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FORECASTING ENERGY REQUIREMENTS

IN

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FORECASTING ENERGY REQUIREMENTS

IN

MINNESOTA

By the
Research Division
Minnesota Energy Agency
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FORECASTING OF ENERGY REQUIREMENTS IN MINNESOTA

The energy crisis, the employment problem, land and other resource conflicts, and environmental issues require immediate policy actions (legislation, new institutions, and regulatory bodies and court decisions) in the area of resource allocation. Thus, there appears a need for a comprehensive framework useful in analyzing the effect of alternative resource and public investment policies. An optimizing simulation model built around inter-relationships among resource, production and consumption activities, private capital stock and public infrastructures becomes an important tool in this setting. Also, separate in-depth analyses of major energy producing and consuming sectors would shift, from among the host of factors affecting energy use, the important variables that should receive first consideration by policy makers.

Two models are being developed for the purpose of forecasting energy requirements/demand by major users in Minnesota. Model I estimates direct requirements of seven major user groups, while Model II uses an Input-Output/Linear Programming/Simulation approach to determine total fuel requirements that will sustain gross outputs, gross state product, and personal income.

Model I, Direct Requirements/Demand Model

The objectives of Model I are threefold:

1. Estimate the direct energy requirements of major users as demographic and economic variables change in the next decade;
2. To show the structural, production, and consumption characteristics of energy producing and consuming groups in the state, and to compare these attributes with the national pattern;

3. To identify important variables that may be susceptible to policy change in order to provide for more "efficient" use of energy supplies.

Major User Groups

Seven major energy producing-consuming sectors are identified in Fig. 1.

Construction of separate projection models for each of the major groups will be done in three steps following a draft flow-chart of relationships:

1. Parameters for energy use equations will be derived from secondary sources;

2. The effect of changes in income, relative prices among competing fuels and equipments, and other choice variables will be included in order to determine the number and type of new and replacement equipment;

3. The effect of changes in income, relative prices of fuels, and other variables will be introduced to estimate the actual fuel use of all equipments.

The prospective outputs of this model are:

1. The beginning or base values as well as the predicted values of energy use by fuel type, by major group, during the next decade;

2. The estimated number of producing-consuming units within each group;

3. Energy intensities or efficiencies of fuel use by equipment, by major group;

4. List of major variables affecting fuel use within each

group, in their order of probable effects on total fuel requirements.

Household (Residential) Demand Model - An Example

The household (residential) demand model shows how energy demand is projected for a major group (Fig. 2). The methodology starts with census estimates of the state population by age and sex categories. The components of population change (fertility-mortality rates and net migration) are then derived along with headship rates, in order to determine the total number of households. Immediately, changes in income will affect the headship rates (or the propensities to form households), as well as the appliance saturation ratios (or the proportion of appliances to households). The saturation ratios translate from total households the number of old and new additional appliances.

Relative prices of competing fuels will also affect the saturation ratio, hence determine new appliances in new households and new-additional appliances in existing households. Energy intensities are derived then, for existing appliances and (estimated) new appliances. Multiplied by the number of appliances, these result into energy demand by appliance. Final estimates of energy intensities are affected by income, relative change in energy prices, and such other variables. For example, the use of clothes dryers may be made more efficient by a family trying to conserve on fuel bills in addition to the manufacturer's energy intensity design.

Further, the effects of relative prices and availabilities of substitute fuels are worked into the choice of new appliances.

The Market Share Approach (Rand Model) allocates total energy demand among specific types of fuel (Fig. 3). For example, a given increase in the price of electricity relative to gas would imply:

1. An increase in the proportion of gas-heating units built into new homes, and
2. The shift in heating units from electric to gas in some existing homes.

The Interfuel Competition Demand model (MIT) is a variant of the market share approach (Fig. 4). It shows explicitly the split of total energy demand into "locked on" fuel demand and fuel demand by replacement and new appliances. The fuel allocator is a function of competing-fuel prices. These two models will be used according to their applicability to different appliances. For example, the Market Share Approach is intended for space heating and other fixtures exhibiting longer replacement lags, while the Interfuel Competition Model will be applied to cheaper and perhaps easily replaceable appliances.

Model II, Input-Output/Linear Programming/Simulation Model

The structure of the Minnesota economy is shown through an exposition of the transactions and interdependencies among various sectors. The input-output model displays these relationships and provides an estimate of total fuel requirements at a target level of gross state product. Where fuel scarcities, energy generation capacities, and permissible pollution levels impose constraints on production and consumption activities, the model is redesigned to maximize either gross state product, employment, or such other

objectives subject to^{the} capital, resource and energy constraint. Thus, output, income and employment will be determined for each producing industry group within the limits of resource and capital use, energy supplies, and emission standards. This establishes a groundwork for an energy allocation strategy.

