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DRAFT FINAL REPORT

MODELLING ENERGY USE IN AGRICULTURE

A SYSTEMS APPROACH

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1.0 INTRODUCTION

Increasing the productivity and output of the agricultural sector has been a major goal of economic planning in developing countries over the last several decades. In fact, since the major fraction of the population in developing countries lives in rural areas, this goal is practically synonymous with the concept of "economic development" itself; raising income levels and living standards. Depending on their resource endowment, comparative advantage, socio-economic setting and related factors, different countries have adopted various packages of policies designed to propel them towards this objective. In general, however, the policies adopted have attempted to promote change in two broad areas: (i) the production technology and (ii) the institutional, social and economic organization of production. Measures such as land reforms, providing security of tenure, guaranteeing minimum support prices, giving access to cheaper credit, etc., fall in the latter category. The former category includes all the combinations of appropriate technical factor inputs required to raise physical yields and intensify cropping patterns in the given soil and climatic conditions of a particular area or region.

The transformation of agricultural production technology in the developing countries has been, in part, an attempt to replicate, with appropriate adjustments, the three major developments which transformed agriculture in the industrialized countries and which could be described as the mechanical, chemical and biological revolutions. The content of these can be respectively described as: (i) substituting or supplementing the animate energy

expended by human and animal labor in agricultural production with mechanical energy derived from inanimate sources, such as fossil fuels (ii) increasing nutrient input and reducing losses through the applications of chemical fertilizers, pesticides, herbicides and weedicides (iii) introducing new seed varieties, developed through new biological techniques, capable of much higher yields.

The extent and content of the attempt at introducing these technological changes have varied between countries. For example, the use of mechanical energy in tillage through tractorization has been comparatively less important in many developing countries due both to its capital intensiveness as well as the less favorable land/man ratio implied by the much smaller sizes of holdings. However, growth in the use of mechanical energy for pumping irrigation water has been significant, if not spectacular, in some individual countries such as in South Asia, and its impact on output has been equally important. Notwithstanding these differences, there is one common denominator in this route to agricultural "modernization" implied by the mechanical-chemical-biological triad; a significant increase in the commercial energy intensity of agricultural production. Greater use of mechanical pumps and other equipment has led to a direct increase in commercial energy intensity while increased application of fertilizers/pesticides implies an indirect increase since these products are usually manufactured from hydrocarbon (petroleum/natural gas) feedstocks. The technical package of high-yield seed varieties associated with the "green revolution" requires greater and more timely inputs of water, fertilizers and pesticide. A number of studies over the last decade have pointed out the correlation between increased crop yield/productivity and the rise in commercial energy intensity

(Bhatia, 1976). Much of this increase in energy inputs has been provided by petroleum products, in particular, diesel oil.

The five-fold increase in oil prices (in real terms) over the 1973-81 period naturally led to an examination of the feasibility of the petroleum route to agricultural modernization.* In a context where energy demands were increasing rapidly in all sectors of the economy and the pressures on the balance-of-payments due to oil imports had reached crisis levels in many countries, there was clearly a need to analyze the implications of continuing the allocation and subsidy policies on petroleum products and fertilizers in the agricultural sector. At the same time, the "energy crisis" had created a resurgence of interest in alternative energy sources and technologies, especially biomass resources, which were believed by their proponents to offer a better potential for meeting the dispersed, decentralized, seasonal energy loads characteristic of rural areas in developing countries. It needs to be recalled, in this context, that agriculture is both a consumer and a producer of energy resources. Residues from crops and livestock wastes can potentially be converted via such technologies as fermentation (biogas) and pyrolysis (producer gas) to produce high quality energy forms capable of

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*The volatility in oil prices over the last year, which has become more pronounced since the downturn experienced over the last four months, does not materially affect the importance of these issues, which are essentially long-term in nature. Developing countries are hesitant to adopt long-term policies based on the essentially unpredictable fluctuations in the price of such a volatile commodity as oil.

substituting for petroleum products. The feasibility of implementing such technologies, from a technological, economic and social standpoint, requires a detailed analysis which takes into account the impact of regional and local factors on the enumeration of costs and benefits.

In recent years, a number of farm-level and sector studies have provided important insights into the use of energy in agriculture. Examples of such studies include Singh and Chancellor (1975), Cox (1977), Gupta and Rao (1981), DeLucia and Jacoby (1982), Makhijani and Poole (1975), and Pimentel (1979). In order to examine the costs and benefits of particular energy sources or technologies, "partial equilibrium" analysis has been most frequently employed. However, it is often difficult to evaluate the potential contribution of particular technologies in the context of a country's overall energy situation. Proponents of a particular option emphasize indirect benefits evaluated at shadow prices, while opponents emphasize indirect costs, also evaluated at shadow prices. In such a situation of conflicting choices of shadow prices for technological assessment, the studies have failed to provide policy makers with tools for analyzing the variety of policy packages that can rationalize agricultural energy use. It is clear, then, that what is needed is a method capable of examining the interrelationships between the patterns of crop production, its energy requirements and energy technologies considered in an integrated way with energy supply.

The present research aims at rectifying this situation. It provides a systems framework for analyzing energy use in agriculture that can be readily integrated into the planning of the energy sector as a whole, and be the basis for an agricultural energy information system. In particular, we adopt

a network structure to model energy flows from resources through fuel types to energy embodied agricultural inputs that are required by each crop type. The transformations at each stage follow constant proportions input-output relationships.

The objective of the research is to provide a simple yet comprehensive economic model, which can be implemented on microcomputers, for use by energy and agricultural planners in the analysis of energy resource and technology choice in agricultural production. The model is illustrated through the use of some preliminary data from the Dominican Republic. The methodology, however, can be applied to many different countries since it is capable of accomodating varying degrees of richness in the data base and does not call for extensive primary data collection. Many countries already have the type of farm management data required by the methodology and in others, such data is becoming increasingly available as sector wide planning in agriculture becomes more widespread.

The methodology can readily be extended to encompass energy utilization in the entire food system, the chain of activities from production to processing, transportation, storage and, ultimately, consumption. In the industialized countries, the most energy-intensive part of the total food chain is the processing, transport and storage links. By contrast, in developing countries, energy consumed in food preparation may be the largest direct use of primary energy due to the low efficiencies of traditional cooking stoves. The choice of system boundaries for analysis is basically determined by the issues being analyzed.

2.0 ENERGY USE IN AGRICULTURE

Agricultural production involves, for all crops, a series of activities which requires inputs of mechanical energy and energy embodied in fertilizers. For pre-mechanized farms, mechanical energy is provided by the animate energy of humans and animals; nutrients are provided by animal manures and plant material. With the advent of farm mechanization, mechanical energy is provided almost exclusively by internal combustion engines using petroleum fuels (diesel, gasoline, etc.) and by electric motors. Table 1 shows the major agricultural activities and the possible fuel-process combinations that meet their energy requirements. The ubiquitousness of petroleum products in meeting many energy requirements no doubt accounts for their rapid spread as a major input to agricultural "modernization." The relative cheapness, convenience and reliability of petroleum products make them a very attractive fuel source.

Fertilizer is the major source of indirect (feedstock) commercial energy use in agriculture. In the U.S. fertilizer accounted for an estimated 33 percent of total energy input in crop production (CAST, 1977). Although the marginal productivity of fertilizer depends upon the level of irrigation available, more than any other input, it has spurred some remarkable food production gains. The contribution of fertilizer to grain production ranges from less than 10 percent in Thailand to over 50 per cent in Japan (Nair, 1976). By 1984, world fertilizer consumption totaled 121 million tons, nearly a ninefold increase since 1950 (Brown, 1985).

Animal waste (i.e., manure) has beneficial effects on the structure and water holding capacity of soil that chemical fertilizers do not have. Also

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Table 1
Energy Sources/Fuels for Agriculture

	Energy Source/Process				
	Human Mechanical	Animal/ Mechanical Chemical	Petroleum/ Mechanical Chemical Heat	Electricity Mechanical Heat	Biomass Chemical Mechanical Heat
Land preparation	X	X	X		
Sowing	X	X	X		
Irrigation	X	X	X	X	X
Fertilization		X	X		X
Pest Control			X		
Inter-Culture	X	X	X		
Harvesting	X	X	X		
Threshing	X	X	X	X	X
Crop Drying			X	X	X
Storage/Refri-geration			X	X	X
Transportation		X	X		

Notes:

1. Mechanical energy required is of two types; mobile (e.g., tilling, sowing, transport), and stationary (e.g., irrigation pumping).

2. Chemical energy, in the sense used here, refers to fertilizer and pesticide. Thus, for example, animal dung or plant residue, composted, can be used as fertilizer.

manure is cheap, has low impact on oil imports and is generally abundant except in areas where it is used as a fuel for cooking purposes. However there are disadvantages. Because the concentration of plant nutrients is low in animal waste, applications of 6 to 14 tons per acre are needed to meet the fertilizer needs of crops. Transporting this bulk of low nutrient material is a costly and inefficient use of energy (CAST, 1977). In addition, manure may carry weed seeds and pathogens causing other costly externalities. Other issues include losses of fertilizer from organic material as it dries, and constraints on the supply of dung from existing animal populations.

When chemical fertilizer use is sought to be increased, one policy issue is whether it should be imported or produced within the country. Domestically produced nitrogen fertilizer can be derived from petroleum products (naphtha, fuel oil), natural gas or coal as a feedstock. If imported crude oil or products are utilized, there would be an indirect effect of fertilizer production on oil consumption and imports. Such issues have been analyzed in a partial equilibrium context for India using a linear programming model (Bhatia, 1976).

