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Microcosm - A Tool for Energy Sector Policy Analysis and Training in Nepal

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INTRODUCTION

This paper has been prepared in support of a series of presentations of the Motor-Columbus Energy Sector Simulation (MICROCOSM) that took place on June 22, 1986 in Kathmandu. Representatives of the Nepal Electricity Authority (NEA), the Water and Energy Commission (WEC) and the International Center for Integrated Mountain Development (ICIMOD) attended. At that time, the model was mounted on the Apple IIe microcomputer, and an indicative data base representing Bangladesh was utilized. The prevailing energy situation of that country was outlined, and the way in which the model can be used for integrated national (and regional) energy sector policy planning and training demonstrated.

The purpose of this paper, then, is to provide the participants of these meetings, as well as the much broader audience of energy economists, planners and engineers in Nepal, with the logic and system of equations that form the basis of what was presented at those sessions. In addition, the way in which the model could be applied to Nepal is incorporated into the discussion which follows.

INTEGRATED ENERGY PLANNING AND MICROCOSM

Integrated energy planning is a continuous process that is often difficult to institute and implement in developing countries. Typically, many public and semipublic offices, agencies and institutions share responsibilities in a country's energy sector; and a portion of the nation's limited capital resources must be shared among them to provide for the necessary growth of the various subsectors. However, these individual subsectors must also develop in a coordinated manner that assures the sector program as a whole will continue to be consistent with overall economic development. This is the role played by integrated energy planning. In order to assist in this process, the MICROCOSM model has been developed with the following functions:

- First, it is a tool for energy analysis work of short duration and is suitable for application in relatively small, data-poor economies;

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- Second, it is useful for quick survey use on a regional or national basis in more complex economies. Sectoral bottlenecks, for instance, can be identified early in a major energy planning project; and

- Third, it provides an excellent framework within which to train energy sector professionals from diverse disciplines in the purpose, value and methods of integrated national planning.

MICROCOSM is a planning tool. It is a simulation model[1] that focuses on the critical interactions within the energy sector. It encompasses causes, effects and relationships, and produces numerical output indicating the order of magnitude results of various policies. Consequently, it does not present an "optimal" solution to supply/demand balancing, nor is it intended to form the sole basis for investment decisions. It is, however, extremely flexible, and therefore quite useful in comparing different policy options or investment programs, and in suggesting various combinations of actions that might be taken to cope with a country or region's energy difficulties.[2]

MICROCOSM is user friendly and produces results of a microcomputer-based simulation run in less than two minutes. Its innovative design allows for the interactive analysis of the entire data base. New data can be used at once. New ideas for solving an energy problem can be tested quickly and their results printed for discussion. Moreover, graphic presentations can also be generated. That is, slide shows of tables, graphs, maps and other figures can be developed and edited showing the results of analyses performed with MICROCOSM, and the powerful graphics capability of microcomputers can be utilized to enhance them.

The model is designed to balance the supply and demand of 24 fuels, both commercial and noncommercial, in a nine-sector economy over 30 years. This is normally sufficient for analysis in a developing country. The base year is user specified, and the length of the six five-year periods can be altered prior to data input. Thus, the model can be used for both short-term and longer-term studies by employing different data bases. Input parameters on both the supply and demand sides of the simulation may be changed to consider the effects of various policies. A large number of investment programs in energy supply infrastructure may also be studied explicitly and their cost flows compared on a discounted basis. Output may be printed at any time with the name of the simulation run noted for easy reference. It should be emphasized, moreover, that the model is designed for use in developing countries with a minimum of hardware, and software support. It is intended for field application, and that is why it is currently mounted on the Apple IIe - the least expensive microcomputer commonly found in developing countries. It can, of course, be mounted on other microcomputers (e.g., the IBM-PC) with only minor software modifications.

MODEL COMPONENTS AND OPERATION

Once data for supply and demand parameters in the base year have been exogenously specified, and once the analyst has determined various growth parameters, the model projects supply and demand iteratively through the entire six interval periods. The supply and demand for each energy product in each interval is projected and displayed separately in both physical units and heat terms.

The model's accounting procedure computes the total national (or regional) supply and demand balance for all energy products in heat terms at the end of each interval, fills any imbalance with product imports and determines if there is a shortage of traditional fuel supplies.

