NATURAL RESOURCES JOURNAL

Volume 24
Issue 1 *Winter 1984*

Winter 1984

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INTRODUCTION

Since 1973, it has been obvious that an increasing portion of our nation's energy requirements will be directly or indirectly provided by coal. Uncertainty over the government's national energy policy and relative advantages of other fuel types have caused speculation about the location and intensity of coal development. Coal and other energy developments have already caused serious problems in the West. The impacts on some rural communities have been severe.

Water is a crucial input in energy conversion. Concerns have been expressed whether sufficient water supplies exist to support increasing rates of energy development, particularly coal conversion projects. Water availability is of special concern in arid and semi-arid regions of the United States. In total, sufficient water supplies exist to support expanded energy development but, unfortunately, water deficit areas of the West coincide with energy rich regions, i.e., the coal fields of Wyoming, Montana, and North Dakota, and the oil shale regions of Colorado and Utah. Water availability and energy conversion requirements play a major role in locating and sizing energy projects.

Water is important in all aspects of energy development. Water is needed in varying quantities for the extraction, processing, and conversion of energy resources and for reclamation of disturbed lands. Since nearly 85 percent of our electric power is generated by steam-driven turbines, water for electricity production requires special attention. The steam-electric generation industry accounts for 25 percent of total annual water withdrawals.[1] The energy sector will compete even more with other water users (agriculture, recreation, municipal, and industrial) in the future. Growth of the domestic energy sector, particularly the steam-electric component, will continue and severely impact both water supply and water quality.

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1. U.S. WATER RESOURCES COUNCIL, SUPPLEMENTAL REPORT TO THE SECOND NATIONAL WATER ASSESSMENT—WATER FOR ENERGY, Number 1 at 34 (1978).

THE RESEARCH PROJECT

In 1975, the United States Department of Agriculture (USDA) and the Enviromental Protection Agency (EPA) entered into an Interagency Energy/Environment research project to analyze impacts on natural resources and rural communities of alternative patterns of coal development stimulated by market forces and government policy. The project is being coordinated by EPA's Office of Research and Development and USDA's Economic Research Service.

Investigation of readily available data bases and models revealed that existing analytical tools and supporting data bases would not provide sufficient detail at the rural community (or county) level without substantial post-model disaggregation. An inventory of existing and potentially available data, however, suggested the possibility of developing a system of data to support interregional competitive analysis at the county level. The primary concern in obtaining and integrating individual data files was to maintain the greatest possible level of disaggregation. Therefore, whenever possible, data were obtained describing activities of individual firms and aggragated only because of proprietary restrictions or computer capacity and cost constraints.

A major sub-objective of the Project has been to identify individual mine suppliers of coal-fired power plants each year from 1975 through 1982. The data, when combined with files describing current plans for new coal-fired units and conversions, can be used to perform short run analyses of coal demand in the electric utility industry. Selected data from the files listed above are analyzed using a linear programming (LP) formulation called the Interregional Coal Analysis Model (ICAM). The ICAM currently is being used only as an accounting tool to simulate historic and short run announced flows of coal to the electric utility industry. Three modules describing production (reserves, mining, and coal cleaning), distribution (transportation), and demand (utility use) compose the ICAM. The ICAM utilization module simulates the operation of existing and scheduled coal-fired power plants through 1990.

WATER USE

Water use for each power plant is calculated by first analyzing and predicting the operating characteristics of that power plant. The operating characteristics which must be developed are the plant capacity factor and the heat rate. (The capacity factor is not to be confused with plant reliability. Reliability refers to the ability of a power plant to generate electricity when called upon.) The plant capacity factor (PCF) is defined using the following formula:

$$\text{PCF} = \frac{\text{Actual Net Generation}}{\text{Hours in Year (8760)} \times \text{Nameplate Mw} \times 1000} \times 100$$

The result is a percent; if a power plant operated all 8,760 hours in a given year, the PCF would be 100 percent.

Operating characteristics for 260 coal-fired power plants for the period 1965 through 1978 were collected and analyzed.[2] Serial cross-sectional analysis was used rather than pooled time-series cross-sectional analysis because of problems with autocorrelation and because serial cross-section analysis also allowed the use of additional data available after 1972. The final equation used to predict the PCF for each year from 1979 through 1990 is

$$\text{PCF} = 82.5 - 0.0048(\text{HR}) - 0.002(\text{NONF}) - 0.0074(\text{GC}) + 0.115\,(\text{CUSE})$$

where HR = heat rate,
NONF = nonfuel operating cost,
GC = generation capacity, and
CUSE = coal use.

The above composite coefficients were obtained by averaging significant coefficients from annual regression equations, a procedure which is appropriate since the annual coefficients are relatively stable in sign and magnitude.

The efficiency coefficient [heat rate or input/output (I/O) ratio] is a measure of a power plant's ability to convert coal to electrical energy. The ratio is expressed as Btu inputted per kWh of electricity generated. Low ratio plants are more efficient and therefore cheaper to operate. The I/O ratios help determine the derived demand for coal and are deterministic variables in the estimation of capacity factors.