After fertilizer, energy use is greatest in irrigation activities. There have been a number of studies that have analyzed energy use in irrigation and technological alternatives for pumping irrigation water for crops. For farms in North India, Bhatia and Mehta (1975) showed that diesel engines were more economic than electric motors as prime-movers in water lifting. The competitiveness of small renewable energy technologies depends on the price of the alternative fuel (primarily diesel), the cost of renewable energy hardware, and the relative availability of the renewable resource

(Mubayi and Lee, 1979). A number of studies (World Bank, 1983; CSIR-SDC, 1985) have found that if solar array prices decline to around $2-$3/peak-watt, solar cells would become competitive with diesel pumps in areas of high solar insolation and high fuel prices ($1.50/gallon or more). The economics of windmills for water pumping is closely dependent on the quality of the wind resource. Areas with high wind velocities, in excess of 10-12 mph on an annual average, are generally good candidates for introduction of wind pumpers. Another option for providing high quality decentralized energy is biogas which can be generated from farm wastes. Bhatia and Niamir (1979) showed that for community biogas plants to be economical, too many factors (especially organizational factors) should be at fairly optimistic levels. In China, the fixed-dome biogas plant has been used quite successfully (Mubayi and Lee, 1979). However it has recently come to light that as many as 60 percent of Chinese biogas plants are out of order at any one time. In addition these plants are apparently used to supply domestic energy rather than energy for irrigation (Hurst, 1985).

Other technologies for energy use in irrigation include the very ancient animal-powered pumps and the pyrolytic gasifiers operating on wood, charcoal, or farm residues. The most common animal powered pumps are the Persian wheel and the chain and washer pump. It is easily the cheapest technology in terms of capital cost. However, considering the fact that animal powered pumps can only be used in dug wells, it is not clear that this technology is cheap on a per unit water pumped basis. Although animals are low efficiency energy convertors (from fodder to work) and animal-powered pumps have an efficiency of around 3.5 percent, fodder is cheap and thus the net energy cost could be low. Pyrolysis gas is an energy source that can be easily used in remote

villages and must be considered a potential alternative (National Academy of Sciences, 1982). Recently there has been a large program to introduce gasifiers into the Philippines, which were to run on charcoal, the only feasible fuel for small applications. However, there has apparently been a rapid discontinuation of their use due to technical problems and an increase in the price of charcoal [Hurst, 1985].

3. METHODOLOGY

3.1 Overview

The analytical framework of the model developed for the study consists of the quantification of agricultural product and energy flows through various stages from production to processing to resource conversions. Quantification of the energy flows in each link of the agricultural chain of activities results in an energy-agriculture network model which is illustrated graphically in Figure 1. Each type of crop or agricultural product requires a number of energy-using activities. These activities, in turn, generate a set of energy demands which are (or can be) met by various combinations of conversion technologies and fuels derived from different primary energy sources. It can be readily recognized that this diagram is, in fact, a subset of the overall national energy system, with the agri-cultural sector disaggregated in some detail. The issues to be analyzed essentially determine the system boundaries and the level of disaggregation. For instance, if the system boundary is set at the farm gate, i.e., if only energy use in agricultural production is being analyzed, transport and off-farm processing could be disregarded. On the other hand, a more comprehensive analysis would

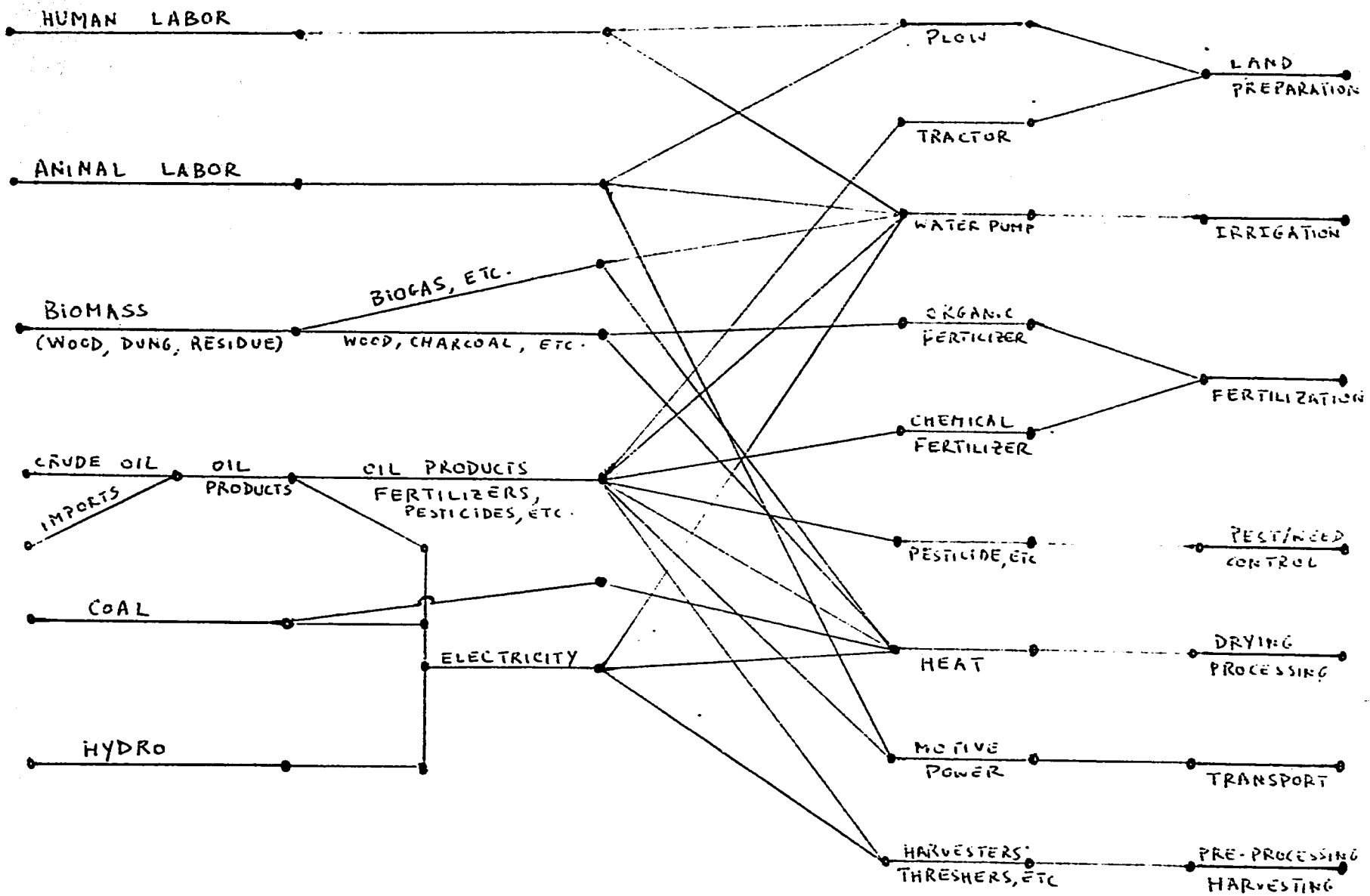

Figure 1. Network Representation of Energy Flow in Agriculture.

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include both primary and secondary processing of raw agricultural products as well as primary and secondary transport of the product (from, say, farm to market town and then to urban center), followed by storage, packaging, and retailing of the final product to the consumer. In this case, the energy consumed, the fuel form and the technological choices in terms of the mix of actual or potential fuels and devices would be elaborated at each step of the production, transformation and transport process. In many cases, data availability will often decide the level of disaggregation possible. However, it is important to note that the model can be a useful guide to the collection and structuring of additional data needed for a more complete analysis. In that sense, the outline of the data required to operate the model can be utilized to develop an agricultural-energy information system which can be updated, as necessary, on an ongoing basis to provide a systematic tool for policy analysis.

Figure 2 summarizes the overall methodology of the analysis. Data from the information system are utilized to construct the physical network flows corresponding to the

- crops chosen for analysis
- energy input - agricultural product output coefficients
- transformation efficiencies
- resource requirements, etc.

Once the network is constructed, the model can be operated either in a <u>simulation</u> mode, to obtain the impact of different scenario assumptions on energy technology, fuel mix, level of crop production, etc., or in an

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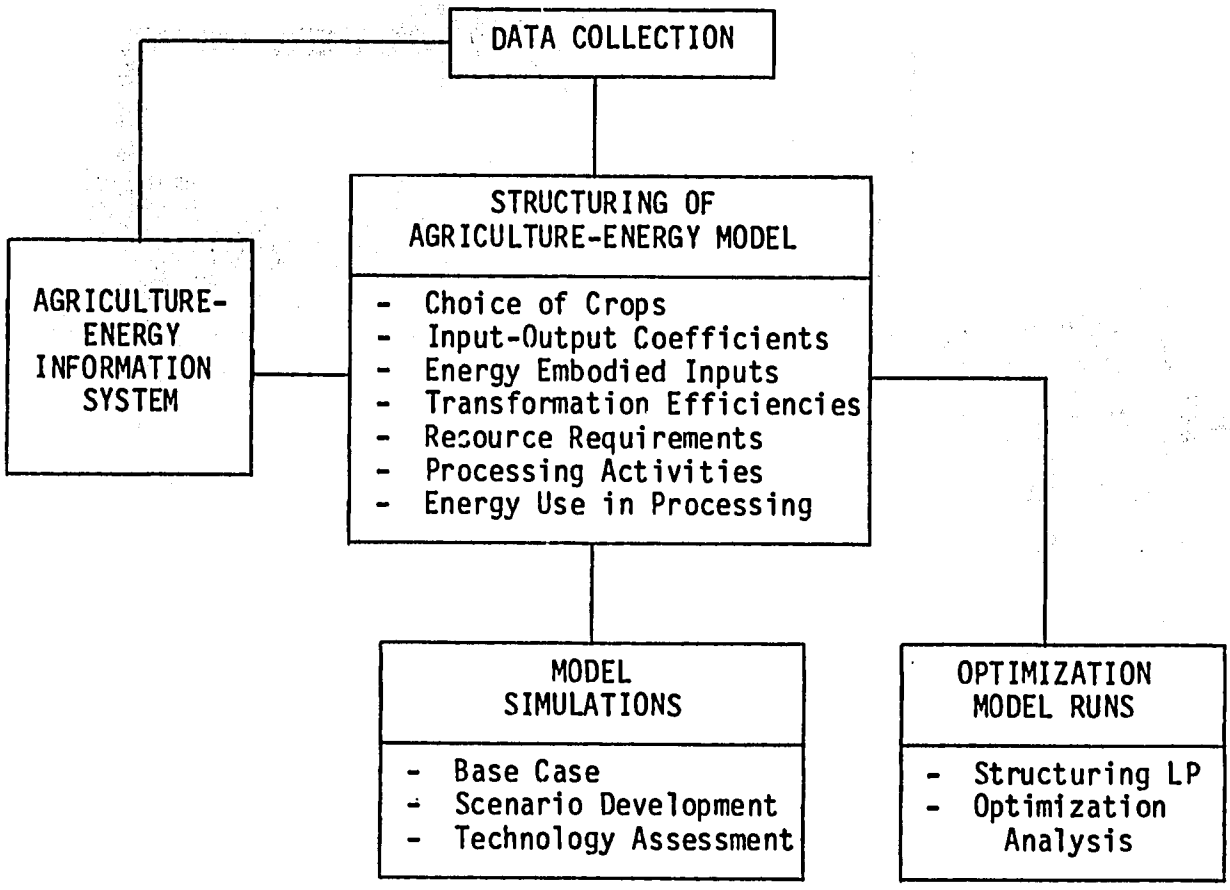

Figure 2. Analysis Methodology

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optimization mode, where a given objective function is maximized or minimized subject to user-specified constraints.

