ENERGY USE IN U.S. AGRICULTURE: AN EVALUATION OF NATIONAL AND REGIONAL IMPACTS FROM ALTERNATIVE ENERGY POLICIES

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ENERGY USE IN U.S. AGRICULTURE:

AN EVALUATION OF NATIONAL AND REGIONAL IMPACTS FROM ALTERNATIVE ENERGY POLICIES

by

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PREFACE

Modern agriculture depends heavily on fossil fuel energy to power its machinery, to pump irrigation water, to produce fertilizers, and for many other uses. Further increases in energy prices will have important impacts on U.S. agriculture. Energy intensive irrigated farming will suffer most severely. But as energy prices continue to increase, other types of farming will also be affected.

This study, made possible by a grant from the National Science Foundation (NSF), Research Applied to National Needs (RANN) program, is the second in a series by The Center for Agricultural and Rural Development (CARD) on energy and agriculture. The study examines both the issues of increased energy prices in general and specific policies related to natural gas use in agriculture.

Several people in CARD helped in this work. Steve Griffin and Bill Boggess in deriving the cost data; Cameron Short, Joesph Campbell, and Shashanka Bhide in summarizing and tabulating the results; Nancy Melton and Elaine White for programming; and Sandy Nelson for typing the various drafts of the report. Tom Van Arsdall, U.S. Department of Agriculture, helped in transferring the Department energy data base to Iowa State University.

The Authors

TABLE OF CONTENTS

I. INTRODUCTION

Since 1972 the world economy has faced two severe shocks: food production and petroleum. Because both commodities are basic to the economic well being of all countries, shortages and rapid price increases for both energy and food have had serious impacts on the world economy. Since 1972 U.S. agriculture has experienced increased foreign demand for its products while energy and other input prices have risen rather sharply. However, since 1974 the value of agricultural exports has not increased as rapidly as energy imports (Figure 1). Further increases in world energy prices could affect the production capacity of U.S. agriculture as well as reduce the buying power of food importing countries.

In the world's economy, the United States has an important role as the largest food exporter. It also has contributed greatly to reducing the large U.S. balance of payments deficit caused by the sharp increases in petroleum prices since the Organization of Petroleum Exporting Countries (OPEC) Cartel was formed in 1972 (Figure 1).

The purpose of this study is to evaluate the long-run impacts of the developing energy situation on agricultural production. An earlier study shows that irrigated farming, more than any other part of agricultural production, is affected by changes in energy supplies and prices [10]. Either high energy prices or an energy shortage would reduce production of irrigated crops. Reduction in irrigated crops than has a "second round" effect on land use and crop production in other regions of the nation. If agricultural exports continue to rise, however, impacts on irrigated agriculture are not expected to be as severe as with lower exports.

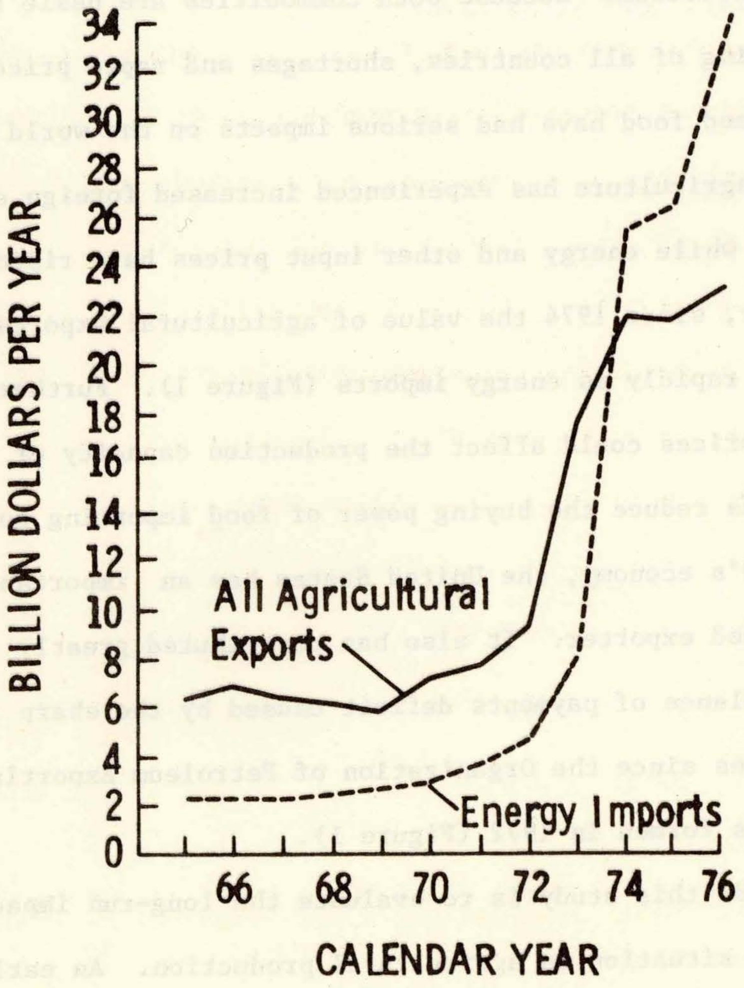

Figure 1. Values of agricultural exports[a] and energy imports[b] for 1965-1976.

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[a] SOURCE: U.S. Department of Agriculture [39].

[b] SOURCE: U.S. Department of Commerce [41, 42].

This study's objectives concentrate on the following questions: What might be the effects of natural gas deregulation, specifically in relation to irrigated farming? How might the impacts of natural gas deregulation differ from those of natural gas curtailment for irrigation? What are the interregional and national effects of the different energy situations on commodity prices and resource values?

These issues are receiving increased attention as oil and natural gas supplies continue to decline relative to demand. The severe winter of 1976-1977, with its sharp increase in natural gas use and major disruption of economic activities nationwide, has caused the nation to begin reexamining its energy policy, expecially its policy on natural gas use. This study generates empirical results relative to future impacts of energy use and prices on agriculture.

Energy Use in Agriculture

Several recent studies have described the use of energy in agriculture. The most detailed information on energy use in agricultural production is provided by a U.S. Department of Agriculture study [40]. Among all crops, corn requires the largest amount of energy. Almost a quarter of all the energy used for crops and livestock in 1974 was used in corn production (Table 1). The 12 endogenous crops included in this study (barley, corn grain, corn silage, cotton, legume hay, nonlegume hay, oats, sorghum grain, sorghum silage, soybeans, sugar beets, and wheat) accounted for 71 percent of all the energy used for crops and livestock in 1974 and for 80 percent of the energy used in crop production, alone.

Table 1. Energy use in agricultural production, 1974

Item	Energy Used	Total Share
Commodity	(Mcal[a])	(Percentage)
Corn	125.8	24.8
Wheat	50.8	10.0
Cotton	37.5	7.4
Soybeans	32.0	6.3
Alfalfa	30.6	6.0
Sorghum grain	25.6	5.0
Other hay	20.0	4.0
Corn silage	19.4	3.8
Oats	8.2	1.6
Barley	6.7	1.4
Sugar beets	3.9	0.8
Sorghum silage	1.3	0.3
All other crops	89.3	17.5
Livestock	56.5	11.1
Total agriculture	507.6	100.0
Farm operations		
Fertilizers	156.5	30.8
Field operations	131.7	25.9
Irrigation	65.7	12.9
Crop drying	26.5	5.2
Pesticide	24.0	4.7
Livestock operations	40.5	8.0
Pick up and auto use	62.7	12.5
Total agriculture	507.6	100.0

SOURCE: U.S. Department of Agriculture [40].

[a] Mcal is one million calories.

In 1974, the energy invested in fertilizers represented about 3 percent of all energy required for crop and livestock production (Table 1), while irrigation accounted for about 13 percent of all the energy used. Thus, crops requiring relatively large amounts of fertilizer and irrigation are the more energy-intensive crops.

Previous studies emphasizing energy and irrigation have dealt only with a state or specific part of a state. Bogle's study, "Impacts of Natural Gas Curtailment on Segments of Kansas Agriculture," describes the possible changes in production costs of irrigated crops if natural gas were not available for irrigation in Kansas [3]. The Cooperative Extension Service's "Proceedings of Groundwater Management and Energy for Irrigation Workshop" includes many articles related to the impacts of the energy crisis on irrigated agriculture in the Great Plains states [6]. Mapp and Dobbins' "Implication of Rising Energy Costs for Irrigated Farms in the Oklahoma Panhandle" describes the possible changes in the irrigated crop production for one area of Oklahoma [28]. Sloggett's "Energy Used for Pumping Irrigation Water in the United States, 1974" shows the total amount of energy used for the pumping of ground and surface water by state in 1974 [35]. Dvoskin, Nicol, and Heady's "Energy Requirements of Irrigated Crops in the Western United States" shows the total amount of energy required to obtain and apply an acre-foot of water in river basins of the western states [9] by river basin. Kliebenstein and Chavas' "A Look at Petroleum Energy Prices and Potential Impacts on Grain Farms" examines some of the adjustments that would take place on the farm in response to increased energy prices [27].

U.S. Energy Situation

Since the Arab oil embargo of 1973, the U.S. energy outlook has become a major public and governmental issue. The embargo clearly demonstrated the dependence of the United States on imported petroleum. The nation's oil imports continued to increase, however, and reached a record high in 1976. Imports accounted for about 50 percent of the daily petroleum consumption [16].

Increased concern over energy issues during the energy crisis of 1974 was the main cause for the establishment of the Federal Energy Administration and the reorganization of the Atomic Energy Commission into the Energy Research and Development Administration. One of the first goals of the present administration has been the reorganization of the many governmental agencies dealing with energy into the Department of Energy (DOE). On April 20, 1977, a proposed policy [30] which strongly emphasized energy conservation was announced. This energy policy is the most comprehensive energy policy submitted to Congress. However, at the time of publication it is still too early to predict how much of the program will pass through Congress and what impact it will have on national energy use. But, it is very clear that the U.S. economy will move toward greater energy efficiency and energy conservation in coming years.

Natural Gas Situation

Among all energy sources currently in use in the United States, natural gas is in the most critical situation. It not only is the least expensive energy source currently available, but its clean burning characteristics make it extremely useful for space heating. Natural gas also is a major resource base for nitrogen fertilizer, liquid petroleum gas (LPG) and many other chemicals.

The shortage of natural gas in combination with extremely cold weather in January 1977 had a severe impact on the U.S. economy. It contributed heavily to unemployment and further dampened economic recovery. As the pressure in the pipes dropped, lay-offs exceeded one million people and home heating was threatened. The crisis was fully as severe as the 1973 Arab oil embargo.

Consumption

Until 1920, only minor quantities of natural gas were used in the United States. Along with the development of the natural gas pipe systems and the recognition of its clean burning properties, natural gas consumption rose rapidly. Natural gas supplied only 4 percent of the U.S. energy needs in 1920. It increased to 18 percent in 1950 and exceeded 30 percent in 1974, growing at the average of 6.5 percent annually in the 1950s and 1960s [17]. Natural gas now accounts for more than 50 percent of direct fossil fuel inputs to household, commercial, and industrial sectors. When compared to previous decades, however, the growth rate of natural gas consumption declined dramatically in the 1970s.

Increased use of natural gas consumption is partly linked to the Federal Power Commission (FPC) regulatory jurisdiction over interstate transmission and sale of natural gas. These regulations have kept natural gas prices much below their potential market prices. For example, in October 1976 the U.S. average price for heating oil was 40.7 cents per gallon [16]. Assuming 35.28 Mcal per gallon, the average cost of one Mcal from heating oil was 1.15 cents. At the same time, the average natural gas price to residential customers for heating uses was $1.894 per 1,000 cubic-feet [16]. Assuming 269.01 Mcal per 1,000 cubic-feet, the average cost of one Mcal from natural gas was only 0.7 cents or 60 percent of the heating oil price. Furthermore, the price of gas to industrial users is only about one half of that for household users.

Production

Natural gas production peaked at 22.6 trillion cubic-feet (Tcf) per year in 1973 and has declined significantly since then. By 1976 yearly production declined to 19.8 Tcf [16]. It is estimated that by 1985 production will decline to 16 Tcf if prices are not deregulated. But even deregulation of natural gas prices is not expected to increase production above 21 Tcf per year [17].

The decline in production is partly due to the low regulated well head price which producers can charge for gas delivered to interstate markets. However, the main reason for the production decline is a substantial reduction in natural gas reserves. It is now estimated that if Alaska supplies are excluded, gas reserves will be completely depleted in 10 years [17]. Furthermore, the cost of finding additional reserves has increased tremendously. Gas wells are now being sunk to 20,000 feet.

Natural gas curtailment

Demand for natural gas exceeded supply for the first time in 1970. Since then natural gas curtailment has been rapidly increasing. It is estimated that from March 1975 to April 1976 total curtailment reached 2.9 Tcf [17]. Because of the cold winter of 1977, natural gas curtailment exceeded that rate. For the first time natural gas was curtailed to schools and many other "nonessential" users, as well as to large industrial users who had been curtailed on a much more regular basis.

Because of increasing curtailments, the Federal Power Commission (FPC) on March 2, 1973, issued order number 467-B establishing a uniform, nine-tier curtailment priority schedule based on the end use of the gas and size of customer [21]. Under this schedule, residential and small commercial users are given the highest priority during service curtailments, followed by large commercial users and industrial users who cannot switch to alternative fuels. More specifically the FPC established the following priorities [21]:

Priority 1. Residential, small commercial (less than 50 Mcf[1] on a peak day).

Priority 2. Large commercial requirements (50 Mcf or more on a peak day), firm industrial requirements for plant protection, feedstocks and process needs, and pipeline customer storage injection requirements.

Priority 3. All industrial requirements not specified in (2), (4), (5), (6), (7), (8), or (9).

Priority 4. Firm industrial requirements for boiler fuel use at less than 3,000 Mcf per day, but more than 1,500 Mcf per day, where alternate fuel capabilities can meet such requirements.

Priority 5. Firm industrial requirements for large for large volume (3,000 Mcf or more per day) broiler fuel use where alternate fuel capabilities can meet such requirements.

Priority 6. Interruptible requirements of more than 300 Mcf per day, but less than 1,500 Mcf per day, where alternate fuel capabilities can meet such requirements.

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[1] Mcf is 1,000 cubic-feet.

Priority 7. Interruptible requirements of intermediate volumes (from 1,000 Mcf per day through 3,000 Mcf per day), where alternate fuel capabilities can meet such requirements.

Priority 8. Interruptible requirements of more than 3,000 Mcf per day, but less than 10,000 Mcf per day, where alternate fuel capabilities can meet such requirements.

Priority 9. Interruptible requirements of more than 10,000 Mcf per day, where alternate fuel capabilities can meet such requirements.

Although natural gas used in irrigation was not specifically mentioned in the original order (467-B), the Federal Power Commission on November 13, 1975 issued an opinion number 745 which affirmed the initial decision reached by the Administrative Law Judge that irrigation pumping would be classified as commercial service, includable within priority 2, rather than industrial use [19]. In arriving at this determination, the presiding judge rejected electricity as an alternate fuel for irrigation, indicating that electricity is either unavailable or the conversion to electricity would be very expensive.

The permanence of any special consideration given to agriculture should be viewed with caution. There is a strong likelihood that other natural gas users will also press for special treatment. Some of these claims may have equal merit with those advanced by irrigation interests. Some government representatives feel that the nation's approach to curtailment should not rest upon judgements based primarily on the needs of particular groups considered in isolation. Speaking before the Senate Commerce Committee on September 15, 1975, FPC Chairman Nassikas said, "I recommend that the commission be allowed to make its decisions on

curtailment priorities based on the demonstrated needs of all gas consumers, not just those of a particular class or classes. I, therefore, oppose the enactment of legislation that would impose an automatic curtailment priority in favor of agriculture uses..." [6].

Natural gas deregulation

The recognition that natural gas regulation is a major cause for the natural gas crisis has led to many attempts to substantially modify the current laws effecting natural gas distribution. Because of the massive effort by consumer groups and some legislators, however, all attempts to deregulate natural gas have failed so far. But there is little doubt that sooner or later some form of natural gas deregulation will take place.

Many deregulation proposals have been suggested by legislators, the Federal Power Commission, and the Federal Energy Administration. Most of the deregulation proposals can be divided into three major categories [16]

1. Deregulate the sales of gas not previously contracted in interstate commerce. This proposal calls for the deregulation of "new" gas and other gas not already dedicated to interstate markets.
2. Deregulate gas from existing contracts that expire of their own terms. Thus, the proposal allows new contracts to be signed without any regulation requirements. This would phase out regulations gradually over time as new contracts are renegotiated.

3. Total deregulation for all present and future gas production. This proposal calls for immediate deregulation and allows contracts to be renegotiated regardless of their expiration dates.

Other proposals basically are variations of the above three proposals. These proposals and other issues of natural gas deregulation are discussed in the FPC report "A Preliminary Evaluation of the Cost of Natural Gas Deregulation [20]. The deregulation scenario examined in this study assumes that by 1985 natural gas will be deregulated except for those contracts still valid. Thus, this study assumes deregulation via proposal 2, i.e., deregulation would take place gradually at the rate in which the current contracts expire.

II. MODEL DESCRIPTION

The interregional model used in this study is a revised version of the energy model developed at The Center for Agricultural and Rural Development (CARD) in 1976 [10]. The analysis of the study is based on 1985, which provides a time span long enough to allow farmers to respond to the changing energy situation. Under all the alternatives analyzed, the model minimizes the total national cost of crop production, transportation, and agricultural inputs. This cost minimization procedure is subject to a set of primary restraints corresponding to land, water, and energy supplies by regions, production requirements by location, the nature of production, and a final set of commodity supply-demand relationships.

Activities in the model simulate crop rotations, soil conservation and tillage practices, water transfer and distribution, commodity transportation, and nitrogen and energy supplies. Endogenous crop activities are specified for barley, corn grain, corn silage, cotton, legume hay, nonlegume hay, oats, sorghum grain, sorghum silage, soybeans, sugar beets, and wheat. The projected production levels of all other crops and livestock are exogenously determined.

Regional Delineation

Two sets of regions are used in the analysis--producing areas and market regions. The boundaries of the market regions are defined from a compatible subset of producing areas and reflect the interregional nature of the study.

The producing areas (PA)

The 105 producing areas (Figure 2) are the basic units of the programming model. These areas are derived from the U.S. Water Resource Council's 99 aggregated subareas [44]. The producing areas are identical except for six aggregated subareas (ASA's) which are subdivided to be more consistent with agricultural production in these regions. Each producing area is an aggregation of contiguous counties approximating the ASA's boundaries. Producing areas 48 to 105 serve dual purposes since they define both agricultural production and water supply regions.

The market regions (MR)

The 28 market regions (Figure 3) are an aggregation of the 105 producing areas. Each market region represents an established commercial and transportation center and serves as the hub of commodity demands and transport linkages. The market regions also serve as the market framework for the two important agricultural inputs, nitrogen, and energy.

The major zones

For reporting purposes only, another set of regions is defined by aggregating adjacent market regions into seven major zones (Figure 4). The major zones are: North Atlantic, South Atlantic, North Central, South Central, Great Plains, Southwest, and Northwest.

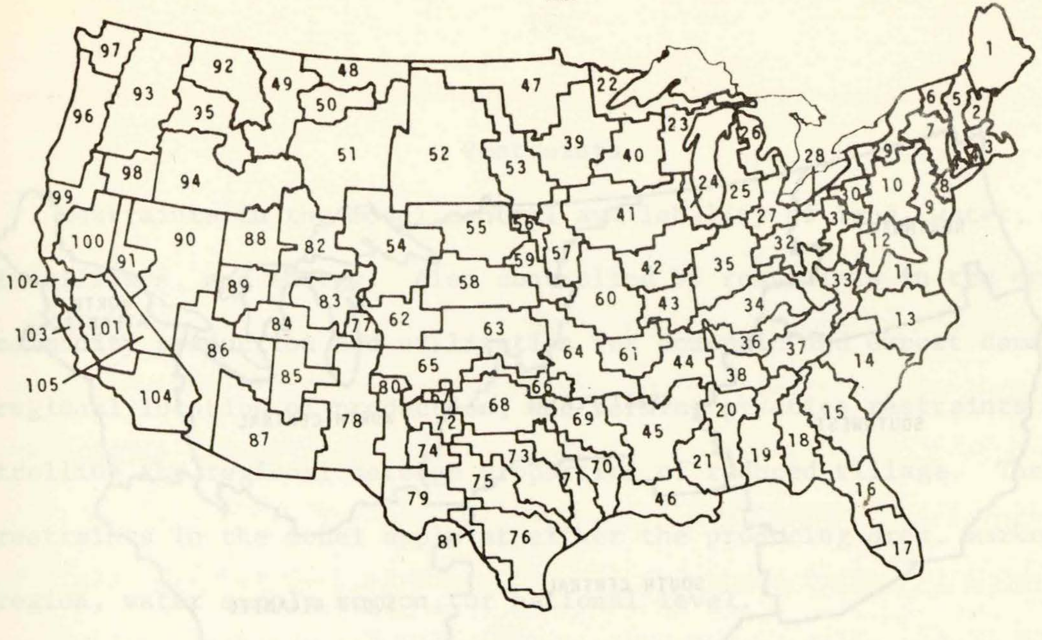

Figure 2. The 105 producing areas.

