AN INPUT-OUTPUT APPROACH FOR ANALYSIS OF ALTERNATIVE ENERGY CHOICES

Tesfa G. Ghebremedhin and Dean F. Schreiner*

The economic and social development of Oklahoma has been directly related to abundant energy supplies at relatively low prices. As a nation, the economy has shifted, in a relatively short period of time, from a position of abundant, low-cost energy to one of potential supply disruptions and sharply rising energy prices. Oklahoma's economy, like the economies of all states, depends on the use of large amounts of energy and its position as a major net producer of oil and gas creates additional current and future energy policy choices revolving around incentives for energy production, for location of energy consuming industries, or for conservation of certain sources of energy. Future revenues to producers and to the state and future costs to energy consumers will be affected by these choices. But state policy makers lack sufficient information for analysis of these alternative energy choices.

The objective of this study is to develop a comprehensive energy information system and to integrate this information into a dynamic simulation model for purposes of evaluating alternative energy choices. Research and development studies need to be accorded much higher priorities in an effort to provide the level of information required for effective policymaking in energy related matters. Such research information is vital for decision-making by planners involved in agriculture, industry and government activities.

An Energy-Based State Simulation Model

Input-Output model interrelationships of social accounts has the advantage of providing an organizational framework and a set of consistency checks that are difficult to achieve with other models. The model used here is patterned after the Iowa model by Maki, Suttor and Barnard (1966) which was later applied to Oklahoma (Doeksen, et al., 1971). The present model differs from previous models by the addition of a comprehensive energy account to allow evaluation of alternative energy choices for the state of Oklahoma. The model simulates the Oklahoma economy from 1972 to 2000.

The Oklahoma simulation and input-output model is composed of five major social accounts: (1) transactions account, (2) capital account, (3) human resource account, (4) government account, and (5) energy account. These accounts comprise the information and data base for the simulation and input-output model. Energy sources are classified as natural gas, petroleum products, coal, and electricity. All the energy statistics by sector are developed from secondary data for the benchmark year of 1972. The principal source of information on energy use by energy source for Oklahoma is taken from Irving Hoch (1978). Data on production of petroleum products, natural gas, and coal are obtained from the U.S. Bureau of Mines (1977), and quantities of electricity produced are obtained from the Edison Electric Institute (1976). Physical quantities of energy production are converted to British Thermal Units (BTUs). The base year of 1972 represents the pre-energy price increase era. Energy use coefficients may have changed significantly from the base year and would continue to change over any projected time period. However, input-output models using secondary data sources are limited by the available 1972 U.S. technology study (U.S. Bureau of Economic Analysis, 1979).

The structure of the simulation model is recursive involving 119 major equations for a given year. There are four main parts in the model which include: (1) estimating final demand, (2) determining sector output, (3) proj-

*Southern University, Baton Rouge, Louisiana and Oklahoma State University, respectively.

ecting state economic variables and (4) projecting state energy requirements and trade. Specification of the model starts with projection of components of final demand including personal consumption expenditures, private capital formation, change in business inventories, net exports, federal government purchases for national defense and non-defense, and state and local government purchases. The second step in model formulation includes determination of sector output of two groups, namely the non-energy "demand determined" output sectors and the energy "supply determined" output sectors, following procedures used by Ekholm, Schreiner, Eidman, and Doeksen (1970). Third, sector output estimates are utilized to derive state economic projections including income, employment, government revenues and expenditures, and gross state product. Fourth, projected output of the non-energy sectors, direct energy requirements of the processing sectors, direct energy requirements of households and government and projected production of state energy are used to determine state energy utilization and trade by energy source. Finally, impact analyses compare alternative growth rates in energy production and efficiencies in energy utilization with baseline projections.