Several options relating energy use and agricultural production can be analyzed using the methodology. If fuel imports constitute a heavy burden on the economy and their use in agricultural production is dependent on subsidies, one possibility is to evaluate the feasibility of new energy technologies which would either provide energy from new sources or would increase the conversion efficiency of existing energy sources through alteration of the mix or introduction of new end-use devices. Another option is to evaluate the possibility of changing the mix of agricultural products produced and/or consumed, within certain bounds determined by national consumer preferences and habits or export requirements, to diversify into crops which need less energy input. A third option could be to alter the relative emphasis of existing methods or techniques required to produce a given crop.

The analysis can be carried out at any chosen geographical or administrative scale, i.e., at the national, regional, or sub-regional level, depending on the objectives of the analyst and the availability of relevant information. Since soil quality, climate and resource availability can differ markedly from one region to another, it may be advantageous to operate the model at a regional level, provided data are available, to highlight the different between optimum policies at the regional and national levels.

3.2 Energy Using Activities

Broadly speaking, agricultural production is the sum of the following activities:

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1) Land preparation and seeding
2) Irrigation
3) Fertilization
4) Pest Control
5) Harvesting

Energy use is also significant in many ancillary activities such as threshing, drying, processing, storage/refrigeration and transportation. As shown in Table 1, the energy embodied inputs (X_p) for these activities are in the form of water pumping requirements, fertilizer needs, and land tillage requirements. The transformation of energy embodied inputs (X_p) into crop output (X_i) is governed by the input-output relationships:

$$X_p = A_{pi} \cdot X_i \tag{1}$$

where the matrix A_{pi} consists of input-output coefficients that give the particular combination of energy embodied inputs to produce unit crop output, X_i.

3.3 Energy Resource Demand

Energy supplies from primary sources (X_s) are converted to energy-embodied inputs (X_p) in two steps: first, the energy sources are converted to fuel types and second, these fuel types are transformed to energy embodied inputs. Energy balances at the resource level are also governed by the input-output relationship:

$$A_{ss} X_s + A_{sp} X_p = X_s \tag{2}$$

where the matrix A_{sp} consists of the inverse of efficiencies of transforming fuels into energy embodied inputs at the farm level for production purposes and A_{ss} consists of efficiencies of converting energy resources into the individual fuels.

The following example clarifies the components of Equation (2). Consider a three resource economy consisting of crude oil, diesel and electricity. Crude oil will be used in refineries to produce diesel. Refinery operations will require diesel and electricity, in addition to crude oil. Thus diesel will be used in refineries to produce diesel, in diesel-pumps for irrigation and perhaps, in small power plants to produce electricity . Electricity will be used to produce diesel and in electric pumps for irrigation. Thus, Equation (2) can be written for each resource as:

$$a_{CD}x_D = x_C \tag{3.1}$$

$$a_{DD}x_D + a_{DE}x_E + a_{DI}x_{DI} = x_D \tag{3.2}$$

$$a_{ED}x_D + a_{EI}x_{EI} = x_E \tag{3.3}$$

where C, D, and E represent crude oil, diesel and electricity respectively. Note that in this case the vector of resources X_S is (X_C, X_D, X_E) and the vector of energy-embodied inputs, X_p, is (X_{DI}, X_{EI}), where I stands for irrigation. The corresponding matrices in Equation (2) will be:

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$$A_{SS} = \begin{bmatrix} 0 & a_{CD} & 0 \\ 0 & a_{DD} & a_{DE} \\ 0 & a_{ED} & 0 \end{bmatrix} \tag{4}$$

and

$$A_{SP} = \begin{bmatrix} 0 & 0 \\ a_{DI} & 0 \\ 0 & a_{EI} \end{bmatrix} \tag{5}$$

a_{DI} and a_{EI} are the inverse of the efficiencies of irrigation pumping with diesel and electricity respectively. The efficiency for pumping water is a product of the engine or motor efficiency and the pump efficiency. A more complete description of irrigation efficiency would also include the losses in different methods of field application, i.e., whether the water is led to the plants in unlined or lined channels, through plastic pipes, or applied by sprinklers, etc. For electric motor pump sets fed from a central grid, the transmission and distribution losses, which are typically quite high in developing countries for rural electric supply, have to be included in the analysis.

3.4 Energy Demand in Processing and Transport

To obtain a complete description of energy use in agriculture, energy consumption in processing, transport, storage and marketing has to be included. Typically, processing of agricultural commodities can be broken

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down into two major components: on-farm processing and off-farm or mill processing. In the case of rice, for example, threshing would be carried out on the farm and de-husking and polishing at a rice mill. Transport energy consumption would involve fuels consumed in transporting the raw or semi-processed product from the farm to the mill for further processing and the finished product to the consumer. Storage and marketing can also imply large energy costs for perishable commodities such as vegetables or dairy products since they involve refrigeration which is energy intensive. Table 2 provides an example of the types of processing energy, heat, and motive power required by various agro-industries.

We confine our analytical framework to agricultural processing and to two components of the energy requirements of these industries: electricity and process heat. We assume that energy demand by processing industries is in constant proportion to the produce processed. Thus, energy demand in agro-processing industries, XH_I, is given by:

$$XH_I = AH_I \cdot X_I \tag{6}$$

where the matrix AH_I consists of input-output coefficients that give electricity and process heat used per unit of agricultural produce processed.

Process energy is made up of different fuel types, including electricity, depending upon the processing activity. The additional energy resources required to meet the industrial process energy can be estimated as before [see Equation (2)] by first accounting for the fuels needed to satisfy

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Table 2
Energy Needs of Agro-Processing Industries

Rural Industries	Process Heat	Mechanical Power
Rice Mills		X
Flour Mills		X
Oil Mills		X
Rice Parboiling	X	
Dairy Industry	X	X
Baking	X	
Sugar Refining	X	X
Crop Drying	X	

process energy requirements and secondly, estimating resources that need to be transformed to obtain these fuels:

$$AP_{SS}X_P + AP_{SP}X_{HI} = X_{SP} \quad (7)$$

Thus the total resource requirement induced by the agricultural sector is given by:

$$X_{STOT} = X_S + X_{SP} \quad (8)$$

It should be noted that the major component of energy demand in most agro-processing industries is likely to be electricity (Table 3). Process heat, while important, forms a smaller proportion of energy demand in these industries. Notable exceptions are sugar and other crop processing industries where large quantities of heat are required.

3.5 Feedstock Energy

The major feedstock energy for agricultural production comes from fertilizers, which are compounds comprised of nitrogen, phosphorus and potassium in varying amounts. Nitrogeneous fertilizers are the most energy intensive, followed by the phosphorus and potassium fertilizers. Since the amounts and proportions of fertilizer application are crop and location specific, the energy embodied in them varies by type of crop, the soil conditions, water application, etc. The other energy commodity which can be considered as a feedstock is pesticide (as also weedicide, herbicide, fungicide, etc.), used to reduce plant losses. This is also crop and location specific.

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Table 3
Shaft Power in Small Agro-Industries (Andra Pradesh, India)

Agro-Processing Industry	Number of Units	Average Connected Load (hp)
Rice mills	260	20.4
Flour mills	102	110.1
Oil mills	57	23.7
Rice and flour	489	13.0
Other agro-processing	71	25.6

Source: Hurst (1983).

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3.6 Optimization Model

Simulations of energy use in the network model are primarily descriptive in nature. Given a set of values of final demand for agricultural products, the model can simulate the effects of particular policies at the national level such as the removal of oil and fertilizer subsidies. The network model can also be extended to yield prescriptive results to guide policy towards optimal interventions to promote energy and economic efficiency.

A preliminary version of an optimization study and model results are presented in this paper. Further research would be required to complete the analysis.