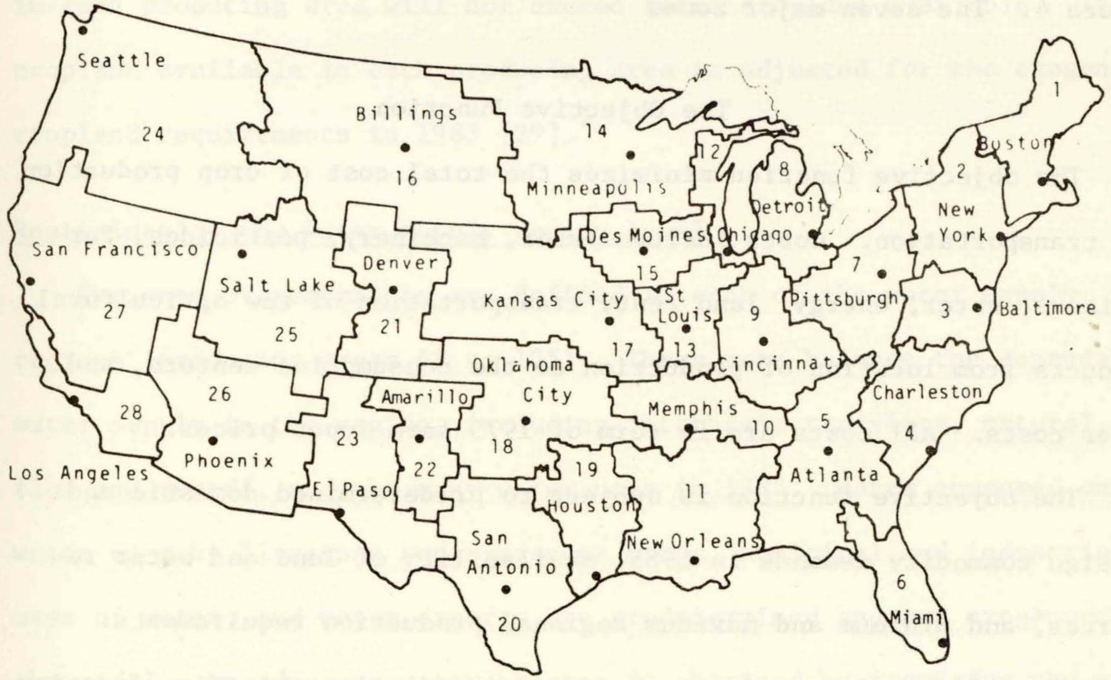

Figure 3. The 28 market regions.

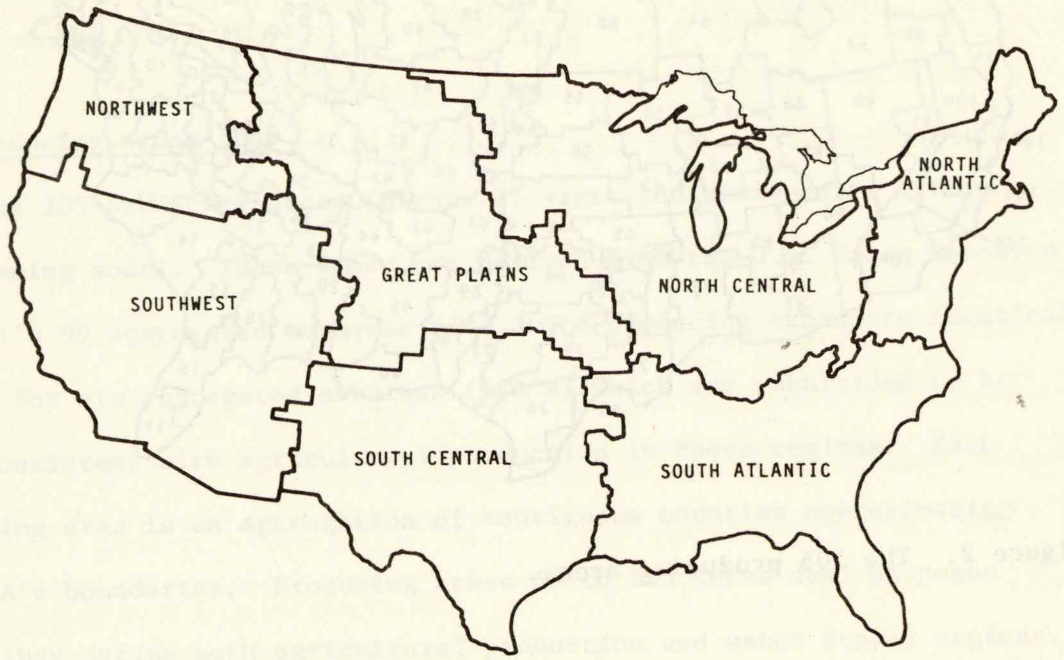

Figure 4. The seven major zones

The Objective Function

The objective function minimizes the total cost of crop production and transportation. Costs include labor, machinery, pesticides, fertilizers, water, energy, land rent, transportation of raw agricultural products from location of production to the consumption centers, and other costs. All costs are in term of 1975 farm input prices.

The objective function is subject to predetermined domestic and foreign commodity demands in 1985, availability of land and water resources, and minimum and maximum regional production requirements. Under one of the alternatives, the cost minimization objective function is also subject to a set of restraints enforcing natural gas curtailment for irrigation.

Restraints

Restraints in the model control availability of land, water, nitrogen fertilizers, and energy. Also controlled by restraints in the model are commodity production and utilization for domestic and export demands, regional location of production, and farming practice restraints controlling the regional acreage proportion of reduced tillage. The 938 restraints in the model apply at either the producing area, market region, water supply region, or national level.

Two sets of restraints are defined at the producing area level. They control the availability of dryland and irrigated cropland. The land restraints guarantee that total cropland (dry or irrigated) used in each producing area will not exceed total cropland available. The cropland available in each producing area is adjusted for the exogenous cropland requirements in 1985 [29].[1]

Restraints at the water supply region level

Two sets of restraints are defined in each of the water supply regions (producing areas 48 to 105). These sets balance the dependable water supply in the region, including interbasin transfers, natural flow and runoff, and the many water uses in 1985. Water consumed onsite, water used by livestock and exogenous crops, municipal and industrial uses of water, and water exports are predetermined and are exogenous to the model. An adequate water balance is obtained by requiring the water supply to be at least as great as the sum of the above exogenous uses

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[1] This adjustment is made by reducing the land available for endogenous crops by the acreage required for exogenous crops in each region by 1985.

and the endogenous crop demands. For the complete explanation of the water sector in the model see Colette [4].

Restraints at the market region level

Five sets of restraints are defined at the market region level. These restraints include commodity transfer restraints, regional location of production restraints, nitrogen market restraints, energy market restraints, and tillage practice restraints.

Commodity demand restraints These restraints simulate the marketplace for some of the endogenous commodities of the study: barley, corn grain, legume hay, nonlegume hay, oats, oilmeal, silage, sorghum, and wheat. Producing areas within each market region supply their commodities directly to their respective market region. Commodity demand restraints in other market regions are linked together by commodity transportation activities.

Regional production restraints One set of restraints is defined at the market region level to provide for minimum and maximum levels of crop production within each region. This set of restraints approximates the immobility of crop production due to economic factors such as risk aversion, and other noneconomic factors. Each region is required to maintain at least 70 percent of its 1969 crop acreages, but not more than 250 percent of 1969 acres [43]. The restraints are defined for the following crops: barley, corn grain, cotton, oats, sorghum grain, soybeans, sugar beets, and wheat.[1] Both irrigated and dryland crops can be used to satisfy the production restraints.

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[1] Other endogenous crops are not transported from region to region, therefore, regional demands served as restraints.

Nitrogen fertilizer transfer restraints Another set of restraints serves as a supply simulation for nitrogen fertilizers (Figure 5). Nitrogen is supplied from livestock by-products, from commercially produced fertilizers, and from the fixation process of the legume crops. It is used by both the endogenous and exogenous crop activities.

Energy transfer restraints Five sets of restraints are defined in each market region to simulate a market for energy sources (Figure 5 and Table 2). These restraints are defined for diesel fuel (R-DIESEL in gallons), natural gas (R-NAT. GAS in 1,000 cubic-feet), liquid pertoleum gas (R-LPG, in gallons), electricity (R-ELCT, in Kwh), and total energy market in terms of Mcal of energy. The regional energy needs are supplied by energy buying activities (R-BUY.DLS, R-BUY.NGAS, R-BUY.LPG, R-BUY.ENRG, Table 3) which withdraw energy from the national energy market restraints. Energy is used by crop activities, transportation activities, water supply activities, and commercial nitrogen fertilizer supply activities.

Tillage practice restraints One restraint in each market region is defined to control the proportion of reduced tillage acreages relative to the total cultivated acreage. This restraint reflects the time lag involved in changing farming practices. The time lag mainly reflects the learning process necessary as various groups of farmers adopt reduced tillage practices and the time for replacing farm machinery.

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[1] Mcal equal to one million calories. See Appendix F for conversion tables.

	CORN. DRY 1	CORN. DRY2	CORN. IRR1	CORN. IRR2	CORN. IRR3	CORN. IRR4	BUY. N	LIVE. N	BUY. G-W	BUY. S-W	NGAS. CONV	R-BUY. DSL	R-BUY. NGAS	R-BUY. LPG	R-BUY. ELCT	R-BUY. ENRG	N-BUY. DSL	N-BUY. NGAS	N-BUY. LPG	N-BUY. ELCT	N-BUY ENRG	row sign	RHS
OBJ	52.5	50.3	98.8	96.6	98.8	96.6	0.18	0.18	10.4	8.37	2.41	0.265	0.90	0.356	0.032							none	none
DRYLAND	1.0	1.0																				L	14949
IRRLAND			1.0	1.0	1.0	1.0																L	2199
NITRO	-138.3	-92.2	-153.9	-102.6	-153.9	-102.6	1.0	1.0														G	18,052
WATER			-1.5	-1.5	-0.75	-0.75			1.0	1.0												G	113.1
CURTL			1.3	1.3	0.65	0.65			3.2	0.1	-1.0											E	0
R-DIESEL	-7.6	-7.6	-17.9	-17.9	-17.0	-17.0			-4.6	-0.14	-2.3	1.0										E	0
R-NAT. GAS	-0.06	-0.04	-1.3	-1.3	-0.7	-0.7	-0.024		-3.2	-0.1	1.0		1.0									E	0
R-LPG	-3.7	-3.4	-17.1	-16.3	-13.3	-12.7			-5.9	-0.18				1.0								E	0
R-ELCT	-9.4	-6.3	-50.4	-47.0	-30.2	-26.9	-0.065		-100.1	-3.04	-57.0				1.0							E	0
R-ENERGY	-392.1	-378.	-1558	-1531	-1221	-1198	-5.572		-1374.2	-41.8	67.4					1.0						E	0
N-DIESEL												-1.0					1.0					E	0
N-NAT. GAS													-1.0					1.0				E	0
N-LPG														-1.0					1.0			E	0
N-ELCT															-1.0					1.0		E	0
N-ENERGY																-1.0					1.0	E	0
CORN	57.6	53.1	120.8	114.2	100.0	94.5																G	153,125
Upper bound	none	none	none	none	none	none	none	727298	1722.2	946.9	none	none	none	none	none	none	none	none	none	none	none		

Figure 5. CARD Energy Model II: A schematic representation.

Table 2. Explanations of restraints in Figure 5

Row Name	Explanation	Unit
OBJ	Objective function	dollars
DRYLAND	Dryland	acres
IRRLAND	Irrigated land	acres
NITRØ	Nitrogen fertilizer equivalent	lb. of N
WATER	Water balance	acre-feet
CURTL	Natural gas curtailment	1,000 cubic-ft.
R-DIESEL	Regional diesel fuel balance	gallon
R-NAT. GAS	Regional natural gas balance	1,000 cubic-ft.
R-LPG	Regional liquid petroleum gas balance	gallon
R-ELCT	Regional electricity balance	kwh
R-ENERGY	Regional total energy balance	Mcal(mil.cal.)
N-DIESEL	National diesel fuel balance	gallon
N-NAT. GAS	National natural gas balance	1,000 cubic-ft.
N-LPG	National liquid petroleum gas balance	gallon
N-ELCT	National electricity balance	kwh
N-ENERGY	National total energy balance	Mcal(mil.cal.)
CORN	Corn transfer restraint	bushel

The amount of reduced tillage acreage in each region by 1985 is allowed to increase by 24 percent from the 1974-1975 average level. A changing energy situation would likely encourage farmers to increase use of reduced tillage methods. To determine the amount of reduced tillage acreage, the tillage practice restraints interact with the tillage practice activities. This simulates the increased adoption of the reduced tillage.

Restraints at the national level

Two restraints are defined at the national level to control the national supplies and demands for cotton and sugar beets. The crop activities producing these commodities in each producing area are capable of supplying these commodities directly into the national market

Table 3. Explanation of activities in Figure 5

Activity Name	Explanation	Unit
CORN.DRY1	Dryland corn (full N)	acres
CORN.DRY2	Dryland corn (reduced N)	"
CORN.IRR1	Irrigated corn (full N, full water)	"
CORN.IRR2	Irrigated corn (reduced N, full water)	"
CORN.IRR3	Irrigated corn (full N, reduced water)	"
CORN.IRR4	Irrigated corn (reduced N, reduced water)	"
BUY.N	Commercial nitrogen supply	pound
LIVE.N	Nitrogen supply from livestock	
BUY.G-W	Ground water supply	acre-foot
BUY.S-W	Surface water supply	acre-foot
NGAS.CONV	Natural gas conversion	1,000 cubic-ft.
R-BUY.DSL	Regional diesel fuel supply	gallon
R-BUY.NGAS	Regional natural gas supply	1,000 cubic-ft.
R-BUY.LPG	Regional liquid petroleum gas supply	gallon
R-BUY.ELCT	Regional electricity supply	kwh
R-BUY.ENGR	Regional total energy supply	Mcal(mil.cal.)
N-BUY.DSL	National diesel fuel supply	gallon
N-BUY.NGAS	National natural gas supply	1,000 cubic-ft.
N-BUY.LPG	National liquid petroleum gas supply	gallon
N-BUY.ELCT	National electricity supply	kwh
N-BUY.ENRG	National total energy supply	Mcal(mil.cal.)
row sign	L = less than, G = greater than, E = equal to	
RHS	Right hand side	

restraints. In other words, no transportation activities are defined for these commodities.

Five energy restraints (one for each energy source) are also defined at the national level. These restraints (N-DISEL, N-NAT. GAS, N-LPG, N-ELCT, N-ENERGY, Figure 5) simulate national energy markets.

Activities

Basically, there are three classes of activities: (1) crop production activities; (2) commodity transportation activities; and

(3) resource supply activities, including water, ntirogen, and energy supply activities. The model has 11,600 activities.

Crop production activities

Crop production variables or activities simulate the rotations producing barley, corn grain, corn silage, cotton, legume and nonlegume hay, oats, sorghum grain, sorghum silage, soybeans, sugar beets, and wheat. The crop production activities represent crop management systems incorporating rotations of one to four crops covering from one to eight years. Each rotation, also, can be produced by conventional or reduced tillage methods (with the exception that rotations producing corn and sorghum silage are defined only as conventional tillage residue removed). Therefore, a maximum of three different conservation practices can be defined for each rotation.

Two levels of fertilizer applications are assumed in defining both dryland and irrigated crop activities. The first level assumes farmers apply an optimum amount of fertilizers. The optimum amount is derived by equating fertilizer costs with the marginal value product of fertilizer. The second level assumes farmers can only apply two-thirds of the above optimum level, a possible realization under a fertilizer shortage.

Two levels of water application are assumed in defining irrigated crop activities. The first level assumes that the amount of water applied is determined by equating the marginal cost of water to the marginal product of water. A water shortage, as well as increasing energy costs, would call for a movement "backward" on the water production function.

This movement would increase the marginal productivity of water and allow farmers to once more equate their marginal cost of water to its marginal value product.

For the second level, water application is reduced to half of the first level. Changes in yields for crops in irrigated regions under reduced water application are obtained from a set of regional weather oriented water production functions developed at The Center for Agricultural and Rural Development [15].

Combining the two nitrogen levels and the two water application levels we obtain four different combinations for irrigated crop activities: optimal nitrogen and optimal water, optimal nitrogen and reduced water, reduced nitrogen and optimal water, and reduced nitrogen combined with reduced water. These four combinations can be viewed as four points on the production function surfaces. By varying the proportions of each of the four combinations, it is possible to obtain irrigated activities with any desired level of nitrogen and water. Thus, the model simulataneously solves for the approximate optimal level of nitrogen fertilization and water application.

Commodity transportation

Transportation routes are defined between each pair of contiguous market regions. Basically the model is one of partial transshipment. However, some heavily used long haul routes between noncontiguous market regions also exist. Transportation routes are defined to represent the long haul routes if the route reduces the mileage by 10 percent over the accumulated short haul routes [29]. The activities are defined for each

commodity over each route--one activity for shipment in each direction. Commodity transportation activities are defined for the following crops: barley, corn, oats, sorghum, oilmeal, and wheat.

Transportation costs All grains and soybean products are assumed to be moved by railroads as the majority of the long hauls (200 miles and more) of grains are by railroads [14]. The costs of grain and soybean transportation, cents per ton-mile, are obtained from the 1975 Carload Waybill Statistics [22]. These costs vary according to the five railroad territories and the direction of the shipments.

Energy for transportation Energy requirements for transportation are greatly dependent upon the transportation mode. In deriving the energy transportation coefficients, it is assumed that all grains are moved by railroads and that one gallon of diesel fuel is required for each 235 ton-miles of shipment [14].

Resource supply activities

Water activities Three components are included in the water activities: downstream flows, interbasin flows, and water-buy activities. The downstream flows are bounded to a maximum of 75 percent of the available water upstream supply. The interbasin flows are bounded to a maximum of the water transfer system's capacity. Water-buy activities are bounded by the maximum available water supply in each water supply region [4].

Nitrogen-buy activities Commercially produced nitrogen-buy activities are not restrained and are defined in each of the market regions with the 1975 regional nitrogen prices. The commercial nitrogen-buy activities supply nitrogen and requires natural gas and electricity for production of the nitrogen (see Appendix C for energy consumed for fertilizer production).

In each market region a livestock by-product activity allows the transfer of the nitrogen produced by livestock to use by crops (Figure 5). The amount of livestock by-products available in terms of N equivalents is determined from the number of livestock units in each region, and the amount of N available from each unit of livestock [34]. The prices of nitrogen obtained from livestock by-products are set equal to the regional commercial nitrogen prices.

Energy-buy activities Five energy-buy activities are defined in each market region (Figure 5). These activities control the regional supply of diesel fuel (R-BUY.DSL in gallons), natural gas (R-BUY.NGAS in 1,000 cubic-feet), liquid petroleum gas (R-BUY.LPG in gallons), electricity (R-BUY.ELCT in Kwh), and a total energy supply (R-BUY.ENRG in Mcal). The activities transfer energy from the national energy markets to the regional energy market rows. Five additional activities allow for the control of the total amount of energy consumed in agricultural production (N-BUY.DSL, N-BUY.NGAS, N-BUY.LPG, NBUY.ELCT, NBUY.ENRG. Figure 5, Table 3). The 1975 regional energy prices (Appendix D) for diesel fuel, LPG and electricity are determined from the Statistical Reporting Service [36, 37]. The price of natural gas is based on the 1975 state commercial natural gas prices [1].

Natural gas conversion activities One set of activities allows for conversion from natural gas used for irrigation to other energy sources (NGAS.CONV, Figure 5, Table 3). The two most likely energy sources to replace natural gas for irrigation are diesel fuel and electricity. No information is available for determining which of these sources is more likely to be used in each region when natural gas is unavailable. Thus, it is assumed that the relative proportion of power units shifted to electricity or diesel will be the same as their relative proportions in 1975 [25]. For example, if in a given region in 1975, one third of the power units was electric, one third was run on natural gas, and one third run on diesel fuel; then after conversion it is assumed that one half of the previously natural gas power units will be converted to electricity and the other half to diesel engine. The conversion rates take into account the amount of diesel fuel or electricity required to replace 1,000 cubic-feet of natural gas while maintaining power output.

The cost of natural gas conversion includes the 1975 costs of the diesel fuel or electricity less the 1975 cost of 1,000 cubic-feet of natural gas. It does not include the cost of the investment in new power units, fuel storage, electric line or other development costs required for the conversion. This procedure is used not because these costs are unimportant, but because we assume that conversion will take place gradually over time as older natural gas power units are replaced.

Land Base

A major factor limiting production in agriculture is the availability of cropland. The total cropland acreage available in each producing area is estimated by data from the Soil Conservation Service

[5]. An adjustment is made for projected changes in exogenous land uses and irrigation development until 1985 (Table 4).

Table 4. U.S. land base acreages in 1985

Item	OBERS E' 1985 Projection[a]
	(thousand acres)
Dry cropland available for endogenous crops	336,690
Irrigated cropland available for endogenous crops	32,874
Total cropland available for endogenous crops	369,564
Land used by exogenous crops	23,662
Land used for pasture and nonrotation hay	941,835
Total cultivated land	1,335,061

SOURCE: U.S. Water Resources Council [45].

[a] OBERS E' projections are those used by the Economic Research Service for the Water Resources Council [31]. The E indicates the series and the prime indicates the adjusted E series.

Commodity Demands

The demands for all commodities in the study are determined exogenously. Regional commodity demands reflect the regional domestic population demands, regional livestock feed demands, and regional exports. The study assumes a U.S. population of 233.2 million people in 1985. The national domestic population commodity demands, U.S. actual export in 1975, U.S. 1985 projected exports, U.S. livestock feed demand, and total commodity demands are shown in Tables 5, 6, 7, and 8.

Table 5. Annual projected domestic human commodity demands by 1985

Commodity	Unit	Level of Demand
		(Million units)
Barley	bushel	185.6
Corn grain	bushel	507.1
Cotton	bale	6.8
Oats	bushel	91.3
Sorghum grain	bushel	12.4
Oilmeals	CWT	156.6
Sugar beets	ton	33.6
Wheat	bushel	640.0

SOURCE: U.S. Water Resources Council [45].

Table 6. NIRAP[a] projected "moderate" exports in 1985 and 1975 exports

Commodity	Unit	1975 Exports[b]	Moderate Exports[c]
		(Million units)	
Barley	bushels	30.2	51.6
Corn grain	bushels	1,316.5	1,608.0
Oats	bushels	13.4	13.2
Sorghum grain	bushels	228.3	213.6
Wheat	bushels	1,177.8	1,476.0
Soybeans	bushels	598.2	960.0
Cotton	bales	3.8	4.0

[a] NIRAP stands for National Interregional Agricultural Projection.