Basic Model

The simulation model presented in this study is formulated around an input-output model. The disposition of output in the basic input-output framework is generally stated as:

$$X = AX + Y$$

where:

- X represents an $n \times 1$ column vector of gross output (outlay) for each endogenous sector ($i = 1$-----n).
- A represents an $n \times n$ matrix of technical coefficients in which $a_{ij} = \frac{xij}{xj}$
- Y represents an $n \times 1$ column vector of sales to final demand for each sector

Empirical application in this basic model to a given economy provides measures that can be used to estimate sectoral impacts resulting from changes in sector final demands. The standard solution to the input-output system is $X = (I\text{-}A)^{-1}Y$ where the Leontief inverse, $(I\text{-}A)^{-1}$, represents the total requirements or direct and indirect coefficients matrix and "I" represents an $n \times n$ identity matrix. Total sector outputs are hence a function only of final demands of each sector. The traditional input-output model can be used to project sector energy requirements and trade. Energy trade is defined as the difference between energy use and production. The consumption of each energy product can be computed from:

$$C = EX + Fe$$

where:

- C represents a vector of energy consumption,
- X represents a vector of energy production levels,
- E represents a matrix of sectoral energy coefficients, and
- Fe represents a vector of final energy consumption

From the basic input-output analysis the standard solution to the model is:

$$C = E\,(I\text{-}A)^{-1}\,F + Fe$$

where F is a final demand vector. Hence, the expression $E(I\text{-}A)^{-1}$ produces energy consumption per unit of final demand. For the energy-based simulation model presented in this study, the processing sectors have been separated into two groups: the demand determined by non-energy sectors, and the supply determined energy sectors.

Disposition of Output

The energy-based state simulation model consists of five final demand sectors and 81 processing sectors of which 77 are demand determined non-energy sectors and four are supply determined energy sectors. Output of non-energy sectors is assumed to follow the standard input-output solution and are thus, a function of final demand. Output of the energy sectors is independently determined and fed into the simulation and input-output model. To identify the structure of this system, the disposition of the output equation is partitioned into submatrices representing the demand determined non-energy sectors and the supply determined energy sectors. Using the subscript "1" for output of the non-energy sectors and the "2" for output of the energy sectors, the system for the disposition of output can be written as follows:

$$\begin{bmatrix} X_1 \\ \cdots \\ X_2 \end{bmatrix} = \begin{bmatrix} A_{11} & \vdots & A_{12} \\ \cdots & + & \cdots \\ A_{21} & \vdots & A_{22} \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ \cdots \\ X_2 \end{bmatrix} + \begin{bmatrix} D_1 + T_1 \\ \cdots \\ D_2 + T_2 \end{bmatrix}$$

where A_{ij}s are the partitions of the direct coefficients matrix, Xs are the sector outputs, Ds are final demands without trade and Ts are net trade. The system for the disposition of output can be rewritten as two equations, the first representing the disposition of output for the demand determined non-energy sectors measured in dollars, the second representing the disposition of output for the supply determined energy sectors measured in energy units of BTU (British Thermal Units):

$$X_1 = A_{11} X_1 + A_{12} X_2 + D_2 + T_1$$
$$X_2 = A_{21} X_1 + A_{22} X_2 + D_2 + T_2$$

The output of the supply determined energy sectors, X_2, is exogenous. It is predetermined and not affected by the level of output of the demand determined non-energy sectors, X_1. The two matrix equations are solved independently on the basis of final demands $(D_1 + T_1)$ and D_2, and the predetermined energy sector's output, X_2. Given as exogenous data, A_{11} and A_{12} as parameters of the model, and $(D_1 + T_1)$ as the final demand for the demand determined sectors, the solution for the output of the non-energy sectors can be derived from the equation for the disposition of X_1:[1]

$$X_1 = (I\text{-}A_{11})^{-1} A_{12} X_2 + (I\text{-}A_{11})^{-1} (D_1 + T_1)$$

Assuming a linear relationship between energy use and output level, disposition of output of the supply determined energy sectors, X_2, is now fully known with energy trade as a residual:

$$T_2 = (I\text{-}A_{22}) X_2 - A_{21} X_1 - D_2$$

Energy trade by energy source, T_2, is the residual between estimated energy requirements and energy production. The submatrices A_{21} and A_{22} represent the direct energy requirements by energy source of the demand determined non-energy sectors and the supply determined energy sectors, respectively.[2] Direct energy requirements of final demand are estimated for households, federal government (for defense and non-defense), and state and local government (for education and others).

The simulation model used a number of parameter ratios and growth rates which provide much of the driving force for the model. Improvements in the estimation of these parameters should lead to overall improvement of the simulation model. Ratios used in the model are generally point estimates derived from 1972 base year data (Ghebremedhin, 1981). Rates of growth as used in the model are estimated using time series data and a logarithmic exponential function. The 1972 state transaction matrix is constructed from the national technical coefficients based on the location quotient technique as developed by Schaffer and Chu (1968).