The constraints of the linear programing formulation of the agriculture-energy model are the same input-output equations used in the network flow analysis. To be specific, the constraints are:

3.6.1 Fertilizer

Fertilizer used for each crop (F_i) is assumed to be in proportion to the level of output of the crop:

$$F_i = a_{1i}X_i \qquad i = 1,\ldots,n \tag{9}$$

where a_{1i} is the fertilizer required per unit of crop output. We assume that the total fertilizer consumed can come from either/or a combination of three sources: imports (Y_1), a domestic fertilizer plant based on naphtha as input (Y_2), or fuel oil input (Y_3):

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$$\sum_{i=1}^{n} F_i = Y_1 + Y_2 + Y_3 \tag{10}$$

Both naphtha and fuel oil are obtained by domestic refinery operations. The amounts of crude oil that are required to produce naphtha (CY_2) and fuel oil (CY_3) based fertilizer are:

$$CY_2 = ay_2 \cdot by_2 \cdot Y_2 \tag{11-1}$$

$$CY_3 = ay_3 \cdot by_3 - Y_3 \tag{11-2}$$

where by_i is the level (in tonnes) of fuel type i required to produce one unit of fertilizer based on that fuel type, ay_i is the level of crude oil (in tonnes) required to produced one tonne of fuel type i, and CY_i is the crude required to produce fertilizer based on fuel type i. In the process of increasing crude oil throughput to produce naphtha (say), increased fuel oil will also be produced. Thus the total increase in crude oil throughput due to the increase in domestic fertilizer use in the agricultural sector is:

$$CY = \text{Max}\ (CY_2, CY_3) \tag{12}$$

3.6.2 Irrigation

The total irrigation water (W) required for agricultural production is:

$$W = \sum_i R_i X_i \tag{13}$$

where R_i is the amount of water required (in cubic meters) per unit quantity X_i of crop i produced. The water comes from either gravity fed channel (surface irrigation) or by groundwater pumping. Diesel (Z_1), electric (Z_2), or newer (Z_3) sources such as solar, wind, biogas, etc., can be used to pump irrigation waters:

$$Z_1 + Z_2 + Z_3 = T \tag{14}$$

where T is the total (useful) energy required for irrigation pumping, Z_i is the part supplied by diesel, Z_2 by electricity and Z_3 by the new source, say, biogas. The amounts of diesel (ID), electricity (IE) and biogas (IB) that are required for meeting the irrigation energy demand are given by:

$$ID = i_1 Z_1 \tag{15-1}$$

$$IE = i_2 Z_2 \tag{15-2}$$

$$IB = i_3 Z_3 \text{ , etc.} \tag{15-3}$$

where i_1, i_2, and i_3 are the respective combined engine/motor and pump efficiencies of diesel, electricity and biogas respectively.

3.6.3 Objective

Various types of objective functions can be chosen to drive the model. One choice could be to maximize the time stream of net revenues derived from the sale of agricultural products. The net revenues would be defined as the total revenues at current or projected product prices minus the production costs. On the other hand, if foreign exchange is at a premium in the economy, the objective function could be chosen to minimize the importation

costs of the inputs (such as energy imports) to agricultural production or processing. The LP formulation allows very flexible use of different objective functions.

The constraints set in the model consist of the demand constraint for agricultural products, i.e., the minimum level of production required to meed demand, supplemented by the constraints on the physical requirements for inputs to production as expressed in Equations (9) through (15). More general or specific constraints can easily be added to the model. For example, if fulfilling some minimum nutritional requirements is desired, additional bounds could be imposed on the production levels of particular nutritionally desirable products. Alternatively, to meet employment goals a lower bound on labor requirements could be incorporated.

Suppose that the objective is to maximize the stream of net revenues over a certain set of time periods, t, and the only costs of production are assumed to be the energy-related costs of irrigation water pumping and fertilization. (This is, of course, a very simplified case; a more complete description of costs would have to include the costs of land rental, if any, labor costs, credit costs and costs of seed. For a family-owned farm with little or no non-family labor input, the simplified model may correspond somewhat closer to reality. It is also possible to assume away labor costs, as is done in many developing country studies, by imputing a zero shadow wage rate for labor on the argument of widespread underemployment in rural areas.) The complete model would then be stated as:

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Maximize $$Z = \sum_t p_i X_{it} - P_d ID_t - p_e IE_t - P_b IB_t - P_c CY_t - p_f Y_{it} \quad (16)$$

subject to $$X_{it} \geq D_{it} \quad (17)$$

the demand constraint for agricultural commodities, and the Equations (9) through (15) with subscript t attached to each variable to denote the specific time period, and where

p_i = price of agricultural product i

p_d = per unit diesel cost

p_e = per unit electric cost

p_c = per unit imported crude cost

p_f = per unit imported fertilizer cost.

D_i = minimum demand (assumed exogenous) for agricultural product i.

Given the objective defined by Equation (16) and the constraints given by Equation (17) and Equations (9) to (15), the optimal solution would give:

- optimal crop mix
- best technology for - fertilizer use
  - irrigation.

Although the model is extremely simple, it can provide interesting and useful results when fed with realistic data.

4. ILLUSTRATIVE APPLICATION OF THE MODEL WITH DATA FROM DOMINICAN REPUBLIC

4.1 Preliminaries

A preliminary application of the model, for illustrative purposes, has been carried out using data from the agricultural sector in the Dominican Republic. The main objective of the application was to develop a working model which can be operated on a personal computer using the LOTUS 1-2-3 spreadsheet package and commercially available linear programming software suitable for implementation on microcomputers. In this way, the entire model resides on a few microcomputer diskettes which can easily be transferred. Learning to operate the model is also relatively simple, since it mainly involves knowing how to manipulate the LOTUS spreadsheets. Appendix A1 describes in some detail the operation of the LOTUS files and the manipulation of the data. The LP package used is LP83, a commercial LP software package from Sunset Software of San Marino, California. This package is quite fast, accurate, and has reasonably good report writing capabilities. It operates in tandem with either the LOTUS or SYMPHONY spreadsheet packages. The package can handle an LP problem with up to 340 rows (constraints) and about 500 columns (variables). This is about the limiting size of a problem one might want to solve on a microcomputer. Since one of the main features of this model is to permit extensive sensitivity analysis to changes in key variables, it is preferable to keep the size more tractable and less cumbersome while still incorporating a fair amount of realistic detail. The illustrative example shown below used 129-181 variables and 197-201 constraints. Solution time was around two to three minutes on an IBM AT-equivalent microcomputer.

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4.2 Data for the Dominican Republic Case

The specific application to the Dominican Republic used a simple formulation with as few variables as sufficient to obtain a complete description of the system. The focus was on using the model to obtain optimal results on the options for irrigation pumping and fertilizer production with the analysis limited to the major crops in the country. Only the agricultural production sector was analyzed and that too in a limited way due to the paucity of available data. As stated earlier, the main objective was to develop a working model and illustrate its use, rather than to perform a complete analysis of agricultural sector options in the Dominican Republic.

The fourteen crops that were selected for analysis are as follows:

- Sugar cane
- Rice
- Corn
- Tobacco
- Coffee
- Cocoa
- Beans
- Peanuts
- Sweet Potato
- Banana
- Potato
- Tomatoes (industrial and salad)
- Cassava
- Other vegetables

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Lack of data prevented inclusion of the livestock (beef, poultry and pork) and the dairy (milk and milk products) sectors. However, the crops included accounted, in 1984, for over 80 percent of value added in agriculture and an estimated 95 percent of energy consumed in agricultural production. Processing and transport energy could not be included at this preliminary stage due to lack of information. Sugarcane is the dominant crop in the Dominican Republic in terms of total production volume and fertilizer consumption. Four of the above crops, sugar, tobacco, coffee, and cocoa, also account for almost all of the export income from agriculture.

The crops that we focus on for this study, along with the energy sources and the energy-embodied inputs, are presented in Table 4. In most cases, the crops are not homogeneous and are composed of traditional and high-yielding varieties. Also, with the exception of sugarcane, none of the other crops are cultivated through the year. To distinguish between crops that require no more than rain-fed irrigation and those that require extensive irrigation, the former are classified as "unirrigated" and the latter as "irrigated." Rice, for instance, may be made up of a combination of irrigated traditional rice, irrigated high-yielding variety (HYV) rice, unirrigated (UI) traditional rice and UI-HYV rice. [See for instance the study by Anandalingam (1982).] For each of these crop types, energy embodied inputs such as fertilizers and irrigation requirements would be different. To keep the analysis within reasonable bounds of tractability and utilize the available data effectively, only aggregate crop types are used in the illustrative application.

Table 5 gives an example of the number of man-days and animal-days of labor input per tonne of crop output for selected crops in the Dominican

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Table 4
Variables Used in Dominican Republic Example

Crops (X_I)	Energy Embodied Inputs (X_P)	Energy Sources (X_S)
		Primary
Rice		Lignite
Corn		Crude oil (imported)
Banana	Cubic-meters water (D)[2]	Coal (imported)
Sweet potato	Cubic-meters water (E)[2]	Hydro
Tomato		Solar
		Secondary
Other Vegetables		Crop residue[3]
Beans		Dung
Potato		Biogas
Sugarcane		Diesel
Peanut	Fertilizer (N)[1]	Gasoline
Tobacco	Fertilizer (P)[1]	Kerosene
Cocoa	Fertilizer (K)[1]	Naphtha
Coffee	Pesticides	Fuel oil
Cassava		Electricity

[1]N = nitrogen, K = potassium, P = phosphorous.
[2]E = electricity, D = diesel.
[3]Primary component is bagasse

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Table 5
Human and Animal Energy Inputs to Crop Production (Dominican Republic)

Crop Variety*		Animal Energy (Bullock-Days/tonne)	Human Energy (Man-Days/tonne)
Rice -	native	1.84	9.39
	improved	0.75	8.74
Corn -	native	2.84	27.33
	improved	1.61	27.19
Sugarcane -	native	0.39	0.31
	improved	0.60	0.38
Peanut -	native	7.35	51.37
	improved	6.21	48.83
Tobacco -	native	4.81	111.68
	improved	0.93	55.77
Cocoa		1.00	32.58
Coffee		0.39	14.11
Yam		1.33	22.72
Kidney Beans -	native	15.54	94.70
	improved	4.24	36.16

*Note that "native" and "improved" are terms used in the PCI report and do not correspond to the terms "traditional" and "HYV" used in the text.

Source: Practical Concepts Inc. (1980).

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Republic. Projections of the total animal and human energy requirements are obtained by multiplying values given in Table 5 by projections of crop output. The requirements in the Dominican Republic of fertilizer, pesticides, and water per unit of production or area are given in Tables 6, 7, and 8 respectively. The values found in Table 5, 6, 7, and 8 would form the elements of the A_{pi} matrix.

