. Given scant statistics and the nature of transport in the region -- a truck will often carry a wide variety of freight as well as passengers -- the estimation of energy used in the transport of agricultural goods is particularly difficult. Therefore, the rough estimate that approximately half of all road freight transport energy in the base year is attributable to agricultural products is used throughout the scenario analyses.[4]

The scenario analyses do not generally consider energy use in animal agriculture, fisheries, or forestry. Animal agriculture is an important source of income and nutrition in many countries and an important potential resource for bioenergy production; however, it is not usually a significant consumer of traditional or commercial energy as it is practiced in most African countries. In some coastal countries, fisheries can consume a significant amount of petroleum products. In Senegal, for instance, pirogues and other fishing boats account for about 9% of total commercial energy, as much as all households, and significantly more than the agriculture sector. (Lazarus, Diallo, and Sokona, 1994) However, fisheries do not appear to consume similarly high levels of energy in the case study countries. The forestry sector might be considered here as well, but is the subject of a separate ADB study.

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[4] In the U.K. in the mid 1960s, food products alone accounted for one-quarter of all road freight transport. (Leach, 1976) Given the greater dominance of agricultural products in African countries (relative to other transported products), and the presence of non-food agricultural products, the assumption that half of road freight transport is attributable to agricultural goods appears reasonable, if not conservative.

c) Selection of time horizon

A time horizon of approximately 15 years, through the year 2010, was used for the scenario analyses. This target date is consistent with the ADB's other sectoral studies. The time horizon is long enough to begin to consider food security, sustainability and resource questions, yet short enough to be useful for planning purposes, with knowledge of available technologies and greater certainty with respect to economic and demographic characteristics.

d) Collection of available data, local studies, and projections

The case studies rely on both local and international data sources. In response to the data questionnaire included as Annex A, focal points in each country provided important inputs, including national statistical publications, local research studies, and in some cases, useful syntheses of the national energy-agriculture situation. (Nour, 1994; Republique du Mali, 1994; Lokolo, 1994) Previous energy and other studies in each country were used for projections of energy use in non-agricultural sectors and for key demographic and economic variables, where appropriate. Where data were lacking or particularly weak, local data were supplemented with data from similar countries.

e) Analysis of past trends

Simple regression analyses were used to evaluate past trends and to assist in the projection of cropping and other patterns for the Reference scenario, which assumes a continuation of past trends. Trends in crop area, yields, aggregate energy, irrigated area, farm machinery purchases, and other important energy-related variables were analyzed, as described in section 4.5b and in the case study sections below. Where feasible and reasonable, income elasticities were also estimated.

f) Development of base year, end-use breakdowns

The development of detailed breakdowns of energy use in agriculture and related activities is a critical element of the analysis. Where available, survey data, billing data, and other "bottom-up" data sources were reconciled with national "top-down" control totals (e.g. total diesel supply) to create consistent profiles of energy use patterns. Earlier end-use analyses in Sudan, Tanzania, and Zimbabwe were also used and updated to reflect recent trends. The goal of this step was to maximize the useful disaggregation of data in order to track how changes in cultivated areas, crop types, and farming methods (e.g. traditional vs. commercial) might affect future energy requirements. The specific end-use breakdowns vary considerably among the case studies, and are described in sections 4.6-4.8.

A base year was selected based on two criteria: 1) the most recent year for which reliable data exist, and 2) a year without unusual circumstances such as drought or civil war. In most cases, 1990 was selected as the base year, since more recent years were subject to either drought or incomplete data. Abnormal data, such as unusually high yields for one year, were normalized to reflected longer-term averages.

g) Establishing agriculture-energy relationships and other assumptions

Judgment and findings from other studies were used to generate basic scenario assumptions, such as the 4% agricultural growth target used in the Accelerated Growth scenario. (see below) These assumptions are discussed in the sections below.

The following four general relationships were used to project future energy use as agricultural patterns change over the next two decades:

1. Changing farming patterns (crops, traditional vs. mechanized vs. irrigated) alters per-hectare energy use characteristics. (Land use and farming pattern projections are discussed for each case study below.)
2. Increasing yield comes with an increase in energy and chemical use per hectare. These changes are based on yield-energy and yield-fertilizer elasticities derived from the Global Technology Matrix (GTM), as described in section 4.5c below. Yield improvement assumptions are discussed under each case study.
3. Energy use for crop curing, drying and processing increases directly with total crop production (yield x area).
4. Energy use in agro-industries increases as function of the tonnage of material processed or total value added, depending on the nature of the industry.

h) Construction of reference and alternative scenarios

Based on the above relationships and assumptions, scenarios were constructed in keeping with the general parameters of each scenario described in section 4.3 below. The reference scenario was first evaluated to ensure reasonableness with respect to past experience and other studies, and subsequently other scenarios developed as modifications to the baseline.

i) Additional steps

Several extensions to the present approach should be contemplated for further national studies of energy and agriculture. In particular, these include:

- the use of local expert teams to conduct more detailed local analyses, including field assessments, expert interviews, and surveys to overcome existing data limitations.

- the use of local expert teams to evaluate how past agricultural and energy policies (fuel subsidies, infrastructure investments, rural electrification, etc.) have affected agricultural practices and energy use. This analysis would in turn enable evaluation of specific policy options for the future.

- integrated analysis of supply-demand relationships, including consideration of fuel switching and renewable energy potentials, analysis of land use and biomass energy production, and evaluation of environmental and economic consequences. In particular, economic and financial analysis could be used examine the merits of alternative demand and supply technological and policy options.

- linked local-national area analysis, wherein supply-demand analyses are conducted at the regional level and integrated into a national analysis, as described in Box 4.2.

Box 4.2 Integrated National-Local Energy Planning

In 1989, FAO organized a workshop to develop an approach to rural and agricultural energy planning and analysis. (UNDP/ESCAP/FAO, 1990) Although grounded in Asian experience, many of the findings have universal relevance. The linkage between energy ministries, planners, and providers and the rural, agricultural sector is generally weaker than with other sectors; as a result, energy needs for rural and agricultural development are often inadequately assessed and emphasized. Methodologies for agricultural/rural energy planning should ideally be carried out at the local, regional, and national levels. Local needs are best addressed with knowledge of specific local conditions and with the involvement of local residents. At the same time, local areas are interdependent, and national planners must ensure that total national energy needs, often with large scale projects that cannot be planned at the local level (e.g. power plants, refineries, or pipelines). The situation thus calls for coordination between local and national levels. (Raskin and Lazarus, 1989) An integrated national-local planning approach can be implemented where resources are available to do so, and tailored to each national situation, as it has been in several countries.[5] While this remains the ultimate objective, the present case studies focus principally on the national level and rely on existing data to generate initial, indicative scenarios.

4.3. Description of Scenarios

Scenarios are stories about possible futures, built from assumptions, best guesses, and a model of interrelationships, either simple or complex. Obviously, many different stories about the future of African agriculture could be told, based on desired outcomes, such as rapid economic growth, or based on other possible economic, demographic, or social developments.

For this study, three scenarios are developed to describe a range of possible outcomes over the next two decades:

1. **Reference/continuation of past trends.** This scenario reflects continued increases in food import requirements, relatively stagnant agricultural growth, modest improvement in yields, and little increase in the use of agricultural inputs. This scenario is consistent with a continuation of the regional agricultural growth rate of

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[5] Countries where linked national-regional-local energy planning approaches have been pursued include China, Costa Rica, Kenya, India, Indonesia, and the Philippines. In the Philippines, for example, the Non-Conventional Resources Division of the Department of Energy has set up 17 affiliated regional planning centers at local universities; these centers are responsible for constructing rural energy plans. (see Van der Werf, 1992)

about 2%/year. Energy use is projected to change as a function of cultivated area, crop type, yield, and farming practice, as described below.

2. **Moderate Improvement**. This scenario assumes moderate increases in agricultural inputs and yields. Moderate growth, however, is unlikely to keep pace with population growth and to stem Africa's rising food supply gap. This scenario is based on a combination of national goals, where available, and recent FAO scenario results, which project regional agricultural production growing at about 3% per year. (FAO, 1993a)

3. **Accelerated Growth.** The ultimate goal of this scenario is not only improved nutrition and food security, but the associated rural and overall economic development that would be stimulated by increased agricultural production. A regional target of 4% annual growth in agricultural production is based upon two studies that estimated growth levels required to gradually eliminate net food imports for the African region. (World Bank, 1989a; Cleaver, 1993)[6] These studies are discussed further below. For this scenario, the growth objective is met principally by the increasing use of high-yield, high-input production methods by farmers presently using more traditional practices. Patterns of crop production and energy use for modern, large-scale commercial farms in African countries provide the along the modern high-input path, through the increasing adoption of mechanized agriculture by traditional farmers.

Conventional high-input farming methods require significant use of mechanization and agricultural chemicals that can increase soil erosion, reduce soil fertility, and contaminate ground and surface waters. To address these concerns, a fourth, **Sustainable Agriculture** scenario was initially pursued, in order to quantify the energy needed to meet the Accelerated Growth targets using more sustainable agricultural practices. Such methods include integrated pest management (IPM), agroforestry, increased use of organic fertilization, low-tillage, and overall improved farm management practices that tend to reduce the need for capital- and energy-intensive inputs without sacrificing yields. In addition, potential energy efficiency improvements in irrigation, traction, and agricultural processing were explored, in order to minimize the financing needs, foreign exchange requirements, and environmental impacts of energy supply. Due the lack of well-documented African cases where these methods have been applied and energy use characteristics measured, this scenario proved difficult to quantify. Nonetheless, some elements, particularly energy saving potentials, of a Sustainable Agriculture scenario are discussed later in this chapter.

Box 4.3 Key Elements of Case Study Scenarios

Reference Scenario

- continuation of past trends, no surprises or major shifts

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[6] If national, rather than regional, food security were the objective, required growth rates would differ dramatically among countries. Food secure countries, such as Zimbabwe, would require only the growth needed to keep pace with population, while others that are heavily dependent on import would need to increase production at infeasible rates to achieve food security by 2010. A regional food security goal is more realistic and economically efficient.

- ~ 2%/year growth in agricultural production, on average
- growth in non-agricultural sectors drawn from other analyses

Moderate Improvement
- changes in cropping patterns guided by FAO AT2010 study and available national projections
- ~ 3%/year growth in agricultural production

Accelerated Growth
- rapid growth in both food and non-food crop production
- ~ 4%/year growth in agricultural production, most crops
- emphasis on high-input, conventional farming techniques

Sustainable Agriculture (not quantified)
- same targets as Accelerated Growth scenario
- utilization of more sustainable farming practices to minimize environmental impacts, external inputs, and farmer risk (e.g. integrated pest management, reduced or no tillage, agroforestry, recycling of agricultural residues, biological nitrogen fixation)
- investment in cost-effective energy-efficiency improvements

4.4. Looking into the crystal ball: regional and global agricultural scenarios

Looking into the future is always a rather subjective undertaking, since it involves choices among projection methods, critical assumptions, and scenario characteristics. It is thus useful to look at available agriculture scenarios at the regional and global levels. Some of these scenario exercises embody important global trends and interrelationships, such as the effect of changing trade patterns and consumption patterns in importing countries, that may affect the African agriculture and energy situation in ways that are hard to predict when looking at the national level alone. Since no independent analysis was undertaken to estimate agricultural production requirements needed to achieve food security and improved nutrition, the two sets of studies described below are used to provide these estimates and targets.

Agriculture: Towards 2010 , “AT2010” (FAO, 1993a); World Agriculture: Towards 2000, “AT2000” (Alexandratos, ed. 1987)

These studies comprise two of the most widely read and reviewed studies of prospective agricultural development, and provide an important source of data and assumptions for the case studies. AT2000, and its update AT2010, assembled the broad expertise of FAO to assess the likely developments over a 15-20 year time horizon, and to help identify and motivate efforts needed to achieve food security and better nutrition, while improving the sustainability of agricultural and rural development. These studies are extremely detailed, looking at demand and production characteristics in each of over 90 developing countries, accounting for international trends in commodity production and trade. The analyses rely heavily on expert judgment, particularly with respect to land use and production patterns.

While prospects are brighter in other regions, for Africa, AT2010 projects the persistence of chronic undernutrition and continued rapid rise in food imports. Almost half of the world's undernourished population, numbering nearly 300 million, are projected to reside in Africa by 2010. The need for food imports will increase almost two and half times from 1990 to 2010. Although overall agricultural production (3.0% per year) and cereal production (3.4% per year) grow faster than in any other region over the 1990-2010 period, per capita food production grows only slightly, due to rapid population expansion (3.2% per year).

Almost half of the projected production growth in Africa is expected to come from expanding cultivated area by either bringing new land under the plow or by multiple cropping. Very little expansion of irrigation, globally or in the region, is expected; most of the better sites have been exploited, and major irrigation projects have often proven too costly to justify the returns for governments and donor agencies. The use of fertilizer is expected to increase at 3.3% per year, the same rate as overall production, and an increase from the 2.8% growth witnessed in the 1980s.