[b] SOURCE: Economic Research Service [14].

[c] SOURCE: U.S. Dept. of Agriculture [39].

Table 7. Projected feed demands by livestock in 1985

Feed	Unit	Quantities
		(Million units)
Barley	bushels	913.8
Corn grain	bushels	4,186.3
Legume hay	tons	102.0
Nonlegume hay[a]	tons	88.9
Oats	bushels	903.6
Oilmeals	CWT	522.5
Silage	tons	146.4
Sorghum grain	bushels	1,092.9
Wheat	bushels	469.7

[a] Include only nonlegume crops grown for hay.

Table 8. Total national commodity demands projected for 1985 and actual production in 1975

Commodity	Unit	1975 production[a]	1985 Demand
		(Million units)	
Barley	bushel	383.9	1,151.0
Corn grain	bushel	5,797.1	6,301.4
Cotton	bales	8.3	10.8
Legume hay	ton	77.8	102.0
Nonlegume hay	ton	54.9	89.9
Oats	bushel	657.6	1,008.1
Sorghum grain	bushel	760.1	1,319.0
Silage	ton	143.7	146.4
Soybeans	bushel	1,546.1	2,326.2
Sugar beets	ton	29.7	33.6
Wheat	bushel	2,134.8	2,585.7

[a] SOURCE: Statistical Reporting Service (1976)[38].

Model Revisions and Modifications

The previous CARD energy model [10] was the first systematic national approach providing a quantitative model model for analysis of energy use in agricultural production. Since the completion of that model, new data on energy use in agriculture have been compiled by U.S. Department of Agriculture [40]. In addition, several project advisers suggested other revisions and modifications which were incorporated into the current model. Some sectors of the current model are based on previous CARD models [29, 31] and on the previous CARD energy model [10]. The following section summarizes the major changes in the current agricultural energy model.

Energy for irrigation

The revised version of this sector of the model has been published as a miscellaneous report [9]. The revision includes (a) using 1975 data from the Irrigation Journal [25], pumping depth by state and pumping of surface water from Slogget [35], (b) incorporating new data on expected fossil fuel to electricity conversion rates by regions from Federal Energy Administration [17], and (c) other minor changes. The amount of energy required to obtain and apply one acre-foot of water by producing area is shown in Appendix B.

Energy use by crops

The amount of fuel required for field operations including diesel fuel, gasoline, LPG, and other minor fuel is obtained from "Energy and U.S. agriculture, 1974 Data Base" prepared by the U.S. Department of

Agriculture and the Federal Energy Administration [40]. The basic data contains the amount of fuel required for each crop by state. State data have been converted to producing area energy requirements (Appendix A) by using weights obtained from [43]. The derivation of energy requirements for crop drying, fertilizers, and pesticide is explained in Appendix C.

Water production functions

Increased energy prices and depletion of ground water tend to increase water cost. Higher water cost would normally call for a reduction in the amount of water applied per acre. A smaller water application is expected to reduce crop yields. To account for the changes in yield as a function of water use, a set of water production functions was developed. These production functions reflect both crop water requirements as well as the local climatical conditions and are explained elsewhere [15].

Ground and surface water supplies

Increased energy prices make it important to differentiate between ground water supply which requires large amounts of energy for pumping, and the surface water supply which uses little or no energy. The cost of ground water pumping is a function of the regional pumping depth (Appendix B, Table B.1) the power units used in the region (Appendix B, Table B.2), the amount of fuel required to produce mechanical pumping power (Appendix B.5), and energy required to apply one acre-foot of water by region (Appendix B, Table B.7). The amount of power required to pump one acre-foot of water one foot (assuming pumping efficiency is 60 percent) is 2.2883 Hp-Hr.[1] Thus, pumping one acre-foot of water from a depth of 100 feet to the surface would require either 17.8 gallons of diesel fuel, or 25.3 gallons of gasoline, or 2,860.4 cubic-feet of natural gas, or 29.6 gallons of LPG, or 258.6 KWH of electricity. The variable cost of water also includes the cost of lubrication and maintenance at the rate of 15 percent of the energy costs for internal combustion power units (diesel, LPG gasoline, and natural gas). No lubrication or maintenance costs are used for electrically powered pumps.

Crop production costs

A set of production costs for dryland and irrigated crops was derived from 1973 and 1974 crop budgets of the Firm Enterprise Data Systems [12]. All costs and prices used in the budgets are updated to 1975. The crop costs data reflect inputs and prices as of 1975. Nitrogen fertilizer costs as well as water costs are charged through the nitrogen and water buying activities.

Alternatives Evaluated and Their Assumptions

Five different alternatives are examined in the study. These alternatives evaluate the national and regional impacts of a potential natural gas crisis and increased energy prices. The alternatives are Base Run (Alternative A), Natural Gas Deregulation (Alternative B), Natural Gas Curtailment (Alternative C), Doubled Energy Prices (Alternative D), and Tripled Energy Prices (Alternative E). The analysis is

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[1] Hp-Hr is an energy unit equal to 641.616 Kcal. See Appendix F for other conversion.

made for 1985, a period far enough in the future to allow adjustments in production methods, inputs used, and possible regional shifts of agricultural production.

Base Run (Alternative A)

This base alternative is used for comparison with all the other alternatives. It assumes energy prices remain at their 1975 level and no natural gas deregulation takes place. The results of this alternative, therefore, reflect the expected changes in production and commodity prices in response to the expected higher agricultural exports assumed for 1985.

Natural Gas Deregulation (Alternative B)

This alternative assumes a complete natural gas deregulation by 1985, except for those natural gas delivery contracts still valid. The deregulated natural gas prices used in the analysis are derived from the FEA's 1977 National Energy Outlook [18]. These prices are expressed in 1975 dollars (Appendix D). Deregulation of natural gas is expected to more than double its 1975 average national price from an average of $1.271 per 1,000 cubic-feet to $2.880 per 1,000 cubic-feet after deregulation.

Natural Gas Curtailment (Alternative C)

This alternative assumes that the Department of Energy requires users of natural gas for irrigation to switch to alternative energy sources. Removal of natural gas from irrigation is achieved by forcing the natural gas use for irrigation in each water supply region to be converted to other energy sources such as diesel fuel and electricity. For simplification, it is assumed that farmers will replace their irrigation power units by either diesel engines or electric motors. The relative proportions of diesel to electric power units after the curtailment are assumed to be the same as their relative 1975 proportions.

Substitution of diesel or electric power units for natural gas engines would require a substantial investment by farmers. The curtailment scenario assumes, however, that the substitution occurs gradually over time and only as old natural gas engines are worn out.

Doubled Energy Prices (Alternative D)

This alternative assumes that energy prices will be twice their 1975 level by 1985. This implies that energy prices will rise at an average annual rate of 7 percent. The reasons for such increases are many and include higher costs for imported oil, some form of natural gas deregulation, stricter environmental restrictions on power plants, increased use of higher energy cost sources such as coal liquification, solar energy, nuclear power, and others.

Tripled Energy Prices (Alternative E)

This scenario is similar to Alternative D except that energy prices are assumed to triple by 1985. Tripling of energy prices in 10 years requires energy prices rise at an average rate of 12 percent per year. By comparison the index of fuel and energy prices used by farmers rose at the average rate of about 15 percent per year from 1972-76 [37].

III. ENERGY AND AGRICULTURAL PRODUCTION

A main component for plant growth is solar energy which continuously flows from the sun. This solar energy is both captured and stored in the plant's structure. Although, physically the process of collecting solar energy by plants can be performed without any fossil fuel energy, an efficient crop production process requires large amounts of nonrenewable fossil fuel energy.

From an economic point of view, the amount of solar energy stored in food commodities is of little concern because this energy is both free and has an unlimited supply. On the other hand, we are urgently concerned with the fossil fuel energy expended in food commodity production because most of the fossil fuel energy use in today's agriculture is both nonrenewable and is rapidly being exhausted.

Energy Costs and Production Costs

From an economic viewpoint, we are not only interested in the amount of energy in crops, but also in the costs of the fossil fuel energy they embody. To further clarify the relationships between crop production and energy use in agriculture, the relationships between fossil fuel energy costs in crop production and total production costs are examined.

In general, energy costs are a relatively small proportion of total production costs (Table 9). Energy costs vary from a low of $2.7 billion per year in the Base Run Alternative to a high of $7.8 billion under

tripling of energy prices (a 186 percent cost increase). Even with the sharp increase in energy costs under the last two alternatives, the proportion of energy costs remains rather small. For example, tripling of energy prices would only cause energy costs to account for 8.0 percent of total production costs. This percentage would be smaller, however, since other input prices are not likely to remain constant as assumed in the analysis. It should be emphasized that energy values in Table 9 are only for direct and some indirect energy uses such as fertilizers and pesticides. The cost of energy does not, for example, include indirect energy costs such as that used in the manufacturing of farm machinery.

Almost two thirds of the total production costs in the analysis are land charges. The land costs are based on the rent values equal to the generated marginal value product of land derived from the model.

All of the alternate energy situations resulted in increased production costs over the Base Alternative. The smallest increase (3.4 percent) occurs under Natural Gas Curtailment for irrigation. Natural Gas Deregulation, however, leads to a larger increase (4.9 percent) in production costs than does Natural Gas Curtailment. Increased costs under Natural Gas Curtailment, however, do not include investment costs associated with replacement of natural gas power units in irrigation with the alternative energy sources, diesel and electricity. If we account for these investment costs, the Natural Gas Curtailment alternative is likely to have a much greater impact on production costs than shown in Table 9.

Table 9. Distribution of production costs by input under the various alternatives

Input	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
			(Millions of dollars)		
Energy[1]	(2,729)	(3,371)	(2,741)	(5,241)	(7,806)
Land	57,392	60,663	60,227	62,726	64,776
Water	952	1,058	1,081	1,218	1,463
Labor	3,854	3,852	3,849	3,843	3,832
Pesticide	1,442	1,483	1,462	1,510	1,606
Nonnitrogen Fert.	2,827	2,825	2,834	2,828	2,817
Nitrogen Fert.	4,467	5,322	4,466	5,193	5,881
Machinery	15,804	15,802	15,797	15,758	15,721
Others	937	939	937	937	937
Total	87,675	91,944	90,653	94,012	97,033
			(Percentage Distribution)		
Energy[1]	(3.1)	(3.7)	(3.0)	(5.6)	(8.0)
Land	65.5	65.9	66.4	66.7	66.7
Water	1.1	1.2	1.2	1.3	1.5
Labor	4.4	4.2	4.3	4.1	3.9
Pesticide	1.6	1.6	1.6	1.6	1.7
Nonnitrogen Fert.	3.2	3.1	3.1	3.0	2.9
Nitrogen Fert.	5.1	5.8	4.9	5.5	6.1
Machinery	18.0	17.2	17.5	16.8	16.2
Others	1.1	1.0	1.0	1.0	1.0
Total	100.0	100.0	100.0	100.0	100.0

[1] Energy numbers are in parentheses because energy is embodied in other inputs. Thus, energy figures should not be added to other figures in their respective columns.

Proportion of Energy Costs by Region

Large variations exist between regions in the percent of total production costs represented by energy costs (Table 10). In the three eastern regions (North Atlantic, South Atlantic and North Central) and the Great Plains region, a relatively smaller proportion of their production costs are energy costs when compared to the western regions. The highly irrigated regions (South Central and Southwest) are likely to devote a much larger proportion of their costs to energy as energy price increases. In the Southwest region, tripling of energy prices would require that almost 15 cents of every dollar in production costs be used for energy. In general, the proportion of energy costs are about twice as large for the irrigated western regions than for rainfed eastern regions.

Natural Gas Curtailment does not seem to have much impact on the proportion of production costs used for energy. However, Natural Gas Deregulation would increase the proportion of production costs due to energy costs especially for the South Central and for the Great Plains regions. In both regions the impact results from the extensive use of natural gas for irrigation.

Energy Use, Prices and Costs

Energy use would be smaller than in the Base Run under all of the alternatives examined. Even though the changes in some energy sources are substantial, total reduction in energy use is quite small even when energy prices are tripled (Table 11). The use of diesel fuel and LPG varies only slightly (less than 2 percent) under all of the alternatives. On the

Table 10 . Changes in energy costs from the Base Run and energy costs as a percentage of total production costs under various alternatives, 1985

Major Zone	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Million Dollars)	(Changes in energy costs from the base run)			
North Atlantic	89	+10.1	No change	+100.0	+200.0
South Atlantic	288	+23.6	-0.7	+97.2	+195.8
North Central	1,052	+20.2	No change	+99.2	+198.8
South Central	458	+32.1	+3.5	+87.1	+175.5
Great Plains	475	+29.7	+1.9	+100.2	+195.6
Northwest	149	+27.5	No change	+41.6	+112.1
Southwest	219	+10.0	-5.9	+74	+156.6
United States	2,730	+23.5	+0.4	+92	+186.0
		(Energy costs as a percentage of total production costs)			
North Atlantic	2.6	2.7	2.5	4.9	7.0
South Atlantic	2.6	3.1	2.5	4.9	7.0
North Central	2.9	3.3	2.8	5.4	7.7
South Central	3.7	4.7	3.7	6.6	9.3
Great Plains	2.8	3.5	2.8	5.2	7.7
Northwest	3.6	4.5	3.5	4.8	6.8
Southwest	6.6	6.8	5.9	10.5	14.7
United States	3.1	3.7	3.0	5.6	8.0

Table 11. Changes in U.S. energy use, prices, and costs in agricultural production under various alternatives

Energy Use, Prices and Costs by Energy Source	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
Energy Use:		(Percentage change from Alternative A)			
Diesel fuel(mil.gal)	4,928	No change	+1.0	-0.6	-0.8
Natural gas(mil.cubic-ft)	437.314	-3.4	-13.0	-4.0	-5.4
LPG (mil. gal)	670	-0.8	-1.3	-1.6	-1.9
Electricity(mil. Kwh)	15,894	-3.4	+13.8	-22.1	-23.7
Total energy(mil. Mcal)	318,496	-1.5	-2.8	-3.1	-3.8
Energy Prices:					
Diesel fuel($/gal)	0.306	No change	No change	+100.1	+200.1
Natural gas($/1,000 cubic-ft)	1,272	+125.9	+0.7	+99.7	+199.9
LPG($/gal)	0.357	+0.2	No change	+100.2	+200.3
Electricity($/Kwh)	0.027	No change	No change	+112.8	+218.9
Total Energy ($/Mcal)	0.856	+25.5	+3.4	+94.7	+197.4
Energy Costs:					
Diesel fuel(mil. dollars)	1,507.200	No change	+0.9	+98.8	+197.6
Natural gas(mil dollars)	556.110	+118.3	-12.4	+91.8	+183.8
LPG(mil.dollars)	239.287	-0.7	-1.3	+96.9	+194.4
Electricity(mil. dollars)	426.650	-3.5	-16.3	+65.7	+143.3
Total Energy(mil. dollars)	2,729.249	+23.5	+0.4	+92.0	+186.0

[a] Kwh is a 1,000 watts (kilowatt).

[b] Mcal is a million calories.

other hand, natural gas and electricity in some alternatives vary substantially. This is the explanation for the small changes in total energy use because diesel fuel and LPG account for about 60 percent of the energy use in agricultural production.

Natural gas prices would increase about 126 percent under Natural Gas Deregulation. The deregulation would result in a 118 percent increase in the costs of natural gas to farmers and an overall increase of 24 percent in energy costs. These increases, however, would result in a decline of less than 4 percent in natural gas use.

Natural Gas Curtailment to irrigation is assumed to have no impact on energy prices. It would have, however, a small impact on energy costs because of changing energy sources. Natural Gas Curtailment would result in a 13 percent reduction in natural gas use and almost an equal increase in electricity use. This shift results because electricity is widely used for irrigation in the West and its use in irrigation is likely to expand as the relatively scarce natural gas is being diverted to other nonagricultural uses. It should be noticed, however, that the 13 percent reduction in natural gas use in agriculture (about 57 billion cubic-feet per year) would have almost no impact on the total U.S. natural gas consumption, since this reduction amounts to less than one third of one percent of the yearly U.S. natural gas consumption (about 20 trillion cubic-feet) for all purposes.

Doubling of Energy Prices does not double energy costs since energy consumption declines. Although total energy costs increase by 92 percent, electricity costs increase by only 66 percent. This dampened increase in electricity is due to a sharp reduction (22 percent) in electricity consumption. Most of that reduction occurs in the use of electricity for irrigation in the West. Doubling of Energy Prices would reduce natural gas use by 4 percent mainly because of reduction in nitrogen fertilizer use.

Impacts similar in direction but different in size result from Tripling of Energy Prices. Although energy prices triple, energy costs increase by only 186 percent due to a percentage reduction in total energy use. The additional reductions in both electricity and natural gas use, because of a 100 percent increase in energy prices (from Doubled to Tripled Energy Prices), are not as large as the reductions after the first 100 percent increase (from the Base Run to Double Energy Prices) in energy prices. This is because energy demands in agriculture become less inelastic as energy prices increase as suggested in Figure 6.

Regional Variation in Use of Energy Sources

Large variations exist in the distribution of energy costs among regions (Figure 7). Eastern regions spend almost three quarters of their energy costs on diesel fuel in the Base Run. In the West, less than a third of the energy costs is spent on diesel fuel (Table 12, Alternative A).

For all alternatives, increased energy prices have only small impacts on the proportion of energy costs in the form of diesel fuel. Natural gas cost is expecially important for the irrigated western regions. In the South Central region, cost of natural gas accounts for one third of

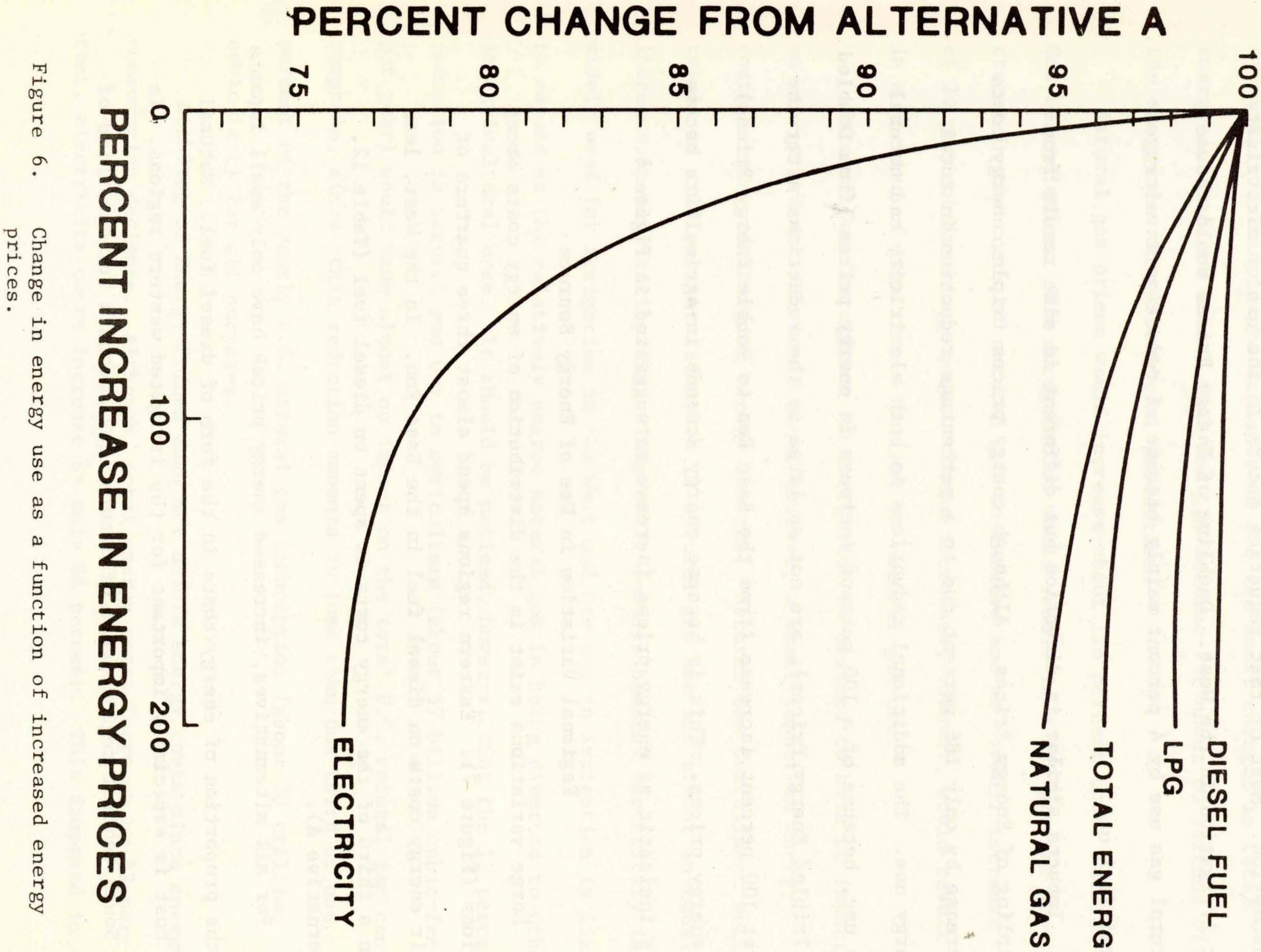

Figure 6. Change in energy use as a function of increased energy prices.

