FACTORS INFLUENCING ENERGY CONSUMPTION AND COSTS IN BROILER PROCESSING PLANTS IN THE SOUTH

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In the United States, 146.5 trillion Btu's[1] of energy were used in the production and marketing of poultry products in 1974, at a cost of $550 million [4, p. 26]. Processing plant operations accounted for about $130 million or 24 percent of these costs. Because of increased mechanization and higher sanitation standards, the poultry processing industry has become more energy intensive over time. Expanding volume and increased emphasis on further processed products also have contributed to greater energy use.

Fuel oil, natural gas, and electricity are the primary sources of energy used in broiler processing plants. The type of fuel used varies with plant location, but most plants in the South use natural gas with fuel oil as a secondary source. Fuel is used for heating broilers for steam and hot water and for heating and singeing operations. Electricity is used in a variety of ways for ventilation and cooling, operating machinery, refrigeration and freezing facilities, ice making, lighting, and supplemental heat.

As a result of the energy crisis stemming from the 1973 oil embargo, there has been renewed interest in energy use and conservation. Natural gas and fuel oil are subject to supply shortages and increasing price levels. Also electricity requirements of processors often peak during the summer months when power supplies are most critical. Processing plants have wide variations in energy use and costs because of differences in technology and operating practices which should provide opportunities for energy savings and reduced costs. The purpose of this study is to identify some important factors influencing energy consumption rates in broiler processing plants and to determine their quantitative impact on consumption and cost levels.

Procedure

Annual data on energy consumption and costs were obtained from 22 broiler processing plants in Georgia and Alabama in the spring and summer of 1976. Information was compiled from plant records and interviews with management and engineering personnel. The plants contacted represented 50 percent of the plants operating in these two states, and they processed 54 percent of the volume. Detailed monthly data on electricity and fuel usage plus monthly costs and volume of poultry processed were obtained for 11 of these plants for 12 to 24 month periods from 1974 to 1976. Certain results of this study are presented in another report [2]. The phase of the study reported herein is concerned with a statistical analysis of specific factors affecting energy consumption and costs.

Theoretical models are developed to explain energy consumption levels for fuel, electricity, and total energy. The three models are the same in theoretical basis and similar independent variables are used. Statistically, the models are formulated as linear equations with parameter estimates based on multiple regression techniques. Use of logarithmic forms of certain variables does not improve the correlation coefficients significantly. Stepwise regression procedures are used to help test variables and structure the models.

Specification of Models

Energy consumption in broiler processing plants is determined by a variety of factors related to plant location and climatic conditions, the technical and engineering characteristics of the plant, and operating procedures and practices. Most processing plants are large operations and many individual functions are performed as the birds are slaughtered, scalded, defeathered, eviscerated, and then chilled, graded, and packaged for shipment. Each operation requires a certain amount and type of energy.[2] Even though all plants perform similar functions, there are certain differences in plant size and layout, machinery compon-

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[1] A Btu is the amount of heat required to raise the temperature of one pound of water through one degree Fahrenheit (from 62° to 63° F).

[2] For a more detailed description of this processing sequence, see research studies by Childs [1] and Jones [2].

ents, and operating procedures and practices.

Energy is a relatively small cost item in the production process, and its use is dictated largely by plant technology. Attempts to include technology as a separate variable in the models were not successful because of the many variations in mechanical processes and operating practices which tended to offset one another. However, differences in consumption rates could be due to scale economies, utilization of plant capacity, and seasonal variations in temperature levels. Volume of poultry processed is used to reflect economies of size in these plants, and percent capacity is used to reflect the costs associated with underutilization of capacity. As a result of technical efficiencies possible in heating boilers and utilizing electrical power, smaller amounts of additional energy may be required to process an added volume of poultry at higher levels of plant operating capacity. Energy prices also affect energy use because management would be expected to respond to changing price levels to the extent possible.