Table 4.1 AT2010 Projected Growth Rates for Africa

Crop	Annual Growth in Production, 1990-2010
Maize	2.7
Wheat	2.1
Rice	2.0
Sorghum	2.5
Millet	1.8
Cassava	1.8
Tobacco	3.0
Sugar Cane	2.1
Cotton	3.2

The regional results of the AT2010 study are more optimistic than recent national trends for Africa and most case study countries. In the Moderate Improvement scenarios, these results, including the growth rates in crop production shown in Table 4.1 above, together with national "targets" where available, to project growth in yields and cultivated area.[7]

Sub-Saharan Africa, From Crisis to Sustainable Growth: A Long-Term Perspective Study (World Bank, 1989a); *A Strategy to Develop Agriculture in Sub-Saharan Africa and a Focus for the World Bank* (Cleaver, 1993)

These two World Bank studies provide a vision for increasing food security and nutrition in the region, and a strategy for Bank investments. Each study includes a series of scenarios to estimate the regional food security achieved under a range of production and population assumptions through the year 2020. Although methods and results differ somewhat between the two studies, both suggest a target of 4% annual growth in food and agricultural production.

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[7] Growth rates for all crops except tobacco are averages for all developing countries except China. Tobacco is based on the average growth in total agricultural production in Sub-Saharan Africa.

Table 4.2 presents the key assumptions and results for the more recent analysis. (Cleaver, 1993) Five scenarios considered variants in population, food production, and average caloric intake. Shown here are the resulting regional food gaps (consumption at projected caloric intake minus projected production) for 2000 and 2020. For reference, the current food gap in 1990 was approximately 10 million tonnes (100 million tonnes consumed minus 90 million produced). The average caloric intake of 2027 assumed in Cases I-IV is the present average, a level insufficient to substantially reduce undernutrition. A continuation of the long-term growth of 2% in agricultural production in leads to food gaps in Cases I and III that substantially exceed those projected in AT2010 above. The 4% production target assumed in Cases II, II, and V, is capable of closing the food gap over the next 10-30 years, thereby achieving the food security objective. But only in Case V is the other major objective, improved nutrition also achieved, with average intake rising to 2400 calories by 2030. A reduction in fertility of 50% by 2030, while not substantially affecting results shown through 2020, is critical to maintaining food security and adequate nutrition in the longer-term.

Table 4.2 World Bank Food Scenarios for Sub-Saharan Africa (Cleaver, 1993)

	Case I	Case II	Case III	Case IV	Case V
Population	-- projected levels --		-- decline in fertility of 50% by 2030 --		
Food Production Growth	2%/yr	4%/yr	2%/yr	4%/yr	4%/yr
Avg. Caloric Intake	2027	2027	2027	2027	2400 by 2030
Food Gap Million T (2000)	24	1	23	0	11
Food Gap Million T (2020)	80	-49	74	-55	-12

As noted by Cleaver, achievement of these objectives will require liberalization of intra-African food trade and improved food distribution capability. This trade could become even more important in light of the projection that world demand for the agricultural commodities produced in Africa are expected to increase more slowly at 1-3% per year.

The 4% production growth target is used in the Accelerated Growth scenarios for all case study countries, with the implicit assumption that improved intra-Africa trade will enable the countries more poorly endowed in agricultural resources to benefit from the improved regional picture. As noted by Cleaver, the 4% growth target is ambitious, yet recent experience in several African countries suggests that this level of growth is achievable.[8]

Box 4.4 A Pessimistic View of Long-Run Food Prospects (Kendall and Pimentel, 1994)

Kendall and Pimentel examine global food prospects through the year 2050 under three scenarios: business-as-usual (BAU), pessimistic, and optimistic. As in most other projections, increases in irrigated area are expected to be modest. Irrigated area rises from the 16% of cultivated area to 18% by 2050 in the BAU scenario, and to 17% and 19% in the pessimistic and optimistic scenarios, respectively. In other respects, their BAU scenario is itself rather pessimistic. Land degradation is expected to depress productivity in developing countries by 15-30%. Grain production increases only 50% by 2050, while global population doubles, thus the projected food situation is rather grim. Grimmer, still, is their pessimistic scenario, where they factor in potential crop losses of 10-20% due to global climate change and

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[8] Cleaver (1993) cites growth rates in excess of 4 percent from 1986-89 in Chad, Cape Verde, Nigeria, Botswana, Guinea-Bissau, Uganda, Benin, Kenya, Tanzania, and Comoros.

stratospheric ozone loss, continued decline in fertilizer use, cropland, and degradation of irrigated land. Per capita grain production drops to almost half of current levels.

To alleviate widespread hunger among a doubled of world population by 2050, they argue that a tripling, or more, of current food supply would be required. They estimate that the energy-intensiveness of developing country agriculture would need to increase 50- to 100-fold, including major increases in irrigation, to achieve this 3-fold increase in food production. Such an increase in input use, they suggest, might be unrealistic, and would imply uncontrollable environmental degradation that could undermine increasing production.[9]

Thus, the essential element of their Optimistic Scenario is rapid stabilization of population growth, lowering world population in 2050 from 13 to 7.8 billion, and thereby reducing grain production requirements to achievable levels. Grain production increases 70% by 2050, boosted by a 20% increase in planted area, and a 450% increase in fertilizer use. Improved food distribution, environmental protection, fuel substitution for agricultural residues (to enable nutrient recycling), technology transfer and assistance, and clear government priorities on food production are essential to achieving this goal.

While none of their assumptions or results are used here, the Kendall and Pimentel long-term, global analysis provides a useful backdrop for shorter-term, regional analysis. Their results indicate the potential importance of controlling population growth and environmental degradation, elements not directly addressed here.

4.5. Analysis of agriculture-related energy use patterns

In the 1970s, two developments combined to bring the energy-agriculture connection to the academic and policy-makers’ agenda. Widely-read global studies, such as “Limits to Growth” (Club of Rome, 1972), questioned the earth’s carrying capacity, particularly the ability to feed its burgeoning human population. Second, the energy crisis, with rising energy prices and the prospect of dwindling fossil fuel supplies, forced a critical examination of the dependence of agriculture and food supply on energy availability. Together, these developments led to a common question: Would the rising costs of energy-intensive inputs (fertilizers, mechanization and irrigation) hinder efforts to modernize agriculture and improve yields in developing countries, and consequently impede the ability to grow enough food? If so, what alternative agricultural practices, consumption patterns, or energy resources might be needed?

a) Energy-agriculture studies and full energetic analysis

These and other concerns helped to spur several seminal studies of energy, food, and agriculture during this period. (Makhijani and Poole, 1975; Leach, 1976; Lockeretz, 1977; Pimentel and Pimentel, 1979; Stout et al., 1979) These studies elaborated methods of *energetic*

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[9] Kendall and Pimentel point out that, at present, irrigation consumes 70% of global fresh water use, that 430 million ha of cropland, equivalent to one-third of presently cultivated area has been abandoned due to soil erosion; and that nutrient depletion, overcultivation, waterlogging, urbanization, soil compaction, acidification, and other forms of land degradation, taken together with soil eroision, reduce annual crop yields and long-term productivity.

analysis, which consider not only the commercial energy used for agricultural production, but the energy embodied in agricultural inputs (e.g. in the manufacture and transport of fertilizers and tractors), the human and animal energy expended, particularly in traditional agricultural production, and the "energy value" of the crops produced. These elements were often combined in detailed energy output/input balances, as illustrated in Table 4.c below.

When all inputs are considered in terms of their energy value, the energy requirements of agriculture and food production increase dramatically when compared to the relatively small amount of commercial energy typically used for agriculture in most countries. In some developing countries, food production and delivery accounts for 60-80% of the total energy -- human plus animal plus fuel -- used. (Pimentel, 1979) Under the conventional path of agricultural development and intensification, land and labor constraints and other factors lead to increased mechanization and use of energy-intensive inputs, and the use of commercial energy increases rapidly, while human and animal labor decrease. Ironically, while the amount of commercial energy is far higher in most countries using modern high-input farming methods, the *share* of total energy used in the agriculture and food systems is typically lower, due to heavier energy use in industrial, service, and transportation sectors.

Under modern, high-input practices, the manufacture and delivery chemical fertilizers dominates energetic analyses for many crops and conditions. This finding holds true in both developing and industrialized countries, as illustrated in Table 4.3 for both barley in the UK and maize in large scale commercial farms in Zimbabwe, where fertilizers account for 57% and 50%, respectively, of total energy-valued inputs. The energy embodied in agricultural equipment and improved seed varieties (their cultivation and delivery) can also be significant. Combined with the energy required to process and deliver products once they leave the farm, modern food production is, as Leach (1976) notes, "an astonishingly energy-intensive process." (p.2) As shown in Table 4.3 (at the end of this chapter), energy output/input ratios for modern agriculture are far lower than for traditional practices. In essence, modern, high-input agriculture substitutes energy in the form of fuels, fertilizer and other inputs for land and labor, resulting in increases in yield and energy intensity.

This tendency is vividly demonstrated by Zimbabwe's "dual" agricultural sector. Large-scale commercial farms employing modern, high-input practices account for 99% of the agricultural use of commercial energy that shows up in the national energy statistics. However, these farms comprise only 21% of farmed area. Most of Zimbabwe's rural population resides on communal or smallholder farms, which produce the bulk of country's cereal output. They rely on human labor and animal draught as energy sources, and yields are typically 2-4 times lower than on large commercial farms.

The findings of energetic analyses provide some important insights. If one were to rely on the low energy consumption figure for agriculture on most national energy balance sheets (commercial energy only), typically in the range of 1-3% in industrialized countries and 5-10% in developing countries, one might underestimate the importance of the agricultural sector's linkage to overall energy requirements. Similarly, one might understate the relevance of energy prices and availability to the agricultural production and competitiveness. When the indirect or embodied energy requirements are considered, the energy requirements of the food and agricultural production are often several times what their direct fuel consumption levels might suggest. Table 4.4 below shows that, energy consumed for on-farm operations (machinery and irrigation; post-harvest uses excluded) ranges from 24% to 42% of total, commercial energy requirements.

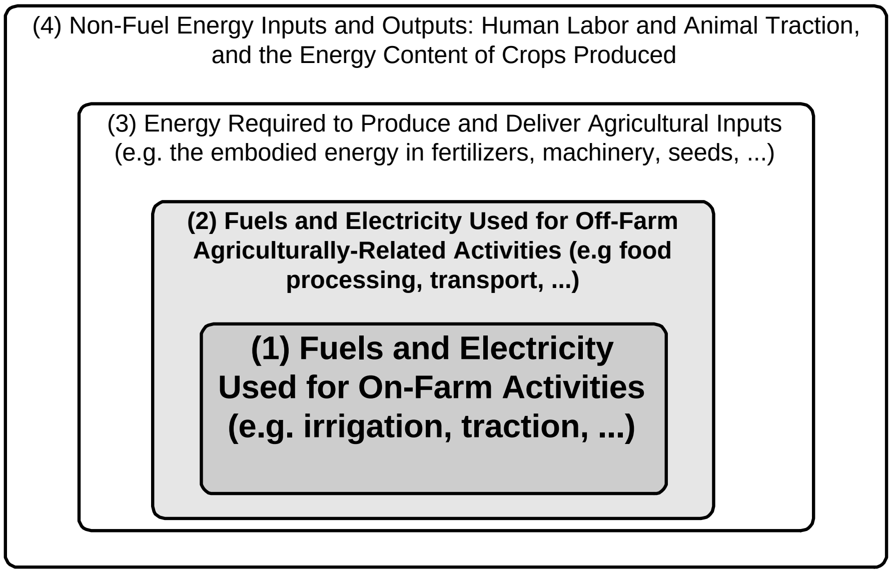
Table 4.4 Commercial Energy Used for Agricultural Inputs and Operations

Inputs	**Industrialized Countries (1972/73)**	**Developing Countries (1972/73)**	**Africa (1972/73)**
Fertilizer	35%	64%	57%
Machinery (Operation/Fuel)	**41%**	**17%**	**23%**
Machinery (Equipment Man)	21%	11%	14%
Irrigation (Operation/Fuel)	**1%**	**7%**	**2%**
Irrigation (Equipment Man.)	--	1%	--
Pesticides	2%	1%	2%
Total (EJ)	4637	921	70

Bold face indicates fuel use categories tracked here (energy that is used during operation in the region).
Sources: Stout et al., 1979; Weiner et al., 1988

While energetic analysis can provide interesting insights, the case study scenarios focus primarily on the consumption of fuels and electricity in agricultural and agriculture-related activities, as indicated by the shaded areas in Figure 4.2 and bold face lines in Table 4.4. To the extent possible, traditional fuels -- fuelwood and agricultural residues -- are included along with more commonly reported commercial fuel uses. For several reasons, limited consideration is given to the two unshaded areas of Figure 4.2 -- the embodied energy in agricultural inputs and human and animal power -- that are typically included in energetic analyses. First, there are inherent limits to valuing inputs and outputs on energy terms. Farmers make production decisions and prosper based on the economic, rather than the energy value, of inputs and outputs. Second, the primarily combined interest of the energy and agricultural sectors is typically how the provision of fuels and electricity relates to agricultural and rural well-being. Agricultural chemicals and machinery are typically imported in most African countries, therefore the energy required to produce them may have little effect on the national energy balance.

Figure 4.2 Levels of Agricultural Energy Analysis



Shaded areas are the focus of the present analysis

Human and animal labor requirements fall outside the traditional boundaries of energy sector planning, and their dynamics are far more complex than those of fuel and electricity supply and are not considered here. However, since human labor remains the predominant source of energy for agricultural production in much of Africa, and transitions to animal traction and fuel-using machinery are important for the social and economic effects, human and animal labor requirements and trade-offs remains an important area for research.