4.3 Remarks on Parameter Values

Derived energy requirements due to irrigation water demand was calculated by assuming that all irrigation was from an underground water source at constant depth. In the Dominican Republic it is assumed that water has to be pumped up from an average depth of 3 meters. In addition, only 7 percent of crop water requirements is met by groundwater irrigation, the rest being met by gravity feeding. Thus the energy used for irrigation in the Dominican Republic applies to only 7 percent of the estimated total water requirement. For the illustrative example, only the existing inventory of pumps, diesel (40%) and electric pumps (60%) were considered for irrigation purposes. Extensions of this analysis will include other pumping technologies such as solar or biogas for a more complete technology assessment. The efficiencies of irrigation pumping from different sources are presented in Table 9.

All of the fertilizer used in the Dominican Republic agricultural system is imported. However, in this study two other options were also analyzed: using naphtha or fuel oil used as feedstocks for the production of fertilizer. It was also assumed that for each tonne of fertilizer produced, 0.25 tonnes of naphtha or 0.20 tonnes of fuel oil will be used. It should be

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Table 6
Fertilizer Use by Crop (Dominican Republic)

Crop Variety*		Fertilizer Required		
		Nitrogen (N) lbs/tonne	Phosphorous (P) lbs/tonne	Potassium (K) lbs/tonne
Rice -	native	65.6	32.4	26.4
	improved	35.1	27.2	13.6
Corn -	native	4.8	3.4	4.2
	improved	0.2	0.5	0.2
Sugarcane -	native	2.1	1.3	2.4
	improved	1.7	1.1	1.1
Peanut -	native	2.7	5.1	2.8
	improved	7.5	12.1	6.9
Tobacco -	native	13.2	12.6	4.8
	improved	56.2	57.8	1.5
Cocoa		0.9	0.6	1.1
Coffee		7.3	5.4	8.2
Yam		0.4	0.8	0.4
Kidney Beans -	native	8.0	14.4	8.0
	improved	22.2	27.8	22.6

*See note under Table 3.
Source: Practical Concepts, Inc. (1980).

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Table 7
Pesticides Usage by Crop (Dominican Republic)

Crop	Pesticide Requirement (liter/tonne)		
	Insecticide	Herbicide	Fungicide
Rice	0.66	3.01	--
Corn	1.10	--	--
Sugarcane	0.33*		--
Peanut	--	1.21	--
Cocoa	8.00	--	--
Yam	0.14	--	--
Plantain	2.15	--	--
Sweet Potato	0.13	--	--
Kidney Beans	8.88	--	1.33

*Includes both insecticide and herbicide.

Source: Dr. F. Villoria, Santo Domingo.

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Table 8
Annual Water Requirements (Dominican Republic)
(m^3/tarea*)

Crop	Water
Rice	800-2,300
Cassava	450-900
Corn	400-700
Banana	700-1,700
Sweet Potato	400-675
Red Beans	300-450
Yautia	450-500
Onion	300-600
Tomatoes	300-600
Sugarcane	1,100-1,500
Potato	350-625
Coffee	800-1,200
Cocoa	800-1,200
Tobacco	300-500

Source: Dr. F. Villoria, Santo Domingo.

*16 tareas = 1 hectare.

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Table 9
Efficiencies of Irrigation Pumping

Device	Fuel	Efficiency*		
		High	Medium	Low
Diesel engine[1]	diesel	30%	25%	20%
Biogas plant[1] -engine	dung	12.5%	10%	7.5%
Small gasifier[1] -engine	crop residues	10%	7.5%	5%
Electric pump	electricity	30%	20%	10%
Animal-powered[2] systems	--	--	3.5%	--

*Efficiency is defined as the ratio of shaft work produced to the heat of combustion (calorific value) of the fuel consumed.
Source: 1. Hurst (1983).
2. Hurst (1984).

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noted that these options are purely hypothetical, and are meant to illustrate the use of the model for policy analysis. Given the current state of the world fertilizer market, the scarcity of capital in the Dominican Republic, the levels of domestic fertilizer demand and the lack of primary resources, it is extremely unlikely that the construction of a world-scale fertilizer plant would be envisaged in the Dominican Republic.

Refinery efficiencies for producing various petroleum products in the Dominican Republic are given in Table 10; conversion efficiencies for electricity from different sources are given in Table 11.

4.4 Base Case Results

Current projections of the demand for agricultural products in the Dominican Republic (Table 12) are used to simulate projections of agricultural energy use. In addition, it is assumed that the technology and fuel share mix remains at the current levels. The derived demand for irrigation and fertilizer are shown in Table 13 and 14, and the resultant energy demand is given in Table 15. Clearly as agricultural production increases, energy consumption becomes quite significant in later years. A complete listing of the equations and the variables used in the optimization model application to the Dominican Republic is given in Appendix A2.

4.5 Analysis of Policy Alternatives

Scenarios that were based on different policy alternatives were developed for analysis. These scenarios are summarized below:

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Table 10
Conversion Efficiencies for Refinery Products
(Dominican Republic)

Petroleum Product	1982 Volume (million bbls) Domestic Production	Total (inc. Imports)	Conversion Efficiency (%)
Gasoline	2.18	2.24	22
Diesel	2.67	2.89	27
Kerosene	0.59	0.65	6
Fuel Oil	3.47	6.70	35
LPG	0.50	1.00	5
Naphtha	0.30	0.60	3
Losses	0.20	0.20	2
TOTAL	9.90	14.28	100

Note: 1) 1982 volume (in millions of barrels) in parentheses. The volume includes product imports which are not included in efficiency estimates.
2) These are actually yields and give the percentage of products obtained from a barrel of oil refined.

Source: Chatterjee (1983).

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Table 11
Conversion Efficiencies for Electricity

Source	Source Input (1000 boe)	Electricity Output (1000 boe)	Conversion Efficiency (%)
Hydro	622	187	30*
Gas Oil	786	165	21
Diesel	16	4	25
Fuel Oil	4,620	1,384	30
Bagasse	5	1	20
Lignite	0	0	25

*This is conventionally used to compare hydropower with power based on other fuels. Not Strictly an efficiency.
Note: boe = barrels of oil equivalent.
Source: Chatterjee (1983).

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Table 12
Agricultural Demand Projections
(in quintals)

Product	1985	1990	1995	2000
Rice	6417	7147	7922	8660
Yucca	1100	1168	1168	1415
Corn	5022	5566	6170	6744
Green Banana (No.)	485000000	541270224	599962176	655842396
Sweet Potato	397000	412344	457056	499626
Red Beans	935250	1030890	1142640	1249065
Yautia	200000	206172	228528	249813
Onion	354097	391726	434203	474644
Tomatoes	339458	412344	457056	499626
Cane Sugar	108531660	120954240	134065760	146556960
Potato	128000	137448	152352	166542
Coffee	13224	13744	15235	16654
Cocoa	300000	229875	365644	399700
Tobacco	363000	398599	441820	482971

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Table 13
Water Requirements
(in million cubic meters)

Product	Year 1985	1990	1995	2000
Rice	718	799	886	968
Yucca	187	199	199	241
Corn	988	1095	1213	1326
Banana	366	409	453	495
Sweet Potato	229	238	264	288
Red Beans	298	328	364	398
Yautia	141	145	161	1762
Onion	333	368	408	446
Tomato	357	433	481	525
Sugar Cane	566	631	699	764
Potato	162	174	193	211
Coffee	20	21	23	25
Cocoa	137	105	167	182
Tobacco	248	272	301	220
Total	4750	5217	5812	6378

Note: Groundwater irrigation only 7 percent of these totals.

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Table 14
Fertilizer Requirements
(in thousand tonnes)

Product	Year 1985	1990	1995	2000
Rice	59.61	66.40	73.60	80.45
Yuca	--	--	--	--
Corn	0.13	0.14	0.15	0.17
Banana	10.10	11.28	12.50	13.66
Sweet Potato	--	--	--	--
Red Beans	0.36	0.39	0.44	0.48
Yautia	--	--	--	--
Onion	1.90	2.11	2.33	2.55
Tomato	1.12	1.36	1.51	1.65
Sugar Cane	521.79	581.51	644.55	704.60
Potato	0.34	0.37	0.41	0.45
Coffee	1.76	1.83	2.02	2.21
Cocoa	2.70	2.07	3.29	3.60
Tobacco	0.10	0.11	0.12	0.13
Total	599.91	667.57	740.92	809.95

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Table 15
Total Energy Use
(TOE)

Scenario	Year 1985	1990	1995	2000
Base Case	2,450	2,524	2,995	3,284
A	2,450	3,062	3,828	4,784
B	1,837	2,297	2,871	3,588
C	1,575	1,986	2,461	3,076
D	19,079	23,848	29,810	37,263
E	3,150	3,937	4,921	6,151

Notes
A= Increase in production by 25%
B= Increase in diesel pumping efficiency by 33%
C= Change in refinery mix + Scenario B
D= Petroleum products for fertilizer production
E= Diesel pumping increased to 80% of total

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Scenario A: Crop production increases by 25 percent over the Base Case for each five-year period.

Scenario B: Diesel pumping efficiency is increased by 33 percent from the present average value of 15 percent to the maximum possible that could be achieved of 20 percent.

Scenario C: Refinery mix is changed in order to produce a higher proportion of middle distillates: Diesel increases from 30 to 35 percent of total product, gas oil increases from 25 to 30 percent, and fuel oil decreases from 35 to 25 percent.

Scenario D: Domestic fertilizer production increased to 50 percent of total--25 percent naphtha based and 25 percent fuel oil based.

Scenario E: Diesel pumping increased from 40 to 80 percent of total pumping. Electric pumps decreased from 60 to 20 percent.