A number of useful energy consumption indicators are also determined at the end of each interval. Gross Domestic Product (GDP) is calculated as are energy product demand per capita, energy product demand per unit of GDP, electricity demand per capita, and electricity demand per unit of GDP. Growth rates of each and their relation to GDP growth are also computed. The per-capita traditional energy gap, and primary and energy product import costs are also projected.

Policy analysis involves working interactively with the data base. Once the information has been typed into the computer and a reference simulation run, the user adjusts parameters of both supply and demand to reflect a particular policy, reruns the simulation and compares the energy balances and consumption indicators for the two sets of assumptions. If an energy supply expansion program has been specified by the analyst prior to the simulation run, the present value of the various costs of that program are also calculated and displayed.

PROJECTING SUPPLY

As noted above, MICROCOSM is a tool to manipulate and analyze the supply and demand for various energy products. These include both commercial and non-commercial (i.e., traditional) fuels. Petroleum products (LPG, gasoline, naptha, kerosene, jet fuel, diesel oil, fuel oil and other petroleum products), natural gas products (natural gas, CNG, LNG, methanol, other natural gas products), treated coal, peat briquettes, electricity, commercially available wood and charcoal are the commercial products. Wood that is not sold and animal dung, as well as four kinds of agricultural wastes, byproducts and other traditional forms are the non-commercial energy products.

Several assumptions are critical here. First, the product supplies projected are domestically produced, while product demands are for all products regardless of where they are produced. Consequently, the model balances product supply and demand through product imports or exports. Second, energy products that are outputs from domestic processes are considered to be domestic products regardless of the source of the primary fuel.[3] Third, the model defines a primary fuel as energy in the form in which it is extracted. Once it is treated, it is considered as an energy product. Fourth, domestic resources of a primary form of energy are defined as that amount of the particular source (petroleum, natural gas, coal, etc.), that can be extracted in a particular year. Total reserves of an energy form (i.e., the maximum amount that may be exploited over time) do not enter model calculations.

The model does not treat the supply of each energy product with the same attention to detail. However, the computer program is designed to allow for product substitutions and the addition of more complex equations where appropriate. It is acknowledged that the energy product mix discussed here and the relative importance of individual products will vary among countries. Consequently the computer program is again very flexible. Where useful, notes on product substitution will be provided.

Commercial Supplies

Petroleum Products

All eight petroleum product supplies in a country are initially specified exogenously. Thereafter, they are determined by that country's exploitable resources of petroleum, its imports of oil, its refinery capacity and its petroleum product imports. First, the model considers the amount of petroleum the nation's oil refinery (or refineries) can actually process. This represents an absolute physical limit on petroleum product supplies from domestic sources. The quantity of usable petroleum is then defined by refinery capacity and the operational efficiency of the refinery. That is:

$$UP_{t+1} = CO_{t+1} * CF_{t+1}$$

where:

UP = usable petroleum;
CO = refinery capacity;
CF = refinery capacity use factor (production efficiency); and
t = subscript denoting base year.

Usable petroleum, however, is some mixture of domestic resources (defined as that quantity of national petroleum reserves that can be extracted from the ground in a year) and imports. The following conditions determine the mixture:

If $PF_{t+1} = CO_{t+1} * CF_{t+1}$, $I_{o,t+1} = \emptyset$ and $E_{o,t+1} = \emptyset$

If $PF_{t+1} < CO_{t+1} * CF_{t+1}$, $E_{o,t+1} = (CO_{t+1} CF_{t+1}) - PF_{t+1}$ and $I_{o,t+1} = \emptyset$

If $PF_{t+1} > CO_{t+1} * CF_{t+1}$, $I_{o,t+1} = PF_{t+1} - (CO_{t+1} * CF_{t+1})$

and $E_{o,t+1} = \emptyset$

where:

PF = domestic resources of petroleum;
CO = refinery capacity;
CF = refinery capacity use factor;
I = imports;
E = exports;
o = subscript denoting petroleum (oil); and
t = subscript denoting base year.