In the scenarios, fertilizer use is projected in both physical and energy terms, according to the typical equivalents found in the literature as illustrated in Table 4.5 above. However, the points noted above should be kept in mind; in most cases, the reported energy value of fertilizer will have little or no bearing on the national energy balance. Given limited data and usefulness, the energy equivalent values for pesticide use and farm machinery are not tracked.

Table 4.5 Energy Equivalents for Agricultural Inputs

Input	kgOE/kg
Nitrogen (N)	1.85
Phosphorus (P)	0.33
Potassium (K)	0.21
Pesticides	2.3
Farm and Irrigation Machinery	2

Source: FAO, 1985; Similar values found in Leach (1976).

b) Energy, agricultural, and economic development: trends and relationships

A few key trends have and may continue to affect agricultural energy use, and play an important role in defining the Reference scenarios:[10]

- Africa's disappointing agricultural performance over the past two decades is well documented: regional average annual growth in agricultural production, value added, and export value have averaged 2% per year or less, failing to keep pace with population expansion of over 3%. Per capita food production declined at a rate of about 2% per year, and imports grew at over 6% per year. (Jaffee in Barghouti et al, 1992; World Bank, 1992). Each of the case study countries witnessed similar declines in per capita food production as shown in Figure 4.3.

- Most developing countries rely heavily on agriculture as a source of value added and export earnings; this reliance tends to decrease as countries industrialize. As shown in Figure 4.4, declining agriculture GDP share strongly correlates with rising income. This tendency, however, does not mean that the agricultural sector should be ignored in favor of industry as a focus for economic growth; indeed, most Western development economists in the 1950s did not consider the agricultural sector instrumental to economic development. Fortunately, this view has been largely abandoned; now agriculture is typically recognized as an important stimulus for industrialization. (Cleaver, 1993; OTA, 1992) As shown in Table 4.6, the agricultural share of GDP ranges from 12% in Zimbabwe (the most industrialized of the study countries) to 59% in Tanzania, averaging 32% for the region.

- Agriculture typically accounts for a small fraction of total energy use, a fraction that tends to decrease with increasing average income, largely for the reasons described above. In the study countries, this fraction ranges from 6% in Tanzania to 11% in Zimbabwe and Sudan. Much of the energy used in traditional agriculture -- human and animal labor and biomass fuels -- is generally not accounted for in these statistics.

- High-input, mechanized agriculture generally increases commercial energy use per hectare by one or two orders of magnitude, compared with more traditional methods. (Kendall and Pimentel, 1994) More intensely mechanized farming in Zimbabwe, combined with government policies that ensure reliable energy supply to farmers, accounts for its higher agricultural energy intensity (per hectare) than other countries, as shown in Table 4.6.

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[10] Several international data sources, including AGROSTAT (FAO, 1990 and FAO, 1993b), World Resources Institute (1994), World Data Tables (World Bank, 1993a), and IEA Energy Statistics (IEA, 1993), were used to supplement local data.

- Overall commercial energy use in most African countries has tended to increase directly with value added. As shown in Figure 4.5, overall energy intensities are highest in Zimbabwe, followed by Sudan and Tanzania. Trends over the past two decades implied income-energy elasticities of 0.7 for Zimbabwe and 1.2 for Sudan, while for other countries the data and/or correlations were too poor to estimate elasticities. An elasticity values of 0.7 is used for Zimbabwe, with its more diversified economy and access to more energy-efficient technologies, and 1 for other countries. The estimated value for Sudan, reflects a very turbulent period where energy use could not always be translated into increased production due to civil strife.

- For the agricultural sector, as shown in Figure 4.6, agricultural energy intensities tend to be lower than for the economy as a whole. Furthermore, the large fluctuations in annual values suggests a weak relationship between agricultural energy use and value added.[11] Therefore, the use of income elasticities to project agricultural value added is problematic.

- Agricultural energy use appears to correlate more strongly with a composite index of agricultural production index than with agricultural GDP, as illustrated by comparing Figure 4.6 with Figure 4.7. Greater disaggregation to farming system (commercial vs. traditional, irrigated vs. rainfed, etc.), region, and crop type would enable more accurate tracking of energy use; this approach is at the core of the methodology used here.

- Estimating and using price response as an explanatory variable is desirable in principle, but problematic in practice. Price effects are clearest where markets function well, and consumers are can respond to price changes by use of substitutes. In many African countries, however, this is not the case; reliability of energy supply often the key concern. Government interventions in the form of subsidies and price controls also further complicate the analysis.[12]

- In the region, the predominant fuels used by the agricultural sector are diesel for farm machinery and irrigation pumps, wood and coal for crop drying and curing, and electricity for irrigation and miscellaneous uses. Electricity use tends to be more cost-effective and efficient than diesel for irrigation pumping, but its use is limited due to in part to the lack of available low-cost electricity and grid connections. Among the case study countries, electricity is used to irrigate sugar cane in the Sudan and several other crops in Zimbabwe; expansion of electricity use will depend on the success of rural electrification efforts, which generally need to be justified in the broader context of rural development.

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[11] This may be a reflection of differing exchange rates and agricultural commodity prices and their influence on agricultural value added, as reported in common monetary units.

[12] In the most detailed econometric analysis reviewed from among the five countries, all estimates of price elasticities for Zimbabwe were considered statistically insignificant, unreliable, and “too low based on experience in other countries”. (p. 154, World Bank/UNDP, 1992)

- Fuel switching and alternative fuels could help to meet increased agricultural energy requirements. As noted in Chapter 5, the agriculture sector has the potential to become a major source of bioenergy supply, providing liquid fuel substitutes, diesel and feedstocks for electricity production, and solid fuels for crop curing and drying. In addition, improvements in wind and solar technologies have made them cost-competitive for power generation in many remote areas, offering the means to increase small-scale irrigation. These potentials are not considered here, but the reader should bear in mind that future energy requirements for the agricultural sector could, and probably should, be met from a broader array of energy resources than shown here.

- Average fertilizer application rates are very low in most African countries. Application rates in Zimbabwe, as shown in Figure 4.10, have remained at 5-10 times the levels found in other case study countries over the past two decades. This is in part a function of Zimbabwe's unique capability to produce sufficient nitrogenous fertilizer to roughly meet demands; most other African countries import most or all of their chemical fertilizers.

In the next section and in the country case study sections below, national and sub-national trends in yield, energy, and fertilizer use are analyzed in greater detail.

c) Energy use in agriculture and related industries; prospects for increasing energy services and efficiencies

Commercial and traditional energy forms are used to manufacture and deliver agricultural inputs, to operate agricultural machinery, to irrigate, dry, and cure crops, to transport agricultural products, and to transform them into consumer goods, such as foodstuffs, clothing, and beverages. Energy-efficiency measures might enable these activities to increase rapidly without proportional increases in energy use. Indicate estimates of achievable efficiency improvement potentials, as might be used in a Sustainable Agriculture scenario, are developed below.

Table 4.7 indicates the relative importance of various end-uses in Sudan and Zimbabwe. Crop drying and curing, generally applied to tobacco, maize, and wheat, is the most energy-intensive process, requiring up to 480 GJ per hectare for tobacco at present yields using traditional methods in Zimbabwe, and possibly requiring even more in Tanzania. (see World Bank, 1989a) As a result, tobacco curing is the single largest energy end-use in Zimbabwe, accounting for over half of all on-farm energy use. Irrigation is also relatively energy-intensive process; depending on the crop, climate, and farm type, energy requirements range from less than 1 GJ per hectare for sorghum, groundnuts and other crops in Sudan to around 20 GJ per hectare for sugar and wheat in semi-arid areas. Operation of farm machinery is somewhat less intensive on a per hectare basis, except for tobacco and sugar cane for which commercial methods are very mechanized.

Table 4.7 Energy Use in Agriculture and Agro-Industry: Zimbabwe and Sudan

	Zimbabwe (1990, est.)	Sudan (1990, est.)

	Comm. Energy (PJ)	Trad. Energy (PJ)	Energy Intensity (GJ/ha)	Comm. Energy (PJ)	Energy Intensity (GJ/ha)
On-Farm Uses					
Irrigation	2.8		6 (maize) - 21 (wheat)		0.5 (sorg.) -18 (sugar)
Mechanization	3.0		0.3 (communal) - 11 (tobacco)		0.2 (gr'nut) - 19 (sugar)
Tobacco Curing	9.0	6.7	203 (com'l) - 480 (trad'l)		--
Grain Drying	2.3	3.2	10 (com'l) - 233 (trad'l)		--
Food, Bev., & Tob. Industry					
Boilers	5.8				
Motor Drive	1.4				
Other	0.8				
Textile Industry					
Boilers	1.5				
Motor Drive	1.4				
Other	0.03				

Data unavailable for industrial subsectors and traditional fuels for Sudan.

Tractors and other farm machinery

Modern farm machinery can enable the rapid performance of routine and heavy operations such as planting, deep plowing, and land clearing. As a result, it can increase yields and production through more timely and effective tillage and planting, and can more readily enable multiple-cropping. (Stout et al., 1979) Its most basic purpose is to substitute for human labor; it thus becomes particularly attractive where farm labor is scarce or costly. Labor productivity can also be improved through effective use of draught animals and better farm tools; efforts which have been the emphasis of many recent development programs.

In most African countries, mechanization tends to be concentrated among large-scale commercial farms. Almost by definition, traditional farmers tend to make minimal use of farm machinery, and when they do, it is usually on a hired basis. Reliance on hand tools is still the norm throughout Africa, and the use of draught animals is generally low compared with other developing regions, particularly South Asia.

Despite generally increasing commercial energy use for agriculture, the number of tractors in use in Mali, Tanzania, and Zimbabwe has grown only slightly since 1970, as shown in Figure 4.8. Mechanization, on an aggregate level, would not appear to be a factor in the significant gains in smallholder maize yields witnessed in Tanzania and Zimbabwe in the 1980s. In the Sudan, as suggested in Figures 4.8 and 4.9, and as discussed in section 4.7 below, mechanized and semi-mechanized agriculture has been on the increase in recent years, owing to its competitive advantage over traditional methods. However, the greater availability of farm equipment has not translated into significant improvements in agricultural productivity, further underscoring the point the energy-intensive inputs alone, cannot guarantee improved performance.

While the number of tractors has increased over 7-fold in Cameroon, the overall level of mechanization remains very low. Measured in terms of tractors in use per hectare of arable land, Zimbabwe's agriculture system was almost 50 times more intensely mechanized than Cameroon's in 1989 and remains 2-4 times more mechanized than in Sudan and Tanzania. (see Table 4.6.)

Table 4.8 Major Mechanized Operations at Sudan's Gezira Irrigation Scheme

Operation	Typical Diesel Use (MJ/ha)	Relevant Crops
Deep Plowing	42.7	Cotton (most)
Disc Harrowing	24.4	Cotton (some), Wheat (some)
Ridging	7.8	All
Split Ridging	7.8	All
Cross Ridging	7.8	All
Leveling	7.8	Wheat
Drill Sowing	9.7	Wheat
Harvesting	14.5	Wheat
Transportation	14.5	Wheat

All includes cotton, sorghum, groundnuts, and wheat. Based on Nour (1994). Original source: Annual Report 1993/94, Mechanical Field Operations, Agricultural Engineering Department, Sudan Gezira, Barakat

Crops can differ substantially in mechanization operations and consequent energy use. Cotton cultivation in Sudan, for example, typically requires deep plowing, which as shown in Table 4.8 above is among the most energy-intensive operations. Not shown in Table 4.8 are all operations required for sugar cane cultivation; it requires 10 times more diesel per hectare for mechanized operations than cotton and 25 times more than wheat.

In the Reference and Moderate Improvement scenarios, mechanization is assumed to continue increasing in Sudan and Cameroon, while remaining relatively constant in other countries. Significant increases in mechanization, however, are implied in the Accelerated Growth scenario. In the Low Input scenario, alternative operations such as low-tillage agriculture are considered, which can simultaneously reduce soil erosion, land degradation, and energy use without significant yield losses for several crops. (Pieri in Srivastava and Alderman, 1993)

Irrigation

Despite theoretical estimates that potentially irrigable land is five times present levels in Africa, many observers do not expect major growth in irrigated area either globally or within the region, because the most favorable sites have largely already been exploited and the generally low success rate of large irrigation projects in Africa, particularly in the sub-Saharan region. (Crosson and Anderson, 1992) There is nonetheless potential for cost-effective irrigation expansion in several countries, including Sudan, Ethiopia, Nigeria, Somalia, and Niger, and notable successes with privately-operated, smaller-scale irrigation projects suggests that revised approaches might enable more of this potential to be realized. (Brown and Nooter, 1992)

Irrigation water is typically delivered using electric or diesel-powered pumps. Where grid electricity is available it is usually the most reliable and least expensive option. (OTA, 1992) Solar, wind, and producer gas are also options for water pumping. Inefficient agricultural pumpsets can be upgraded to reduce energy consumption by up to 30-50%, with as short as a 4 month payback to farmers. (OTA, 1992; Miller et al., 1994) Improved water delivery, using drip irrigation, better scheduling and other methods can provide additional benefits in terms of both reduced energy and water use. In the Sustainable Agriculture scenario, half of all irrigated farms might be assumed to adopt improved pumpsets by 2010, lowering irrigation energy requirements per hectare by 20%.