The impact of these scenarios on total energy use are given in Table 15. Clearly domestic production of fertilizer leads to a tremendous increase in demand for crude oil; this demand is primarily due to the derived demand for naphtha. Fuel oil based fertilizers require less refinery through put of crude oil. Another option is for the petroleum products (i.e., naphtha and fuel oil) to be imported directly (i.e., scenario D1). Even in this case, the increase in domestic energy consumption is very large. This feature, of course, is a result of the hypothetical scenario analyzed here. The model only examines crude oil going into refineries and estimates total energy use by computing the energy content of crude oil. Clearly if large amounts of crude oil are used to produce naphtha (only 3% naphtha is produced from 1

barrel of crude) for use in fertilizer plants, the level of other refinery products will also be very large. It is clear that in the process of producing naphtha for fertilizer, the oil refineries in the Dominican Republic will produce much more refined petroleum products than it requires, which would then need to be exported. As pointed out earlier, this scenario is not realistic for the Dominican Republic but has been analyzed here only for illustrative purposes.

If the diesel pumps with higher efficiency are used, as expected, the total energy use decreases (Table 15). Changes in the refinery mix to produce a larger percentage of diesel (Scenario C) will further reduce crude inputs and thus total energy demand. However, electric pumping leads to a lower total energy use in Dominican Republic agriculture. Increasing the percentage irrigation due to diesel pumping (i.e., Scenario E) actually leads to a higher energy use. Of course the choice between electric and diesel pumps will also depend on cost and institutional problems associated with each option. An additional consideration is reliability and it has been found in many developing countries, and the Dominican Republic is a case in point, that availability of electric power is quite unreliable. Thus additional considerations such as these could also favor diesel pumps.

It was not possible to completely analyze technology assessment issues in the Dominican Republic, due to data limitations. It was shown in the previous case that electric pumping was more energy-effective than diesel pumping for irrigation purposes. No data was available on animal power, biogas or producer gas from gasifiers. Thus in this illustrative study it

was not possible to analyze the consequences of using these as energy sources for diesel pumps. Data did not exist on organic fertilizer use in order to assess the relative feasibility of using organic versus chemical fertilizer. It is not energy-effective to produce chemical fertilizer in the Dominican Republic. It is also not economic to produce fertilizer domestically in the DR because, on the one hand, domestic demand does not seem sufficiently large to justify a world scale fertilizer plant, and on the other hand, international fertilizer markets are depressed at the moment.

4.6. Optimal Solutions from the LP Model

Four cases are analyzed in the optimization framework: (A) assuming a nominal (2 percent) growth in the production of crops over the time horizon of the study, (B) no lower bounds on the production of any crops, (C) upper bound on the production of minor crops - red beans, Yautia, and tomato, and (D) twofold increase in the international price of fertilizer (in addition to case A). Cases (B) and (C) were used just as tests of the model to see if it would replicate the intuitively correct results expected of a linear program.

All model runs were performed on an IBM AT computer using LOTUS 1-2-3 and the LP 83 software package. Due to lack of price data, we only examined 12 crops (with reference to Table 12, Cocoa and Tobacco were dropped from the analysis and industrial and salad Tomatoes were combined). Analysis was only carried out for the three snapshot years 1990, 1995, and 2000, starting at 1985. After taking into account all variables for all time periods the problem had 129-181 variables and 197-201 constraints, and typically took two to three minutes of computer time to execute.

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Model results for case A are presented in Table 16. Other model runs give substantially the same results for technology choice. In all cases, importing fertilizer was preferred to producing it domestically by any means; this was true even when imported price of fertilizer was doubled. In all cases, diesel pumping was preferred to the use of electric pumps.

In the test cases of the model, when there were no lower bounds on crop production (case B), model results show that the optimal policy was to only produce beans. This shows that the model is operating correctly as one would expect since beans are the crop with the lower resource cost in terms of fertilizer and water used in the Dominican Republic. When upper bounds were placed on the minor crops including beans (Case C), optimal policy was to produce only Cassava (Yucca). These solutions which were generated just to test the model show, in fact, that when there are no bounds on production only the crop with the lowest resource cost enters the basis since crop production is on the basis of profitability.

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Table 16
Technology Use
(Case A)

Technology	Year 1985	1990	1995	2000
Irrigation (million cu.m.)				
Diesel	272.63	350.53	430.00	511.00
Electricity	--	--	--	--
Fertilizer				
Import	2588	2640	2693	2747
Naphtha-Based	--	--	--	--
FO Based	--	--	--	--

5 CONCLUDING REMARKS

The primary purpose of this report was to present a methodology that can be used to analyze energy use in the agricultural sector of developing countries. A network model that captures energy flows through the agricultural sector was presented and simulations of the model using LOTUS 1-2-3 were performed. The network model was extended to the optimization framework and formulated as a linear programming problem. Model results of the LP were obtained using a personal computer and the software suitable for implementation on microcomputers. Overall results for the cases run with preliminary test data from the Dominican Republic show that while diesel pumps are preferred to electric pumps energy use in agriculture depends critically on diesel pumping efficiency and that it would be preferable to use imported fertilizer than to produce it domestically. Other questions that need to be answered are the sensitivity of the results to international fertilizer price, the crude oil price, fertilizer plant costs, etc.

All model results depend critically on inputs and data. The data on the Dominican Republic, as in most developing countries, are subject to a number of measurement error problems and inconsistencies. The model results were presented here primarily for illustrative purposes; data unavailability in the Dominican Republic prevented us from analyzing the impacts of on-farm processing activities, irrigation technologies such as biogas, producer gas from gasifiers and animal powered systems, and tractorization versus animal-energy use. However, the model can be a starting point for further analysis of more complex issues.

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6 RECOMMENDATIONS

Commercial energy use in agriculture is a significant component of overall energy use in developing countries. If "non-commercial" animate energy sources, which are a major energy source in agriculture, are included, agriculture would account for almost 25 percent of total energy use. The analysis of non-commercial energy inputs is vital for a comprehensive study of energy use in agricultural production. Such an analysis would only be possible after the necessary data are assembled. Thus, one recommendation is for a survey of agricultural energy use. Since agricultural households can number several million in most developing countries, such a survey should be based on a sample chosen with statistical rigor (see Williams, 1979).

The general principles of an agricultural energy use survey is as follows (Desai, 1985 and Howes, 1985):

- Secondary sources of information in the form of official government reports and the results of already completed pieces of research can be of crucial importance. Usually this secondary information on the agricultural sector is found in the Ministries (or Departments) of Agriculture and Forestry, Finance and Planning, and in Statistical Yearbooks, usually compiled by census bureaus.

- Secondary sources of information are also a vital basis upon which to draw up sampling frames, and in identifying which fuel using activities require the most attention.

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- Objectives of the survey should be clearly identified. Since we are interested in agricultural energy use, surveys should be carried out in the context of rural production, consumption, and exchange.

- The information gathered should not only be on magnitudes but on the inter-relationships among them. Also key related information such as rainfall data, acidity of the soil, etc., and contrasts between data sets for different households (regions) should also be noted.

- There should be flexibility in data collection. It is important to avoid reliance upon any particular method of gathering data, and time should be allocated for letting the methodology (and certainly the surveyors) mature.

- In any sizeable survey it is futile to try and ensure every figure is accurate. It is more important to ensure that there are no biases in the information obtained.

It is highly recommended that the analysts and agricultural surveyors have training in carrying out the rural based surveys. It would be most helpful if they are also given a detailed briefing on the issues addressed by Desai (1985) and Howes (1985) in their publications.

One of the essential tools these days for strategic economic planning are microcomputers and microcomputer based models. This report provides the

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basic features of an agricultural energy analysis modelling system using a microcomputer. In order to use the model for policy analysis of agriculture and energy options in a developing country, the following inclusions and extensions would be necessary:

1) Energy inputs into land preparation: tractorization, human labor inputs, animal-energy inputs;

2) Energy inputs into harvesting: mechanization, human and animal labor inputs;

3) Agricultural processing activities;

4) Other irrigation technologies such as biogas, producer-gas from gasifiers and animal powered systems;

5) Fertilizer from natural gas and other fuels;

6) Changes in technology coefficients over time as agro production efficiency improves.

The model could also be extended to allow the incorporation of impacts of large agricultural projects. Large irrigation projects that have economy-wide impacts are becoming quite common in developing countries. There are many ways in which such projects can be incorporated in an economy-wide model (see Anandalingam, 1985; Bell et al., 1982). Such projects affect the agricultural sector in particular. An agricultural-energy use model should be

flexible enough to allow project interaction. Such a hybrid model would prove to be a useful tool for agricultural project evaluation from a sector- or nation-wide perspective.

Take for example the Muda paddy economy in Malaysia that is analyzed in the Clive et al. (1982) publication. Important paddy production decisions impact directly on the regional paddy output, water and fertilizer use, labor, draft power, and land rental markets. These direct impacts also have indirect results through linkages to the rest of the economy. Increased income in farm households lead to increased demand for goods and services outside the farm economy. Labor demand leads to increases in wage rates and thus inflation. Increase in draft power use leads to an organized market in the form of either private initiative or cooperatives for bullocks and tractors. There are multiplier effects associated with almost all inputs. Indeed the authors of the Muda study found that for every dollar of value added generated directly, another 80 cents were generated "downstream." Thus examining the agricultural sector in isolation would be limited at best.

The model developed in this study was simulated using the LOTUS 1-2-3 and a linear programming software package. This combination of software packages is menu driven and user friendly. Should the extensions recommended above be followed, it could prove to be an essential tool for desk-top evaluation of projects affecting energy use in agriculture.

The linear programming (LP) model results were illustrative at best. The LP model needs to be expanded to take into account, constraints for land area, labor and water availability, minimum fertilizer requirements etc. In

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addition, as mentioned before, a number of other objectives can be considered including minimizing foreign exchange use or cost of meeting time stream of time stream of crop demands. Indeed, in a simple model, a cost minimizing objective is the best one to ensure reasonable agricultural production and cropping patterns. We recommend that the optimizing model also be expanded to include uncertainty, which is a very real aspect of the agricultural economy. Vagaries of weather and food prices may need to be included in a stochastic model that also analyzes food security issues (See Anandalingam, 1982 for instance). In this way, analysts and policy makers will be able to use a micro-computer based LP model in order to make strategic planning decisions.