Empirical Results of the State Energy Simulation Model

This section presents results of the simulation model. Evaluation with the model is limited at this time to analysis of trends in energy production, consumption, and trade with further use projected in areas of state energy policy analysis. A baseline projection of energy production, consumption, and trade from 1972 to 2000, is presented first. Second, a 25 percent increase in the rate of growth of fossil fuel production (or 25 percent decrease in the rate of decline) is compared to the baseline projection. Third, a 25 percent increase in energy use efficiency by the year 2000 for the final demand sectors is compared to the baseline projection.

Baseline Projection

Baseline projections of state energy production, consumption, and trade by energy source in trillion BTUs from 1973 to 2000 are presented in Table 1. Production of petroleum products is projected to decrease by 1.05 percent annually, whereas natural gas production is projected to decrease only marginally, 0.06 percent annually. Electricity production is assumed to be endogenously determined in the model with a small proportion of total electricity available for export to neighboring states. This export proportion is held constant at the 1972 level. Thus, total energy production is projected to equal 3,226,895 billion BTUs in 2000 compared to 3,258,327 billion BTUs in 1973, decreasing by 1.0 percent during the simulated period of time. Natural gas is projected to decrease from 1,863,607 billion BTU to 1,834,147 billion BTUs over the 1973 to 2000 period. Coal is projected to increase from 58,784 billion BTUs in 1973 to 143,476 billion in 2000 and electricity from 106,693 billion BTUs in 1973 to 324,530 billion in 2000. These assumed rates of growth in production of crude petroleum, natural gas, and coal are quite arbitrary

TABLE 1

Projections of State Energy Production, Consumption and Energy Trade
By Energy Source and Year in Billions of BTU, Oklahoma, 1973-2000