The basic theoretical framework for the energy consumption models for broiler processing plants can be stated as:

$$C_F = f(V, T, U, P_F)$$
$$C_E = f(V, T, U, P_E)$$
$$C_T = f(V, T, U, P_F, P_E)$$

where

C_F = average monthly consumption rate for fuel oil and natural gas in therms per 1,000 pounds of broilers processed

C_E = average monthly consumption rate for electricity in kilowatt hours per 1,000 pounds of broilers processed

C_T = average monthly consumption rate for total energy used (fuel plus electricity) in therms per 1,000 pounds of broilers processed

V = average monthly volume of broilers processed in million pounds

T = average monthly maximum temperature at the weather station closest to the plant in degrees Farenheit

U = average monthly utilization of plant operating capacity as percentage of the highest monthly volume observed for each plant

P_F = average monthly price for natural gas and fuel oil combined in cents per therm

P_E = average monthly price for electricity in cents per kilowatt hour.

Units of energy are expressed in therms in the fuel and total energy models and in kilowatt hours for the electricity model.[3] Broilers processed are in ready-to-cook eviscerated weight. An alternate form of the dependent variables was considered whereby they were expressed in terms of total therms and kilowatt hours used rather than rates of use per 1,000 pounds processed, but the results in terms of R^2 values were essentially unchanged.

Results of Analysis

The theoretical models are estimated by least squares multiple regression with parameter estimates given in Table 1.

Energy Consumption Models

The energy consumption models explain a substantial amount of the variation in monthly energy use as indicated by R^2 values (Table 1). *Fuel use* in the plants ranged from 3.88 to 13.84 therms per 1,000 pounds of broilers processed with a mean of 8.14 therms. The fuel model explains 65.4 percent of the monthly variation in fuel consumption with the four variables specified. *Electricity consumption* ranged from 37.5 to 180.7 kilowatt hours per 1,000 pounds of broilers processed with a mean of 106.5 kilowatt hours. The electrical model accounts for 53.7 percent of the monthly variation in electricity consumption with the four variables specified (Table 1). *Total energy use* for both fuel and electricity ranges from 6.0 to 19.3 therms per 1,000 pounds processed with a mean of 11.8 therms. The total energy model explains 74.2 percent of the monthly variation in energy consumption which is a somewhat higher percentage than is obtained by either the fuel or electrical model.

Factors Affecting Energy Consumption

The relative importance of each variable in its effect on energy consumption is determined by beta coefficients, or standard b values, which measure the amount of variability in the dependent variable (C) that is explained by each independent variable.[4] The beta coefficient values are converted to percentages and then reduced proportionately to correspond to the level of variance explained by the total

[3] Various types of fuel were converted to therms on the basis of 10.24 therms per 1,000 cubic feet of natural gas, 1.5 therms per gallon for No. 5 or 6 fuel oil, 1.4 therms per gallon for No. 2 fuel oil, and .9 therms per gallon for LP gas. One therm equals 100,000 Btu's of energy, and one kilowatt hour of electricity is equal to 3,413 Btu's or .03413 therms.

[4] The beta coefficient estimates the change in the dependent variable, as a fraction of the standard deviation of the dependent variable, produced by one standard deviation of change in the independent variable [3, p. 473; 6, p. 24]. Snedecor and Cochran call these values standard partial regression coefficients [5, p. 398].

TABLE 1. STATISTICAL RESULTS OF MULTIPLE REGRESSION ANALYSIS OF ENERGY CONSUMPTION AND COSTS FOR BROILER PROCESSING PLANTS, GEORGIA AND ALABAMA, 1974-76

Models	Multiple Regression Coefficients[a]						R^2	F Value
	a	b_1V	b_2T	b_3U	b_4P_F	b_5P_E		
	(therms or kilowatt hours per 1,000 pounds)							
Energy Consumption[b]								
Fuel (C_F)	25.635	-.631 (.083)	-.105 (.014)	-.050 (.013)	-.204 (.033)	--	.654	48.18
Electricity (C_E)	205.857	-8.358 (1.129)	+.574 (.177)	-.606 (.169)	--	-18.389 (3.773)	.537	29.58
Total Energy (C_T)	33.684	-.918 (.086)	-.093 (.014)	-.069 (.013)	-.239 (.034)	-.695 (.297)	.742	58.03
	(cents per pound)							
Energy Costs[c]								
Fuel	--	-.0081	-.0014	-.0006	+.0055	--	--	--
Electricity	--	-.0216	+.0015	-.0016	--	+.0590	--	--
Total Cost	--	-.0291	-.0029	-.0022	+.0050	+.0540	--	--

[a]Various types of energy were converted to therms for the fuel and total energy models. One therm equals 100,000 Btu's of energy and one kilowatt hour of electricity is equal to 3,413 Btu's or .03413 therms. The electrical model was expressed in terms of kilowatt hours.