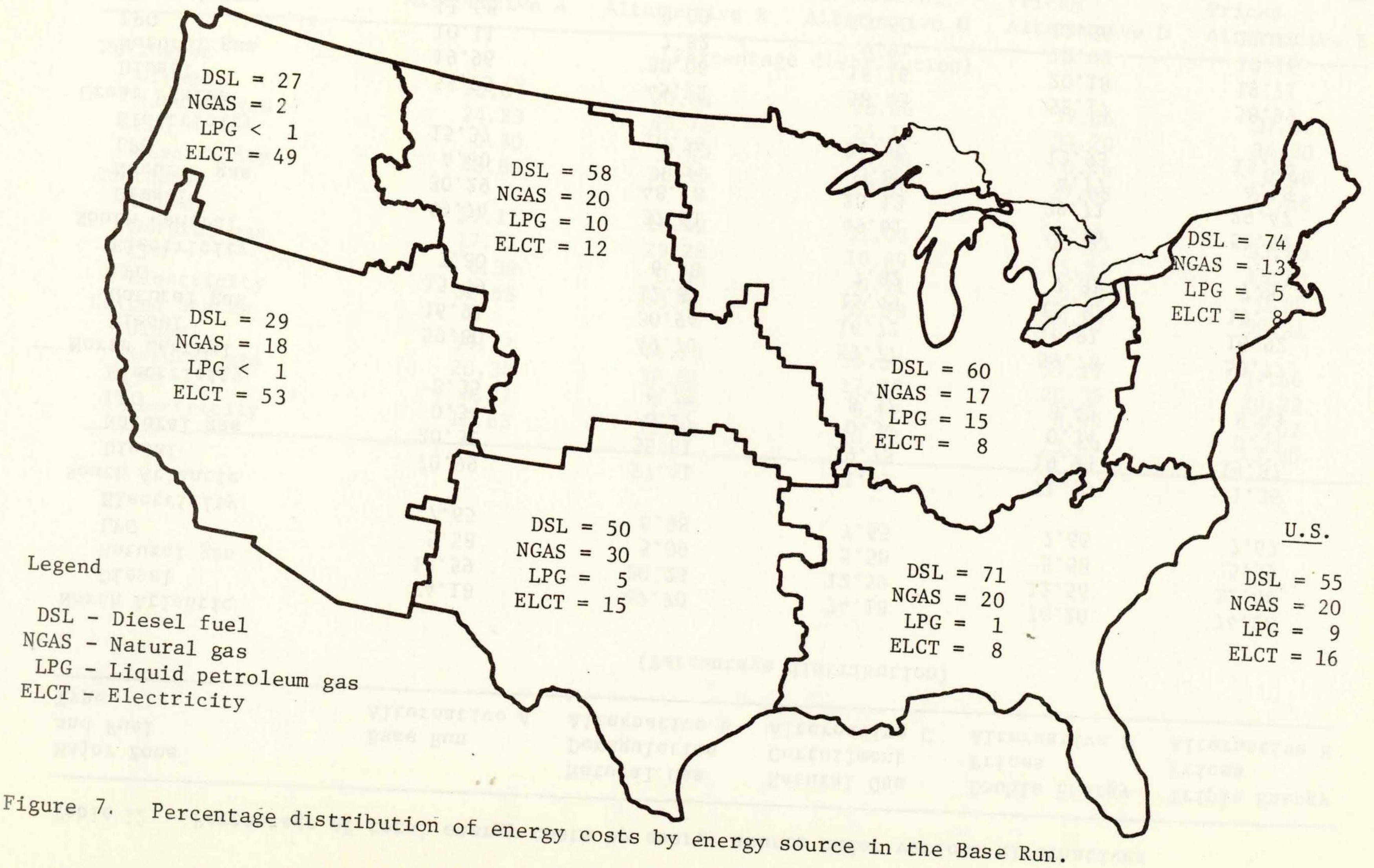

Figure 7. Percentage distribution of energy costs by energy source in the Base Run.

Table 12. Percentage of total energy costs by energy source under various alternatives

Major Zone and Fuel Type	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Percentage distribution)				
North Atlantic					
Diesel	74.18	67.70	74.18	74.20	74.28
Natural gas	12.59	20.23	12.59	12.56	12.46
LPG	5.58	5.09	5.58	5.58	5.59
Electricity	7.65	6.98	7.65	7.66	7.67
South Atlantic					
Diesel	70.99	57.41	71.51	71.30	71.36
Natural gas	20.32	35.61	19.78	19.93	19.87
LPG	0.34	0.27	0.34	0.34	0.34
Electricity	8.35	6.71	8.37	8.43	8.43
North Central					
Diesel	59.80	49.73	59.77	59.78	59.77
Natural gas	16.91	30.94	16.72	16.91	16.92
LPG	15.49	12.85	15.49	15.50	15.50
Electricity	7.80	6.48	7.82	7.81	7.81
South Central					
Diesel	49.74	37.51	49.61	52.19	52.56
Natural gas	30.29	48.48	20.13	29.71	29.47
LPG	4.60	3.25	3.80	4.17	4.18
Electricity	15.37	10.76	26.46	13.93	13.79
Great Plains					
Diesel	58.25	45.12	58.43	58.17	58.99
Natural gas	19.96	38.06	18.16	20.18	19.71
LPG	10.11	7.82	9.91	10.09	10.16
Electricity	11.68	9.00	13.50	11.56	11.14

Table 12. (continued)

Major and Fuel Type	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Percentage distribution)				
Northwest					
Diesel	26.67	20.84	26.66	37.66	37.66
Natural gas	24.23	40.78	24.18	34.20	34.20
LPG	0.30	0.23	0.30	0.46	0.46
Electricity	48.80	38.15	48.86	27.68	27.68
Southwest					
Diesel	29.11	26.42	31.02	33.33	33.83
Natural gas	17.82	29.28	10.69	15.25	15.50
LPG	0.39	0.35	0.41	0.45	0.46
Electricity	52.68	43.95	57.88	50.97	50.21
United States					
Diesel	55.22	44.73	55.50	57.17	57.46
Natural gas	20.38	36.01	17.78	20.35	20.22
LPG	8.77	7.05	8.62	8.99	9.02
Electricity	15.63	12.21	18.10	13.49	13.30

the total energy costs. Its proportion increases to almost half of all energy costs under Natural Gas Deregulation. It declines to only 20 percent under Natural Gas Curtailment (Table 12).

Liquid petroleum gas (LPG), used for drying corn, is an important part of the energy costs in the North Central and the Great Plains regions. LPG costs in western regions are small since little crop drying takes place there; and only 4 percent of the power units in the West are powered by LPG [25].

Electricity accounts for only 16 percent of the total energy costs in the Base Run. However, in western irrigated regions (Northwest and Southwest) about half of all energy costs is for electricity. In the dryland regions, electricity accounts for less than 10 percent of all energy costs. A sharp reduction in the proportion of energy costs represented by electricity occur in the Northwest region under Double Energy Prices Natural Gas Deregulated and Trible Energy Prices. This large reduction occurs as less land is irrigated and less electricity is required for irrigation.

Energy Distribution by Inputs

On the average, about half of all the energy in agriculture is used as a source of power for the various machines employed in farming (Table 13). The second most energy intensive input is nitrogen fertilizers. About a quarter of all energy required in crop production is consumed in the production of nitrogen fertilizers. The third most energy intensive input is irrigation. It requires about 10 percent of all the energy in

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Table 13. Energy use in crop production and percentage distribution by inputs under various alternatives

Inputs	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative	Triple Energy Prices Alternative E
			(Million Mcal)		
Fuel for Machinery	147,070.5	147,217.9	147,124.5	146,205.2	145,947.3
Pesticides	6,970.0	6,977.1	6,991.8	7,039.1	7,089.8
Nitrogen fertilizers[a]	81,452.4	80,825.8	81,391.3	81,109.1	79,754.8
Nonnitrogen fertilizers	9,381.7	9,393.6	9,402.4	9 394.7	9,396.4
Crop Drying	13,781.4	13,766.1	13,788.9	13,753.6	13,752.7
Irrigation	37,041.0	32,833.3	29,267.8	28,705.0	28,059.0
Transportation	22,799.0	22,728.8	21,735.4	22,584.1	22,475.1
Total	318,496.0	313,742.6	309,702.1	308,790.8	306,556.9
			(Percentage distribution)		
Fuel for Machinery	46.17	46.93	47.50	47.35	47.62
Pesticides	2.19	2.22	2.26	2.28	2.31
Nitrogen fertilizers[a]	25.57	25.76	26.28	26.27	26.03
Nonnitrogen fertilizers	2.95	2.99	3.04	3.04	3.07
Crop Drying	4.33	4.39	4.45	4.45	4.49
Irrigation	11.63	10.47	9.45	9.30	9.15
Transportation	7.16	7.24	7.02	7.31	7.33
Total	100.00	100.00	100.00	100.00	100.00

[a] Energy for nitrogen fertilizers indicates energy for commercially manufactured nitrogen fertilizers.

agricultural production. Other inputs account for a small proportion of the total energy use.

The proportions of energy used by inputs do not change much between the alternatives examined. However, a few changes occur. Natural gas curtailment to irrigation reduces energy used in irrigation by about 21 percent (Table 13). Because of that reduction, the proportion of energy used for irrigation declines and the proportion of energy used for fertilizer increases. Natural gas deregulation reduces energy use for irrigation by 11 percent. Energy use for irrigation declines by 23 and 24 percent under Doubling and Tripling of Energy Prices, respectively. Energy used for nitrogen fertilizer declines by only 2 percent under a tripling of energy prices. In general, irrigation is the most flexible input in response to the changes in the energy alternatives examined. When energy prices are tripled, 75 percent of the reduction in total energy use results from changes in irrigation.

Regional Energy Demands

Great differences exist in the regional responses to increased energy prices. In general, the patterns of energy consumption in the dryland regions (North Atlantic, South Atlantic, and North Central) change but little in response to increased energy prices (Figure 8). On the other hand, the western irrigated regions (South Central, Great Plains, Northwest and Southwest regions) show substantial reductions in energy use when energy prices rise.

Except for the Great Plains region, all the regional derived demand curves slope downward. The demand curve for the Great Plains region

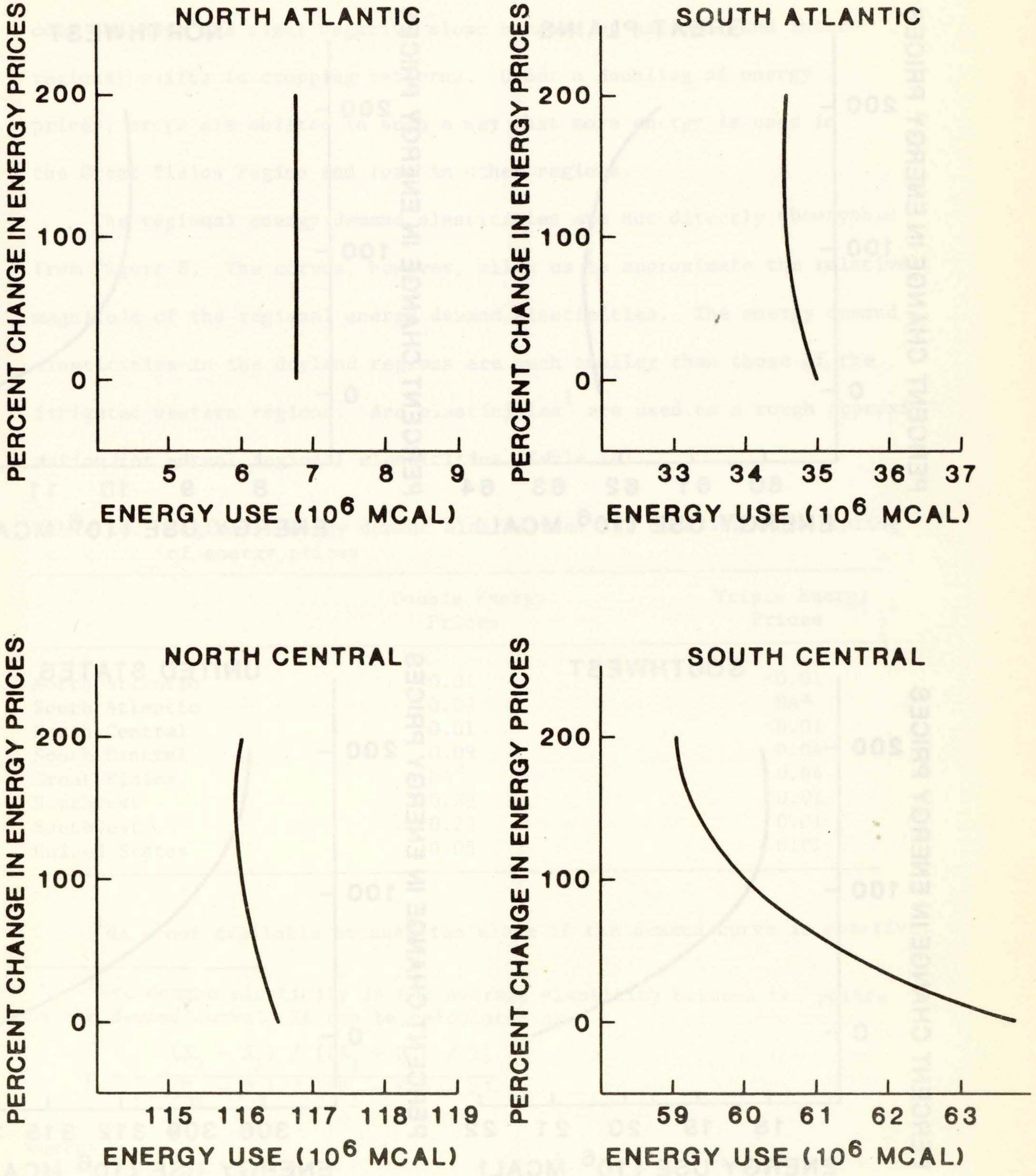

Figure 8. Regional changes in energy consumptions under increased energy prices.

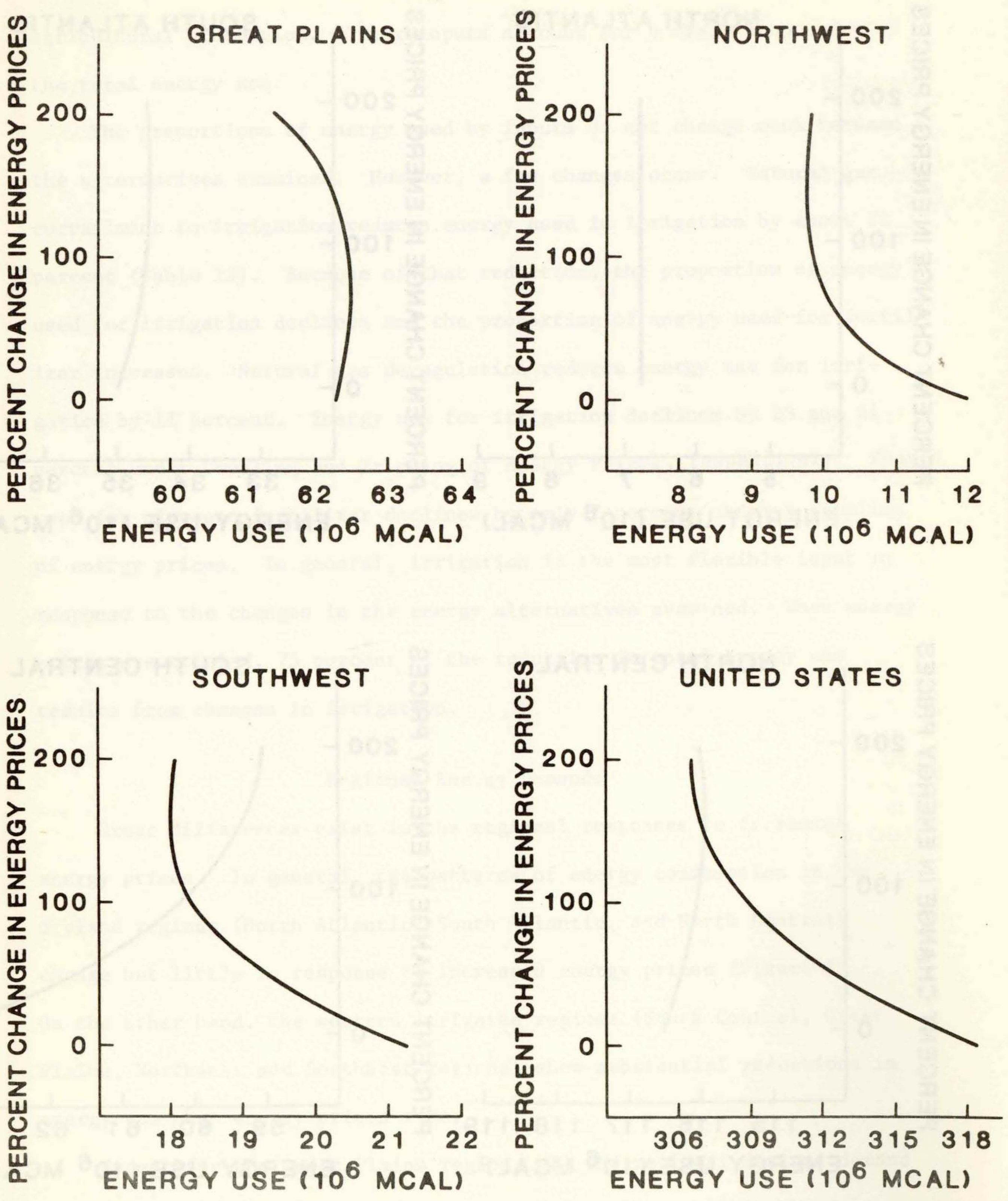

Figure 8. (continued)

does not have the right negative slope because of national and interregional shifts in cropping patterns. Under a doubling of energy prices, crops are shifted in such a way that more energy is used in the Great Plains region and less in other regions.

The regional energy demand elasticities are not directly observable from Figure 8. The curves, however, allow us to approximate the relative magnitude of the regional energy demand elasticities. The energy demand elasticities in the dryland regions are much smaller than those of the irrigated western regions. Arc elasticities[1] are used as a rough approximation for actual regional elasticities (Table 14).

Table 14. Regional energy demand elasticities for doubling and tripling of energy prices

	Double Energy Prices	Triple Energy Prices
North Atlantic	<0.01	<0.01
South Atlantic	0.02	NA[a]
North Central	0.01	<0.01
South Central	0.09	0.04
Great Plains	NA[a]	0.04
Northwest	0.29	<0.01
Southwest	0.23	0.01
United States	0.05	0.01

[a] NA - not available because the slope of the demand curve is positive.

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[1] Arc demand elasticity is the average elasticity between two points on the demand curve. It can be calculated as

$$\eta = - \frac{(X_2 - X_1) / [(X_1 + X_2) / 2]}{(P_2 - P_1) / [(P_1 + P_2) / 2]}$$

where:

X_1, X_2 are the quantities demanded; and

P_1, P_2 are the prices.

The regional arc energy demand elasticities are computed at two intervals. The first interval is between 1975 and Double Energy Prices. The second interval is between Double Energy Prices and Triple Energy Prices. All the regional elasticities are inelastic (elasticity coefficient < 1.0). However, under Doubling of Energy Prices, the energy demand elasticities of western irrigated regions are much larger than those for dryland regions. The Northwest and the Southwest regions have the most elastic energy demands. Thus, these regions are expected to show considerably larger changes in energy use than other regions in response to rising energy prices.

The regional demands are very inelastic as energy prices are tripled (Table 14), and some regional elasticities approach zero. Although the Northwest and Southwest regions have high elasticities under Doubling of Energy Prices, they decline to around 0.01 for Tripling Energy Prices. Thus, without introducing new energy-saving technology, most of the opportunity to reduce energy use in farming is eliminated after energy prices have doubled.[1]

Changes in Cropping Patterns

The various energy alternatives are expected to change the cropping pattern over the U.S. For example, increased energy costs increase the relative advantage of dryland crops. Thus, some shifts from irrigated crop production toward dryland crop production should take place. In the study, these shifts are quite limited as most of the dry cropland is already utilized in the Base Run Alternative.

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[1] It should be remembered, however, that the analysis assumes unchanged exports and domestic commodity demands. The demand levels assumed in the study require almost a complete utilization of cropland. If these demands are not maintained at their assumed levels, then energy use in agriculture could be reduced further.

The overall changes for seven crops are shown in Table 15. Changes for other crops are relatively small and, therefore, they have been left out of Table 15.

Natural gas deregulation would increase dryland production mainly for barley, cotton, and sorghum grain. It also would reduce irrigated production for the above crops. The reductions in irrigated sorghum and cotton would take place in the South Central region. Increased dryland production for these crops would take place in the Great Plains and in the South Central regions (Figure 9). Thus, Natural Gas Deregulation would shift irrigated cotton to dryland cotton production in the South Central region. It also would shift some irrigated sorghum production out of the South Central region without a compensating increase in dryland sorghum production.

Curtailment of natural gas to irrigation would reduce irrigated acres especially for barley, cotton, and sorghum grain. Irrigated crop acreages of these crops would be reduced by more than 3 percent. Again, most of the reduction in irrigated acres would take place in the South Central region. Although under Natural Gas Curtailment, irrigated sorghum grain is reduced in the South Central region, there is an increase of irrigated sorghum grain in the Southwest. This is because natural gas is not as important a power source for irrigation in the Southwest regions as it is in the South Central region.