On-farm processing: crop curing and drying

Curing and drying, principally for tobacco and maize, are the predominant on-farm uses of energy in both Tanzania and Zimbabwe. Firewood, and in Zimbabwe, coal, are the principal fuels used for this purpose. In the case of Tanzania, curing and drying accounts for 4% of total national firewood use, and has been suggested as major contributor to localized fuelwood problems.

Tobacco curing alone accounts for over half of Zimbabwean on-farm energy use in 1982, and over one-fifth in Tanzania. In many cases, current tobacco curing practices are highly inefficient both in terms of energy use and crop damage and losses. In Tanzania, efforts have been made to address this problem by designing improved curing practices, which could reduce firewood use by 50%, improve the profitability for tobacco farmers, and thereby provide multiple benefits in terms of rural development and environment. (World Bank/UNDP, 1989b) In the Low Input scenario, half of these estimated savings are assumed to be achievable by 2010. For other crops, a more modest 10% reduction in energy intensity, due improved technologies and practice, is assumed.

Agro-industry

Agro-industry can be defined as comprising: a) the food, beverage, and tobacco manufacturing sector (ISIC 31); b) the textile, wearing apparel, and leather industries (ISIC 32); and c) any informal industries that process agricultural commodities and are not reported in formal statistics. Coal and oil use for boilers and process heat are commonly the predominant energy uses in agro-industry, as typified by the estimated 63% of total energy use shown in Table 4.7 for Zimbabwe food and textile industries. Electricity use for motors is also usually significant, as well, accounting for an estimated 24% of Zimbabwe agro-industry demand.

The energy efficiency of boilers and electric motors can often be improved at low-cost, with rapid payback time. (OTA, 1992) The potential for substantial, cost-effective energy savings in food and textile industries has in fact been a focus for the SADC Energy Efficiency Program. Initial estimates for energy savings in Zimbabwean agro-industries, as shown in Table 4.9, show that a greater potential exists for coal and oil savings, as compared to electricity. Based on a weighted average of these audits, scenarios savings of 30% and 4% in fuel and electricity in agro-industries might be achievable throughout Africa by 2010.

Table 4.9: Energy Savings Potential in Zimbabwe Agro-Industries

	Potential Savings	
Plant Type	**Fuels**	**Electricity**
Textiles	53%	4%
Leather Tanning	39%	4%

Brewery	13%	4%
Distillery	15%	7%
Cigarette Manufacturing	17%	7%
Bakery	50%	2%
Edible Oils	8%	2%
Sugar Refinery	30%	3%

Source: Shawmont, 1990

Agro-industry activity is tightly linked with agricultural production. (Cleaver, 1993) For the scenarios here, agro-industries are assumed to grow at about 1.5 times the rate of agricultural growth, based roughly on the 1.5 multiplier noted above. This is similar to Cleaver (1993) who suggests that 4% growth in agricultural production is necessary to achieve a target growth of 5-7% for agro-industries.

d) Prospects for increasing yields: the low vs. high input debate

When looking in detail at energy-agriculture relationships, it bears repeating that energy is but one of many important inputs for agricultural production. Increasing energy availability and use does not guarantee increased yields and production, and likewise, increased yields will not necessary require increased energy use. However, increased yields and production do lead to other important outputs: improving incomes, providing agriculture-related rural employment, freeing labor for other productive enterprises, and supplying the raw materials for increased agro-industry activity -- all of which will tend to increase energy requirements.

While few would disagree that increasing agricultural productivity is a central goal for rural and national development, there is wide diversity of opinion on the soundest and most sustainable means to do so. The debate between advocates of so-called “low-input” and “high-input” agricultural techniques may have lessened with the growing recognition of that methods can be effectively integrated, taking advantage of the merits of each (FAO, 1993a), sharp contrasts remain between the levels of chemical use and mechanization suggested by each. The more conventional high-input view typically holds that increasing mechanization, irrigation, and energy-intensive inputs such as fertilizers, pesticides, and herbicides are required for increasing yields.

The low-input advocates commonly point to examples of high-yield agriculture where few if any manufactured chemicals are required, and the best elements of traditional practices are maintained. Green manures and agricultural residues are used in place of mineral fertilizers, integrated pest management (IPM) substitutes for pesticides, and animal draught or low-tillage techniques are used instead of heavy machinery. Not surprisingly, energy use, foreign exchange requirements, and farmers’ cash outlays can be significantly reduced. Both traditional and modern, alternative agriculture techniques can have distinct benefits, often achieving comparable yields with lower external requirements and more positive ecological interactions. New low-input, high-yield farming techniques are under development at research centers in Africa, such as the French Agricultural Research Center (CIRAD) in Cote D’Ivoire, International Institute for Tropical Agriculture (IITA) in Nigeria, and the International Center for Research in Agro-Forestry (ICRAF) in Kenya.

Despite the wide variation among farming practices and conditions, projecting agricultural energy use requires simplified assumptions regarding the relationship between yields and energy use. The overwhelming majority of well-documented yield-energy use data describes the high-input agricultural path. The Global Technology Matrix (GTM), for example, is a detailed cross-sectional database that provides estimates of input requirements (fertilizer, power, seed, and plant protection) for a range of crops at 4 increasing levels of inputs and yields. (Bruinsma et al., 1983) From GTM data, yield-energy use and yield-fertilizer use elasticities were derived for the crops and yield levels found in each of the countries studied. By using these numbers, the first three scenarios implicitly assume that yields grow as the result of increasing inputs, thus adopting the conventional view. Typical values for yield-energy elasticities and yield-fertilizer elasticities range from 0.3 to 0.6, and 1.6 to 4.3, respectively.[13]

4.6. Zimbabwe

Zimbabwe's generally high yields and production levels, high degree of self-sufficiency, and abundance of cash crops for export all contribute towards the country's reputation as an African agricultural success story. Commercial farmers utilizing high-input techniques grow tobacco, maize and wheat with yields comparable to, or higher than, many industrialized countries. Since independence in 1980, maize yields have also increased substantially for communal farmers, contributing towards an improved standard of living for a large fraction of the population. Except in drought years, tobacco, sugar, beef and maize, Zimbabwe's staple crop, have been exported each year since independence.

Large-scale commercial farms (LSCFs) account for 21% of Zimbabwe's cultivated area and roughly 75% of total production. These farms, almost exclusively settler-owned and located on the most fertile soil, employ modern, high-input methods. In 1990, 30% of LSCF cultivated area was devoted to maize production, while tobacco, wheat and cotton accounted for 12%, 10% and 9%, respectively (CSO, 1994a). While all wheat is irrigated, maize, tobacco and cotton are grown on both rainfed and irrigated land. LSCFs contribute significantly to Zimbabwe's foreign exchange earnings, since they produce tobacco, sugar cane and maize for export. In the early 1990s, Zimbabwe's flue-cured tobacco accounted for 15% of world trade (NNU, 1992). Because of their intensive use of mechanization, irrigation, and on-farm processing of tobacco and maize, LSCFs account for 98% of agricultural energy use in Zimbabwe[14].

During colonial times, the local population was displaced onto more marginal, low rainfall land for communal farms. It is not surprising that traditional farmers have encountered lower yields, topsoil loss, firewood depletion and a range of other linked economic and environmental

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[13] The GTM reports total power requirements in man-day equivalents, including both commercial, animate, and human energy. We assume, over the yield increases considered here, that commercial energy use increases in the same proportion as the total. This may underestimate commercial energy requirements, since as yields rise, proportionately greater reliance on mechanization might be expected.

[14] The 98% does not account for energy embodied in fertilizer production. This percentage declines to 92% when fertilizer is included.

problems. In 1990, communal farms accounted for 70% of total cultivated area (CSO, 1994a-e), and 65% of Zimbabwean farmers (Chaguma, 1994). One-half of communal cultivated area was devoted to maize, while 12% and 6% were devoted to cotton and sorghum, respectively. Since communal farmers typically practice traditional low-input agriculture, non-human and non-animate energy use accounts for less than 1% of the national total. Although food-secure in normal rainfall years, a lack of irrigation leaves communal land dwellers vulnerable to seasonal food shortages, particularly during the winter months of June-September (NNU, 1992).

Other farm types include small-scale commercial farms, resettlement schemes and state-run farms. Small-scale commercial farms, founded before independence in an attempt to create an elite class of black freeholder farmers, grow mostly maize, and make up a small portion of agricultural land area, production and energy use. Since independence, the government has instituted several resettlement schemes to provide good-quality land and mechanized equipment for families and cooperatives. These farms also predominantly grow maize. Though more mechanized than communal farms, as a result of their small total area, these farms still do not contribute significantly towards national totals. State-run farms comprise less than 1% of total cultivated area, but with irrigation and other high-input techniques obtain yields comparable with large-scale commercial farms.

Since 1980, the government has promoted a two-pronged agricultural policy, designed to maintain a strong commercial farming sector while improving smallholder yields. Large-scale farms, important for their production of cash crops, also help ensure a reliable food surplus. Between 1980 and 1986, smallholder maize production in communal areas doubled, due largely to increased yields, but also to expanded cultivated area. Expanded access to credit enabled smallholders, for the first time, to take advantage of indigenously-developed hybrid seeds, a small degree of mechanization and nitrogen fertilizer (Eicher, 1994). Between 1979 and 1986, smallholder fertilizer purchases increased by 400% (World Bank, 1989a).

Because of government policies that favor agricultural production, agricultural energy use is considerably higher than in most other African countries. Preferential tariffs, diesel subsidies, and priority access to fuel supplies provide farmers with reliable and low-cost access to energy resources, particularly during periods of peak demand, such as planting and harvesting. For instance, the government ensures that coal is available for curing tobacco after harvest.[15]

Compared to most African countries, Zimbabwe possesses a diversified, robust industrial sector, largely as a result of the international trade embargo against the Rhodesian government in the 1970s. Now, roughly 30% of GDP comes from external trade, with gold and tobacco contributing the largest fractions of exports (World Bank/UNDP, 1992). In 1984, 47% of manufacturing industry value added originated from subsectors directly reliant on agricultural production: foodstuffs, drink and tobacco, and textiles (CSO, 1989).

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[15] Personal communication, R.S. Maya.

Zimbabwe is unique among the countries studied, because it produces most of its nitrogenous fertilizer needs[16]. Sable Chemical Company, which produces this fertilizer with an electrolytic plant, consumes roughly 10% of national electricity production. However, Sable has been described as an anachronism, built to provide a domestic source of fertilizer when Rhodesia was isolated from the international community. As originally conceived, the Sable facility was to be mothballed when excess capacity from the Kariba hydropower plant was no longer available. However, since the coal-fired Hwange plant began generation in 1984, Sable has played an important role in purchasing Hwange power, and thus helping to pay off Hwange's large construction debt. Consideration has been given to retrofitting the plant to use natural gas from Mozambique or domestic coal as feedstocks. Ammonia and urea imports have also been explored as options, but due to Sable's now-important role in the Zimbabwean industrial and overall economy, the plant has continued to operate despite its questionable economic status.

a) Case Study Method and Analysis

Because of the extensive analysis of the agricultural sector conducted as part of ZEAP Project[17], a rather detailed model for Zimbabwe was possible. The five farm types introduced above -- large-scale commercial, small-scale commercial, communal, resettlement and state-run -- were considered separately. Within each farm type, the area under cultivation, yield, energy use, and production for several major crops were analyzed.

Earlier detailed survey results were reconciled with more recent data on total agricultural energy use and land use patterns (CSO, 1994a-e) to develop a base year energy use profile for 1990. Irrigation, tractors, trucks (on-farm transport), curers, dryers and fans were considered, with separate per-hectare energy intensities for each crop and farm type. Per-hectare application rates for N, P, and K fertilizer for each crop and farm type were also developed, based on recent government statistics (CSO, 1994a-e).

In the Reference Scenario, future area under cultivation is based on a continuation of recent trends. During the last two decades, cultivated area has increased gradually for tobacco, wheat, cotton and sugar cane. By extrapolating these trends, as illustrated in Figure 4.11, cultivated areas were projected to 2010, shown in Figure 4.14. The area under wheat cultivation increases from 60,000 hectares in 1990 to 70,000 hectares in 2010. Since total cultivated area by farm type has stayed roughly constant over this time period, except for some shift to resettlement areas, there is no assumed change in total cultivated area. Thus, instead of clearing new land, land is shifted to tobacco, wheat, cotton and sugar cane from other, presumably less profitable crops.

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[16] On average, indigenous production accounted for 88% of consumption from 1987-89 (FAO, 1992).

[17] ZEAP, the Zimbabwe Energy Accounting Project, was a joint project between the Beijer Institute of the Royal Swedish Academy of Sciences and the Ministry of Water and Energy Resources and Development of the Government of Zimbabwe (now the Ministry of Transport and Energy), and was conducted from 1982-85.