[b]Based on monthly data from 11 plants with 107 observations used in each equation. Standard errors of the b coefficients are in parentheses. The b and F values in all equations were statistically significant at the 99 percent level of probability.

[c]Cost coefficients were based on b values for energy consumption multiplied by the mean price of energy which gives the change in cost per pound for each unit change in the independent variables. Price effects on consumption were subtracted from the cost impact of unit changes in the price of energy.

TABLE 2. RELATIVE IMPORTANCE OF INDEPENDENT VARIABLES IN THE ENERGY CONSUMPTION MODELS USING BETA COEFFICIENTS FROM THE MULTIPLE REGRESSION EQUATIONS

Independent Variable	Fuel Consumption		Electrical Consumption		Total Energy Consumption	
	Beta Coefficient[a]	% of Variance Explained[b]	Beta Coefficient[a]	% of Variance Explained[b]	Beta Coefficient[a]	% of Variance Explained[b]
Volume (V)	.454	18.5	.521	20.4	.567	23.7
Capacity (U)	.245	10.0	.257	10.1	.291	12.2
Temperature (T)	.507	20.6	.240	9.3	.383	16.0
Fuel Price (P_F)	.400	16.3	--	--	.402	16.8
Electric Price (P_E)	--	--	.355	13.9	.133	5.5
Unexplained	--	34.6	--	46.3	--	25.8
Total	--	100%	--	100%	--	100%

[a]Beta coefficients are regression b values weighted by their respective standard deviations divided by the standard deviation of the dependent variable. This weights each b value by the variability of the independent variable it represents relative to the variability of the dependent variable. See [3, p. 473; 5, p. 398; 6, p. 24].

[b]Percent of variance explained is based on beta coefficient values converted to relative percentage terms and then reduced proportionately to the level of variance explained by the total regression (R^2). Variance values for the independent variables are: V = 3.141, U = 146.089, T = 140.846, P_F = 23.323, P_E = .30075; and for the dependent variables: C_F = 6.055, C_E = 809.079, and C_T = 8.245. The square roots of these values are the standard deviations which were used to calculate the beta coefficients.

regression (Table 2). The unexplained variation is still relatively large, especially in the electrical model. Unexplained variance can be due to several factors: (1) technical design and layout of the plant, (2) age and condition of equipment, (3) specific functions performed in each operation, (4) operating and management practices, and (5) statistical discrepancies due to data collection and sampling differences.

Volume. The volume of poultry processed (V) is the most important factor affecting energy consumption in the electrical and total energy models. This variable tends to reflect overall size of plant. The plants in the study had average monthly volume ranging from 1.9 to 9.5 million pounds with a mean of 5.2 million pounds, ready-to-cook weight. This variable accounts for 23.7 percent of the variation in total energy consumption, 20.4 percent of the variation in electrical consumption, and 18.5 percent of the variation in fuel consumption (Table 2). Interpretation of the b values from the regression equations in Table 1 indicates that an increase of one million pounds in volume is accompanied by a decline of .918 therms of total energy used per 1,000 pounds processed. Similarly, electrical and fuel consumption rates are related inversely to changes in volume.

Capacity. Utilization of plant operating capacity (U) is the fourth ranking variable in the fuel and total energy models and the third ranking variable in the electrical model. This variable reflects the degree to which the plant is not using its maximum plant and equipment capacity. The plants in the study had average monthly capacity utilization ranging from 41 to 100 percent with a mean of 81.8 percent. This variable explains 12.2 percent of the variation in total energy consumption and 10 percent of the variation in fuel and electrical consumption (Table 2). The b values from Table 1 show that a one percentage point increase in use of plant capacity results in a decline of .069 therms of total energy used per 1,000 pounds of broilers processed, and similar inverse changes in both fuel and electrical consumption.