Table 15 . U.S. crop acreages in the base run and changes from the base run under various alternatives

Crop	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Thousand acres)		(Percentage change from base run)		
Barley dryland	19,015	+1.9	+2.4	-0.3	+0.5
irrigated	3,122	-0.7	-3.5	-1.6	-2.7
Corn dryland	62,294	+0.1	No change	-0.9	-1.1
irrigated	1,546	No change	-1.4	+23.3	+28.7
Cotton dryland	7,851	+0.6	+1.0	+1.2	+2.1
irrigated	1,473	-0.8	-3.7	-3.7	-7.9
Hay dryland	64,332	No change	-0.1	+0.1	+0.1
irrigated	6,788	+0.2	+0.4	-0.2	-0.2
Oats dryland	14,899	-0.2	-0.2	-0.1	No change
irrigated	212	No change	No change	No change	No change
Sorghum dryland	14,615	+1.5	+2.7	+4.6	+5.9
irrigated	6,421	-1.9	-3.2	-8.1	-10.3
Soybeans dryland	70,074	No change	No change	+0.2	+0.3
irrigated	1,299	No change	No change	-8.0	-10.9

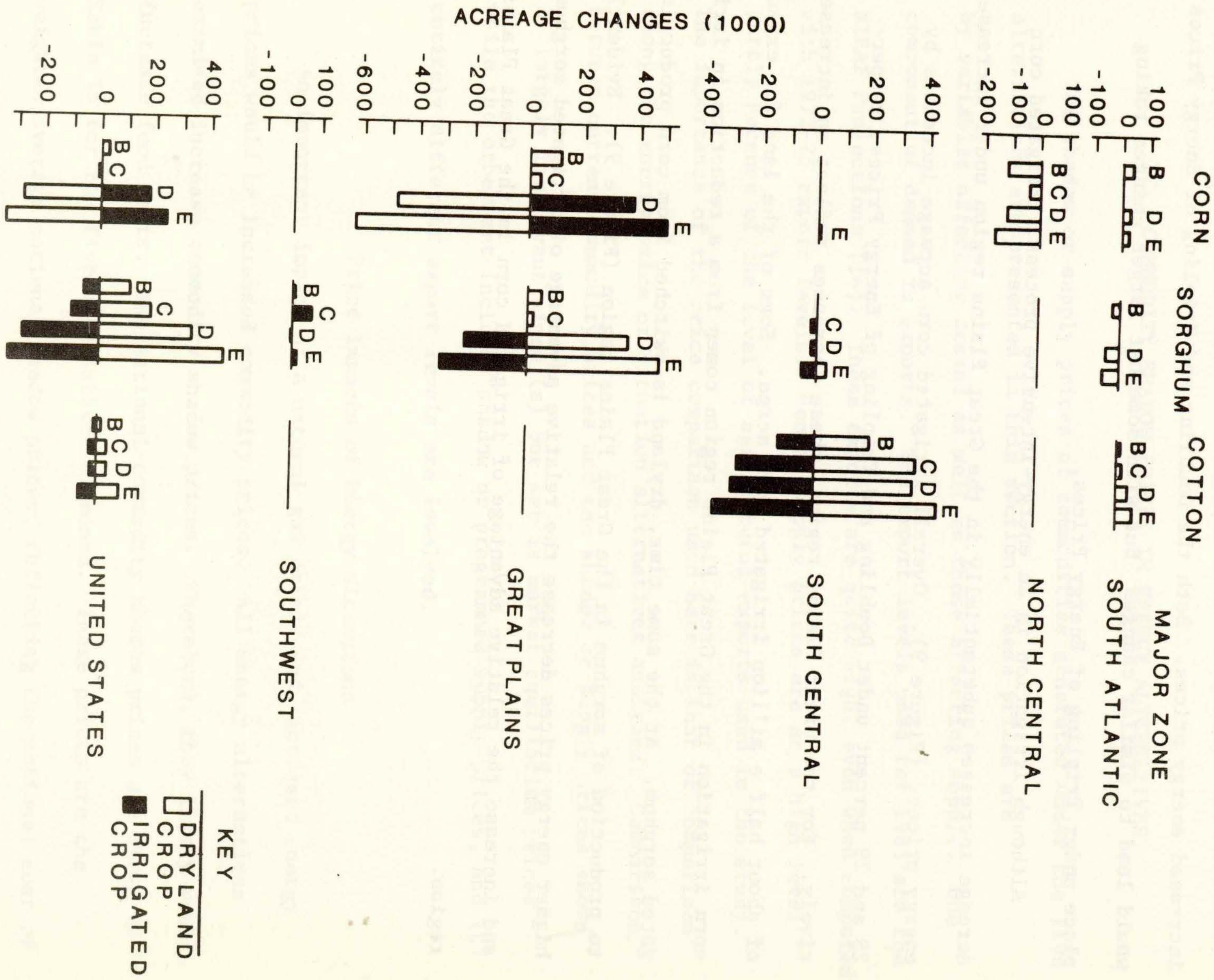

Figure 9. Regional changes in crop acreages as affected by energy policy alternatives--Natural Gas Deregulation (B) Natural Gas Curtailment (C), Doubled Energy Prices (D), and Tripled Energy Prices (E).

The most extensive changes in cropping pattern take place under increased energy prices. Both the Doubling and Tripling of Energy Prices would lead to similar changes but with somewhat larger changes taking place under Tripling of Energy Prices.

Although irrigation is an energy-intensive process, irrigated corn acreage increases substantially in the Great Plains region under increased energy prices, (Figure 9). Overall irrigated corn acreage increases by 23 and 29 percent under Doubling and Tripling of Energy Prices, respectively. For the Great Plains region, these increases reflect an increase of about half a million irrigated corn acres. Some of the land for expanded corn irrigation in the Great Plains region comes from a reduction in irrigated sorghum. At the same time, dryland is switched from corn production to production of sorghum in the Great Plains region (Figure 9). Evidently, higher energy prices decrease the relative advantage of irrigated sorghum and increase the relative advantage of irrigated corn in the Great Plains region.

IV. COMMODITY SHADOW PRICES IN ENERGY ALTERNATIVES

The shadow or supply prices of commodities generated under the five alternatives are presented in this section. These prices are by variables affecting demand as well as those affecting supply. One component of demand is exports. The export levels used for 1985 are the NIRAP Projections [14]. These exports are quite high, even when compared with 1972-75 export levels. Hence, supply prices are at a high level partly because of the level of agricultural exports used in the study. The importance of the price comparison used here is that of comparison among the energy price or situation alternatives analyzed. Comparison between current commodity prices and the shadow or supply prices shown is largely irrelevant since (a) one set is market equilibrium prices while the other set includes shadow or programmed supply prices, and (b) entirely different export levels are involved.

Price Impacts of Energy Situations

An important impact of a natural gas crisis and increased energy prices would be increased commodity prices. All energy alternatives examined increase commodity shadow prices. Therefore, they likely would increase food costs. The national commodity shadow prices are shown in Table 16 for the five alternatives examined. These prices are the weighted average national shadow prices, reflecting the national cost of producing the last unit of each commodity to meet domestic and export

Table 16. Crop shadow prices and index of crop shadow prices under various alternatives

Crop	Units	Base Run Alternative A	Natural Gas Deregulation Alternative D	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
				(Dollars per unit)		
Barley	bu.	4.08	4.32	4.24	4.46	4.71
Corn	bu.	3.02	3.19	3.11	3.34	3.59
Cotton	lb.	0.50	0.53	0.51	0.55	0.59
Hay	ton	83.94	88.14	87.03	91.61	97.00
Oats	bu.	3.68	3.88	3.84	4.02	4.23
Silage	ton	18.29	19.24	18.90	20.08	21.42
Sorghum	bu.	3.43	3.68	3.60	3.78	4.08
Soybeans	bu.	8.84	9.23	9.13	9.63	10.11
Sugar beets	ton	26.86	27.96	27.72	29.13	30.73
Wheat	bu.	6.87	7.25	7.14	7.56	8.02
			(Index of crop shadow prices)			
Barley	--	100.00	105.88	103.92	109.31	115.44
Corn	--	100.00	105.63	102.98	110.60	118.87
Cotton	--	100.00	106.00	102.00	110.00	118.00
Hay	--	100.00	105.00	103.68	109.14	115.56
Oats	--	100.00	105.43	104.35	109.24	115.95
Silage	--	100.00	105.19	103.34	109.79	117.11
Sorghum	--	100.00	107.29	104.96	110.20	118.95
Soybeans	--	100.00	104.41	103.28	108.94	114.37
Sugarbeets	--	100.00	104.16	103.20	108.45	114.41
Wheat	--	100.00	105.53	103.93	110.04	116.74

demands. For example, in the Base Run the last unit of barley produced costs $4.08.

Natural Gas Deregulation increases national commodity shadow prices by 5.3 percent over the base levels. But the national average sorghum price would increase by more than 7.0 percent. Natural Gas Curtailment has a slightly smaller impact on national commodity shadow prices than does Natural Gas Deregulation. Overall, commodity shadow prices increase by less than 4.0 percent under the former.

National results obscure differences in the regional impacts of each policy. The impacts of Natural Gas Deregulation are felt by all regions (it would increase nitrogen fertilizer prices); however, the impacts of Natural Gas Curtailment impact mainly the irrigated western regions. especially those heavily dependent on natural gas for water pumping as in the South Central and the Great Plains regions. This is caused by the national energy costs under Natural Gas Curtailment increasing only slightly higher (0.4 percent) than the Base Run, while the energy costs in the South Central and the Great Plains regions increase by 3.5 and 1.9 percent, respectively.

Regional Commodity Shadow Prices

The energy alternatives examined would lead to different impacts on regional commodity shadow prices. Only the results for corn, wheat, and cotton are presented here since these crops are grown on both dry and irrigated cropland. They also are grown over a wide area of the United States and, thus, demonstrate variations in the regional price changes. The changes in the regional prices reflect the relative regional advantage or disadvantage for each crop considered. Regions with lower than average commodity shadow prices are those which have a relative regional advantage. Regions with higher than average commodity shadow prices are those with a relative regional disadvantage.

Regional wheat shadow prices

Regional wheat shadow prices in the Base Run Alternative vary from $6.48 per bushel in the Northwest region to $7.75 per bushel in the South Atlantic region (Table 17). The regions which have higher than average wheat shadow prices (North Atlantic, South Atlantic, North Central and South Central) in the Base Run Alternative have a smaller increase in wheat shadow prices under all of the energy alternatives examined. For example, a tripling of energy prices increases wheat shadow prices slightly more in the Northwest region (17.3 percent) than in the North Atlantic region (16.0 percent).

Regional corn shadow prices

The lowest corn shadow price is in the North Central region which includes most of the Corn Belt. The low corn shadow price in the North Central region reflects the relative regional advantage of the region in corn production. Natural Gas Deregulation increases the overall corn shadow price about 5.6 percent (Table 18). But in regions using large quantities of nitrogen fertilizers or with substantial irrigated corn acreages, the changes in corn shadow prices are somewhat higher (Table 18). As compared to the Base Run Alternative, increases in corn shadow prices are most pronounced in the South Central and the Southwest regions.

Table 17. Regional wheat shadow prices for the Base Run prices and percentage changes for the other alternatives

Major Zone	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Dollars per bushel)	(Percentage change from base run)			
North Atlantic	7.8	+4.9	3.4	+9.4	+16.0
South Atlantic	7.3	+5.2	+3.7	+9.9	16.6
North Central	7.1	5.4	3.7	9.9	+16.5
South Central	7.1	5.8	4.0	+9.9	+16.6
Northwest	6.5	+5.7	4.0	+10.3	+17.3
Southwest	6.7	5.7	+4.3	+10.3	+17.2
United States	6.9	+5.5	+3.9	+10.1	+16.7

Table 18. Regional corn shadow prices for the Base Run and percentage changes for the other alternatives

Major Zone	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Dollars per bushel)	(Percentage change from base run)			
North Atlantic	3.33	+5.1	+3.0	+9.6	+16.8
South Atlantic	3.44	+5.2	+2.9	+4.9	+18.0
North Central	2.94	+5.8	+3.1	+10.2	+19.0
South Central	3.26	+6.4	+4.3	+11.4	+19.6
Northwest	4.80	+5.4	+3.8	+11.5	+20.0
Southwest	4.14	+6.8	+5.3	+9.4	+14.2
United States	3.02	+5.6	+3.0	+10.6	+18.9

Both regions use large amounts of natural gas for irrigation. Doubling of Energy Prices increases overall corn shadow prices by 10.6 percent. But, by region the increase varies from 5.2 percent in the South Atlantic region to 11.5 percent in the Northwest region. The average increase in corn shadow prices is 18.9 percent for Tripling Energy Prices, with a range of 14.3 to 20.0 percent.

Regional cotton shadow prices

Cotton is grown only in the South Atlantic, South Central and Southwest regions. Therefore, shadow prices are not available for other regions. Under all of the energy alternatives examined, increases in regional cotton shadow prices are less for the South Atlantic region than for the South Central or the Southwest regions (Table 19). For example, Natural Gas Deregulation increases cotton shadow prices by only half as much as in the South Atlantic region as in the South Central region. The ratio is even larger under Natural Gas Curtailment where cotton price in the South Atlantic region increases by 2.1 percent compared with a 7.1 percent for the South Central region. The relative regional advantage of dryland cotton in the South Atlantic region increases and the relative regional advantages of irrigated cotton in the South Central and the Southwest regions decreases when energy prices increase (Table 19). Thus, we might anticipate some shifts of cotton eastward toward dryland cotton regions as energy becomes more expensive.

Table 19. Regional cotton shadow prices for the Base Run and percentage change for the other alternatives

Major Zone	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Dollars per bushel)	(Percentage change from base run)			
North Atlantic	NA[a]	NA	NA	NA	NA
South Atlantic	0.48	+4.17	+2.08	+6.25	+12.50
North Central	NA	NA	NA	NA	NA
South Central	0.56	+8.93	+7.14	+10.71	+25.00
Great Plains	NA	NA	NA	NA	NA
Northwest	NA	NA	NA	NA	NA
Southwest	0.46	+6.52	6.52	+15.22	+26.09
United States	0.50	+6.00	+2.00	+10.00	+18.00

[a] NA means that the information is not available.

V. LAND, WATER AND NITROGEN USE

This section summarizes the impacts of the various energy alternatives examined on the use of land, water, and nitrogen.

Land Use

Because of the export levels used in the analysis, most of the available cropland is used for crop production. Cropland utilization is more than 99.5 percent under all the alternatives examined. Thus, the study operates close to full employment of land resources. This fact is highly important because it limits the regional shifts that might otherwise take place in response to changing energy situations. Most of the changes in the study involve changing cropping patterns or farming technology while most of the cropland available is still used (Table 20). For example, Natural Gas Deregulation substantially increases nitrogen fertilizer prices and restricts nitrogen fertilizer use. Total land in dryland crops would increase by more than 200,000 acres when nitrogen use is curtailed under Natural Gas Deregulation (Table 20). Furthermore, Tripling of Energy Prices would cause reduced nitrogen fertilizer application on more than 10 million acres.

Shadow prices for land

The high rate of cropland utilization is reflected through high shadow prices for land (Table 21). The values in the table are values for the Base Run and changes from the Base Run for dry and irrigated

Table 20. Use of cropland under the various alternatives

	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
			(Thousand acres)		
Total Dryland	340,199	340,387	340,589	340,626	340,837
Full nitrogen	310,301	306,299	309,695	308,011	300,797
Reduced nitrogen	29,898	34,088	30,894	32,615	40,040
Total Irrigated	28,442	28,298	28,084	28,057	27,872
Full nitrogen, full water	25,053	24,842	24,892	24,601	24,469
Reduced nitrogen, full water	611	628	298	594	541
Full nitrogen, reduced water	2,788	2,828	2,894	2,862	2,862
Total land use	368,641	368,685	368,673	368,683	368,709
		(Percentage distribution of total cropland used)			
Total Dryland	92.28	92.32	92.38	92.39	92.44
Full nitrogen	84.17	83.07	84.00	83.54	81.58
Reduced nitrogen	8.11	9.25	8.38	8.85	10.86
Total Irrigated	7.72	7.68	7.62	7.61	7.56
Full nitrogen, full water	6.79	6.74	6.76	6.67	6.63
Reduced nitrogen, full water	0.17	0.17	0.08	0.16	0.15
Full nitrogen reduced water	0.76	0.77	0.78	0.78	0.78
Total land use	100.00	100.00	100.00	100.00	100.00

Table 21. Land rent or shadow prices by major zones for Base Run and percentage changes under various energy alternatives

Major Zone	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Dollars per acre)		(Percentage change from base run)		
Dryland:					
North Atlantic	201.51	+6.3	+4.6	+7.8	+12.2
South Atlantic	153.64	+6.5	+5.0	+10.6	+16.1
North Central	200.33	+6.3	+4.8	+9.9	+15.4
South Central	122.26	+7.8	+6.2	+10.2	+18.1
Great Plains	135.96	+6.3	+5.2	+10.8	+18.1
Northwest	181.21	+5.9	+5.0	+11.5	+19.0
Southwest	102.99	+6.2	+7.6	+11.1	+16.9
United States	167.50	+7.0	+5.2	+10.4	+16.8
Irrigated:					
North Atlantic	NA[a]	NA	NA	NA	NA
South Atlantic	NA	NA	NA	NA	NA
North Central	NA	NA	NA	NA	NA
South Central	149.76	+7.2	+4.6	+7.5	+13.4
Great Plains	216.43	+5.4	+3.7	6.0	+7.6
Northwest	246.44	+6.8	+4.9	+10.9	+17.0
Southwest	184.05	+8.2	+7.2	+9.5	+13.1
United States	192.50	+6.9	+4.9	+8.8	+12.5

[a] NA indicates information not available.

cropland. In general, shadow prices are greater for irrigated cropland than for dry cropland, reflecting the higher productivity of irrigated land. Increased energy prices would increase dry cropland shadow prices slightly more than for irrigated cropland. For example, Tripling of Energy Prices would increase the average dry cropland shadow prices by 16.8 percent and the average irrigated cropland shadow prices by only 12.5 percent (Table 21). Thus, as energy prices increase dry cropland shadow prices approach those of irrigated land.

Great regional variations exist in shadow price increases. The Northwest region shows the largest impacts in both dry and irrigated cropland (Table 21). Natural Gas Deregulation and Natural Gas Curtailment have a relatively greater impact in the Southwest region than in other irrigated regions. Under both policies, however, land shadow prices would increase by a smaller percentage than energy prices. Although higher energy prices increase land shadow prices, the percentage increase is much smaller than for the inputs of water and nitrogen fertilizers.

Water Use

Total water used by the crops included in this study varies only slightly among alternatives (Table 22). Most of the changes in water use relate to water source. All the energy situations examined substitute less energy-intensive surface water for more energy-intensive ground water. Except for the Base Run alternative, depletion of ground water remains constant at the maximum allowed levels assumed in the study.

Natural Gas Deregulation reduces overall ground water pumping by 7.5 percent and increases surface water use by 3.4 percent (Table 22)

Table 22. Water use in the Base Run and percentage changes from the Base Run under various alternatives

	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Thousand acre-feet)	(Percentage change from base run)			
Great Plains Total	12,518	+12.9	+12.9	+10.4	+10.7
Surface	8,379	+10.0	+11.9	+10.0	+17.6
Ground	4,139	+18.6	+14.8	+11.0	-3.4
Depleted	0	No change	No change	No change	No change
South Central Total	16,662	-12.2	-15.7	-15.7	-17.3
Surface	8,302	-0.9	+7.1	+8.1	+7.5
Ground	5,199	-33.7	-57.7	-59.3	-63.6
Depleted	3,161	-6.5	-6.5	-6.5	-6.5
Northwest Total	9,682	+0.3	+0.3	+10.0	+10.0
Surface	9,682	-0.1	-0.1	+9.6	+9.6
Ground	0	No change	No change	No change	No change
Depleted	0	No change	No change	No change	No change
Southwest Total	30,010	+1.2	+1.1	+3.9	+4.0
Surface	24,328	+4.0	+3.9	+8.4	+15.7
Ground	3,218	No change	No change	-8.6	-62.9
Depleted	2,464	-24.8	-24.8	-24.8	-24.8
Western U.S. Total	68,872	No change	-0.9	+1.2	+0.9
Surface	50,691	+3.4	+5.0	+8.8	+13.5
Ground	12,556	-7.5	-18.7	-22.8	-43.2
Depleted	5,625	-14.5	-14.5	-14.5	-14.5

while total water used remains unchanged. In the Great Plains region, however, water use increases by 12.9 percent while the South Central region reduces water use by 12.2 percent. Most of the reduction in water used in the South Central region (under Natural Gas Deregulation) is due to a reduction of more than a third in ground water pumping. Ground water pumping is a large user of natural gas in that region. The gain in the Great Plains region results from a larger proportion of surface water used and the shallow pumping depth of ground water.

Natural Gas Curtailment has similar impacts on the Great Plains region but reduces ground water pumping by more than half in the South Central region. The impact of Natural Gas Curtailment is greater than that of Natural Gas Deregulation in the South Central region.

Doubled and tripled energy prices generally have effects in the same direction, but tripling of energy prices has a somewhat larger impact. Increased energy prices reduce total water used by 15.7 and 17.3 percent in the South Central region under a doubling and tripling of energy prices, respectively (Table 22). These reductions are accompanied by about an 8 percent increase in surface water use and about a 60 percent reduction in ground water use. The other three western regions increase their water use even with higher water costs caused by the higher energy prices. The increase in water use in these regions is due to a shift of irrigated crop production from the South Central region to all other western irrigated regions which are less energy intensive than the South Central region.

Under doubled and tripled energy prices, surface water use increases in all regions. Overall surface water used increases by 8.8 and 13.5 percent under doubled and tripled energy prices, respectively. Ground water declines substantially in all the regions under doubled energy prices except for the Great Plains and Northwest regions. The major declines in ground water used under tripled energy prices, as noted earlier, are for the South Central region (down by 63.6 percent) and for the Southwest region (down by 62.9 percent).

Water prices

Water pumping is a very energy-intensive process. Increased energy prices, therefore, can be expected to have a substantial impact on water prices. The average shadow price of water in the western United States increases by 18.5 percent under doubled energy prices and 41.2 percent under tripled energy prices (Table 23).

The response of water shadow prices to increased energy prices vary greatly among regions (Figure 10). Regions that depend on ground water pumping have much larger increases in water shadow prices. For example, water shadow prices increase by 128.1 and 262.4 percent under doubled and tripled energy prices, respectively, in Arizona where pumping depths are relatively deep and surface water supplies require considerable energy for transfer. On the other hand, water shadow prices would increase by 11.3 and 24.4 percent for doubled and tripled energy prices, respectively, in the Northwest (Table 23). Most water in the Northwest region is supplied from surface water requiring a relatively small amount of energy for transfer.