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REFERENCES

1. Anandalingam, G. (1982). "Models for Optimal Crop Planning Under Uncertainty," Asian Economies, No. 42, September.

2. Anandalingam, G. (1985). "Evaluating Economy-Wide Impacts of Large Irrigation Projects," unpublished manuscript, University of Virginia.

3. Bhatia, R.K. (1976). "Energy Requirements of Different Farm Systems," Indian Journal of Agricultural Economics, Vol. 31, No. 8, July.

4. Bhatia, R.K. and M. Mehta (1975). "Tubewell Irrigation in India: An Economic Analysis of Some Technical Alternatives," mimeo, Center for Population Studies, Harvard University.

5. Bell, C., P. Hazell and R. Slade (1982) Project Evaluation in Regional Perspective, Johns Hopkins University Press.

6. Bhatia, R.K. and M. Niamir (1979). "Renewable Energy Sources: The Community Biogas Plant," mimeo, Center for Population Studies, Harvard University.

7. Brown, L. (1985). "Reducing Hunger," VITA News, April, pp 4-7.

8. CAST (1977). Energy Use in Agriculture, Report 68, Council for Agricultural Science and Technology, Ames, Iowa, August.

9. Chatterjee, R. (1983). Energy Sector Issues and Investment Priorities in the Dominican Republic, Report, IDEA, Inc., Washington, D.C.

10. Cox, P. (1977). Energy Costs of Food Production: Rice Sector in the Ivory Coast, Master Thesis, Tufts University, Medford, MA.

11. DeLucia, R. and H. Jacoby (1982). Energy Planning for Developing Countries: A Study of Bangladesh, Johns Hopkins Press, Baltimore, MD.

12. Desai, A.V. (1980). India's Energy Economy: Facts and Interpretation Center for Monitoring India's Economy, Bombay.

13. Desai, A.V. (1985). Ends and Means in Rural Energy Surveys, Report No. 1 DRC-MR 112e, International Development Research Centre, Ottawa, Canada.

14. Gupta, C.L. and K. Usha Rao (1981). "Energy Inputs for Irrigated Farming with Mixed Crops," Urja, May.

15. Howes, M. (1985) Rural Energy Surveys in the Third World, Report No. 1DRC-MR107e, International Development Research Centre, Ottawa, Canada.

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16. Hurst, C. (1983). "Energy for Development: A Case Study in Bihar, India," Ph.D. thesis, Division of Applied Sciences, Harvard University.

17. Hurst, C. (1984). "A Model of an Indian Village: A Study of Alternative Sources of Energy for Irrigation," World Development, Vol. 12, No. 2, pp. 141-156.

18. Hurst, C. (1985). Personal Communication.

19. Makhijani, A. and A. Poole (1975). Energy and Agriculture in the Third World, Ballinger Press, Cambridge, MA.

20. Mubayi, V. and J. Lee (1979). "Irrigation in Less Developed Countries," mimeo, Brookhaven National Laboratory, Upton, NY.

21. National Academy of Sciences (1982). Producer Gas: A Little Known Fuel for Motor Transport, Washington, D.C.

22. Nair, N.K. "Contribution of Fertilizer to Food Production in India," Productivity, Vol. 17, No. 1, April-June, pp. 108-125.

23. Pimentel, D. and M. Pimentel (1979). Food, Energy and Society, John Wiley, New York.

24. Practical Concepts, Inc. (1980). Energy in the Food System: Dominican Republic, report to Brookhaven National Laboratory, Upton, NY.

25. Rogers, P. (1981). "The Economics of Small Producer Gas-Engine Systems," mimeo, Division of Applied Sciences, Harvard University.

26. Singh, G. and W. Chancellor (1975). "Energy Inputs and Agricultural Production in North India", Transactions of the American Society of Agricultural Engineers, Vol. 18, No. 2.

27. Williams, B. (1978), A Sampler on Sampling, Wiley, New York.

28. Halcrow, William H. and ITDG (1983). "Small-Scale Solar Powered Pumping Systems: the Technology, its Economics and its Advancement," Report to the World Bank, Washington, DC.

29. Bhatia, Ranesh (1984). "Energy Alternatives for Irrigation Pumping," World Employment Programme Working Paper, International Labor Organization, Geneva.

30. Council for Scientific and Industrial Research (CSIR) and Swiss Development Council (SDC) (1985). "Choice of Technology for LIfting Water: A Comparative Study of Energy Alternatives," New Delhi.

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Appendix A

USER GUIDE TO
LOTUS 1-2-3 AGRESEARCH WORKSHEETS

A.1 The Basic Worksheet

All simulation runs for the agricultural energy use study were performed on LOTUS 1-2-3. The AGRESEARCH worksheets can be used together with the LOTUS 1-2-3 system diskettes in order to perform sensibility analysis. This Appendix is a User Guide to the AGRESEARCH worksheets.

Once the worksheets are on the screen, the first set of entries are assumptions and input data. These entries go from Column A to Column E. All macro descriptions start at Column A. So the USER should to set the cursor at Column A in order to obtain input/assumption descriptions.

The first set of assumptions are the percentage of water demand that is met by irrigation (Cell D11) and the average depth of the water table in meters (Cell D12). The depth of water is used to estimate energy required for irrigation pumping (see text).

The next set of assumptions is the distribution of pumping work between diesel (Cell D21) and electric (D22) pumps. All figures that are displayed as percentages should be entered in decimals. For example, irrigation pumping with diesel may have a share of 40% of total ground water irrigation, however at the top left-hand corner of the LOTUS worksheet the entry in cell D21 would be 0.4.

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The third set of inputs are the calorific values of the fuels given in joules/kg of fuel (Cells D27 to D29). The fourth set of inputs are the output of refineries in terms of percentages of petroleum products produced (Cells D34 to D36). The refinery proportions change for country-to-country. (See next section on how to change or edit entries.) The fifth set of inputs are average specific gravities of fuels in barrels/ton of fuel (Cells D41 to D44).

Next we have inputs for the different crops. The first table gives the yield in quintals/tareas (Cells C51 to C65), use of insecticides (E51-E65), and herbicides (F51-F65), together with total production in 1984 in tonnes (B51-B65), and area (D51-D65).

Projections of crop production are given in the next table, from 1990 to 2000, with 1985 as the base year. In the illustration, the growth every 5 years is taken to be 25 percent. This figure will change from year-to-year from country-to-country, and from scenario to scenario.

Table 2 uses crop production from Table 1 to project irrigation water requirement in cubic meters. Table 3 which starts on Cell A117 projects fertilizer requirements.

Next (rows 145 to 151), the calculations used to estimate energy use for irrigation pumping are displayed. This is followed by the calculation of crude oil required for irrigation. In order to compute crude oil required for irrigation, first diesel and electricity required for the different types

of pumps are estimated. Then crude oil required to produce diesel and the fuels going into electricity production are estimated. The next calculation displayed is that of crude oil required to produce fertilizer. Finally the total crude oil required is estimated (Rows 259 to 270).

A2 Changing Entries

It is highly recommended that the user learns the LOTUS 1-2-3 commands. These would be necessary for making major changes to the worksheet or for developing a new worksheet.

Changing a Number. In order to change any non-equation entry, simply type in the new information. For instance, if the percentage of irrigation by pumping (Cell D11) is to be 20% instead of 7%, place the cursor on D11 and type in 0.20 (NOTE that only decimal figures are entered for percentages). After some time (a few seconds) the change will appear on the screen.

Changing a Formula. As before, a formula can be changed by simply typing in the new information. For instance, in order to change growth of rice production from 25% to 10% between 1985 and 1990, place the cursor on Cell E72, and type "+ D72 * 1.10." Note that all formulae start with a plus (+) sign. Formulae can also be edited using the function keys. Just type F2 and this would put the user in the edit mode. Then move the cursor using the arrows to the number that needs editing, delete the old number (25 say) by the backspace key and type in the new number (10 say). Return to usual LOTUS operations by typing "ESC."

In most cases, and certainly in Table 1 (projections of crop production),the user may want to change the formula in all entries. This can be accomplished by the copy command. First go to the first occurrence of the formula. (In the example this is in Cell E72.) Change the single entry as before. Then type "/." This gets the user into the command mode, and the different commands would be displayed on the top of the LOTUS worksheet. In order to use the copy command, either move the cursor to the copy command and type Carriage Return (CR or "Return" in most computers) or type "C." The computer will respond with questions regarding the copying: from where (i.e., which Cell) to copy and to where to copy. Since the copying action was started after Cell E72 was changed, the first response of the computer will be: "FROM E72..E72." Since this is not going to be changed, first type "." (a period) and RETURN. Then move the cursor (using the arrows) to the right to cover entries up to year 2000 (Cell G72); you will notice that row 72 has now been shaded. Next move the cursor down to the bottom of the table. You will notice that, now, the whole table has been shaded. Finally press RETURN again. All formulas would not have a 10% growth rate.

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APPENDIX A2

COMPUTER LISTING OF EQUATIONS IN THE OPTIMIZATION MODEL

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The following is a computer listing of the objective function and the constraint equations in the optimization model, discussed in Section 4, of the illustrative application for the Dominican Republic. The definition of each of the variables in the computer listing are given below in Table A.2.1.

The numerical coefficients on each of the variables in the objective function are unit prices (in RD$/unit) of the respective variables as of March 1985. The calculations assume constant 1985 prices (in RD$) for all variables.

The numerical coefficients in the constraint equations are technical coefficients such as fertilizer and irrigation water requirements per unit of crop output, efficiencies of diesel and electric irrigation pumps, etc. derived from the tables in the text of the report.