Temperature. The temperature variable (T) is the most important factor affecting fuel consumption, and the third and fourth ranking factor affecting total energy and electrical consumption. Seasonal weather patterns create higher fuel consumption in the winter and higher electricity consumption in the summer. The processing plants in the study had average monthly maximum temperature ranging from 47° to 92° F with a mean of 71.4° F. Temperature changes account for 20.6 percent of the variation in fuel consumption, 16 percent of the variation in total energy consumption, and 9.3 percent of the variation in electrical consumption (Table 2). The b values from Table 1 indicate that each one degree increase in average monthly maximum temperature results in a decline of .105 therms of fuel used and an increase of .574 kilowatt hours of electricity used per 1,000 pounds processed. Because temperature changes have opposite effects on fuel and electrical consumption, the impact of temperature on total energy consumption will be a net effect with the sign of the coefficient reflecting the predominant factor. Thus, in the total energy model the finding that a one degree increase in temperature results in a net decline of .093 therms of energy per 1,000 pounds of broilers processed reflects the greater importance of temperature on the fuel component of the model.

Fuel Price. The fuel price variable (P_F) is a composite variable reflecting the price of fuel oil and natural gas combined.[5] It accounts for 16.3 percent of the variation in fuel consumption and 16.8 percent of the variation in total energy consumption (Table 2). Fuel prices are influenced by a variety of factors such as types of fuel used, location of plants, the rate structure of suppliers, and season of the year. In the study monthly average fuel prices ranged from 7.2 to 24.6 cents per therm with a mean of 12.8 cents. The b values from Table 1 show a decline of .204 therms per 1,000 pounds processed for each one cent increase in the price of fuel in the fuel model, and a decline of .239 therms per 1,000 pounds in the total energy model.

Electricity Price. The price of electricity (P_E) varies greatly with plant location, level of use, source of power, and the rate structure of power companies. Monthly electricity prices in the study ranged from 1.53 to 4.17 cents per kilowatt hour with a mean of 2.58 cents. This variable explains 13.9 percent of the variation in electricity consumption and 5.5 percent of the variation in total energy consumption. Electricity price changes therefore have a lower overall impact on energy consumption than fuel prices. The b values from Table 1 show that an increase of one cent per kilowatt hour in electricity price would result in a consumption decline of 18.4 kilowatt hours per 1,000 pounds processed in the electrical model, and a decline of .695 therms per 1,000 pounds processed in total energy consumption.

[5]All fuel units were converted to therms. For more detailed information on fuel prices and their impact on plant operating costs, see [2, pp. 25-33].

Changes in Energy Costs

Energy costs are a function of energy consumption rates and the prices of the various forms of energy. *Fuel costs* for the plants in the study ranged from .032 to .272 cents per pounds of poultry processed with a mean of .104 cents per pound. *Electricity costs* ranged from .110 to .512 cents per pound with a mean of .269 cents. *Total energy costs* ranged from .170 to .684 cents per pound with a mean of .373 cents per pound. From these figures it is evident that fuel costs on the average account for only 28 percent of total energy costs even though fuel usage accounts for 69 percent of total energy consumption. Electricity costs account for 72 percent of total energy costs but electricity accounts for only 31 percent of total energy consumption. The cost impact of variables affecting energy consumption therefore will depend on the form of energy used and its price level.

The estimated impact of the independent variables on energy costs is reflected by the cost coefficients in Table 1.[6] These coefficients are based on the b values from the energy consumption models multiplied by the mean prices of the various energy forms. These values show the effect of unit changes in the independent variables on energy costs. For example, an increase in *volume* of one million pounds results in declines of .0081 cents per pound in fuel costs, .0216 cents per pound in electricity costs, and .0291 cents per pound in total energy costs. A decrease in volume results in increases in costs of similar magnitude.