Table 23. Water supply shadow prices for the Base Run and percentage changes from the Base Run under various alternatives, by market region[a]

Market Region	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Dollars per acre-ft.)	(Percentage change)			
16	3.13	No change	No change	+17.89	+36.10
17	10.16	+13.09	+18.21	+55.51	+122.44
18	10.53	+26.40	+51.00	+63.53	+126.78
19	8.62	+11.95	+22.27	+25.64	+50.46
20	13.44	+37.35	+73.66	+81.70	+102.90
21	10.48	+4.87	+10.50	+20.80	+44.08
22	72.62	+15.31	+15.89	+16.18	+25.65
23	15.28	+41.56	+90.38	+104.25	+174.80
24	3.90	+1.03	+0.77	+11.28	+24.36
25	4.60	+2.39	+2.83	+35.22	+75.65
26	11.46	+31.50	41.27	+128.10	+262.39
27	8.32	+0.72	No change	+28.37	+53.25
28	50.62	+0.04	+0.06	+3.10	+6.20
United States	15.43	+9.66	+13.28	+18.47	+41.15

[a] Western regions only.

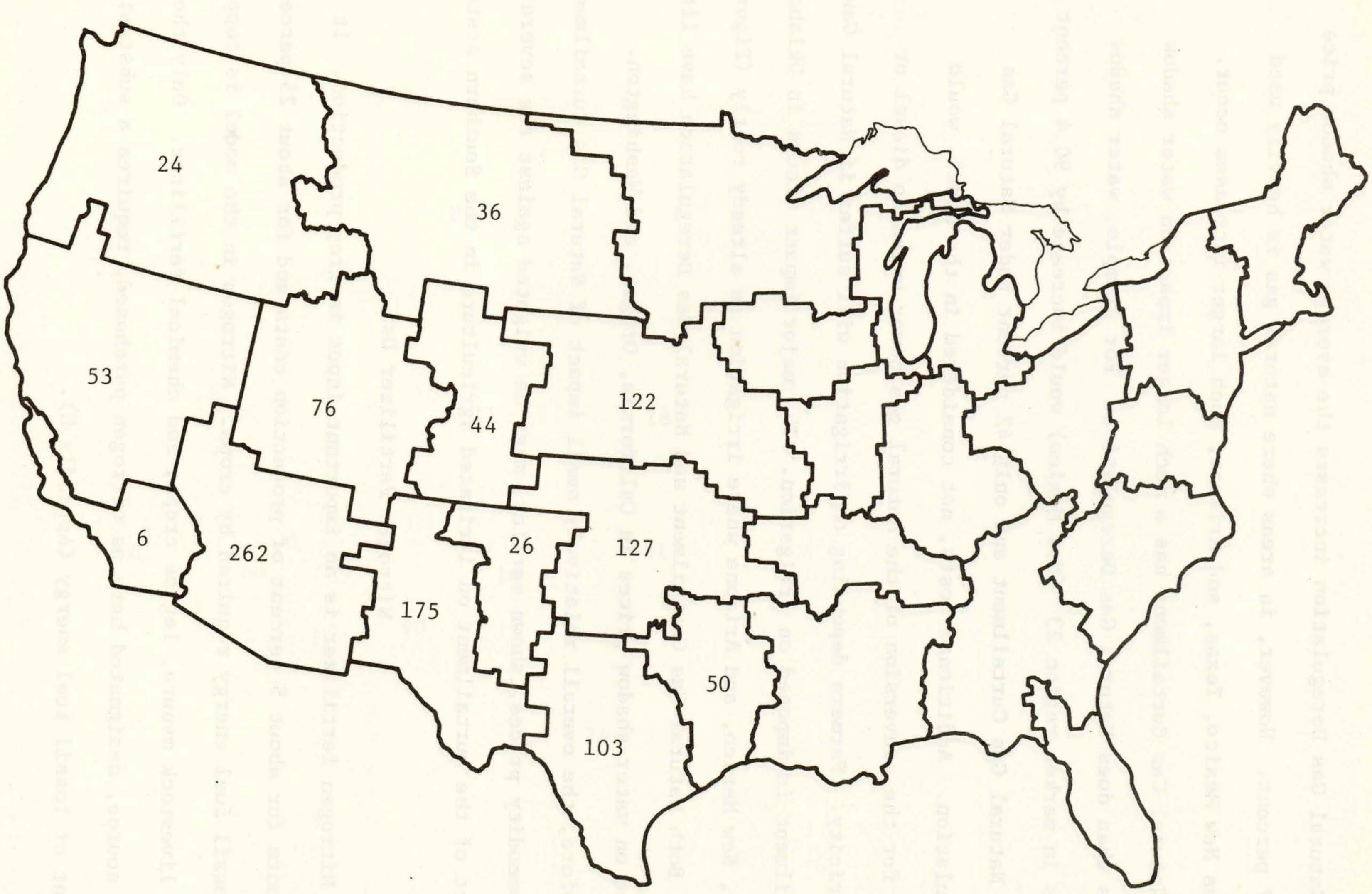

Figure 10. Increased water shadow prices by market regions under Tripling of Energy Prices.

Natural Gas Deregulation increases the average water shadow price by 9.7 percent. However, in areas where natural gas is heavily used such as New Mexico, Texas, and Arizona, much larger increases occur.

Natural Gas Curtailment has a much larger impact on water shadow prices than does Natural Gas Deregulation. For example, water shadow prices in market region 23 (New Mexico) would increase by 90.4 percent under Natural Gas Curtailment and only 42 percent under Natural Gas Deregulation. Additional costs, not considered in the model, would occur for the conversion of the natural gas power units to diesel or electricity. Farmers depending on irrigation will suffer if Natural Gas Curtailment is imposed on irrigation. The major impact occurs in Oklahoma, Texas, New Mexico, and Arizona where irrigation is already costly (Figure 11). Both Natural Gas Curtailment and Natural Gas Deregulation have little impact on water shadow prices in California, Oregon, and Washington. Therefore, the overall relatively small impact of Natural Gas Curtailment on commodity prices, shown earlier, must be weighted against the severe impact of the curtailment on irrigated agriculture in the Southern states.

Nitrogen Fertilizer Use

Nitrogen fertilizer is an important input in crop production. It accounts for about 5 percent of production costs and for about 25 percent of fossil fuel energy required by crops. Nitrogen in the model is supplied from livestock manure, legume crops, and chemical fertilizer. Only the last source, designated here as nitrogen purchased, requires a substantial amount of fossil fuel energy (Appendix C).

Figure 11. Increased water prices by market regions under Natural Gas Curtailment to irrigation.

Changes in total nitrogen use as well as nitrogen purchased are quite small under all alternatives (Table 24). Natural Gas Deregulation slightly reduces nitrogen purchased, especially in the North Atlantic and the South Central regions. Natural Gas Curtailment is assumed to have no impact on natural gas prices. Therefore, it has little impact on nitrogen use. Doubled and tripled energy prices both reduce nitrogen use. However, energy prices must triple before total nitrogen use is reduced by 1 percent.

The small changes in nitrogen use reflect the high rate of cropland utilization under all of the alternatives. The levels of domestic and foreign demands used in the study do not allow much substitution between land and nitrogen fertilizers. Thus, despite a 35.0 percent increase in fertilizer prices (from $.20 per pound in the base run to $.27 per pound under tripled energy prices), the amount of nitrogen purchased declines by only 2.1 percent.

Table 24. Nitrogen used and purchased by major zones under the various energy alternatives

Major Zones	Base Run Alternative A	Natural Gas Deregulation Alternative B	Natural Gas Curtailment Alternative C	Double Energy Prices Alternative D	Triple Energy Prices Alternative E
	(Thousand tons)	(Percentage change from base run)			
Nitrogen used for:					
North Atlanta	303.32	+0.1	No change	No change	+0.1
South Atlantic	1,250.10	+0.2	No change	+0.2	+0.1
North Central	4,489.13	-0.2	+0.1	No change	No change
South Central	2,061.42	-1.9	-1.1	-2.2	-3.8
Great Plains	2,596.75	No change	No change	+0.1	-2.1
Northwest	532.47	No change	No change	No change	No change
Southwest	592.78	-0.1	+0.5	No change	No change
United States Total	11,825.97	-0.4	-0.1	-0.3	-1.1
Nitrogen purchased for:					
North Atlantic	90.02	-1.6	No change	-0.4	-1.52
South Atlantic	789.08	No change	+0.1	+0.2	-0.1
North Central	2,426.02	-0.1	+0.2	-0.3	-0.3
South Central	1,686.95	-2.3	-1.3	-2.7	-4.6
Great Plains	1,606.58	No change	No change	+1.4	-2.8
Northwest	375.46	No change	No change	No change	No change
Southwest	336.28	No change	+1.0	-0.4	-0.2
United States Total	7,310.39	-0.8	-0.1	-0.4	-2.10

VI. SUMMARY AND CONCLUSIONS

The diminishing supply of natural gas in the United States has occurred at the same time that demand has been increasing for this clean-burning energy. There has been a sharp decline in its production over the last five years. Although many agricultural users of natural gas (especially those in the intrastate markets), have been paying higher prices for gas, the overall impact of the natural gas shortage on agriculture has been minimal. Because the natural gas supply is continuously declining, its supply to agriculture as well as to other sectors of the economy can be expected to decline. Increased pressure from legislators to divert the dwindling supplies of natural gas from what they consider "less essential areas," such as irrigation, to high priority such as households can also be expected. In the future it is likely that the current natural gas price regulation will be either phased out or modified such that interstate natural gas prices are allowed to reach market levels. A substantial increase in natural gas prices would result for all users. One objective of the study, therefore, is to evaluate the impact of natural gas deregulation on agriculture. The evaluation is then expanded to examine the impact of natural gas curtailment on irrigation.

A second objective of the study deals with the impact of general increases in energy prices on agricultural production. Since 1972, U.S. agriculture has faced increasing costs for all inputs. Energy price increases have been especially pronounced. From 1972 and the formation of the Organization of Petroleum Exporting Countries (OPEC) to the end of 1976, the index of fuels and energy prices paid by farmers rose at the average annual rate of 15.0 percent [37]. This was a sharp change from earlier years (Figure 12). Under ongoing developments in the world energy market, future energy prices are highly unpredictable. If energy prices continue to rise at the 1972-76 rate of 15 percent per year, the price in 1985 will be 300 percent higher than the 1975 price. On the other hand, if energy prices rise only at their 1965-72 rate (about 1.5 percent per year), energy prices by 1985 will be 21.0 percent above the 1974 level. Two alternatives examined in this study include doubling and tripling of energy prices by 1985.

Natural Gas Deregulation

Natural Gas Deregulation by 1985 would increase total agricultural energy costs by 23.5 percent over the Base Run alternative. The energy cost increase is caused primarily because deregulation would increase the natural gas price by 125.9 percent. It would also reduce natural gas use in agricultural production by 3.4 percent. This reduction of 14.9 million cubic-feet per year in natural gas use in agricultural production is insignificant when compared to the 20 trillion cubic-feet consumed annually by the United States. Under Natural Gas Deregulation, 36.0 percent of the agricultural energy costs would be for natural gas. This compares with only 20.4 percent in the Base Run alternative.

Natural Gas Deregulation would increase average commodity shadow prices by 5.3 percent. Sorghum grain prices, however, would increase

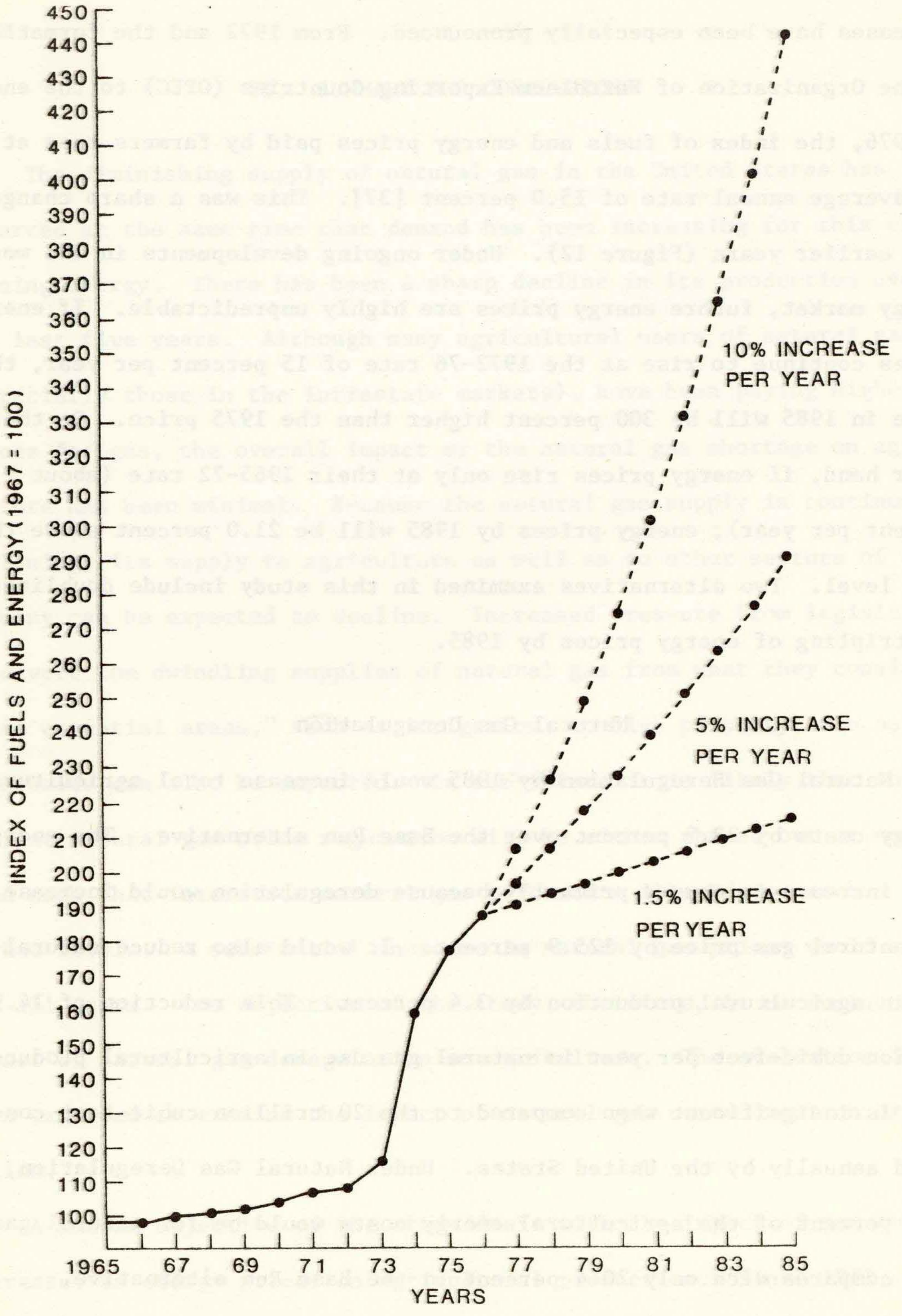

Figure 12. Index of fuels and energy prices 1965-1976 [41] and projected changes 1977-1985.

by 7.3 percent because much of the sorghum is grown in the South Central region. This region depends heavily on natural gas for irrigation.

Natural Gas Deregulation would not have much impact on the total water use by agriculture under the assumptions used in the study. The source of water for irrigation, however, would be shifted somewhat from ground to surface water. Overall use of ground water would decline by 7.5 percent from levels of the Base Run alternative. In the South Central region, Natural Gas Deregulation has a much greater impact and ground water use declines by 33.7 percent. The decline in ground water use in the South Central region also causes a 12.2 percent reduction in total water use in the region. Thus, it is evident that Natural Gas Deregulation is especially important for the South Central region.

Even with higher natural gas prices caused by deregulation, nitrogen fertilizer use declines only slightly from the Base Run alternative. Nitrogen use declines only slightly due partly to the level of exports used in the study. To meet these export levels, a high rate of fertilization is required. Since lower nitrogen use reduces yields, more land is required to meet the export demands specified in the model. Most cropland in the model, however, is already utilized in the Base Run alternative and thus not available to be substituted for fertilizer.

Natural Gas Curtailment to Irrigation

Natural gas curtailment has become a frequent event for many industrial users of natural gas in the United States in the last few years. Agriculture has thus far been excluded from the various curtailment plans designated by the Federal Power Commission (FPC). But, is to evaluate the for natural gas by the residential sector, accompanied by a continuous decline in its supply, makes future supplies of the gas highly uncertain. Policy makers are under increased pressure to reexamine the FPC curtailment plans to include all sectors of the economy without preferences to any of the sectors.

Natural Gas Curtailment to irrigation leads to a sharp reduction in agricultural natural gas usage. The amount of natural gas use in agriculture declines by 13.0 under this alternative. However, the reduction is less than one third of a percent of the 20 trillion cubic-feet of natural gas consumed annually by the United States. This reduction in natural gas use is accompanied by a 13.8 percent increase in electricity use in agriculture. Hence, curtailment would require large investments in power stations and transmission lines. However, direct agricultural energy cost would only rise by 0.4 percent from the Base Run alternative. The shift from natural gas to electricity would also save some energy (2.8 percent of the Base Run level) because electricity is a more efficient way of converting fossil fuel energy than other energy sources.

Natural Gas Curtailment, when not accompanied by increased natural gas prices, has very little impact on commodity shadow prices. On the average, under Natural Gas Curtailment, commodity shadow prices increase less compared to the Base Run than they would under Natural Gas Deregulation. Because of increased use of electricity, the most expensive energy source, large impacts on commodity shadow prices would occur in the Southwest region.

Prohibiting the use of natural gas for irrigation causes some decline in water use as ground water pumping declines. In many regions

the increased costs of energy due to the shift toward electric power units increase water prices so much that many farmers would find irrigation to no longer be profitable.

Increased Energy Prices

Increased energy prices in 1985 are examined under two alternatives: Doubling of Energy Prices and Tripling of Energy Prices. The impacts of these two alternatives on agricultural production are similar in direction but different in magnitude. In general, Tripling of Energy Prices has a much larger impact on agricultural production than does Doubling of Energy Prices.

Increased energy prices, as experienced since 1972, cause farmers to spend a larger proportion of their production costs on energy. For example, 5.6 and 8.0 percent of the farm production costs are devoted to energy under doubled and tripled energy prices, respectively. Only 3.1 percent of total production costs for the crops endogenous to the study is devoted to energy in the Base Run Alternative. For some regions increased energy costs have a large impact on farming. For example, under tripled energy prices 14.7 percent of the agricultural production costs in the Southwest region are for energy.

Neither of these two alternatives lead to a substantial energy saving. Little change in energy use occurs because of the low elasticity of energy demand in farming and the lack of opportunity (because of the high export demand levels used) to substitute dryland production for irrigated cropland production. Although the overall energy reduction declines but little, electricity use declines substantially under both alternatives. The sharp decline in electricity use (22.1 and 23.7 percent under doubled and tripled energy prices, respectively) is due to a substitution of surface water with its low energy demand for pumped ground water which is a heavy energy user.

As might be expected, increased energy prices raise commodity shadow prices. On the average, commodity shadow prices increase by 9.7 and 16.4 percent under doubled and tripled energy prices. Hence, the impact on commodity prices is less than the magnitude of increase in energy prices. An increase in energy prices affects all regions. The more energy intensive western regions, however, have larger increases in their commodity shadow prices than do dryland crop producing regions. This is especially true for the South Central and the Southwest regions where irrigation is very important in agricultural production.

Ground water use would be reduced by 22.8 and 43.2 percent, respectively, under doubled and tripled energy prices. However, increased energy prices have a small impact on total water use for irrigation. Although overall changes in water use are small, large changes would take place in the Great Plains, South Central, and the Northwest regions. For example, a sharp decline (17.3 percent) in water use for irrigation would take place in the South Central region. But a 10.7 and 10.0 percent increase in water use from surface sources would occur in the Great Plains and the Northwest regions, respectively.

Shadow prices of water, nitrogen, and cropland change with the increases in energy prices. Of the three resources mentioned, water shadow prices increase the most and land prices increase the least under doubled and tripled energy prices.

The impacts of increased energy prices on farm income would be largest for farmers depending on pump irrigated agriculture. Their water costs would rise substantially and many of them would not be able to overcome the adverse impact of rising energy prices.

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APPENDIX A: FUEL USE IN CROP PRODUCTION

Energy coefficients (diesel fuel, gasoline and LPG) by crop and state were obtained from "Energy and U.S. Agriculture: 1974 Data Base" [40]. The data base has been developed by the Economic Research Service with the cooperation of the Federal Energy Administration. It derives many of the coefficients from Firm Enterprise Data System (FEDS) [12] using 1974 crop budgets. The amounts of gasoline and LPG used by crops have been converted to diesel fuel equivalent as most of fuel consumed by tractors and other self propelled machinery in the U.S. is diesel fuel [40].

The state crop data has been converted to producing area crop coefficients (Table A.1) by weights based on crop acreages in the 1969 census of Agriculture [43]. The 1974 data base does not differentiate between dry and irrigated crops. Therefore, for every crop and producing area the ratios of irrigated to dryland fuel coefficients are assumed to be similar to the relative ratio of total irrigated variable costs (excluding water and nitrogen costs) to total dryland variable costs. Thus, if variable costs for a given crop are twice as high for irrigated crop than for dryland, then it is assumed that fuel coefficients would also be twice as high for the irriated crop. Total variable costs for both irrigated and dryland crops have been derived from the FEDS [12].