Figure 4.11 Cutlivated Area, Wheat

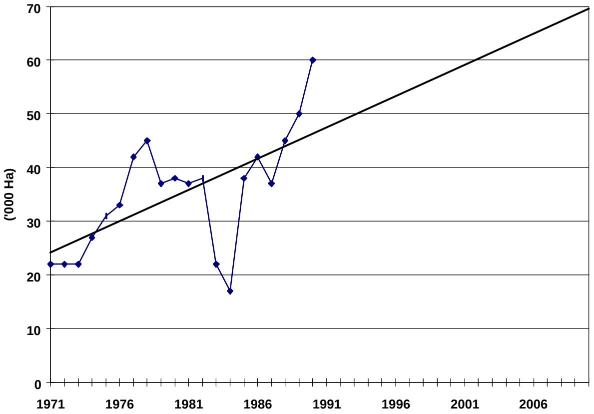
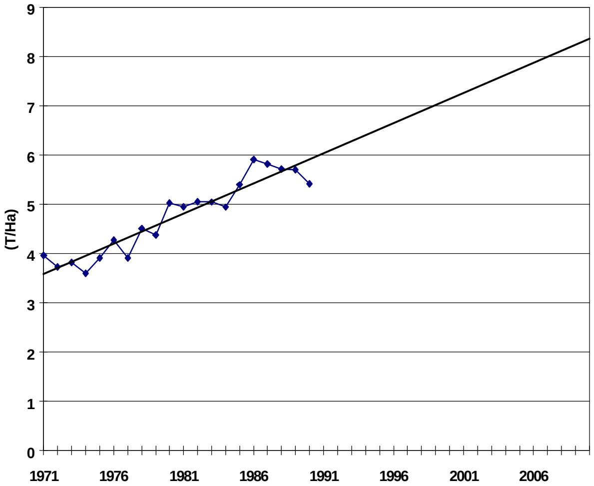


Figure 4.12 Wheat Yield



Future yield increases are calculated in a similar manner to areas, as illustrated in Figure 4.12. Based on historical yield increases from 1971-90, linear trend lines are used to project 2010 values. According to the trend line, wheat yields grow to 8.4 tonnes per hectare in 2010, an increase of 2.2% per year from 1990. This method leads to similar estimated growth for tobacco yields, slower average growth for sugar cane (1.6% per year), and no growth for cotton.

For on-farm product processing end-uses, such as curing, drying and fans, energy use is assumed to grow directly with the tonnage of crops produced. Future fertilizer application rates and energy intensities for irrigation, tractors and trucks grow with yield and energy-yield elasticities derived from the GTM, as described above.

In the Reference Scenario, agriculture-related industries are assumed to grow at 4% per year, near the average of growth projections for 1990-95 and actual performance from 1980-90 (Republic of Zimbabwe, 1991). For off-farm transport related to agriculture, the movement of primary agricultural and finished products within the country is assumed to account for half of road freight transport. Transport of agricultural products increases proportionally with total tonnage produced.

For the remainder of the economy, a previous projection was adopted for comparative purposes (Talbot and Hansen, 1993). Value added in other sectors grows at 4% per year, with the exception of the mining sector, which grows more slowly, at 3% per year. An income elasticity of 0.73 is applied to the industry, mining, and commercial sectors, based on national historic growth in energy consumption and GDP. Projections of domestic energy consumption are based on a more detailed end-use analysis, with assumptions of increasing rural electrification and shifts towards electricity and other commercial fuels.

b) Reference Scenario Results

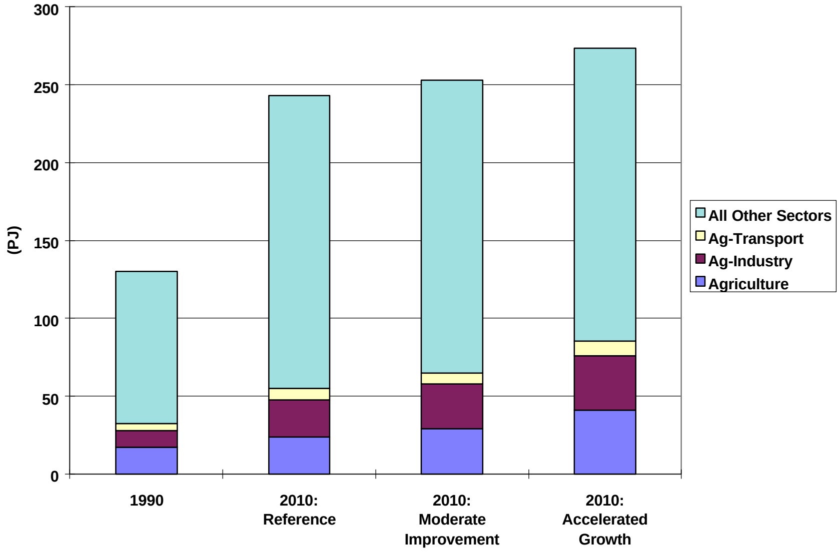
As shown in Table 4.10, total energy requirements in the Reference Scenario, including commercial and traditional fuels, increase to 429 PJ in 2010. Energy use in agriculture, agro-industry, and the transport of agricultural goods, combined, maintain an approximate 15-20% share of national energy consumption through 2010. Due to the healthy growth assumed for other modern sectors, commercial energy use in agriculture-related activities declines from 25% to 23% of commercial energy consumption in 2010, as shown in Figure 4.13.

Table 4.10 Zimbabwe Total Energy Requirements (PJ)

		2010		
Sector	**1990**	**Reference**	**Moderate Improvement**	**Accelerated Growth**
Agriculture	27	38	47	65
Agro-Industry	11	24	29	35
Ag-Transport	4	7	7	9
Other Industry	37	65	65	65
Other Transport	32	69	69	69
Mining	8	13	13	13
Commercial	14	24	24	24
Households	118	188	188	188
Total	251	429	443	469

Note: Agriculture does not include energy embodied in fertilizer production. Totals may not match due to rounding.

Figure 4.13 Zimbabwe Commercial Energy Use by Sector



Coal and firewood, used for drying and curing, account for over 80% of total on-farm agricultural energy use throughout the study horizon, as illustrated in Table 4.11. The remaining electricity and diesel are consumed for irrigation and mechanization. Agro-industries rely heavily on electricity, coal and coke, while diesel is used almost exclusively for the transport of agricultural goods.

Table 4.11 Energy Requirements by Fuel (PJ)

		2010		
	1990	**Reference**	**Moderate Improvement**	**Accelerated Growth**
Agriculture				
Electricity	2.9	3.8	4.2	6.5
Diesel	3.0	3.4	4.6	7.3

Coal	11.3	16.8	20.1	27.2
Firewood	10.0	14.3	18.1	23.9
Subtotal	27.2	38.3	47.0	64.9
Agro-Industry				
Electricity	3.6	7.8	9.5	11.5
Diesel	0.1	0.3	0.3	0.4
Gas/Ethanol Blend	<0.1	<0.1	<0.1	<0.1
Coal and Coke	7.2	15.7	19.0	23.0
Subtotal	10.9	23.8	28.9	34.9
Ag-Transport				
Diesel	4.2	7.0	6.8	9.3
Gas/Ethanol Blend	0.1	0.1	0.1	0.2
Subtotal	4.3	7.1	7.0	9.4
National Total				
Electricity	31.9	58.7	60.8	65.0
Diesel	21.1	39.4	40.6	45.8
Gas/Ethanol Blend	11.1	24.3	24.3	24.3
Other Petro Prods	6.0	12.6	12.6	12.6
Coal and Coke	60.0	108.0	114.6	125.7
Firewood	121.3	186.4	190.2	196.1
Total	251.3	429.4	443.0	469.5

Note: Totals may not match due to rounding.

In this scenario, the story of on-farm energy use remains the story of large-scale commercial farms, since they are the only mechanized farm type with land areas large enough to significantly affect national totals. In 2010, LSCFs still account for over 98% of on-farm commercial and traditional energy use, and three-quarters of embodied energy in applied fertilizer. Tobacco remains the most energy-intensive crop, accounting for over half of LSCF energy consumption in 2010. Increases in maize yields continue for smallholders on communal farms, as fertilizer application and mechanization increase. By 2010, one-quarter of all fertilizer is applied in communal areas. Overall, total agricultural production grows by 2.5% per year while population grows by 2.7% per year, thus, per capita production declines slightly.

c) Moderate Improvement Scenario

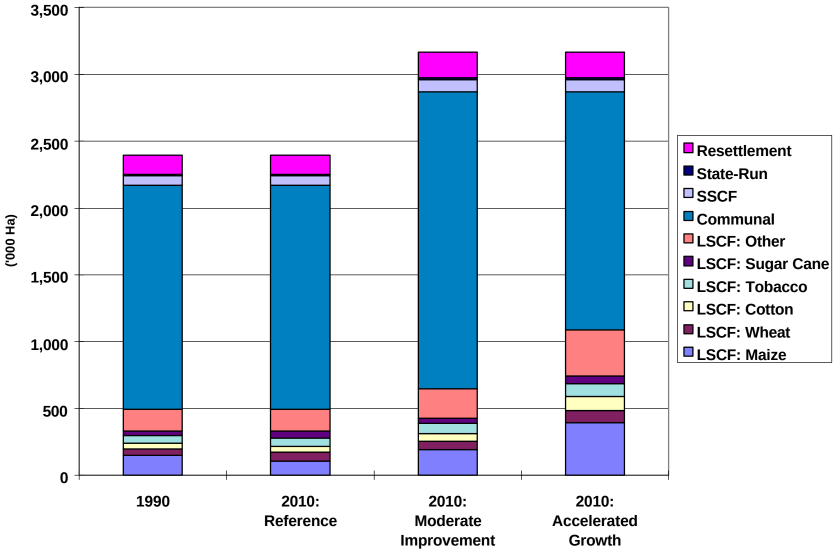
The Moderate Improvement Scenario is based on recent FAO projections of achievable production increases (FAO, 1993b). Based on the average for Sub-Saharan Africa, increases in cultivated area and yield are assumed to contribute equally to gains in production. Production growth rates vary by crop, and range from 2% to 3% per year. Production grows faster than in the Reference Scenario for all crops, with the exception of wheat and sugar cane.

Table 4.12 Fertilizer Requirements, thousand tonnes (*PJ embodied energy*)

		2010		
Fertilizer Type	**1990**	**Reference**	**Moderate Improvement**	**Accelerated Growth**
N	150.8 *(12.1)*	219.7 *(17.6)*	333.1 *(26.7)*	497.6 *(39.8)*
P	15.3 *(0.2)*	26.6 *(0.4)*	33.8 *(0.5)*	51.9 *(0.7)*
K	6.0 *(0.1)*	11.7 *(0.1)*	15.2 *(0.1)*	23.0 *(0.2)*
Total	172.1 *(12.4)*	258.0 *(18.1)*	382.1 *(27.3)*	572.5 *(40.7)*

Total fertilizer applied in the Moderate Improvement Scenario more than doubles from its 1990 value, reaching 382 tonnes (27 PJ embodied energy) in 2010, as shown in Table 4.12. As illustrated in Figure 4.14, cultivated area grows steadily, from 2.4 to 3.2 million hectares in 2010. The additional cultivated area comes from both land clearing and an increased cropping intensity.

Figure 4.14 Zimbabwe Cultivated Area



Note: LSCF = large-scale commercial farms. SSCF = small-scale commercial farms. In the Accelerated Growth Scenario, large-scale commercial farming area includes area shifted to high-input methods.

d) Accelerated Growth Scenario

As noted above, a 4% per year growth in agricultural production has been estimated as a target for achieving regional food security. In the Accelerated Growth Scenario, the overall area and yield improvements in the Moderate Improvement Scenario are used as a starting point. To achieve the target of 4% growth in production for each crop, a shift towards agricultural practices used in large-scale commercial farms is assumed.

With these assumptions, approximately 25% of communal farming area, or 440,000 hectares, adopt commercial high-input methods. This shift represents a doubling of high-input farming area during the study horizon. Since some of this land is of poorer quality than existing LSCF land, substantial increases in inputs will be required to match LSCF yields. To facilitate this transition, fertilizer requirements jump over 300% between 1990 and 2010. With Sable already operating near capacity to satisfy current fertilizer needs, a major expansion of indigenous manufacturing or an increased reliance on imports will be required -- both costly propositions. Large quantities of other inputs, such as improved seeds and pesticides, would also be required. Additional credit would need to be made available to smallholders to allow for the purchase of required inputs, as well as for the initial capital investment in machinery.

In addition to increased fertilizer, pesticide, and improved seed use, energy requirements will more than double by 2010. Coal and firewood requirements for on-farm curing and drying grow fastest; in 2010, almost 30% of coal and 12% of firewood consumed in Zimbabwe would be used on farms. As shown in Table 4.13, tobacco production will continue to account for the largest share of on-farm agricultural energy use, reaching 36 PJ in 2010.

Table 4.13 Energy Requirements by Crop and Farm Type (PJ)

		2010		
	1990	Reference	Moderate Improvement	Accelerated Growth
Large-Scale Comm'l				
Maize	2.7	1.9	4.3	8.9
Wheat	1.6	2.8	2.3	3.4
Cotton	0.4	0.4	0.6	1.2
Tobacco	16.4	26.6	29.6	36.0
Sugar Cane	0.4	0.7	0.5	0.8
Other	5.3	5.3	9.1	14.2
Communal	<0.1	<0.1	<0.1	<0.1
Small-Scale Comm'l	<0.1	<0.1	<0.1	<0.1
State-Run	0.2	0.2	0.3	0.3
Resettlement	0.1	0.2	0.2	0.2
Other	0.1	0.1	0.1	0.1
Total	27.2	38.3	47.0	64.9

Note: Requirements do not include energy embodied in fertilizer production. Totals may not match due to rounding.