Cross-sectional and trend analysis were both used to predict heat rates. Comparison of the estimates for existing plants using both methods indicated that the trend method provided more consistent results. The trend estimates were nearly all lower than regression equation estimates. Inspection of each projection was necessary to prevent inconsistent results. Water use coefficients must be estimated in conjunction with plant operating factors to predict total demand for water by each plant in any given year. Data for four types of cooling systems were collected and analyzed. The four types are once-through fresh (OTF), once-through saline (OTS), wet cooling towers (WCT), and cooling ponds (CP). Ordinary least-squares serial cross section analysis was also used to estimate

2. ENERGY INFORMATION ADMINISTRATION, U.S. DEPARTMENT OF ENERGY, THERMAL-ELECTRIC PLANT CONSTRUCTION COST AND ANNUAL PRODUCTION EXPENSES (various years).

equations describing water use for each of the four types of cooling systems commonly used.[3]

Land use and pollution coefficients have also been developed for each power plant using statistical analysis of historical data and engineering estimates of technology design and performance.[4]

The equations derived above were used to create a matrix of coefficients for each power plant for each year from 1975 through 1990. The plant capacity factor was predicted for each year for each plant. Once the percent of time each year the plant would be operating was known, its water use and demand for coal could be determined. Knowing the characteristics of the coal being used, the amount of effluents that will be produced can also be predicted.[5]

The result is an estimate of the annual amount of kilowatt-hours of electricity produced, coal demanded, water required, and effluents produced. The coefficients for each plant for any specified year from 1975 through 1990 can then be entered into a linear programming matrix and the tightly constrained matrix optimized to generate a picture of the coal network in the specified year. The matrix also includes land use estimates which do not depend upon operating characteristics.

RESULTS AND POLICY ANALYSIS

The methodology described above was developed and tested for the Western States.[6] Model runs were made for 89 power plants using western coal in 1975, and 154 plants using the same coal in 1985. Steam-electric coal production in the western states (Wyoming, Montana, North Dakota, New Mexico, Utah, Colorado, and Arizona) was projected to increase from 65 million tons in 1975 to 286 million tons in 1985. The largest increase was projected to occur in northeastern Wyoming (Powder River) from 3.5 million tons in 1975 to 106 million tons in 1985.[7]

Dalsted has made more recent estimates of national water demands by coal-fired power plants.[8] He analyzed 297 coal-fired plants larger than

3. A description of the statistical analysis and resulting equations will not be given here because of space limitations. N. Dalsted, Water Consuption in the Coal-Fired Electric Generation Industry: An Analysis and Projections. (1981) (Unpublished Ph.D. dissertation, Economics Department, Colorado State University.)

4. W. McMartin & K. Ebeling, Land Used by Coal-Fired Electric Generating Plants (October, 1981)(Economic Research Service and Department of Industrial Engineering, North Dakota State University).

5. *Id.*

6. Office of Environmental Engineering & Technology, U.S. Environmental Protection Agency, Western Energy: The Interregional Coal Analysis Model, Tech. Bull. 1627, ERS-USDA and EPA-600/7-79-139 (August, 1980).

7. These projections are now out of date; they are currently being updated. *Cf.* N. Dalsted & J. Green, Water Use by Coal-Fired Power Plants in 1975, Staff Report No. AGERS 810326, NRED-ERS-USDA (March, 1981).

8. *Id.*, and N. Dalsted, *supra* note 3.

100 megawatts. Most of the plants (181) used once-through cooling fresh water but 38 plants used cooling towers, 36 plants used combination systems, 23 used cooling ponds, and 13 plants utilized once-through cooling saline water. Estimated total consumption of water in 1975 by these plants was 1.67 million acre-feet. Once-through fresh systems consumed 39 percent of that total, combination systems 25 percent, cooling towers 20 percent, ponds 12 percent, and once-through saline systems 4 percent. Only 2 percent of the water withdrawn in 1975 was actually consumed, although the portion consumed is rising.[9] Greater emphasis on evaporative cooling technologies, such as "wet" cooling towers, will significantly increase total consumption of water.

Once base runs describing best estimates of the structure of the coal network for any year have been made, the linear programming constraints can be selectively relaxed to generate a picture of the coal network resulting from alternative policy scenarios. For example, if a power plant wants or needs to change its coal supplier, the data base can be searched to see which counties have available coal with the desired characteristics. These counties then can be presented to the linear programming problem as alternatives to be maximized within the general constraint that the entire network must operate. The entire problem does no have to be run to determine the most efficient alternative supplier for one plant; however, if alternative suppliers for 100 plants must be optimized, the base case could be expected to change significantly. Furthermore, the resulting changes in water and land use and pollution production may be significant.

Many other analyses are possible with the comprehensive data bases organized at Colorado State University. Current work includes coal selling price models, coal reserves and characteristics models, transportation cost analyses, data books, and computer mapping systems.