The domestic supply of any petroleum product can now be considered as a function of usable petroleum, the share of total refinery output represented by that product and the use of that product for non-energy purposes. Thus:

$$PP_{a,t+1} = (UP_{t+1} * RS_{t+1}) - NP_{a,t+1}$$

where:

- PP = domestic supply (production) of a petroleum product;
- UP = usable petroleum;
- RS = share of that product of total refinery output;
- NP = quantity of a product used for non-energy purposes;
- a = subscript denoting a product from the refinery (8 products); and
- t = subscript denoting base year.

While Nepal neither has a refinery nor current plans to build one, the logic of the model is still applicable. Model operation would simply allocate all product supplies to imports.

Natural Gas Products

The supplies of these five natural gas products are also specified exogenously in the base year. Thereafter, they are projected in the same manner as those of petroleum products. That is:

$$UG_{t+1} = CG_{t+1} * GF_{t+1}$$

under the following conditions:

If $PG_{t+1} = CG_{t+1} * GF_{t+1}$, $I_{g,t+1} = \emptyset$ and $E_{g,t+1} = \emptyset$

If $PG_{t+1} < CG_{t+1} * GF_{t+1}$, $E_{g,t+1} = (CG_{t+1} * GF_{t+1}) - PG_{t+1}$ and $I_{g,t+1} = \emptyset$

If $PG_{t+1} > CG_{t+1} * GF_{t+1}$, $I_{g,t+1} = PG_{t+1} - (CG_{t+1} * GF_{t+1})$ and $E_{g,t+1} = \emptyset$

and

$$GP_{a,t+1} = (UG_{t+1} * GS_{t+1}) - NF_{a,t+1}$$

where:

- UG = usable natural gas;
- CG = natural gas production and refining capacity;
- GF = production efficiency;
- t = subscript denoting base year;
- PG = domestic resources of natural gas;
- I = imports;
- E = exports;

g = subscript denoting natural gas (primary);
GP = domestic supply (production) of a natural gas product;
GS = share of a product of total natural gas product output;
NF = quantity of a product used for non-energy purposes; and
a = subscript denoting a product from the production process (5 products).

Coal

The projection of coal supply from the amount specified for base year is computed a bit differently. The MICROCOSM model assumes that raw coal is never imported, but that only treated coal is traded internationally due to obvious transportation cost savings. Consequently, projecting domestic coal product supply is somewhat simpler as only one product is considered.

$$SC_{t+1} = (RC_{t+1} * PE_{t+1}) - NC_{t+1}$$

where:

SC = domestic supply of treated coal;
RC = domestic resources of coal;
PE = coal preparation rate in the transformation of raw coal to treated coal;
NC = quantity of treated coal used for non-energy purposes; and
t = subscript denoting base year.

Peat[4]

It is assumed that peat is never traded internationally and that there is only one energy product manufactured from it - peat briquettes. The projection of the specified base year supply of peat briquettes is accomplished in the same way as that for treated coal:

$$SP_{t+1} = (RP_{t+1} * PR_{t+1}) - NU_{t+1}$$

where:

SC = domestic supply of peat briquettes;
RP = domestic resources of peat;
PR = peat briquetting efficiency factor;
NU = quantity of peat briquettes used for non-energy purposes; and
t = subscript denoting base year.

Electricity

Electricity supply figures are also exogenously specified for the base year, but the subsequent projections are developed in a more complicated manner. First, it is necessary to compute the total amount of electricity generated in the country. This is normally expressed in gigawatt hours (GWh), and is determined here by the amount of installed capacity in megawatts (MW) and the amount of that capacity actually used. Therefore, for Nepal, if:

$$GG_{t+1} = GH_{t+1} + GS_{t+1} + GT_{t+1}$$

where:

GG = total gross electricity generation in GWh;
GH = gross hydroelectric generation in GWh;
GS = gross small hydroelectric generation in GWh;
GT = gross thermal electric generation in GWh; and
t = subscript denoting base year;

then:

$$GH_{t+1} = HC_{t+1} * HF * h$$

$$GS_{t+1} = SC_{t+1} * SF * s$$

$$GT_{t+1} = TC_{t+1} * TF * th$$

where:

GH = gross hydroelectric generation in GWh;
HC = installed hydroelectric generating capacity in MW;
HF = hydroelectric capacity use factor;
h = constant to transform hydroelectric generation capacity to GWh produced;
GT = gross thermal electric generation in GWh;
TC = installed thermal electric generating capacity in MW;
TF = thermal electric capacity use factor;
th = constant to transform thermal electric generating capacity to GWh produced;
GS = gross small hydroelectric generation in GWh;
SC = installed small hydroelectric generating capacity in MW;
SF = small hydroelectric use factor;
s = constant to transform small hydroelectric generating capacity to GWh produced; and
t = subscript denoting base year.