Table A.1. Crop average fuel coefficients (diesel fuel equivalent) by producing area

Producing Area	Barley	Corn	Corn Silage	Cotton	Legume Hay	Nonlegume Hay	Oats	Sorghum	Sorghum Silage	Soybean	Sugar	Wheat
						(Gallons per acre)						
1	0.0	0.0	22.4	0.0	26.9	2.6	13.6	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	16.9	0.0	26.9	2.7	13.6	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	22.7	0.0	27.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	22.6	0.0	26.9	2.7	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	19.9	0.0	26.9	2.7	13.6	0.0	0.0	0.0	0.0	0.0
6	15.0	21.7	23.0	0.0	26.8	2.6	14.8	0.0	0.0	16.3	0.0	14.0
7	15.0	21.7	22.5	0.0	27.0	2.4	14.8	0.0	0.0	16.3	0.0	14.0
8	14.9	21.6	20.7	0.0	27.1	2.7	14.8	0.0	0.0	16.3	0.0	15.3
9	14.8	21.3	21.5	0.0	27.0	2.7	14.9	0.0	0.0	16.2	0.0	14.4
10	15.1	22.8	22.6	0.0	27.1	2.6	15.6	0.0	0.0	16.2	0.0	14.1
11	13.3	19.0	22.2	19.9	25.0	2.7	11.7	14.8	22.0	15.9	0.0	12.2
12	11.1	17.9	22.1	0.0	24.5	2.7	11.9	14.8	22.0	15.7	0.0	10.8
13	9.9	16.7	20.7	20.1	24.2	2.6	9.7	15.1	22.1	15.1	0.0	9.7
14	9.6	16.4	20.3	33.4	24.1	2.7	9.3	15.4	20.6	13.7	0.0	9.7
15	9.3	16.3	20.1	24.4	23.4	2.8	8.9	14.9	19.4	13.6	0.0	9.4
16	9.3	16.0	21.3	24.3	26.0	2.8	8.7	14.9	19.4	13.8	0.0	9.3
17	0.0	16.0	21.6	0.0	26.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0
18	9.3	16.2	20.7	24.3	20.6	2.8	8.8	14.9	19.4	13.8	0.0	9.3
19	9.3	16.4	20.4	24.0	20.5	2.7	9.0	14.8	19.5	13.8	0.0	9.6
20	0.0	18.1	19.7	26.5	24.2	2.7	9.3	14.1	19.5	13.4	0.0	10.4
21	0.0	20.0	19.6	29.2	24.2	2.7	9.3	12.9	19.5	13.5	0.0	9.1
22	6.8	14.8	21.4	0.0	23.8	4.0	7.0	0.0	0.0	12.5	0.0	8.0
23	6.6	15.1	20.6	0.0	26.2	4.0	6.7	0.0	0.0	11.9	0.0	8.0
24	6.2	15.5	23.0	0.0	28.1	3.2	6.4	12.6	20.9	12.2	0.0	7.9
25	6.7	14.7	22.3	0.0	23.1	3.8	6.8	12.8	21.0	12.2	16.6	6.8
26	6.9	14.6	21.8	0.0	22.1	4.0	7.0	0.0	0.0	12.1	16.6	6.8
27	6.6	14.7	22.0	0.0	25.0	3.4	6.7	12.8	21.0	12.3	17.6	7.0
28	9.9	20.5	22.1	0.0	26.7	2.5	12.4	0.0	0.0	15.9	0.0	12.7
29	15.0	21.7	22.4	0.0	27.1	2.3	14.8	0.0	0.0	16.3	0.0	14.0
30	13.8	20.1	22.3	0.0	25.2	2.6	12.9	0.0	0.0	16.2	0.0	12.3

Table A.1. (continued)

Producing Area	Barley	Corn	Corn Silage	Cotton	Legume Hay	Nonlegume Hay	Oats	Sorghum	Sorghum Silage	Soybean	Sugar	Wheat
						(Gallons per acre)						
91	6.5	0.0	24.6	0.0	8.2	4.3	5.9	0.0	0.0	0.0	0.0	6.0
92	6.5	15.9	30.1	0.0	5.5	4.2	5.9	0.0	0.0	0.0	32.2	7.1
93	6.9	15.9	29.8	0.0	6.5	4.0	6.0	0.0	0.0	0.0	20.2	7.1
94	6.0	15.7	28.5	0.0	7.8	4.1	6.1	0.0	0.0	0.0	21.5	6.7
95	6.3	15.8	29.4	0.0	7.4	6.1	0.0	0.0	0.0	0.0	0.0	6.9
96	7.4	15.9	25.8	0.0	7.4	4.0	7.7	0.0	0.0	0.0	0.0	7.1
97	6.2	15.9	30.5	0.0	6.1	4.0	5.9	0.0	0.0	0.0	0.0	7.2
98	7.5	0.0	26.1	0.0	7.6	4.0	7.9	0.0	0.0	0.0	0.0	7.1
99	7.9	16.8	29.5	0.0	8.0	5.2	8.2	0.0	7.4	0.0	0.0	9.1
100	9.8	16.8	30.1	28.6	8.9	5.8	9.5	11.1	7.4	0.0	24.5	9.7
101	9.8	16.8	30.1	28.6	8.9	5.8	9.5	11.1	7.4	0.0	24.5	9.7
102	9.8	16.8	30.1	28.6	8.9	5.8	9.5	11.1	7.4	0.0	24.5	9.7
103	9.8	16.8	30.1	28.6	8.9	5.8	9.5	11.1	7.4	0.0	24.5	9.7
104	9.8	16.8	30.1	28.6	8.9	5.8	9.5	11.1	7.4	0.0	24.5	9.7
105	0.0	16.8	30.1	0.0	8.9	5.8	9.5	0.0	7.4	0.0	0.0	9.7

SOURCE: Energy and U.S. Agriculture: 1974 Data Base [40].

APPENDIX B: ENERGY USE FOR IRRIGATION[1]

Irrigation is one of the major users of energy in agricultural production. Energy required for irrigation varies widely across the nation as a function of the water source and the irrigation methods. Two primary sources of water are used for irrigation, surface water (streams and lakes) and ground water obtained from wells. The importance of irrigation to crop production varies substantially from area to area. Examination of state data suggests that it is practically impossible for some states to produce crops without irrigation while others require little or no irrigation for crop production. In general, irrigation is very important in the 17 Western states.

Energy and Irrigation Relationships

The basic relationship used in this study assumes that energy requirements for irrigation in each of the irrigated regions can be expressed by the following function:

$$IE_i = f(PD_i, PE, ME_j, SH_i, RL_i, WP_{ij}, WS_i, GW_i, SA_i, EC_i) \qquad \text{(B.1)}$$

$i = 48, \ldots, 105$ for the producing areas including irrigation alternatives in the 17 Western states; and

$j = 1, \ldots, 5$ for the five major types of power units: electric, gasoline, diesel, LPG, and natural gas.

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[1] A more detailed explanation which includes some of the data, is available in "Energy Requirements of Irrigated Crops in the Western United States [12].

where:

IE_i is the energy required to obtain and apply one acre-foot of water in the ith producing area;

PD_i is the average pumping depth of groundwater in the ith producing area;

ES_i is the average feet of lift for surface water in the ith producing area;

PE is the average water pump efficiency;

ME_j is the jth power unit efficiency in converting fuel energy to mechanical energy;

SH_i is the weighted average head required for sprinkler irrigation in the ith producing area including friction losses;

WP_{ij} is the proportion of the total energy used for irrigation in the ith producing area by the jth power unit;

WS_i is the proportion of the irrigated acres having the water applied by sprinklers in the ith producing area;

GW_i is the proportion of total water used for irrigation obtained from groundwater in the ith producing area;

SA_i is the proportion of surface water that required pumping in the ith producing region; and

EC_i is the efficiency of converting fossil fuel to electricity in the ith producing region.

Many variables such as rate of pumping, size of power units, variations in pumping depth between seasons, etc., are omitted from equation B.1 because data to determine these variables are not available. Therefore, a complete accounting for all such factors, while important, cannot be done at this time. In the following sections we explain the derivation, assumptions, constant parameters, sources, and use of the data required to quantify equation B.1.

Pumping Depth

Pumping depth is defined as the yearly average depth (in feet) relative to the ground surface from which water is pumped for irrigation. Pumping depth, by state, has been estimated by irrigation experts [35]. The variation in pumping depth within the 17 Western states was obtained by collecting water level and well depth information on more than 10,000 wells. The producing area pumping depth (Table B.1) is, therefore, related to both the states' pumping depth as described in [35], and to the pumping depth variations within the corresponding states. For the 17 Western states, the average pumping depth is 192 feet. The deepest pumping depth is in region 78 (New Mexico and Northwest Texas) where water for irrigation is pumped from 357 feet.

Water Pumping Efficiency

Pump efficiencies vary greatly as a function of the pump type, rate of pumping, and the pump age. Although a good pump can have efficiency as high as 75 percent, most pumps have a much lower efficiency. For the purpose of this study, pump efficiency is assumed to be a constant equal

Table B.1. Weighted water depth and pumping depth in the 17 Western states by producing regions (in feet)

Producing region	Water depth	Pumping depth	Producing region	Water depth	Pumping depth
		(Feet)			
48	14.653	45.086	78	174.530	357.287
49	41.938	129.038	79	133.971	187.988
50	13.678	42.086	80	90.264	212.446
51	22.869	114.998	81	34.120	47.877
52	76.293	159.952	82	26.204	141.971
53	16.364	22.866	83	29.440	195.225
54	23.418	96.012	84	47.910	317.707
55	35.028	71.079	85	116.306	185.182
56	21.269	43.159	86	124.862	230.707
57	22.110	44.861	87	238.594	381.817
58	94.543	192.645	88	59.025	252.584
59	81.137	164.433	89	34.254	227.147
60	29.730	41.535	90	28.735	214.122
61	12.000	82.400	91	45.086	335.959
62	26.077	77.249	92	41.189	113.788
63	132.654	195.585	93	96.137	260.619
64	33.450	64.825	94	127.127	276.554
65	213.628	336.272	95	54.166	242.864
66	98.823	160.843	96	21.136	109.092
67	156.766	219.974	97	77.545	188.326
68	91.411	151.208	98	16.345	90.908
69	69.295	146.634	99	30.480	131.529
70	46.981	65.924	100	31.103	48.480
71	70.264	98.595	101	86.830	135.342
72	160.900	240.608	102	36.139	56.330
73	99.046	138.982	103	66.976	104.395
74	92.702	136.503	104	84.707	132.033
75	57.513	152.321	105	75.200	117.214
76	124.900	175.259			
77	18.342	54.333	AVERAGE	115.423	191.622

SOURCE: Dvoskin, Nicol, and Heady [9].

to 60 percent [26], and this value is applied uniformally across the 17 Western states.

Type of Power Units and Their Energy Efficiency

The proportion of the power units employed in each region is derived by weighting the state proportion of power units into the producing regions. Only five types of power units are considered -- diesel, gasoline, natural gas, LPG, and electricity. State data on the power unit distribution are reported in "1975 Irrigation Survey" [25]. The data reported in the survey disclose the proportion of the number of power unit types used in irrigation in 1975. For simplicity we assume no substantial difference in power unit sizes, operation hours, and overall efficiency. Therefore, the proportion of the total energy used in irrigation by each of the power units for a given region is approximately equal to the power unit's relative proportion of the total number of power units used for irrigation in the region.

Energy waste always occurs in the conversion of fuel energy to mechanical energy such as powering engines and turning generators for electricity production. This also is the case for power units used in powering water pumps for irrigation needs.

In the case of electricity, additional losses take place in the conversion of fossil fuel to electricity. The amount of fossil fuel energy consumed in generating electricity varies substantially across the nation. Moreover, it is estimated that by 1985 more than 26 percent of the energy consumed by the electric utility industry will come from nuclear energy sources [17].

The energy required to generate a Kwh of electricity is shown in Table B.2. Because of increased use of nuclear power and other nonfossil fuel energy sources, it is expected that by 1985 the national average electricity conversion efficiency would be close to 50 percent. This is a substantial improvement over the 1975 efficiency estimated to be only 32 percent [8].

Table B.2. Fossil Fuel energy required to produce one Kwh of electricity[a] and electricity generating efficiency[b] by region in 1985

Region	Fossil fuel energy required	Generating efficiency
	(Mcal)	(Percentage)
New England	1.577	54.5
Middle Atlantic	1.766	48.7
East North Central	1.815	47.3
West North Central	2.066	41.6
South Atlantic	1.575	54.6
East South Central	2.096	41.0
West South Central	2.134	40.3
Mountain	1.992	43.1
Pacific	0.860	99.9
United States	1.762	48.8

SOURCE: Federal Energy Administration [17].

[a] One Kwh is equivalent to 0.859 Mcal.

[b] Electricity generating efficiency is defined as Mcal of electricity output over Mcal of fossil fuel energy input.

No data are available on regional differences in power unit efficiencies. Energy output coefficients per unit of fuel or electricity were obtained from Hunt [24] and Peterson, et. al. [32]. Converting output and input energy to Mcal and dividing output energy by input energy allows us to derive power unit efficiencies (Table B.3).

Table B.3. Energy output and power unit efficiencies of common motors used in water pumping

Power unit	Unit	Energy output	Energy efficiency
		(HP-HR[a] per unit)	(Percentage)
Diesel	gallon	12.860	0.2339
Gasoline	gallon	9.040	0.1856
LPG	gallon	7.730	0.2086
Natural gas	100 ft^3	8.000	0.1908
Electricity	KWH	0.885	0.8425

SOURCE: Hunt [24], Peterson et al., [32].

[a] Horsepower-hour, 1 HP-HR is equivalent to 0.642 Mcal.

The regional energy efficiency is calculated by the following equation:

$$RE_i = \sum_{j=1}^{5} WP_{ij} ME_j \qquad (B.2)$$

i = 48, ..., 105 for the producing areas, and

j = 1, ..., 5 for the five types of power units

where:

RE_i is the overall efficiency in converting fuel energy to work use in pumping water in the ith region;

WP_{ij} is the proportion of the jth power unit employed for water pumping in the ith region; and

ME_j is the efficiency of the jth power unit employed in converting fuel energy to mechanical energy (Tables B.2 and B.3).

Energy for Water Pumping

The energy required for water pumping is a function of pumping depth (for groundwater) and the feet of lift required (for surface water). Pumping depth by producing area is reported in Table B.1. Feet of lift required for pumping of surface water is derived from Slogget [35]. The energy required (Mcal) to pump one acre-foot of water is calculated as:

$$ER_i = (PD_i * .880945) / (RE_i * .60) \qquad (B.3)$$

$i = 48, \ldots, 105$ for the producing regions

where:

ER_i is the energy in Mcal required to pump one acre-foot of water from either an underground source or for lifting of surface water in the ith region;

PD_i is the pumping depth in feet in the ith region (Table B.1) or feet of lift of surface water derived from [35];

RE_i is the regional energy efficiency from equation B.2; .880945 is the amount of energy in Mcal required to lift one acre-foot of water one foot; and

.60 is the pumping efficiency.

Energy Required for Supply of Surface Water

In addition to the energy used by farmers for lifting surface water, a large amount of energy is consumed yearly by Bureau of Reclamation projects when providing water for irrigation. The yearly Kwh consumption by the Bureau's projects is adjusted for yearly average electricity consumption of nonagricultural users.

Energy Required for Sprinkler Irrigation

Sprinkler irrigation is a very energy-intensive operation, mainly because of the high pressure required to rotate the system and to distribute the water equally across the field. The head (pressure) required is mainly a function of the sprinkler system employed.

The head required for each of the six major sprinkler methods (Table B.4) includes friction losses and is assumed to be uniform across the 17 Western states.

Table B.4. Head required (including friction losses) in sprinkler irrigation methods

Sprinkler method	Head
	(feet)
Tow line/side roll	175
Center pivot	196
Hand rove	173
Solid set	175
Gun	312
Drip	115

SOURCE: Batty et al., [2].

The total energy use for sprinkler irrigation in a given region is a function of the acres of cropland under sprinkler irrigation derived from [25]. For the 17 Western states only 23 percent of the irrigated cropland was sprinkler irrigated in 1975 [28].

Energy for Supplying Water to the Field

The weighted average energy requirement to obtain one acre-foot of water at the head of the field (prior to irrigation) is based on weighting ground and surface water in the following equation:

$$EF_i = EG_i * GW_i + EO_i * (1 - GW_i) * SA_i \tag{B.4}$$

$i = 48, \ldots, 105$ for the producing regions

where:

EF_i is the weighted average energy requirement to provide one acre-foot of water at the head of the field;

EG_i is the energy requirement to pump one acre-foot of water from an underground source to surface level in the ith region;

GW_i is the proportion of the total delivered water represented by groundwater in the ith region;

EO_i is the energy requirements to provide one acre-foot of water from surface sources; and

SA_i is the proportion of irrigated acres with surface water pumped [38a].

Total Energy Requirements of Irrigation

The energy requirements of irrigation is divided between groundwater pumping (Table B.5), surface water pumping (Table B.6), and water application (Table B.7). The total amount of energy required to obtain and apply one acre-foot of water is shown in Table B.8. Groundwater pumping covers only the pumping of groundwater to the surface. Thus, it is mainly a function of water pumping level. Surface water pumping covers any lift of surface water from canals, rivers and reservoirs. It depends on local conditions and the location of the irrigated farmland relative to the surface water source. Energy for application includes

only the energy used for sprinkler irrigation. It assumes that other irrigation methods do not require more energy in addition to the energy that already used in pumping. Total energy is a combination of the proportion of ground water, surface water pumped, and sprinkler irrigation of the total for each region.

Table B.5. Energy required to pump one acre-foot of ground water by producing areas

Producing Area	Total Energy	Fuel Needs Gasoline	Natural Gas	LPG	Diesel	Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
48	249.25	0.5	1.3	0.1	0.9	97.1
49	713.37	1.4	3.7	0.4	2.6	277.9
50	232.67	0.4	1.2	0.1	0.9	90.6
51	634.52	0.7	69.1	0.5	2.0	250.4
52	934.54	1.7	82.4	5.7	5.3	262.2
53	142.33	0.2	54.9	1.2	1.1	26.0
54	553.90	0.5	280.1	2.6	1.8	168.6
55	461.71	0.2	467.6	2.9	4.4	49.6
56	280.35	0.1	283.9	1.8	2.7	30.1
57	292.49	1.6	159.1	1.5	2.5	34.7
58	1,268.64	0.7	1,873.5	6.8	6.4	168.9
59	1,068.64	0.4	1,110.0	6.8	10.1	113.9
60	285.04	2.1	162.8	3.7	1.2	20.8
61	554.86	5.2	87.2	9.4	1.8	42.6
62	445.88	0.6	221.0	2.7	0.7	139.8
63	1,374.21	0.6	3,200.1	5.9	4.0	100.1
64	446.91	3.1	304.1	6.2	1.3	35.2
65	2,326.61	1.2	5,232.6	8.8	3.8	252.2
66	1,109.41	1.1	2,240.6	6.4	2.2	113.1
67	1,526.28	0.0	3,775.3	3.3	2.0	170.6
68	1,043.78	0.8	2,210.2	5.2	1.9	108.7
69	1,012.17	3.4	1,589.6	7.0	3.2	92.9
70	457.29	0.0	1,125.8	1.0	0.6	51.0
71	684.10	0.0	1,692.1	1.5	0.9	76.5
72	1,668.90	0.2	4,026.2	4.1	2.3	186.6
73	964.32	0.0	2,385.3	2.1	1.2	107.8
74	945.67	0.1	2,276.3	2.4	1.3	105.9
75	1,056.88	0.0	2,614.2	2.3	1.4	118.2
76	1,216.03	0.0	3,007.9	2.6	1.6	136.0
77	313.61	0.4	155.4	1.9	0.5	98.3

Table B.5. (continued)

Producing Area	Total Energy	Fuel Needs Gasoline	Natural Gas	LPG	Diesel	Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
78	2,445.96	3.1	4,731.8	12.5	5.3	277.2
79	1,304.35	0.0	3,226.3	2.8	1.7	145.8
80	1,447.54	2.7	2,430.7	9.4	3.8	164.8
81	332.19	0.0	821.7	0.7	0.4	37.1
82	774.07	0.7	154.3	1.6	1.7	306.5
83	1,127.83	1.5	558.4	6.9	1.7	353.9
84	1,835.93	2.7	990.6	9.7	3.2	573.4
85	1,113.73	0.3	1,657.9	1.0	0.4	310.8
86	1,348.96	0.1	1,748.8	0.1	0.7	425.9
87	2,264.22	0.1	3,309.2	0.5	0.2	679.2
88	1,345.85	1.9	14.4	1.7	2.2	585.8
89	1,218.00	2.0	0.0	1.8	2.4	516.9
90	916.63	0.5	0.0	0.6	7.6	431.9
91	1,438.19	0.9	0.0	1.0	12.0	677.6
92	330.88	1.1	3.3	0.3	2.1	249.2
93	587.99	0.0	0.0	0.0	0.4	665.5
94	666.57	0.6	71.2	0.7	0.5	689.3
95	570.77	0.4	41.7	0.4	0.3	612.9
96	243.03	0.0	0.0	0.0	0.0	281.9
97	426.41	0.0	0.0	0.0	0.3	482.1
98	202.15	0.0	0.0	0.0	0.0	235.1
99	489.71	0.0	33.9	0.0	0.0	337.0
100	182.64	0.0	27.7	0.0	0.0	122.8
101	509.88	0.0	77.4	0.0	0.0	343.0
102	212.22	0.0	32.2	0.0	0.0	142.7
103	543.02	0.0	59.7	0.0	0.0	142.5
104	686.78	0.0	75.5	0.0	0.0	334.6
105	609.70	0.0	67.1	0.0	0.0	297.0

Table B.6. Energy required for pumping of one acre-foot of surface water by producing areas

Producing Area	Total Energy	Fuel Needs				
		Gasoline	Natural Gas	LPG	Diesel	Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
48	29.00	0.1	0.1	0.0	0.1	11.4
49	38.47	0.1	0.1	0.0	0.1	16.0
50	28.03	0.1	0.1	0.0	0.1	10.9
51	37.22	0.0	1.8	0.0	0.1	16.7
52	105.19	0.2	8.4	0.6	0.5	31.6
53	335.44	0.6	129.5	2.7	2.5	61.3
54	35.01	0.0	9.1	0.1	0.1	14.0
55	65.76	0.0	66.4	0.4	0.6	7.2
56	65.52	0.0	66.4	0.4	0.6	7.0
57	73.87	0.4	40.2	0.4	0.6	8.8
58	37.74	0.0	54.4	0.2	0.2	5.3
59	65.29	0.0	67.8	0.4	0.6	7.0
60	108.11	0.8	61.7	1.4	0.5	7.9
61	118.25	1.1	18.6	2.0	0.4	9.1
62	12.06	0.0	6.0	0.1	0.0	3.8
63	41.76	0.0	97.2	0.2	0.1	3.0
64	112.37	0.8	76.5	1.6	0.3	8.9
65	224.49	0.1	504.9	0.8	0.4	24.3
66	191.76	0.2	387.3	1.1	0.4	19.6
67	277.54	0.0	686.5	0.6	0.4	31.0
68	210.66	0.2	446.1	1.1	0.4	21.9
69	171.86	0.6	269.9	1.2	0.5	15.8
70	275.95	0.0	679.3	0.6	0.4	30.8
71	277.54	0.0	686.5	0.6	0.4	31.0
72	255.86	0.0	617.3	0.6	0.4	28.6
73	277.54	0.0	686.5	0.6	0.4	31.0
74	252.43	0.0	607.6	0.6	0.4	28.3
75	277.54	0.0	686.5	0.6	0.4	31.0
76	277.54	0.0	686.5	0.6	0.4	31.0
77	12.06	0.0	6.0	0.1	0.0	3.8
78	84.44	0.1	163.3	0.4	0.2	9.6