Interpretation of the other cost coefficients is similar. An increase in utilization of *plant capacity* by one percentage point results in a decline of .0022 cents per pound in energy costs, and a one point drop in capacity results in an increase of .0022 cents per pound. Increases in *temperature* are accompanied by a drop in fuel costs and a rise in electricity costs. The magnitude of the temperature cost coefficients in the fuel and electricity models indicates that the decline in fuel costs would be largely offset by the increase in electricity costs. However, the b value from the total energy model shows a slight net decline in energy costs when all variables are considered. Thus, the net effect of a one degree increase in temperature is a decline of .0029 cents per pound in energy costs, whereas a one unit decrease in temperature would result in an increase of .0029 cents per pounds.

Changes in fuel and electricity prices have a positive effect on energy costs (Table 1). However, it is partially offset by the price-induced consumption declines reflected by the b values in the consumption models. Thus, the cost coefficients indicate that a one cent per therm increase in *fuel price* results in a net increase of .005 cents per pound in total energy costs. Similarly, an *electricity price* increase of one cent per kilowatt hour results in a net increase of .054 cents per pound in total energy costs. Decreases in energy prices would reduce costs by an equivalent amount. Changes in electricity prices would be expected to have a greater impact on costs than equivalent percentage changes in fuel prices as electricity accounts for 72 percent of total energy costs.[7]

Conclusions and Implications

Broiler processing plants have wide variations in energy use and costs which can be attributed to numerous technical, environmental, and operating characteristics. The variables in the study explained 74 percent of the monthly variation in energy consumption. Environmental temperature differences account for 16 percent of the variation, differences in plant volume and utilization of capacity account for 36 percent, and energy price variables account for 22 percent of the variation in energy consumption.

A certain amount of unexplained variation remains, particularly for the electrical component of energy use. Much of it probably is related to differences in design and layout of plants, the age and condition of processing equipment, and the type of pack and size of birds processed. Some plants also perform slightly different functions in their cut-up, chill pack, and bulk freezing operations. Other sources of variation include differences in operating practices and the extent to which management and employees emphasize energy conservation. The wide variations found in energy use among individual plants is evidence of additional opportunities for energy conservation in many of these plants.

Because of the nature of processing operations, where energy costs are still a very small item in the overall cost structure, technological factors will probably continue to predetermine energy requirements in the near future. There-

[6]Multiple regression analyses of factors affecting energy costs per pound using the same independent variables as in the consumption equations produced b values very similar to these cost coefficients. The R^2 values were slightly lower, however. Compared to their effects on energy consumption, the temperature and fuel price variables were more important in the fuel cost model and less important in the total cost model. Electricity price effects more than doubled, accounting for 12.7 percent of the variation in total energy costs.

[7]A 20 percent increase in both fuel and electricity prices, for example, after allowing for price response effects, would increase fuel costs by .013 cents and electricity costs by .028 cents per pound. Electricity price changes thus have twice the impact on costs.

fore, in terms of public policy, energy conservation efforts may be more effective if oriented toward equipment manufacturers and improved plant design rather than direct taxes or alteration of energy prices imposed on processing plants. Such policies could emphasize the development of more energy-efficient equipment and greater use of controls and monitoring devices in plants. Internal design specifications also could consider type and location of alternate equipment and placement of power substations and outlets, switches, etc., and their possible compatibility with new technology.

This study shows that changes in energy prices had only limited effects on consumption, most of the impact being on fuel usage where the price effects on consumption in terms of costs were not particularly sensitive. Changes in electricity prices had even less impact on energy consumption than fuel price changes, even though they had a somewhat greater effect on costs, i.e., they were more cost sensitive. Therefore, because of the limited price effects on consumption and the relatively small magnitude of energy costs in terms of total costs, policies to encourage the development and adoption of more energy-efficient facilities and equipment by processors may be more effective than increasing energy prices. Such policies could be accomplished by increased investment tax credits or accelerated depreciation for more energy-efficient equipment and controls. Other changes in practices and equipment, installation of measuring devices, and adjustment for peak demand power loads also would be helpful in conserving energy in the short term.

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