1. Objective Function

```
********************
MAXIMIZE
*TO MAXIMIZE NET REVENUES
********************
42.16C1P1+42.16C2P1+42.16C3P1+42.16C4P1+
20.00C1P2+20.00C2P2+20.00C3P2+20.00C4P2+
18.00C1P3+18.00C2P3+18.00C3P3+18.00C4P3+
00.10C1P4+00.10C2P4+00.10C3P4+00.10C4P4+
18.00C1P5+18.00C2P5+18.00C3P5+18.00C4P5+
100.0C1P6+100.0C2P6+100.0C3P6+100.0C4P6+
20.00C1P7+20.00C2P7+20.00C3P7+20.00C4P7+
28.00C1P8+28.00C2P8+28.00C3P8+28.00C4P8+
04.31C1P9+04.31C2P9+04.31C3P9+04.31C4P9+
27.00C1P10+27.00C2P10+27.00C3P10+27.00C4P10+
20.65C1P11+20.65C2P11+20.65C3P11+20.65C4P11+
192.0C1P12+192.0C2P12+192.0C3P12+192.0C4P12+
24.30C1P13+24.30C2P13+24.30C3P13+24.30C4P13
-3.95ID1-3.95ID2-3.95ID3-3.95ID4
-0.03IE1-0.03IE2-0.03IE3-0.03IE4
-6176CR1-6176CR2-6176CR3-6176CR4
-660Y11-660Y21-660Y31-660Y41
```

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2. Constraints

2.1 Fertilizer Demand Equations by Crop

```
*FERTILISER REQUIREMENT
*
F11-0.1858C1P1.EQ.0
F21-0.1858C2P1.EQ.0
F31-0.1858C3P1.EQ.0
F41-0.1858C4P1.EQ.0
F13-0.0005C1P3.EQ.0
F23-0.0005C2P3.EQ.0
F33-0.0005C3P3.EQ.0
F43-0.0005C4P3.EQ.0
F14-0.0004C1P4.EQ.0
F24-0.0004C2P4.EQ.0
F34-0.0004C3P4.EQ.0
F44-0.0004C4P4.EQ.0
F16-0.0077C1P6.EQ.0
F26-0.0077C2P6.EQ.0
F36-0.0077C3P6.EQ.0
F46-0.0077C4P6.EQ.0
F18-0.1075C1P8.EQ.0
F28-0.1075C2P8.EQ.0
F38-0.1075C3P8.EQ.0
F48-0.1075C4P8.EQ.0
F19-0.0123C1P9.EQ.0
F29-0.0123C2P9.EQ.0
F39-0.0123C3P9.EQ.0
F49-0.0123C4P9.EQ.0
F110-0.1197C1P10.EQ.0
F210-0.1197C2P10.EQ.0
F310-0.1197C3P10.EQ.0
F410-0.1197C4P10.EQ.0
F111-0.0538C1P11.EQ.0
F211-0.0538C2P11.EQ.0
F311-0.0538C3P11.EQ.0
F411-0.0538C4P11.EQ.0
F112-2.6562C1P12.EQ.0
F212-2.6562C2P12.EQ.0
F312-2.6562C3P12.EQ.0
F412-2.6562C4P12.EQ.0
F113-0.0962C1P13.EQ.0
F213-0.0962C2P13.EQ.0
F313-0.0962C3P13.EQ.0
F413-0.0962C4P13.EQ.0
```

(Note: Some crops do not require any fertilizer.)

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2.2 Fertilizer Supply-Demand Balance

```
*****************************************
*TOTAL FERTLISER
*
F11+F13+F14+F16+F18+F19+
F110+F111+F112+F113-Y11-Y12-Y13.EQ.0
F21+F23+F24+F26+F28+F29+
F210+F211+F212+F213-Y21-Y22-Y23.EQ.0
F31+F33+F34+F36+F38+F39+
F310+F311+F312+F313-Y31-Y32-Y33.EQ.0
F41+F43+F44+F46+F48+F49+
F410+F411+F412+F413-Y41-Y42-Y43.EQ.0
*****************************************
```

2.3 Crude Oil Demand for Domestic Naphtha/Fuel Oil Based Fertilizer

```
CR12-2.247Y12.EQ.0
CR22-2.247Y22.EQ.0
CR32-2.247Y32.EQ.0
CR42-2.247Y42.EQ.0
CR13-0.939Y13.EQ.0
CR23-0.939Y23.EQ.0
CR33-0.939Y33.EQ.0
CR43-0.939Y43.EQ.0
CR1-CR12-CR13.EQ.0
CR2-CR22-CR23.EQ.0
CR3-CR32-CR33.EQ.0
CR4-CR42-CR43.EQ.0
```

2.4 Irrigation Water Demand by Crop

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```
*********************************
*IRRIGATION REQUIREMENTS
*
I11-111.82C1P1.EQ.0
I21-111.82C2P1.EQ.0
I31-111.82C3P1.EQ.0
I41-111.82C4P1.EQ.0
I12-170.18C1P2.EQ.0
I22-170.18C2P2.EQ.0
I32-170.18C3P2.EQ.0
I42-170.18C4P2.EQ.0
I13-196.63C1P3.EQ.0
I23-196.63C2P3.EQ.0
I33-196.63C3P3.EQ.0
I43-196.63C4P3.EQ.0
I14-0.7500C1P4.EQ.0
I24-0.7500C2P4.EQ.0
I34-0.7500C3P4.EQ.0
I44-0.7500C4P4.EQ.0
I15-576.52C1P5.EQ.0
I25-576.52C2P5.EQ.0
I35-576.52C3P5.EQ.0
I45-576.52C4P5.EQ.0
I16-318.43C1P6.EQ.0
I26-318.43C2P6.EQ.0
I36-318.43C3P6.EQ.0
I46-318.43C4P6.EQ.0
I17-705.15C1P7.EQ.0
I27-705.15C2P7.EQ.0
I37-705.15C3P7.EQ.0
I47-705.15C4P7.EQ.0
I18-940.30C1P8.EQ.0
I28-940.30C2P8.EQ.0
I38-940.30C3P8.EQ.0
I48-940.30C4P8.EQ.0
I19-234.27C1P9.EQ.0
I29-234.27C2P9.EQ.0
I39-234.27C3P9.EQ.0
I49-234.27C4P9.EQ.0
I110-1869.1C1P10.EQ.0
I210-1869.1C2P10.EQ.0
I310-1869.1C3P10.EQ.0
I410-1869.1C4P10.EQ.0
I111-1267.8C1P11.EQ.0
I211-1267.8C2P11.EQ.0
I311-1267.8C3P11.EQ.0
I411-1267.8C4P11.EQ.0
I112-1510.9C1P12.EQ.0
I212-1510.9C2P12.EQ.0
I312-1510.9C3P12.EQ.0
I412-1510.9C4P12.EQ.0
I113-5.2200C1P13.EQ.0
I213-5.2200C2P13.EQ.0
I313-5.2200C3P13.EQ.0
I413-5.2200C4P13.EQ.0
```

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2.5 Total Irrigation Water Demand Constraints

```
*********************************
*TOTAL IRRIGATION REQUIREMNTS
*
I11+I12+I13+I14+I15+I16+I17+I18+I19+
I110+I111+I112+I113-W1.EQ.0
I21+I22+I23+I24+I25+I26+I27+I28+I29+
I210+I211+I212+I213-W2.EQ.0
I31+I32+I33+I34+I35+I36+I37+I38+I39+
I310+I311+I312+I313-W3.EQ.0
I41+I42+I43+I44+I45+I46+I47+I48+I49+
I410+I411+I412+I413-W4.EQ.0
*****************************************
```

2.6 Gravity and Pumped Irrigation Water Demand Constraints

```
*
S1-0.93W1.EQ.0
I1-W1+S1.EQ.0
I2-W2+S1.EQ.0
I3-W3+S1.EQ.0
I4-W4+S1.EQ.0
```

Assumes all further increases in irrigation water demand after 1985 are met
›y pumped irrigation.)

2.7 Diesel and Electric Irrigation Water Pumping Balance Equations

```
Z11+Z12-I1.EQ.0
Z21+Z22-I2.EQ.0
Z31+Z32-I3.EQ.0
Z41+Z42-I4.EQ.0
```

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2.8 Diesel Fuel and Electric Energy Demand for Pumped Irrigation

```
ID1-0.0000043Z11.EQ.0
ID2-0.0000043Z21.EQ.0
ID3-0.0000043Z31.EQ.0
ID4-0.0000043Z41.EQ.0
IE1-0.008175Z12.EQ.0
IE2-0.008175Z22.EQ.0
IE3-0.008175Z32.EQ.0
IE4-0.008175Z42.EQ.0
*****************************
```

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Table A.2.1
Definitions of Variables in the Model

Variable	Definition
C1	Year 1: 1985
C2	Year 2: 1990
C3	Year 3: 1995
C4	Year 4: 2000
P1	Crop 1: Rice
P2	Crop 2: Cassava (Yucca)
P3	Crop 3: Corn
P4	Crop 4: Banana
P5	Crop 5: Sweet Potato
P6	Crop 6: Beans
P7	Crop 7: Yautia
P8	Crop 8: Onion
P9	Crop 9: Tomato
P10	Crop 10: Potato
P11	Crop 11: Coffee
P12	Crop 12: Cocoa
P13	Crop 13: Sugarcane
C_iP_j	Production in year "i" of crop "j"
F_{ij}	Fertilizer demand in year "i" for crop "j"
Y_{i1}	Fertilizer supply in year "i" from imports
Y_{i2}	Fertilizer supply in year "i" from domestic naphtha based fertlizer plants
Y_{i3}	Fertilizer supply in year "i" from domestic fuel oil based fertilizer plants
CR_{i2}	Crude oil demand in year "i" for naphtha production for naphtha fertilizer plants
CR_{i3}	Crude oil demand in year "i" for fuel oil production for fuel oil fertilizer plants
I_{ij}	Irrigation water demand in year "i" for crop "j"
W_i	Total irrigation water demand in year "i" for all crops
S_i	Fraction of total irrigation water supply in year "i" met by surface (gravity-fed) irrigation
I_i	Irrigation water supply in year "i" met by pumped irrigation
Z_{i1}	Pumped irrigation in year "i" from diesel pumps
Z_{i2}	Pumped irrigation in year "i" from electric pumps
ID_i	Diesel fuel demand in year "i" for diesel pumps
IE_i	Electricity demand in year "i" for electric pumps