Table B.6. (continued)

Producing Area	Total Energy	Fuel Needs				
		Gasoline	Natural Gas	LPG	Diesel	Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
79	277.54	0.0	686.5	0.6	0.4	31.0
80	10.70	0.0	18.0	0.1	0.0	1.2
81	277.54	0.0	686.5	0.6	0.4	31.0
82	8.39	0.0	1.7	0.0	0.0	3.3
83	13.30	0.0	6.0	0.1	0.0	4.4
84	11.23	0.0	5.5	0.1	0.0	3.7
85	1.78	0.0	2.7	0.0	0.0	0.5
86	433.81	0.0	5.0	0.0	0.0	217.1
87	297.86	0.0	0.6	0.0	0.0	149.4
88	3.64	0.0	0.0	0.0	0.0	1.6
89	4.31	0.0	0.0	0.0	0.0	1.8
90	2.53	0.0	0.0	0.0	0.0	1.2
91	2.53	0.0	0.0	0.0	0.0	1.2
92	19.62	0.1	0.2	0.0	0.1	14.8
93	587.02	0.0	0.0	0.0	0.2	673.9
94	36.10	0.0	0.5	0.0	0.0	41.3
95	30.09	0.0	2.2	0.0	0.0	32.3
96	126.66	0.0	0.0	0.0	0.0	146.9
97	441.58	0.0	0.0	0.0	0.3	499.2
98	113.34	0.0	0.0	0.0	0.0	131.8
99	52.87	0.0	3.7	0.0	0.0	36.4
100	92.68	0.0	0.5	0.0	0.0	64.9
101	106.03	0.0	0.5	0.0	0.0	74.3
102	3.02	0.0	0.5	0.0	0.0	2.0
103	4.17	0.0	0.5	0.0	0.0	2.0
104	4.17	0.0	0.5	0.0	0.0	2.0
105	4.17	0.0	0.5	0.0	0.0	2.0

Table B.7. Energy required for application of one acre-foot of water by producing area

Producing Area	Total Energy	Fuel Needs Gasoline	 Natural Gas	 LPG	 Diesel	 (Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
48	147.85	0.3	0.8	0.1	0.5	57.6
49	147.85	0.3	0.8	0.1	0.5	57.6
50	147.85	0.3	0.8	0.1	0.5	57.6
51	117.31	0.1	12.8	0.1	0.4	46.3
52	643.11	1.2	56.7	3.9	3.6	180.4
53	724.07	1.2	279.5	5.9	5.5	132.3
54	178.38	0.2	90.2	0.9	0.6	54.3
55	363.35	0.1	368.0	2.3	3.5	39.1
56	363.35	0.1	368.0	2.3	3.5	39.1
57	541.87	3.0	294.8	2.8	4.7	64.3
58	319.75	0.2	472.2	1.7	1.6	42.6
59	363.13	0.1	377.2	2.3	3.4	38.7
60	320.68	2.3	183.1	4.2	1.4	23.4
61	126.59	1.2	19.9	2.2	0.4	9.7
62	186.71	0.2	92.5	1.1	0.3	58.6
63	361.84	0.2	842.6	1.6	1.1	26.4
64	225.19	1.5	153.2	3.1	0.7	17.7
65	330.68	0.2	743.7	1.2	0.5	35.8
66	426.10	0.4	860.5	2.5	0.9	43.4
67	286.95	0.0	709.8	0.6	0.4	32.1
68	395.95	0.3	838.4	2.0	0.7	41.2
69	268.19	0.9	421.2	1.4	0.9	24.6
70	285.02	0.0	701.7	0.6	0.4	31.8
71	286.95	0.0	709.8	0.6	0.4	32.1
72	280.77	0.0	677.3	0.7	0.4	31.4
73	286.95	0.0	709.8	0.6	0.4	32.1
74	279.56	0.0	672.9	0.7	0.4	31.3
75	286.95	0.0	709.8	0.6	0.4	32.1
76	286.95	0.0	709.8	0.6	0.4	32.1
77	186.71	0.2	92.5	1.1	0.3	58.6

Table B.7. (continued)

Producing Area	Total Energy	Fuel Needs Gasoline	 Natural Gas	 LPG	 Diesel	 Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
78	226.47	0.3	438.1	1.2	0.5	25.7
79	286.95	0.0	709.8	0.6	0.4	32.1
80	197.94	0.4	332.4	1.3	0.5	22.5
81	286.95	0.0	709.8	0.6	0.4	32.1
82	131.38	0.1	26.2	0.3	0.3	52.0
83	186.91	0.2	92.5	1.1	0.3	58.6
84	187.99	0.3	101.4	1.0	0.3	58.7
85	61.46	0.0	91.5	0.1	0.0	17.1
86	50.79	0.0	65.8	0.0	0.0	16.0
87	49.23	0.0	71.9	0.0	0.0	14.8
88	208.31	0.3	2.2	0.3	0.3	90.7
89	183.81	0.3	0.0	0.3	0.4	78.0
90	15.55	0.0	0.0	0.0	0.1	7.3
91	15.55	0.0	0.0	0.0	0.1	7.3
92	91.13	0.3	0.9	0.1	0.6	68.6
93	192.24	0.0	0.0	0.0	0.1	218.6
94	140.38	0.1	15.0	0.2	0.1	145.2
95	153.23	0.1	11.2	0.1	0.1	164.5
96	169.75	0.0	0.0	0.0	0.0	196.8
97	199.86	0.0	0.0	0.0	0.2	226.0
98	167.59	0.0	0.0	0.0	0.0	194.9
99	158.19	0.0	10.9	0.0	0.0	108.9
100	11.59	0.0	1.8	0.0	0.0	7.8
101	11.59	0.0	1.8	0.0	0.0	7.8
102	11.59	0.0	1.8	0.0	0.0	7.8
103	16.00	0.0	1.8	0.0	0.0	7.8
104	16.00	0.0	1.8	0.0	0.0	7.8
105	16.00	0.0	1.8	0.0	0.0	7.8

Table B.8. Total energy requirements to obtain and apply one acre-foot of water by producing area

Producing Area	Total Energy	Fuel Needs				
		Gasoline	Natural Gas	LPG	Diesel	Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
48	182.33	0.3	0.9	0.1	0.7	71.1
49	191.13	0.3	0.9	0.1	0.7	75.5
50	177.58	0.3	0.9	0.1	0.7	69.2
51	161.44	0.2	15.3	0.1	0.4	65.7
52	791.94	1.5	68.9	4.8	4.4	224.3
53	892.15	1.5	344.4	7.2	6.8	163.1
54	305.62	0.3	145.9	1.4	0.9	96.4
55	665.68	0.3	674.0	4.2	6.4	71.6
56	612.71	0.2	620.6	3.9	5.9	65.9
57	786.27	4.4	427.7	4.1	6.8	93.2
58	1,315.81	0.8	1,941.8	7.1	6.6	175.5
59	1,369.51	0.5	1,422.5	8.7	13.0	146.0
60	495.13	3.6	282.7	6.5	2.1	36.2
61	648.49	6.1	101.9	11.0	2.1	49.8
62	225.82	0.3	111.9	1.4	0.3	70.8
63	1,705.22	0.7	3,970.9	7.3	5.0	124.3
64	480.35	3.3	326.8	6.7	1.4	37.8
65	2,466.10	1.3	5,546.3	9.3	4.1	267.3
66	1,271.68	1.3	2,568.3	7.4	2.6	129.7
67	1,809.35	0.0	4,475.4	3.9	2.3	202.3
68	1,281.50	1.0	2,713.5	6.4	2.4	133.4
69	805.40	2.7	1,264.9	5.6	2.6	73.9
70	567.19	0.0	1,396.3	1.2	0.8	63.2
71	715.78	0.0	1,770.5	1.5	0.9	80.0
72	1,948.18	0.3	4,699.9	4.3	2.7	217.9
73	905.50	0.0	2,239.8	1.9	1.2	101.2
74	1,220.59	0.2	2,938.1	3.1	1.7	136.7
75	920.44	0.0	2,276.7	2.0	1.2	102.9
76	1,342.97	0.0	3,321.8	2.9	1.7	150.1

Table B.8. (continued)

Producing Area	Total Energy	Fuel Needs				
		Gasoline	Natural Gas	LPG	Diesel	Electricity
	(Mcal)	(Gallons)	(Cubic feet)	(Gallons)	(Gallons)	(Kwh)
77	302.32	0.4	149.8	1.9	0.5	94.8
78	698.10	0.9	1,350.5	3.6	1.5	79.1
79	1,536.45	0.0	3,800.4	3.3	2.0	171.8
80	1,645.48	3.1	2,763.1	10.7	4.3	187.3
81	566.99	0.0	1,402.4	1.2	0.7	63.4
82	150.47	0.1	30.0	0.3	0.3	59.6
83	201.26	0.3	99.0	1.2	0.3	63.4
84	244.22	0.4	131.2	1.3	0.4	76.5
85	469.53	0.1	699.0	0.4	0.2	131.0
86	724.52	0.0	381.9	0.0	0.1	308.9
87	2,180.85	0.1	2,752.6	0.4	0.2	714.3
88	309.65	0.4	3.3	0.4	0.5	134.8
89	575.95	0.9	0.0	0.9	1.1	244.4
90	191.50	0.1	0.0	0.1	1.6	90.2
91	44.81	0.0	0.0	0.0	0.4	21.1
92	125.49	0.4	1.2	0.1	0.8	94.5
93	801.47	0.0	0.0	0.0	0.3	917.7
94	267.14	0.2	25.2	0.3	0.2	280.3
95	440.92	0.3	32.2	0.3	0.2	473.5
96	332.95	0.0	0.0	0.0	0.0	386.1
97	637.03	0.0	0.0	0.0	0.5	720.2
98	289.00	0.0	0.0	0.0	0.0	336.0
99	254.98	0.0	17.6	0.0	0.0	175.5
100	194.10	0.0	15.9	0.0	0.0	133.1
101	370.04	0.0	40.6	0.0	0.0	251.8
102	201.17	0.0	30.5	0.0	0.0	135.3
103	483.04	0.0	53.1	0.0	0.0	235.3
104	197.03	0.0	21.7	0.0	0.0	96.0
105	561.11	0.0	61.7	0.0	0.0	273.3

APPENDIX C: ENERGY FOR FERTILIZERS AND PESTICIDES

Fertilizers, and more specifically nitrogen fertilizers, are a large consumer of energy in agriculture. Two pieces of information are used in estimating energy requirements for a pound of of fertilizer nutrient. The first are estimates of energy requirements to produce one ton of fertilizer obtained from Davis and Blovin [7] and White [46]. The second are the quantities of different fertilizers consumed in the United States in 1974 by type of fertilizer [23]. These quantities are used to convert the energy requirements for different fertilizers into common units of nutrients, N, P, P_2O_5, K, and K_2O.

Table C.1. Energy requirements for production of one pound of fertilizer nutrient N, P_2O_5, K_2O

Nutrient	Natural Gas	Electricity	Total Energy
	(Cubic feet)	(Kwh)	(Mcal)
N	24.321	.065	5.571
P	1.429	.257	.544
P_2O_5	3.274	.588	1.247
K	1.162	.180	.418
K_2O	1.400	.217	.504

[a] The total energy data are the summation of the natural gas and electricity converted to millions of calories.

Energy consumed by crop production as pesticides is assumed to be directly related to the quantities of pesticides applied to the crops. The cost per acre of pesticides (insecticides and herbicides) by crops and producing areas are derived from the 1971 pesticide use survey [11]. The cost per acre of pesticides when multiplied by the proportion of acres treated is assumed to represent the cost of pesticides under conventional tillage. For reduced tillage, it is assumed that costs of herbicide treatments for a crop grown under reduced tillage are the same as those of the other treated acres in the region.

In a few cases where most of the crop acreage is treated and, therefore, no difference in herbicide use occurred, it is assumed that reduced tillage requires 25 percent more herbicide than conventional tillage. Silage and hay crops are not defined with reduced tillage. Therefore, energy needs for pesticides by these crops do not change between conventional and reduced tillage.

For the purpose of converting pesticide costs to energy, prices per pound of pesticides for each of the endogenous crops have been obtained from the Economic Research Service [12]. It is then assumed that the manufacture of one pound of pesticide required, on the average, 33 Mcal [32]. Thus, energy use (Mcal) for pesticides is equal to pesticide costs divided by pesticide prices and multiplied by 33 Mcal.

APPENDIX D: 1975 ENERGY PRICES

Table D.1. 1975 energy prices by market region

Market Region	Diesel[a]	Gasoline[a]	LPG[a]	Electricity[a]	Natural Gas Regulated[b]	Natural Gas Deregulated[c]
	($/Gallons)	($/Gallons)	$/Gallons)	(Kwh/$)	(Dollars per 1000 cubic feet)	
1	.4435	.4635	.3799	.0384	2.7676	3.6135
2	.4142	.4291	.3763	.0345	2.0560	3.5669
3	.3754	.4024	.3748	.0372	2.0151	3.7957
4	.3452	.4141	.4103	.0335	1.7725	3.8267
5	.3361	.4129	.3921	.0329	1.3058	2.8895
6	.3548	.4460	.3819	.0391	1.5542	3.7121
7	.3371	.4283	.3768	.0328	1.5350	3.1629
8	.2142	.4220	.3616	.0348	1.5029	3.2386
9	.3284	.4213	.3664	.0300	1.3046	2.8778
10	.3131	.4155	.3622	.0311	1.1360	2.6064
11	.3294	.4170	.3575	.310	1.1150	2.4053
12	.3100	.4160	.3547	.0330	1.4387	3.0853
13	.3012	.4184	.3708	.0340	1.3599	2.8891
14	.3098	.4213	.3571	.0295	1.3148	3.0641
15	.2920	.4151	.3549	.0332	1.2634	2.9425
16	.3030	.4204	.3561	.0252	1.0796	2.6121
17	.2727	.4142	.3459	.0293	1.0805	2.6921
18	.2650	.4003	.3557	.0315	.9275	2.1786
19	.2887	.3771	.3331	.0325	1.2510	2.7081
20	.2850	.3670	.3300	.0330	1.3237	2.8502
21	.2831	.4167	.3340	.0269	1.0401	2.5029
22	.2831	.3740	.3339	.0328	1.2786	2.7759
23	.2820	.3944	.3419	.0330	1.2218	2.6783
24	.3625	.4094	.3568	.0174	1.9107	4.1121
25	.3109	.4301	.3848	.0247	.9522	2.5209
26	.3450	.4012	.3746	.0265	1.2916	3.1946
27	.3550	.4423	.4247	.0306	1.3326	3.1499
28	.3550	.4410	.4270	.0310	1.3023	3.0851
United States						

[a] SOURCE: Statistical Reporting Service [22,37].

[b] SOURCE: American Gas Association [1].

[c] SOURCE: Federal Energy Administration [18].

APPENDIX E: ENERGY USE COEFFICIENTS

Table E.1. U.S. average per acre energy use coefficients by dryland crops in the base run (Alternative A)

Crop	Mach. Diesel	Pest.	Fertilizer		Crop Drying. LPG	Irrigation				Total
			Elect.	Nat. Gas		Diesel	Nat. Gas	LPG	Elect.	
	(Gal.)	(Mcal)	(Kwh)	(1,000 ft.^{3})	(Gal.)					(Mcal)
Barley	8.2	14.2	9.3	1.3						609.7
Corn Grain	14.9	23.3	24.0	3.4	8.8					1,560.9
Corn Silage	21.1	13.3	17.4	2.4						1,314.1
Cotton	16.0	266.1	17.5	2.5						1,388.2
Legume Hay	19.3	2.4	17.7	0.2						739.9
Nonlegume Hay	4.3	0.6	13.1	1.7						547.5
Oats	7.2	12.3	10.2	1.2						522.6
Grain Sorghum	10.5	15.0	12.9	2.3	0.7					941.8
Sorghum Silage	18.3	13.0	8.2	1.7						1,039.2
Soybeans	12.1	18.9	18.2	0.2						518.1
Sugar Beets	14.9	59.0	47.9	2.8						1,260.0
Wheat	8.4	9.6	9.6	1.4						785.7
Total	11.2	19.2	15.5	1.6	1.7					818.7

Table E.2. U.S. average per acre energy use coefficients by irrigated crops in the base run (Alternative A)

Crop	Mach. Diesel	Pest.	Fertilizer		Crop Drying LPG	Irrigation				Total
			Elect.	Nat. Gas		Diesel	Nat. Gas	LPG	Elect.	
	(Gal.)	(Mcal)	(Kwh)	(1,000 ft.^{3})	(Gal.)	(Gal.)	(1,000 ft.^{3})	(Gal.)	(Kwh)	(Mcal)
Barley	10.1	12.4	7.1	1.3		2.3	1.3	2.6	244.3	1,541.4
Corn Grain	17.3	48.7	15.7	3.4	9.3	4.9	3.8	7.3	262.6	3,421.5
Corn Silage	26.3	41.2	7.2	2.3		2.7	2.4	2.7	241.9	2,821.7
Cotton	25.7	77.1	14.9	2.4		2.3	3.3	4.0	688.7	3,635.6
Legume Hay	10.5	4.3	25.5	0.2		3.6	2.0	3.5	736.5	3,122.2
Nonlegume Hay	5.0	0.1	7.7	1.7		0.9	0.0	0.3	116.8	780.6
Oats	10.4	8.0	7.0	1.2		2.5	0.1	2.1	447.1	1,495.4
Grain Sorghum	17.6	14.0	15.2	2.3	0.8	6.3	4.3	6.7	254.8	3,128.8
Sorghum Silage	17.2	16.2	7.2	1.6		7.4	0.8	5.0	207.6	1,904.6
Soybeans	11.9	8.5	7.2	0.2		5.7	2.9	5.3	163.6	1,829.7
Sugar Beets	29.8	51.9	13.3	2.6		2.8	1.0	2.8	498.3	2,893.2
Wheat	10.9	9.8	7.7	1.4		1.7	0.9	2.0	581.8	1,944.5
Total	14.5	17.5	14.2	1.5	0.7	4.0	2.3	4.2	434.8	2,427.7

Table E.3. U.S. average per acre energy use coefficients by total crops in the base run (Alternative A)

Crop	Mach. Diesel	Pest.	Fertilizer		Crop Drying LPG	Irrigation				Total
			Elect.	Nat. Gas		Diesel	Nat. Gas	LPG	Elect.	
	(Gal.)	(Mcal)	(Kwh)	(1,000 ft.^{3})	(Gal.)	(Gal.)	(1,000 ft.^{3})	(Gal.)	(Kwh)	(Mcal)
Barley	8.5	13.9	9.0	1.3		0.3	0.2	0.4	34.5	734.9
Corn Grain	14.9	23.9	23.8	3.4	8.8	0.2	0.1	0.2	6.3	1,605.6
Corn Silage	21.3	14.5	17.0	2.4		0.1	0.1	0.1	14.7	1,379.0
Cotton	17.5	236.4	17.1	2.5		0.4	0.5	0.6	108.1	1,741.1
Legume Hay	17.5	2.8	19.3	0.2		0.7	0.4	0.7	153.2	1,235.4
Nonlegume Hay	4.3	0.6	13.1	1.7		0.0	0.0	0.0	1.8	551.0
Oats	7.2	12.3	10.2	1.2		0.0	0.0	0.0	5.8	564.8
Grain Sorghum	12.7	14.7	13.6	2.3	0.7	1.9	1.3	2.0	77.5	1,606.6
Sorghum Silage	18.0	13.9	7.9	1.7		1.9	0.0	1.3	53.6	1,262.4
Soybeans	12.1	18.7	18.0	0.0		0.1	0.1	0.1	3.0	541.7
Sugar Beets	25.3	54.1	23.7	2.7		2.0	0.7	2.0	348.3	2,401.6
Wheat	8.5	9.6	9.5	1.4		0.1	0.1	0.1	33.2	851.0
Total	11.4	19.1	15.4	1.6	1.5	0.3	0.2	0.3	33.9	944.2

APPENDIX F: ENERGY CONVERSION TABLE

Table F.1. Energy conversion factors

	1 BTU	1 KCAL	1 Kg-meter	1 KWH	1 Barrel Crude Oil	1 Ft.-lb.
1 BTU	1	.252	107.514	2.93×10^{-4}	$1.724. \times 10^{-7}$	777.65
1 KCAL	3.9683	1	426.649	1.622×10^{-3}	6.842×10^{-7}	3,085.96
1 HP-HR	2,546.14	641.616	273,745	0.7456	4.39×10^{-4}	1,980,000
1 Joule	9.4845×10^{-4}	2.3885×10^{-4}	.1019716	2.7777×10^{-7}	1.635×10^{-10}	.73756
1 KWH	3,409.52	859.184	367,098	1	5.878×10^{-4}	2,655,220
1 Barrel crude oil	5,800,000	1,461,600	6.2358×10^{8}	1,699.4	1	4.5104×10^{9}
1 Ft.-lb.	1.284×10^{-4}	$3,241 \times 10^{-4}$	.13825	3.766×10^{-7}	2.2138×10^{-10}	1

SOURCE: Cervinka et al. [3].

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