4.7. Tanzania

Tanzanian agriculture relies heavily on smallholders, with less than 10% of cultivated area located on large-scale estates (Bureau of Statistics, 1994). Smallholders provide the foundation for Tanzania's economy; in 1990, agriculture contributed roughly half of total GDP, and agro-industries made up half of all manufacturing establishments (Bureau of Statistics, 1994). In many recent years, Tanzania has produced a food surplus, but, as witnessed in 1988 and 1990, droughts and floods can wreak havoc on the fragile smallholder production systems, and force the reliance on international food aid. Tanzania's staple crops -- maize, rice, sorghum, and cassava -- are produced almost exclusively by smallholders. Coffee, Tanzania's most important export crop, accounted for 39% of total merchandise export value in 1987, while cotton and tobacco accounted for 12% and 5%, respectively (World Bank, 1989). Thus, these three crops, together, represent more than half of the country's exports. Other crops, including cassava and maize, are exported in surplus years.

Tanzanian agriculture has undergone three broad periods of development. From 1961-71, favorable weather, market prices, and an availability of inputs led to high production levels. In the next decade, production declined due to the creation of inefficient national estates, villagization, and increased government price controls (Bureau of Statistics, 1993). From 1981-92, the government implemented a variety of economic reforms aimed at increasing production, including exchange rate adjustments, price decontrols, grain marketing reforms, and the encouragement of private sector participation. Since 1981, agricultural GDP has grown consistently, averaging over 4% per year (Bureau of Statistics, 1993).

Of the 3 million hectares cultivated by smallholders, 50% is devoted to maize, and over 10% is devoted each to paddy and sorghum. Coffee, millet, cassava, and groundnuts are also important smallholder crops. (Bureau of Statistics, 1994). Smallholder field sizes average 0.4 hectares, while half occupy less than 0.25 hectares (Bureau of Statistics, 1988). During the Masika season of long rains, roughly 85% of cultivated area is harvested, with the remainder harvested during the Vuli season of short rains (Bureau of Statistics, 1988). Smallholders, using traditional hand and hoe or oxen and plow techniques, consume an insignificant amount of commercial fuels. Large amounts of firewood, however, are utilized for on-farm tobacco curing. Although largely unmechanized and unirrigated, a small amount of fertilizers and pesticides are applied.

Smallholders, largely subsistence farmers, do not always rely on crops sales to provide a cash income. In 1986, one-third of smallholders relied on non-agricultural activities for their main source of income, and over one-quarter did not sell any produce. During that year, only 12% earned considerable profits from crop sales (Bureau of Statistics, 1988).

The Tanzania Fertilizer Company (TFC), commissioned in 1972, is located in Tanga. Recent production levels, less than 10,000 tonnes per year, are well below the attainable capacity of 100,000 tonnes. On average, indigenous production accounted for 9% of consumption from 1987-89 (FAO, 1992).

a) Case Study Method and Analysis

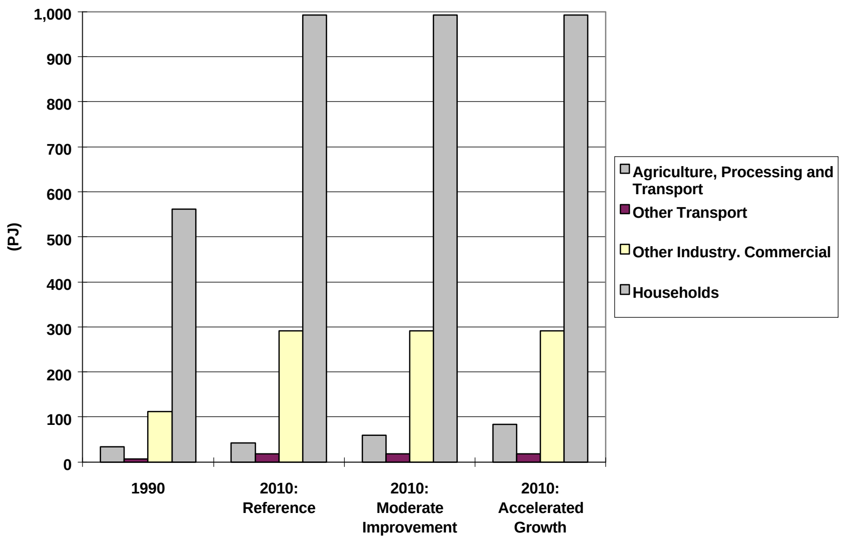
Since smallholders, who consume very small quantities of energy, make up the majority of Tanzania's agricultural system, on-farm energy consumption for mechanization or irrigation is not emphasized in this analysis. Instead, the significant amount of energy consumed in agricultural processing, agro-industry, and the transport of agricultural goods is considered in detail. Agro-processing and agro-industry are considered together, since data limitations prevent a full differentiation between on-farm processing (e.g., tobacco curing and tea drying) and agro-industry (e.g., sugar milling). Processing energy intensities are derived from a previous energy analysis of Tanzania (Mrindoko and Lazarus, 1990).

To track on-farm energy use, the country is split into small-scale and large-scale farms, with crops, yields and energy use assigned to both farm types (Bureau of Statistics, 1994, FAO, 1992, and FAO, 1992). In the Reference Scenario, future area under cultivation is based on a continuation of recent trends, using the method described for Zimbabwe. During the last two decades, total cultivated area has grown steadily, with maize and paddy increasing most significantly. By extrapolating these trends through 2010, maize area is projected to grow by 3.1% per year, paddy area by 2.6%, and total area by 1.7%. Maize yield is also projected to increase by 2.3% per year through 2010, while areas and yields for other crops stay constant.

As in Zimbabwe, processing energy use is assumed to grow directly with the tonnage of crops produced. Fertilizer application rates and energy intensities for irrigation, tractors and trucks grow with yield and energy-yield elasticities. For the off-farm transport of agriculture-related products, we assume that the movement of primary agricultural and finished products within the country accounts for half of total diesel and gasoline consumed in freight transport. We assume that transport of agricultural products increases proportionally with total tonnage produced.

For the remainder of the economy, we have adapted a previous projection for comparative purposes (Mrindoko and Lazarus, 1990). Value added in other sectors grow at 4.7% per year. Domestic energy consumption grows at 2.9% per year for rural households, and 2.2% per year for urban households.

Figure 4.15 Tanzania Total Energy Use by Sector



b) Reference Scenario Results

As illustrated in Figure 4.15, energy use in agriculture, processing, and the transport of agriculture-related products, combined, increases slightly from 34 to 42 PJ between 1990 and 2010. Due to the large increase in firewood consumption in rural households and the healthy growth assumed for other sectors, total energy use in the three agriculture-related sectors declines to 3% of the total consumption in 2010.

As illustrated in Figure 4.16, energy use in on-farm operations, including mechanization and irrigation in traditional and high input farms, grows from 2.7 to 3.8 PJ in 2010. These additional energy inputs are required to increase both yields and cultivated areas. Roughly 1.5 million hectares are brought under cultivation in the Reference Scenario, with most of the new harvested area under smallholder maize cultivation, as shown in Figure 4.17. A modest increase in high-input large-scale farms also occurs.

Figure 4.16 Tanzania On-Farm Operations Energy Use

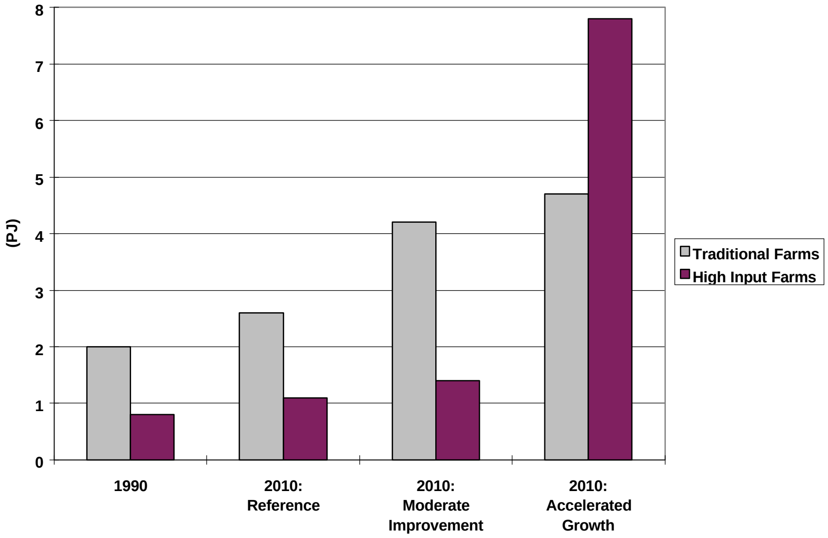
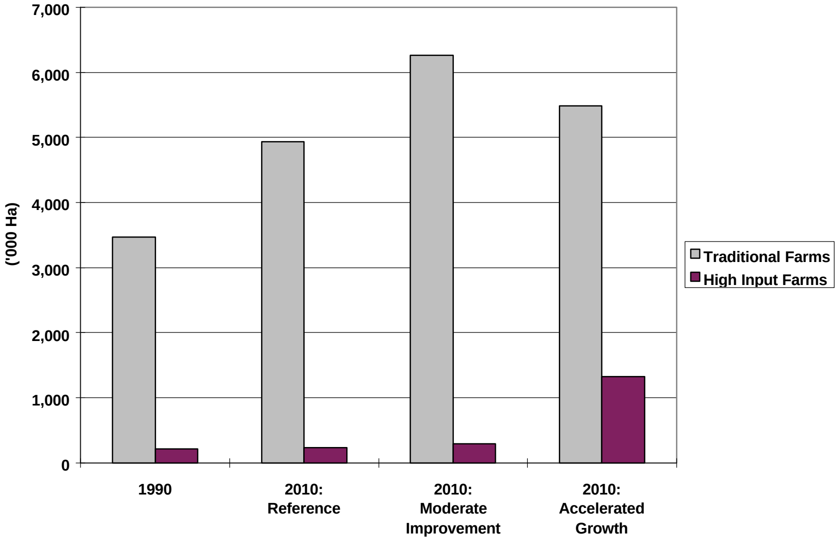


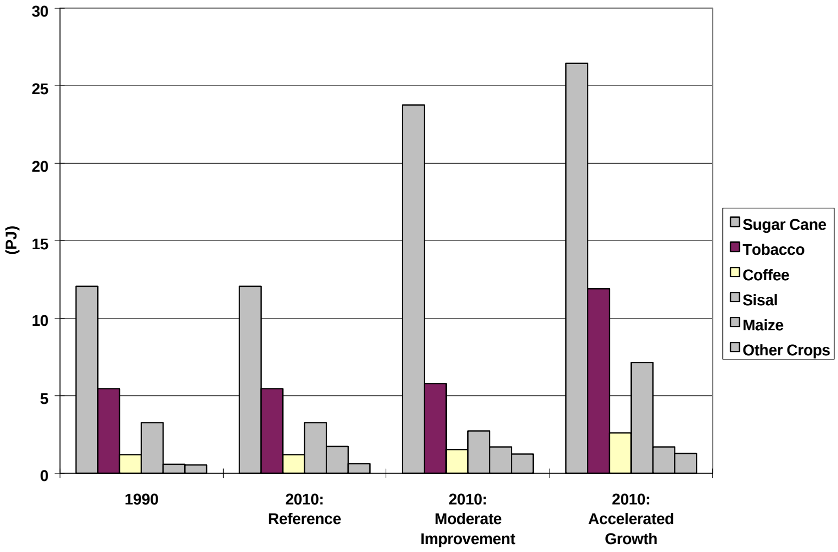
Figure 4.17 Tanzania Total Cultivated Area



c) Moderate Improvement Scenario

In the Moderate Improvement Scenario, areas and yields grow roughly in accordance with FAO projections (FAO, 1993). Yields for tobacco, tea, coffee, and some other crops increase faster than in the Reference Scenario, while areas for sugar cane and tea also grow more rapidly. Total energy use in agriculture, processing, agro-industry, and transport of agricultural products increases only slightly compared to the Reference Scenario, reaching 59 PJ in 2010. Most of this growth is due to a doubling of energy use in sugar milling due to increased sugar cane production, as seen in Figure 4.18.

Figure 4.18 Tanzania Agricultural Processing Energy Use

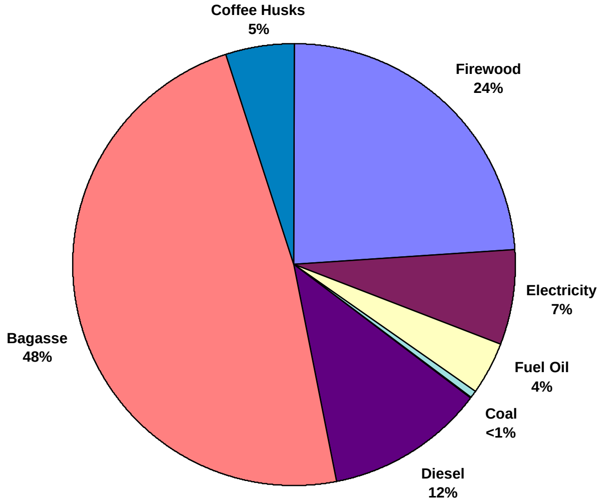


d) Accelerated Growth Scenario

In the Accelerated Growth Scenario, yields increase at the same rate as in the Moderate Improvement Scenario. New area is also placed under cultivation in order to increase production for each crop by 4% per year. Half of the new maize area is assigned to smallholders using traditional methods, and half is assigned to new high-input farms. New area for other crops is fully assigned to high-input farms, which are assumed to consist largely of smallholders utilizing new, intensive techniques.