	Energy Production					Energy Consumption					Energy Trade				
Year	Petroleum Products	Natural Gas	Coal	Electricity & Hydropower	Total	Petroleum Products	Natural Gas	Coal	Electricity & Hydropower	Total	Petroleum Products	Natural Gas	Coal	Electricity & Hydropower	Total
1973	1,229,350	1,863,607	58,784	106,586	3,258,327	325,259	643,329	1,885	77,082	1,047,555	904,091	1,220,278	56,899	29,505	2,210,772
1974	1,216,454	1,862,508	60,760	111,074	3,250,796	332,105	656,468	1,902	79,234	1,069,709	884,348	1,206,040	58,857	31,840	2,181,086
1975	1,203,693	1,861,409	62,801	115,750	3,243,653	342,824	674,084	1,953	82,090	1,100,951	860,869	1,187,325	60,848	33,660	2,142,701
1976	1,191,066	1,860,311	64,911	120,623	3,236,911	354,606	692,963	2,000	85,206	1,134,775	836,461	1,167,348	62,911	35,416	2,102,136
1977	1,178,572	1,859,213	67,092	125,701	3,230,578	367,381	713,157	2,051	88,543	1,171,132	811,191	1,146,056	65,041	37,158	2,059,446
1978	1,166,209	1,858,116	69,346	130,993	3,224,664	381,042	734,535	2,105	92,082	1,209,764	785,167	1,123,581	67,242	38,911	2,014,901
1979	1,153,975	1,857,020	71,676	136,508	3,219,179	395,505	757,027	2,161	95,815	1,250,508	758,470	1,099,993	69,515	40,693	1,968,671
1980	1,141,187	1,855,924	74,085	142,255	3,213,451	410,838	780,716	2,221	99,754	1,293,527	731,032	1,075,209	71,864	42,501	1,920,607
1981	1,129,892	1,854,829	76,574	148,244	3,209,539	427,341	805,954	2,288	103,945	1,339,528	702,551	1,048,875	74,286	44,299	1,870,011
1982	1,118,039	1,853,735	79,147	154,485	3,205,406	445,047	832,782	2,362	108,410	1,388,600	672,993	1,020,952	76,785	46,075	1,816,806
1983	1,106,311	1,852,641	81,806	160,989	3,201,747	463,861	861,078	2,439	113,137	1,440,515	642,450	991,563	79,367	47,852	1,761,232
1984	1,094,706	1,851,548	84,555	167,766	3,198,575	483,576	890,573	2,516	118,088	1,494,753	611,130	960,975	82,039	49,679	1,703,822
1985	1,083,222	1,850,456	87,396	174,829	3,195,903	504,369	921,504	2,595	123,291	1,551,760	578,854	928,951	84,801	51,538	1,644,144
1986	1,071,859	1,849,364	90,333	182,190	3,193,746	526,314	953,947	2,677	128,770	1,611,708	545,546	895,416	87,655	53,420	1,582,037
1987	1,060,616	1,848,273	93,368	189,860	3,192,117	549,478	987,974	2,761	134,539	1,674,752	511,138	860,299	90,606	55,321	1,517,364
1988	1,049,490	1,847,182	96,505	197,853	3,191,030	574,103	1,023,869	2,851	140,639	1,741,462	475,387	823,313	93,654	57,214	1,449,568
1989	1,038,481	1,846,092	99,747	206,182	3,190,502	600,246	1,061,691	2.945	147,089	1,811,972	438,235	784,401	96,802	59,093	1,378,531
1990	1,027,587	1,845,003	103,099	214,863	3,190,552	627,974	1,101,507	3.044	153,904	1,886,429	399,613	743,496	100,055	60,959	1,304,123
1991	1,016,808	1,843,915	106,563	223,908	3,191,194	657,622	1,143,684	3,151	161,132	1,965,589	359,186	700,230	103,412	62,776	1,225,605
1992	1,006,141	1,842,827	110,144	233,335	3,192,447	689,139	1,188,156	3,263	168,783	2,049,341	317,003	654,670	106,881	64,552	1,143,106
1993	995,587	1,841,739	113,844	243,158	3,194,328	722,472	1,234,863	3,379	176,858	2,137,571	273,115	606,876	110,466	66,301	1,056,758
1994	985,143	1,840,653	117,670	253,395	3,196,861	757,780	1,283,979	3,499	185,386	2,230,644	227,363	556,674	114,170	68,010	966,217
1995	974,809	1,839,567	121,623	264,063	3,200,062	795,196	1,335,639	3,624	194,394	2,328,853	179,613	503,928	117,999	69,669	871,209
1996	964,583	1,838,482	125,710	275,180	3,203,955	834,869	1,390,000	3,755	203,915	2,432,539	129,715	448,481	121,955	71,265	771,416
1997	954,465	1,837,397	129,934	286,766	3,208,562	876,968	1,447,240	3,891	213,984	2,542,082	77,497	390,157	126,043	72,782	606,478
1998	944,452	1,836,313	134,299	298,838	3,213,902	921,674	1,507,547	4,034	224,636	2,657,891	22,778	328,766	130,266	74,202	556,012
1999	934,545	1,835,229	138,812	311,419	3,220,005	969,168	1,571,107	4,163	235,911	2,780,369	-34,623	264,122	134,629	75,508	439,637
2000	924,742	1,834,147	143,476	324,530	3,226,895	1,019,641	1,638,116	4,339	247,849	2,909,946	-94.899	196,030	139,137	76,681	316,948

and are expected to be highly influenced by factors exogenous to Oklahoma.

Total state energy consumption is projected to equal 2,909,946 billion BTUs in 2000 compared to 1,047,555 billion BTUs in 1973. Consumption of petroleum products is projected to increase from 325,259 billion BTUs to 1,019,641 billion over the 1973 to 2000 period, natural gas from 643,329 to 1,638,116 BTUs and coal from 1,885 to 4,339 billion BTUs. Electricity consumption is projected to increase from 77,082 billion BTUs in 1973 to 247,849 billion BTUs in 2000.

The projected increase in energy consumption for the state is substantial, equalling a 178 percent increase over the 27 year period. For comparative purposes, the 1950 to 1977 period showed an increase of 124 percent for the U.S. as a whole. The baseline projections assumed the same efficiency of energy use to output as existed in the base year, 1972. Substantial energy use efficiencies have occurred with increased energy costs and are expected to continue over the projected period. Thus, the baseline projections are expected to be gross overestimates of energy consumption for Oklahoma but useful for comparative analysis as shown in the following sections.