The I-O/LP model is incorporated in a general model of the state's population and economy in order to trace its long-term growth under a host of alternative public policies. Also, the model can show the immediate impacts of changes in policies on the population, economy and environmental quality.

The model simulates industrial sector output, population, employment, unemployment, capital structure and gross investment, personal incomes, consumption-savings and taxes, energy facilities and natural resource use. It is designed for use in planning future production and consumption activities, procurement of resources, investments in infrastructures and employment of labor force. A computer model of the state's economy is manipulated by varying input variables and model parameters. A list of variables and parameters may be prepared in their order of influence on output, employment, and quality of life goals and targets in order to show critical areas for public policy.

Output of the I-O/LP/Simulation Model

1. Gross state product by expenditure categories
2. Employment by producing sector
3. Capacity of plant and equipment including energy facilities
4. Gross investment in private and public infrastructure
5. Energy requirements/supply by fuel type

6. Labor force and unemployment rate
7. Population and net migration rates
8. Personal income received from business
9. Government tax collections
10. Unallocated value-added
11. Waste emissions from production and consumption.

Inputs to the I-O/LP/Simulation Model

1. Demographic variables: base year population by age and sex; fertility, survival and net migration rates
2. Production coefficient matrix
3. Final demand distribution matrix
4. Gross output vector for the base year
5. Capital-output ratio matrix
6. Labor-output ratio matrix
7. Energy-output ratio matrix
8. Waste emission-output ratio
9. Unemployment rate constraints
10. Waste emission constraints, energy supply, facility capacities and land use constraints
11. Energy conversion coefficient matrix
12. Substitution elasticities in production (with respect to price) matrix.

Input-Output Model of a Simplified Economy - An Example

The Input-Output/Linear Programming/Simulation model begins with a transactions table (Fig. 5). For example, the pattern of purchases of the agricultural sector from all sectors of the economy are given in the first column. In this simplified economy, agriculture retains \$10M of its own output, buys \$5M from manufacturing, purchases \$60M from households in the form of salaries and wages, imports \$20M from the rest of the world,

and produces \$5M in value-added. The second column shows the pattern of purchases of manufacturing, while reading across rows shows the equivalent sales of producing sectors among industries and net users or final demand.

This accounting table permits estimation of gross state product from both product account and income account (Fig. 6). The sum of sales to final demand less imports yields gross state product in the product account, while payments to households and value-added estimate gross state product from the income side.

The Input-Output Model and Energy Requirements

Balanced equations formed from the transactions table are shown in Fig. 7. The first equation shows that industry sales to all producing sectors (or intermediate products) plus sales to net users (or final demand) exhausts total output. Production coefficients are then derived by taking the ratio of intermediate product purchases to total output for each sector. Finally, total output can be made a function of final demand or gross state product. Projections of the various components of gross state product will yield projections of total output for each producing sector. For example, increasing agricultural exports will increase output not only of agriculture, but also related industries, i.e., industries supplying agriculture.

Projecting Energy Requirements

Energy requirements are estimated through the use of two additional sets of information:

1. Energy intensities by fuel type for producing sectors, e.g. kilowatt hour energy use per dollar output, and

2. Energy purchases of net users as a proportion of total purchases.

Insertion of these matrices into the balance equation formed earlier results into an estimate of total energy requirement by fuel type that will sustain target gross state product or final demand.

Energy and Resource Constraints

Thus far, energy supplies and resource constraints are not accounted for in the model. Returning back to the production relationships derived from the transactions table, a set of constraint equations relating to:

1. Final demand realized may be less than or equal to target final demand, and

2. Resource and capital requirements as a function of output cannot be greater than supplies (Fig. 8).

Objective functions such as gross state products or employment may be formed and maximized, given these constraints. Thus the framework transforms the I-O Model into a Linear Programming problem. The power of the new format lies in its ability to allocate limited resources among competing users according to their contribution to the policy objective.

Simulation Model

The I-O/LP Model is included in the simulation model as the "goods and services factory." However, the simulation model begins with population estimates in a demographic sector. Births, deaths and net migration are elements that determine the population for each year; the size and distribution of which determine household consumption and final demand, and the supply of labor. The other final demand components are either projected outside the model, e.g., exports being tied to national conditions, or determined by policy makers such as public expenditures.

Estimates of final demand are transformed by the output sector into total industry output requirements. In the process, the output sector draws resources in the form of fuel imports, purchases materials, pays taxes to government, and distributes salaries and wages to labor. Also, industries emit pollutants into the environment.

The process indicates the extent of use of public and private infrastructures and shows what new facilities will be required to satisfy outputs and projected final demand. On the other hand, siting of new infrastructures are determined by land use controls. Where capital, labor and other resources, and environmental constraints, are effective, the output sector responds by initiating a production activity level within the limits of these constraints.