In this scenario, total energy use in agriculture-related sectors increases 250% from 1990 through 2010, with significant increases in sugar milling and tobacco curing. As shown in Figure 4.19, biomass fuels continue to predominate in agricultural processing, with demand for bagasse (sugar milling) and firewood (tobacco curing) surpassing all commercial fuels. Coffee husks are also an important biomass fuel, used for coffee processing. In 2010, energy used for mechanization and irrigation is more than double that in the Moderate Improvement Scenario, with most of the increase seen in high-input farms (see Figure 4.16).

Figure 4.19 Tanzania Fuel Use in Agricultural Processing, 2010: Accelerated Growth Scenario



Ironically, in the Accelerated Growth scenario, the largest increases in energy use are for non-staple and non-food crops -- tobacco, sisal, sugar cane, and coffee -- which account for over 90% of agricultural processing energy use in 2010, as they do presently and in other scenarios. This is partly due to data availability and the case study methodology, which accounts for crop processing energy, and to the traditional, smallholder nature of most food production in the country. The results would seem to suggest that commercial energy is not a critical input for increasing food production in Tanzania, however, this finding depends on two assumptions: a) that there is no missing data on energy use for other food production-related activities and b) that a more pronounced shift to high-input or irrigated agricultural does not occur. With respect to the former, it could be that the energy used by farm machinery and irrigation is simply “hidden” among the national statistics, and if included would alter the scenario results. Furthermore, if sugar milling were included in the industrial sector, as is often the case, reported agricultural energy use would drop by approximately one-half. (The sugar production can, and often is, a net supplier of energy.)

4.8. Sudan

Sudan is Africa’s largest country, with a total area of over 237 million hectares. More than one half of the country is classified as arid, with 75 days or less per year when precipitation exceeds evapotranspiration. (World Resources, 1992) Because 80% of the cropland is not irrigated,. the quantities and distribution of rainfall play a dominant role in the success of the agricultural harvest. (Ministry of Agriculture, Natural Resources and Animal Wealth, 1993) In addition to rainfall, agricultural prices, wages, exchange rates, and energy availability are important determinants of food production patterns in the country. In 1983 energy shortages led to agricultural losses with a value of approximately $120 million, while the cost of the un-supplied energy would have been only about $17 million. (National Energy Planning Commission, 1985) Civil unrest and large refugee movements have also contributed to a lack of food security and an agricultural sector characterized by a high degree of production variability.

The agricultural sector is responsible for more than 40% of Sudan's GNP and employs more than 70% of the country's labor force. (Nour, 1994) Agricultural production systems in Sudan are commonly classified into three types: irrigated, rainfed mechanized, and traditional. Irrigation represents Sudan's most significant development investment. Close to 1.5 million hectares of land are irrigated in the Sudan. Approximately 63% of the irrigated land is fed by gravity schemes, with the remainder depending on diesel and electric pumps. With an area of more than 900,000 hectares, the Gezira, located on a triangular flood plain between the confluence of the Blue and White Niles, is the world's largest irrigation scheme under single management. The area of the Gezira alone is equivalent to one-half or more of the arable land in 25 individual African countries. (Jaffee, 1992)

The historical production focus of much of Sudan's irrigated land has been cotton, the country's main export commodity. Other important export crops for Sudan are gum arabic (Sudan is the world's largest producer), livestock and oil seeds. (Nour, 1994) However, due to declining net returns for cotton production, the area and total production of cotton have shown marked declines. Over the period of 1970 to 1980 the average net return to Gezira farmers for cotton was significantly lower than for both groundnuts and sorghum. (Jaffee, 1992) While farmers perceive greater benefits from alternative crops, the management of the Gezira scheme has continued to promote the growth of cotton. The emphasis on cotton comes at the expense of providing more water, land, and technical inputs for food crops, both in the irrigated and non-irrigated sectors.

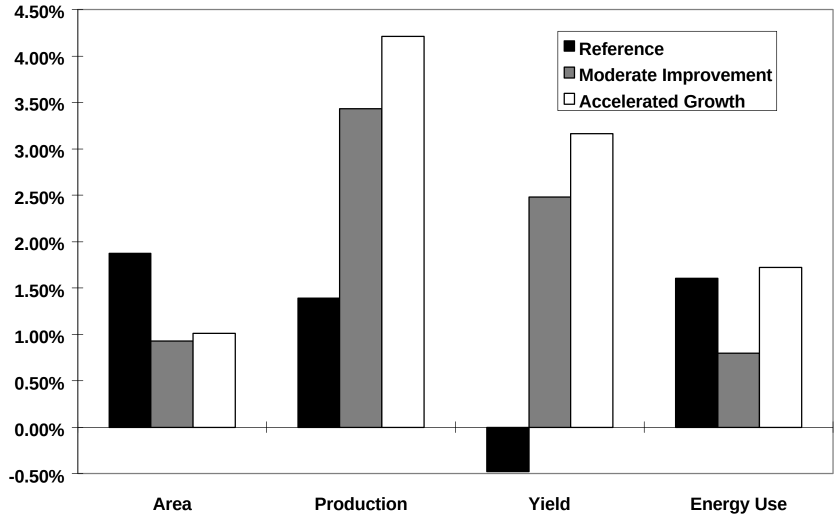
With the exception of wheat, which is grown on irrigated land, grain yields in Sudan have been declining for decades. (FAO, 1990) To compensate for declining yields, the traditional and rainfed mechanized farming in Sudan has become more extensive (i.e. expanding the area under cultivation). The resulting stagnant to slightly positive growth in total food production has not been able to keep pace with population growth, which has averaged 2.9% per year since 1970. (World Resources Institute, 1992) As a result, per capita food production has declined 20% to 30% since the early 1970s.

a) Case Study Scenarios

As noted earlier, increased commercial energy use, by itself, does not guarantee successful agricultural development, nor does an increase in agricultural production necessarily require increased commercial energy inputs. Preliminary results from the Sudan case study, as shown in Table 4.14 and Figures 4.20 through 4.23, illustrate this point. With assumed continuation of recent trends in the Reference Scenario, cultivated area continues to expand rapidly while yields continue to deteriorate; as a result, energy use increases faster than agricultural production. In the Moderate Improvement Scenario, the decline in yields are reversed and agricultural production increases by 50% relative to the Reference Scenario. Agriculture becomes more intensive rather than extensive, and more resource efficient and productive from the farmer and national perspective, and as a result, the 17% drop in cultivated area leads to a 15% drop in energy use. The Accelerated Growth Scenario nearly doubles projected total agricultural output by 2010 in comparison to the Reference Scenario, and yet it requires less total land, and only slightly higher energy use.

The Reference Scenario was developed by examining past trends in farm type, crop areas, yields and total production. Per-hectare agricultural energy intensities were drawn primarily from a 1992 national energy planning study. (NEA, 1992) In the Moderate Improvement Scenario yields and land areas for farm and crop types were derived from AT 2010. (FAO, 1993a) Per-hectare energy intensities rise as yields improve, but because less land is under cultivation, the mix of farm types and crops differs from the Reference Scenario, and overall energy use is lower. The increase in energy intensity is attributable to greater use of mechanization and a somewhat higher fraction of irrigated land. The Accelerated Growth Scenario combines the yield improvements projected under Moderate Improvements with additional changes in crop mix by farm type. These changes are designed to bring all crops up to a 4.0% average annual production growth rate. Figure 4.20 displays the annual average growth rates (1990-2010) for area, production, yield, and energy use for the Reference, Moderate Improvement, and Accelerated Growth Scenarios.

Figure 4.20 Average Annual Growth Rates for Sudan Scenarios



Note that aggregate figures for yield and production can be difficult to interpret, since changing cultivation patterns to crops that yield more tonnage (though not necessarily more food or economic value) per hectare can inflate apparent aggregate yields and production.

Table 4.14 Summary of Sudan Scenario Results

	1990	2010 Reference	2010 Moderate Improvement	2010 Accelerated Growth
Area (Million Ha)				
Irrigated	1.4	1.7	1.5	2.2
Rainfed Mechanized	3.5	5.5	5.1	5.1
Traditional	3.4	4.9	3.4	2.9
Total	8.3	12.1	10.0	10.2
Agricultural Production by Farm Type (Million Tonnes)				
Irrigated	6.2	8.9	10.7	13.8
Rainfed Mechanized	1.6	1.6	3.9	4.0
Traditional	0.7	0.7	1.9	1.6
Total	8.5	11.2	16.5	19.4
Production by Crop (Million Tonnes)				
Sorghum	2.7	3.3	5.4	6.0
Wheat	0.2	0.3	0.8	0.8
Groundnuts	0.4	0.4	0.8	0.9
Sugar Cane	4.3	6.6	8.0	9.7
Cotton	0.4	0.1	0.8	1.0
Millet	0.2	0.2	0.6	0.6
Energy Use (PJ)				
Irrigated	3.8	5.8	4.6	6.1
Rainfed Mechanized	2.5	3.0	2.9	2.9
Total	6.3	8.8	7.5	9.0

The projected yields in the Moderate Improvement and Accelerated Growth Scenarios are not high in comparison to average African yields. However, they are significant improvements over the declining or stagnant yields projected in the Reference Scenario. The yield differences have an obvious impact on total production and future food security in Sudan. Average annual growth rates of total production are 3.4% for the Moderate Improvement Scenario, and 4.2% for the Accelerated Growth Scenario. In comparison, the same figure for the Reference Scenario is 1.4%. If population growth remains within expected bounds, the Moderate Improvement and Accelerated Growth Scenarios offer the prospect of increasing per capita food output, reversing past declines and moving towards a potential role for the country as a “bread-basket” of the region.

The results of each scenario by farm type are presented in Figure 4.21 through 4.23. The patterns evident in these charts helps to further clarify the driving forces behind the scenario results, and suggest general directions for policy response. As Figure 4.21 illustrates, in the Reference Scenario agricultural production from rainfed mechanized and traditional farming systems is stagnant. The projected expansion of lands under traditional agriculture is offset by declining yields, resulting in no net growth for traditional production. While traditional farms currently use little or no commercial energy, they support most of the rural population, who are most at risk for crop failure due to drought, or other natural and social factors.

Rainfed mechanized farms, which rely to a greater extent on commercial energy inputs, also perform poorly in the Reference Scenario. Land area and energy use increase, but production, again due to declining yields, is stagnant. In effect greater inputs to rainfed mechanized lands provide no return to the agricultural economy.

Figure 4.21 Average Growth Rates by Farm Type, Reference Scenario

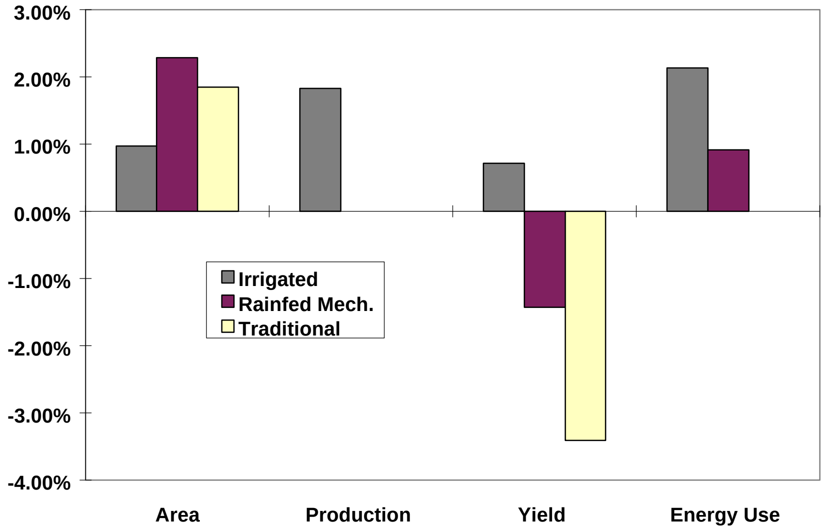
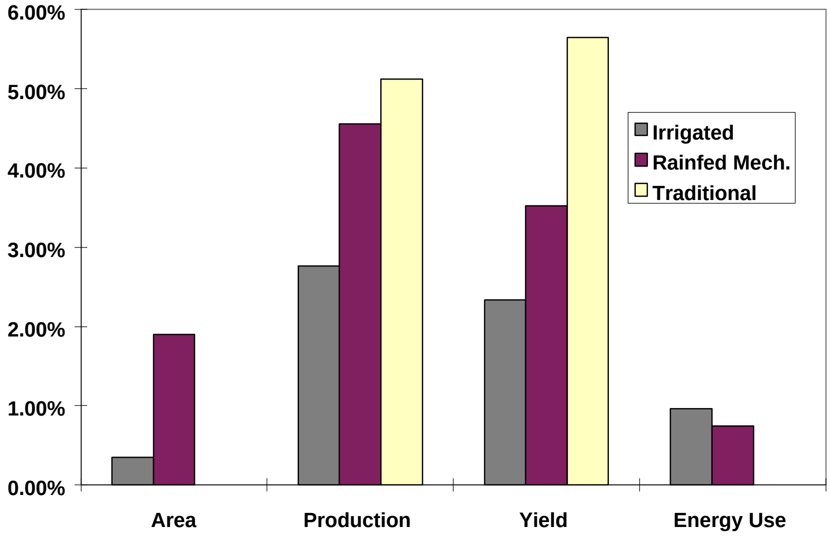


Figure 4.22 displays the estimated average annual growth rates for the Moderate Improvement Scenario. As noted above, this scenario requires less total energy and results in less marginal land under cultivation than the Reference Scenario. Both of these impacts bode well for the national economy and the environment. A major contributing factor to the observed reduction in commercial energy use between the Reference and Moderate Improvement Scenarios is a reduction in land area under sugar cultivation which is highly energy-intensive. Nonetheless, due to higher projected sugar yields, total sugar production is greater in the Moderate Improvement Scenario.