Oklahoma experiences a declining net energy surplus in which total state energy trade is projected to equal 316,948 billion BTUs in 2000 compared to 2,210,772 billion BTUs of energy surplus in 1973. The decline in net energy trade is due to the projected decline in natural gas and of petroleum products production and increased consumption of total energy. Oklahoma is projected to have a deficit of 94,899 billion BTUs of petroleum products in 2000 compared to a surplus of 904,091 billion BTUs in 1973, and a surplus of 196,030 billion BTUs of natural gas in 2000 compared to a surplus of 1,220,278 billion BTUs in 1973. The net coal trade is projected to increase from 56,899 billion BTUs in 1973 to 139,137 billion BTUs in 2000. The surplus in electricity is projected to increase from 29,505 billion BTUs in 1973 to 76,681 billion BTUs in 2000 and represents marginal exports of electricity to neighboring states.

Increased Energy Production

Higher energy prices should stimulate increased activity in energy exploration and development in Oklahoma and increased energy production. Effects of events that are not reflected in the historical trend are not included in projections provided by the Oklahoma simulation model. These events, whether economic or non-economic, may have considerable impact on energy production, consumption, and trade. Further, increased energy production is expected to have impacts of state economic variables such as employment, income, and government revenues and expenditures.

The impact of a 25 percent increase in the growth rates (or 25 percent decrease in the rate of decline) of petroleum products and natural gas production on employment, personal income, and energy trade is presented in Table 2. For instance, total employment is projected to increase by 1,042 in 1980 over the baseline projection, 2,036 in 1990, and 2,606 in 2000. Total personal income is projected to increase by $9,745,000 in 1980, $23,199,000 in 1990, and $36,259,000 in 2000. Total energy trade is projected to increase by 24,210.8 billion BTUs in 1980 and 71,285.8 billion BTUs in 2000. Trade in petroleum products is projected to change by 23,915.3 billion BTUs in 1980 and 69,431.0 billion BTUs in 2000. Natural gas is projected to increase by 362.7 billion BTUs in 1980 and 2,086.2 billion BTUs in 2000. Marginal decreases in energy trade for coal and electricity occur due to direct and indirect effects of increased production of petroleum and natural gas.

The impact of a 25 percent increase in the growth rate of coal production on total employment, personal income, and energy trade is presented in Table 3. Total employment is projected to increase by 109 in 1980, 353 in

TABLE 2

Changes in Employment, Personal Income and Energy Trade as a result of 25 Percent Increase in the Growth Rates of Petroleum Products and Natural Gas Production, Oklahoma

Year	Change in Total Employment (Number)	Change in Total Personal Income (1972 Dollars)	Change in Energy Trade (Billion BTUs)
1975	370	3,242,000	9,515.6
1980	1,042	9,745,000	24,210.8
1985	1,625	16,701,000	37,611.6
1990	2,036	23,199,000	49,897.2
1995	2,374	29,883,000	61,082.2
2000	2,606	36,259,000	71,285.8

TABLE 3

Changes in Employment, Personal Income and Energy Trade as a Result of 25 Percent Increase in the Growth Rate of Coal Production, Oklahoma

Year	Change in Total Employment (Number)	Total Personal Income (1972 Dollars)	Energy Trade (Billion BTUs)
1972	25	239,000	1,496.0
1980	109	1,072,000	4,777.2
1985	215	2,341,000	9,336.3
1990	353	4,281,000	15,555.7
1995	537	7,220,000	23,918.3
2000	775	11,539,000	35,044.3

TABLE 4

Changes in Energy Trade as a Result of 25 Percent Increase in Energy Efficiency in the Final Demand Sectors, Oklahoma

(Billion BTUs)

Year	Petroleum Products	Natural Gas	Electricity & Hydropower	Total
1975	4,927.0	3,028.0	988.3	8,943.6
1980	16,110.5	9,901.3	3,231.1	29,242.9
1985	32.738.8	20,115.6	6,563.9	59,412.3
1990	57,361.4	35,248.7	11,501.3	104,111.4
1995	94,011.6	57,767.6	18,848.2	170,627.3
2000	148,306.6	91,126.9	29,731.5	269,164.9

1990, and 775 in 2000. Total personal income is projected to increase by $1,072,000 in 1980, $4,281,000 in 1990, and $11,539,000 in 2000, in 1972 prices. As a result of the assumed increase in coal production, total state energy trade is projected to increase by 4,777.2 billion BTUs in 1980 and 35,044.3 billion BTUs in 2000. This is the net effect of an increase in coal production and a marginal decrease in energy trade from petroleum products, natural gas, and electricity due to direct and indirect effects associated with increased coal production.