Relative prices enter the output sector by revising the production relationships through a technological change matrix. Included also in this matrix are possible ways by which energy use and emissions change in accordance with new public regulations.

Finally, the output sector determines employment. Given the size of the labor force, skills, and such other attributes of workers, unemployment levels will be estimated. Net migration into the state is determined using unemployment, income, wage rates and such other variables generated by the system. Net migration augments or reduces the state population for the next period, and an estimate of the new population starts the next round of computations.

Fig. 1

DIRECT REQUIREMENTS/DEMAND MODELS

1. Sectors

- Households (residential)
- Agriculture
- Industrial (including mining, construction, and manufacturing except utilities and refineries)
- Utilities and refineries
- Transportation
- Government (including public schools)
- Commercial and miscellaneous

2. Objectives

- Estimate direct energy requirements of major users by fuel types as demographic and economic variables change.
- Show structural production and consumption characteristics of energy producing and consuming groups in the state and compare these attributes with the national pattern.
- Identify important variables that may be susceptible to policy change in order to provide for more "efficient" use of energy supplies.

3. Procedures

1. Identify parameters for energy use equations.
2. Insert the effect of changes in income, relative prices among competing fuels and equipments, and other choice variables to determine the number and type of new equipment.
3. Insert the effect of changes in income, relative prices of fuels, and other variables to estimate actual fuel use by all equipment.

4. Output

1. Beginning or base values and predicted fuel use, by fuel type, by sector.
2. Number of producing-consuming units within each sector.
3. Energy intensities or efficiencies of fuel use by equipment, by major group.
4. List of major variables affecting fuel use within each group, in their order of probable effects on total fuel requirements.