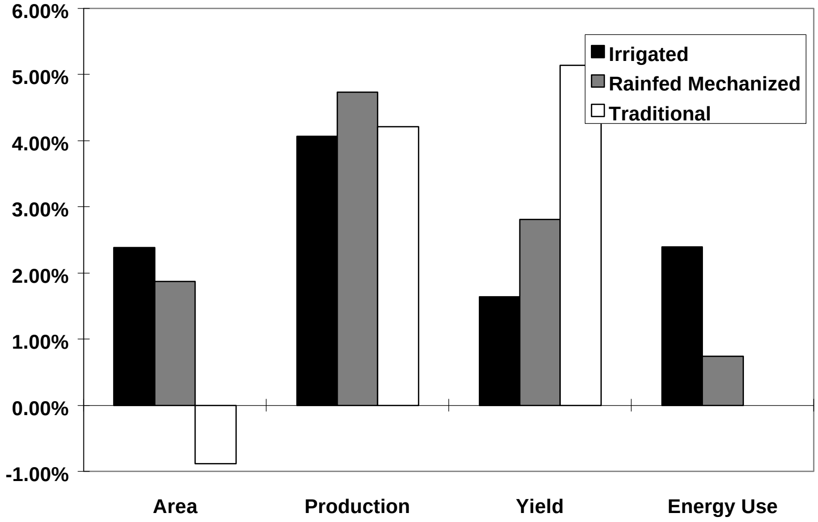
Figure 4.22 Average Growth Rates by Farm Type, Moderate Scenario



The results of the Moderate Improvement Scenario suggest that, in the special case of Sudan, significant gains in overall food security may be possible without a significant increase in sectoral energy consumption.[18]

The results of the Accelerated Growth Scenario (Figure 4.23) indicate that large production gains (4.1% per year) may be possible with relatively moderate expansion of total agricultural land area, (1.0% per year) and commercial energy use (1.8% per year). Note that the estimated total commercial energy requirements for the Accelerated Growth Scenario in 2010 are less than 3% higher than the projected total energy requirements for the Reference Scenario. Again, as with the Moderate Improvement Scenario, the results suggest that increasing agricultural production and overall food security does not have to be tied directly to large increases in energy consumption.

Figure 4.23 Average Annual Growth Rates by Farm Type, Accelerated Growth Scenario



While intriguing, this result must be placed in the context of the Sudanese situation, data availability, and the analytical approach. First, the deterioration of Sudanese rural infrastructure is linked with civil and political disturbances which have hindered the ability of farmers to use available resources more efficiently. The findings are thus most relevant to other countries which have experienced instability in the 1970s and 1980s. Second, the Sudan scenario analysis is based on published data for per hectare energy use in land preparation and cultivation by farm type. As a result, energy use is most closely tied to changing cultivation patterns (e.g. irrigated vs. rainfed, cotton vs. wheat, etc.) as measured by area. In contrast, in Tanzania, the available data point to energy used for crop processing, with little data to indicate how much energy is used to operate

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[18] Note that commercial energy is likely to be required to build and support the agricultural research, extension, and supply and distribution networks that can lead to the improved yields projected in this scenario, and these indirect energy requirements may not be fully captured by the increasing energy intensity of higher yielding crops in this analysis.

machinery or irrigation systems. As a result, agricultural energy use in Tanzania appears to depend largely on the tonnage of crops produced, which in turn are cured, dried, and milled.

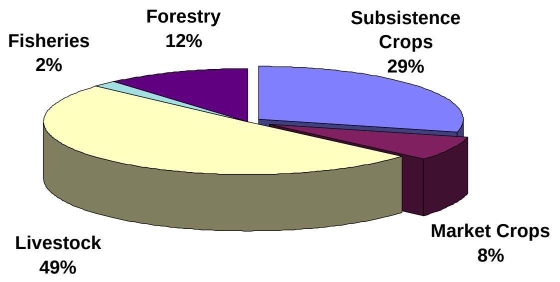
Are these data and approaches accurate? In other words, is agricultural energy use in Tanzania largely confined to post-harvest processing and in Sudan to on farm machinery and irrigation? Or is this an artifact of data collection inadequacies? Based on the much higher area under mechanized farming practice in Sudan, and given the high energy intensity of tobacco and sugar processing in Tanzania, there may be some truth to the findings. However, better data are needed to fully answer this question.

4.9. Mali

Mali remains a country dominated by subsistence agriculture, which accounts for half of the national GDP and occupies 80% of the population. Furthermore, Mali's industrial sector is comprised largely of agro-industries, which account for about 75% of industrial GDP.[19] As a result, its people and economy are highly dependent on the fluctuating climate of the Sahelian region. Since the drought of 1982-85, favorable climatic conditions have enabled the achievement of substantial improvements in agricultural and economic production. Since 1985, per capita GDP has risen an average of 1.2%/year and agricultural GDP has grown over 5% per year.[20]

Farming methods in Mali remain largely traditional; many efforts to intensify agricultural production have fared poorly. Animal agriculture is very important to the Malian economy; livestock account for half of the value added in the primary sector, exceeding the 29% contribution of subsistence crops (millet, sorghum, rice, and maize) and the 8% contribution of market crops (principally cotton and peanuts) as shown in Figure 4.24.

Figure 4.24 Shares of Primary Sector GDP in Mali, 1990



Since 1980, the government has adopted a medium-term objective of food security, and several policies to achieve it (market restructuring, augmenting food stocks and storage, improved distribution, etc.). Its longer-term objective of food self-sufficiency is more ambitious; during recent climatically favorable years, it appears that such an objective might be feasible for basic cereals, at least at present population levels. Ambitious efforts along four directions would be needed to protect against recurring droughts: irrigation development, agricultural intensification, crop diversification, and security measures in drought-prone regions. (Republique du Mali, 1994) To date, such efforts have met with limited success.

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[19] In 1982, food and beverage industries accounted for 33% of industrial GDP, while textiles and leather accounted for 42%. (Republique du Mali, 1994)

[20] These figures are based on constant CFA values from 1985 through 1994 estimates. (Republique du Mali, 1994)

The low rate of agricultural mechanization and intensification likely means that commercial energy use in Malian agriculture is quite low. It is principally confined to rice cultivation and peri-urban farms. On the other hand, the use of animal traction is unusually well-developed, relative to most African countries.

Commercial energy is no doubt consumed to pump and deliver water at irrigation sites in Mail, although no specific figures were obtained. Large-scale irrigation schemes in the Niger River basin, managed by the Office du Niger, and smaller-scale perimeter and peri-urban irrigation projects are an important part of Malian agriculture, providing water to about 10% of arable land in the country. Private small-scale irrigation has fared much better than large-scale irrigation schemes. (Brown and Nooter, 1992) Peri-urban irrigation is increasing rapidly, and small diesel pumps are often used.

Unfortunately, the absence of reliable data on energy use in Malian agriculture precludes meaningful quantitative scenario analysis at present. For example, the energy balance for Mali shows an energy demand under agriculture of "0" tonnes oil equivalent. (Republique du Mali, 1994) The zero entry under agriculture is not unique to Mali. Most African countries, in fact, do not officially measure or report energy use for the agricultural sector.[21] In addition, many countries do not measure or report energy use among industrial sub-sectors, making it difficult to estimate the energy used by agro-industries. The availability of detailed data on agricultural use appears to be confined to larger countries and those where major demand-side energy studies and surveys have been undertaken.

Further analysis of the energy-agriculture nexus in Mali will inevitably require better data on energy use patterns. This in turn might enable a better assessment of efforts to seek food security and the levels of energy input -- for small-scale irrigation, large-scale irrigation, and other more intensive production methods -- that might be required.

4.10. Cameroon

Agriculture remains an important part of Cameroon's economy. As in other higher-income African countries, such as Zimbabwe, its percentage share of total GDP is relatively low (around 24-27%), but this reflecting the strength of other sectors of the economy. Since the late 1970s, the petroleum sector has maintained Cameroon's relatively high per capita GDP (around US $1000). Nonetheless, agriculture is still the main occupation of three-quarters of its population, and is the basis of the rural economy.

Agriculture in Cameroon remains largely traditional. Traditional agriculture produces over 90% of national food demand. As shown in Table 4.6, the reported intensity of commercial energy use in agriculture is very low (6 GJ/1000 ha), and the use of tractors is the lowest among countries studied. For the past decade, national food production has grown at 2.2%, slower than

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[21] Based on their reports submitted to the International Energy Agency. (e.g. IEA, 1993)

population (3.2% per year), leading to a worsening of food security. Most of the increase in production has come from expanding land area under traditional cultivation; traditional farming area grew at a rate of 2.2% per year from 1972-84. (Njiti and Sharpe, 1994)

Inadequate access to technology, credit, and markets are important constraints to improving yields and production. With soil erosion and land degradation rapidly become major concerns in Northern Cameroon, the potential exists for severe problems in the agricultural sector and national food supply. (Njiti and Sharpe, 1994)

As in many developing countries, much of the existing high-input agriculture is oriented toward export crop production. The value added from export crops -- principally bananas, coconuts, coffee, and cotton -- grew at 4.7% per year in the 1980s. (FAO, 1993) The major irrigation projects, Semry I and II, have been notable technical and institutional successes compared with other large-scale irrigation projects in sub-Saharan Africa, and have resulted in high-yield rice production.[22]

Data on energy use in agriculture is relatively sparse; as in Mali, agriculture does not appear as a consumer of energy in Cameroon national energy balances, except for a very minimal amount of electricity.[23] Other data available for Cameroon show a small amount of diesel, gasoline, and electricity used for water pumping and somewhat larger amount of wood used for agro-industrial drying. (Lokolo, 1994) The energy used for other mechanized end-uses is not reported, but given the very low level of tractorization -- approximately 1000 reported for the whole country -- this may not be surprising.

Sectoral energy consumption statistics from the 1987/88 energy balance are illustrated in Figure 4.25. This figure demonstrates the very small reported contribution of the agricultural and other primary sectors to national energy demand. This is likely the result of a lower policy emphasis given to promotion of the agriculture sector and agricultural intensification, in comparison particularly with Zimbabwe, as well as the presence of other energy-intensive industries, such aluminum production. As shown, agro-industries, including breweries, accounted for almost a third of industrial energy use in 1987/88, and about 10% of total commercial energy in the country. Thus there is a significant connection between agricultural activity and national energy use.

The level of agricultural energy use in Cameroon needs to be clarified through further data collection or surveys, to determine whether the very low reported energy use levels are accurate or an artifact of limited data availability. As in Mali, the absence of data precludes any detailed scenario analyses of energy use in the agriculture sector at present.

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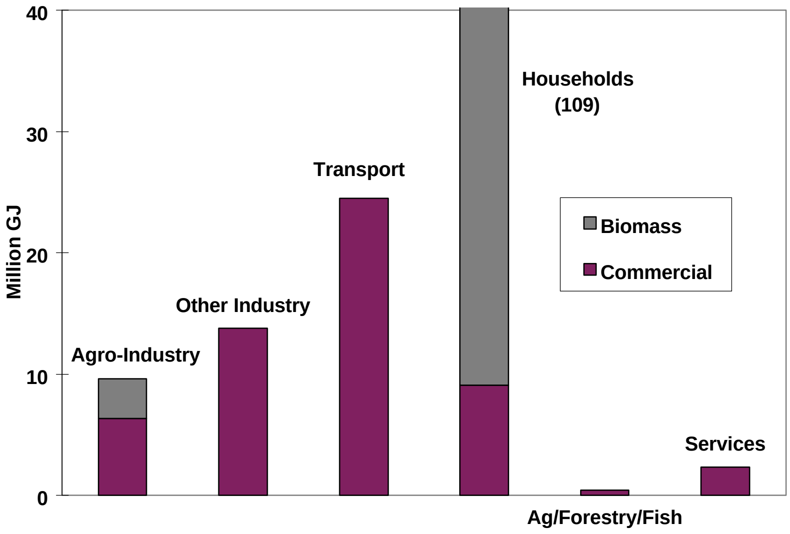
[22] The social aspects of these projects, particularly, Semry I, have been questioned, however. Semry I essentially stripped local farmers of their rights to the land, and vested it in larger agro-business management. (Brown and Nooter, 1992)

[23] Some additional data are shown on a 1987/8 balance under “Secteur Primaire”. However, the subtotals appear to be inconsistent, making interpretion and use problematic.

Figure 4.25 Energy Use by Sector in Cameroon, 1987/8



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