Increase Energy Use Efficiency

Energy efficiency in the final demand sectors is assumed to increase by 25 percent in the year 2000 compared to the efficiency in the 1972 base period. The results are presented in Table 4. Total energy trade is projected to increase 29,242.9 billion BTUs in 1980 and 269,164.9 billion BTUs in 2000. Trade is projected to increase in petroleum products by 16,110.5 billion BTUs in 1980 and 148,306.6 billion BTUs in 2000, natural gas by 9,901.3 billion BTUs in 1980 and 91,126.9 billion BTUs in 2000, and electricity by 3,231.1 billion BTUs in 1980 and 29,731.5 billion BTUs in 2000. Since energy production is not affected by the proposed change, energy consumption is expected to decline by equal amounts as indicated for energy trade in Table 4.

Policy Implications and Conclusions

Before the recent energy boom in Oklahoma, the trend in total energy production was on a decline with petroleum products showing more than a one percent annual decrease. Economic growth in Oklahoma has increased energy consumption substantially. An energy-based simulation model was developed to project the results of these trends and provide baseline data on energy production, consumption, and trade to the year 2000 (Table 1). These results assume 1972 levels of energy use efficiency. Under these conditions, Oklahoma remains a net exporter of energy by 2000 but only at about 15 percent of the 1973 level of exports.

The recent surge in state energy exploration and production has added a great deal of economic activity to the state. Changes in energy price policies and future growth in energy demand are uncertain and the effects on state economic activity are difficult to predict. The simulation model was used to determine the impact of a 25 percent increase in the rate of growth of petroleum products and natural gas production by the year 2000. Employment is expected to increase over the 1972 base period by about 2,600 people, total personal income by $36,000,000 and energy trade by 71,000 billion BTUs. With the present energy boom, Oklahoma far exceeds these assumed rates of change in petroleum and natural gas production. In fact, the assumed rates still show a decline in state production from these energy sources. The model, however, could trace the impact of various alternative growth rates.

The energy simulation model was also used to show the impact on energy trade of an assumed 25 percent increase in energy use efficiency for the final demand sectors by the year 2000. Final demand accounted for more than 25 percent of total energy consumption in Oklahoma for 1972. The assumed increase in efficiency in energy use allowed an additional 269,165 billion BTUs to be traded by the year 2000. This quantity equals about 12 percent of the amount of energy traded by the state in 1973 and allows for about an 85 percent increase in total energy trade in 2000, assuming the baseline projections. Increased efficiency in energy use should allow for substantial increases in future energy trade for the state.

The search for alternative energy choices is of great concern at the present time. With higher energy prices, more options exist now than ever before in meeting energy needs. Such options include coal, nuclear, biomass, solar, geothermal, oil shales, tide, wind and gasohol. These alternative energy sources are becoming more feasible with increased energy prices. The impact of the development of these alternative energy sources on the economy of Oklahoma is a critical importance. The present energy information system should be useful in assessing these impacts.

The assumptions involved in the present simulation model and the lack of more current data for many components of the present data base limit the usefulness of results for definitive policy analysis. Inability of the model to adjust the changes in energy prices, as well as other relative price changes, does not allow much confidence to be placed on predictive power. Lack of current energy-to-output relationships and projected trends in these relationships grossly over estimates energy consumption. However, the logic of an energy balance sheet for an energy producing state such as Oklahoma and the consistency checks provided by input-output should prove useful in analyzing alternative energy choices.

FOOTNOTES

[1]A_{11} represents direct requirements from the non-energy sectors per unit output of non-energy sectors ($/$) and A_{12} represents direct requirements from non-energy sectors per unit output of the energy sectors ($/BTU).

[2]A_{21} represents direct energy requirements from the energy sectors per unit of output of the non-energy sectors (BTU/$) and A_{22} represents direct energy requirements from the energy sectors per unit of output of the energy sectors (BTU/BTU).

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