Fig. 2

HOUSEHOLDS (RESIDENTIAL) DEMAND FOR ENERGY

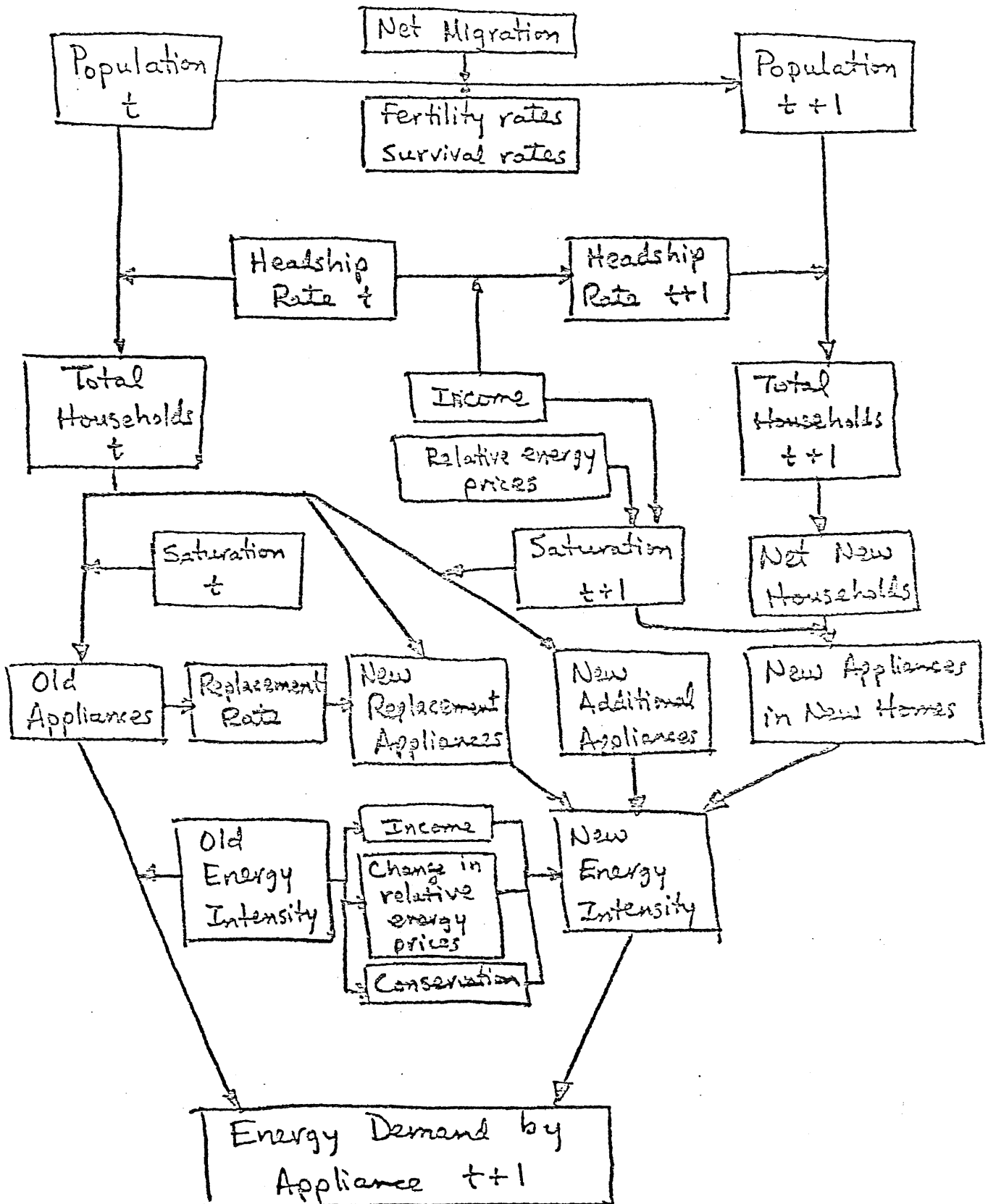


Fig. 3

Market Share Fuel Allocator for Electricity and Gas (RAND)

$$\hat{D}_{et} = \hat{D}_t \left[\lambda \left(\frac{P_{et}}{P_{e0}} \right)^{e_e} \left(\frac{P_{gt}}{P_{g0}} \right)^{e_g} + (1 - \lambda) A_{t-1} \right]$$

where:

$\hat{D}_{et}$ = demand for electricity in year t

$\hat{D}_t$ = energy demand without the price effect in year t

λ = replacement lag for equipment

P_{et} = price of electricity in year t

P_{e0} = price of electricity in base year

e_e = price elasticity for electricity

P_{gt} = price of gas in year t

P_{g0} = price of gas in base year

e_g = price elasticity for gas

A_{t-1} = lagged value of allocator (bracketed term in equation)

Fig. 4

~~MIT (Baughman)~~ Inter-fuel Competition
Demand Model (H⁻)

$$Y_{i(t+1)} = B_i Y_{i(t)} + d_i(t) \left[\sum_{i=1}^n (1 - B_i) Y_{i(t)} + G(t) \right]$$

where :

$Y_{i(t)}$ = fuel demand by appliance i at time t

B_i = proportion of appliance i "locked on" to fuel i

$d_i(t)$ = allocator of replacement and new appliance demand to fuel i
(e.g., $d_i(t) = A_i e^{a_{i1} P_{1t}} e^{a_{i2} P_{2t}} \dots e^{a_{in} P_{nt}}$)

$G(t)$ = new appliances

Fig. 5

INPUT-OUTPUT / LINEAR PROGRAMMING / SIMULATION MODELExample of input-output transactions table

Producing / Purchasing	Agriculture	Mfg., etc.
Agriculture	10	30
Mfg. etc. producers	5	15
Primary inputs:		
Households	60	30
Imports	20	10
Value added	5	15
Total	100	100

Include sales to final demand

Producing Sector	Final Demands			Total output
	Households	Exports	Other	
Agriculture	10	50	0	100
Mfg. etc.	40	30	10	100
Total	50	80	10	

INPUT-OUTPUT MODEL (EXAMPLE)GROSS STATE PRODUCT

Product accounts:

Households	50
Exports	80
Other	10
less Imports	<u>-30</u>
	110

Income accounts:

Households	60 + 30
Value added	<u>5 + 15</u>
	110

INPUT-OUTPUT MODEL^{Fig. 7}: BALANCE EQUATIONS

$$M + FD = Q$$

$$A = M/Q$$

$$\therefore AQ + FD = Q$$

$$Q(I-A) = FD$$

$$Q = (I-A)^{-1}FD$$

where: M = intermediate product sales

FD = sales to final demand or net users

Q = total output

A = input coefficient relating intermediate product purchases to gross output

Energy Requirements (Univ. of Illinois, CAC-Urbana)

$$E_i = [R_i(I-A)^{-1}]FD + [S_i]FD$$

$$E_i = [R_i(I-A)^{-1} + S_i]FD$$

where: E_i = energy of type i required to produce gross outputs that will satisfy final demands and supply energy requirements of net users

R_i = matrix of energy intensities for type i for all producing sectors (e.g. kWh/\$ output)

S_i = energy purchases of net users as a proportion of total purchases

LINEAR PROGRAMMING / INPUT-OUTPUT MODEL

$$Q[I-A] = FD$$

$$\text{from: } Q(I-A) - FD = 0$$

$$FD \leq \hat{FD}$$

Add constraints:

$$RQ \leq C$$

$$Q \geq 0$$

and decide whether:

$$\text{Max } IQ_{GSP} \quad \text{or} \quad \text{Max } LQ$$

where: Q = vector of gross outputs of producing sectors

I = identity matrix

A = technical coefficient matrix

FD = final demand matrix

R = fuel intensity matrix

C = vector of available fuels

L = vector of labor-output ratios

SIMULATION MODEL