The constants (h, th and s) are conversion factors, and these are composite figures that need some elaboration. To transform capacity (MW) to electricity generated (GWh), the constant of 8.76 is used. However, for the purposes of an indicative model such as MICROCOSM, that number can be combined with a plant factor (e.g., 6 for hydroelectric plants, higher for thermal ones) and an efficiency factor (high for hydroelectric, low for thermal) to develop a composite figure. Normally, these factors range widely according to local conditions and are, therefore, considered separately. Here, the model need not be so precise. The constants actually used are 8.98 for hydropower and 3.193 for thermal power.

Next, net electricity is computed. This is the electricity produced that is actually available for delivery, that is, actual supply. It depends on the electricity generated, the losses prior to delivery and the electricity used by power generation stations for their own purposes. So:

$$NE_{t+1} = GG_{t+1} - GG_{t+1} * (SU_{t+1} + EL_{t+1})$$

where:

- NE = electricity supply;
- GG = total gross electrical generation in GWh;
- SU = electrical generating station use factor;
- EL = energy loss factor (transmission losses, distribution losses, theft, etc.); and
- t = subscript denoting base year.

Wood - Commercial

The consideration of wood as an energy product is different from that of any other because it has both commercial and non-commercial components, as well as numerous non-energy uses. Wood resources in a country are composed, in forestry terms, of big logs and small logs. Big logs provide wood for sawlogs, plylogs and matches, while small logs provide wood for posts and poles, newsprint, paper, hardboard, particle board and fuelwood. Thus, the maximum wood resources available for fuelwood purposes are confined to those of small logs. These resource calculations are exogenous to the MICROCOSM model. Furthermore, since the model considers any energy resource as an annual exploitable quantity, the sustainable forest yield, not the stock of the forest, is the relevant quantity.

In addition, these wood resources must be separated into their commercial use and their non-commercial use. Again, this is done outside the model, and the quantities determined are considered as data input in the base year. Keeping in mind that the figure assumed below will vary from country to country, the UN Food and Agriculture Organization (FAO) has determined that approximately 59 percent of small log consumption in Bangladesh, for example, is by the rural poor. Assuming, then, that the rural poor gather but do not purchase wood, the commercial supplies of small logs would be that 41 percent remaining.[5] From this quantity are subtracted the non-energy uses for small logs specified above and that amount of wood transformed into charcoal. The remainder is the nation's resource of commercial wood for fuelwood purposes.

The actual model equation, then, is rather simple:

$$FC_{t+1} = (WC_{t+1} - NW_{t+1}) * (1 - CF_{t+1})$$

where:

- FC = supply of commercial fuelwood;
- WC = commercial supply of small log resources;
- NW = non-Energy uses of small logs;
- CF = charcoal factor, i.e., that portion of potential commercial fuelwood converted into charcoal; and
- t = subscript denoting base year.

Charcoal

Charcoal is assumed to be produced only for sale. The calculation is, therefore, straightforward once the wood-commercial calculations have been completed. That is:

$$CL_{t+1} = (WC_{t+1} - NW_{t+1}) * CF_{t+1} * CP_{t+1} \div c$$

where:

- CL = supply of charcoal;
- WC = commercial supply of small log resources;
- NW = non-energy uses of small logs;
- CF = charcoal factor, i.e., that portion of potential commercial fuelwood converted into charcoal;
- CP = charcoal conversion efficiency factor;
- c = constant that converts 10^6 cubic feet of wood into 10^3 metric tons of charcoal = 13.567; and
- t = subscript denoting base year.

Traditional or Non-Commercial Supplies[6]

Energy supplies considered here are defined as outside the money economy. They might be bartered, but they are assumed not to be bought or sold. Provision has been made in the model for six such fuels. In Nepal, the appropriate choices would be wood-traditional, dung, rice waste (both rice husk and rice straw), maize waste, wheat (including barley and millet) waste and bagasse. Since these supplies are computed by the multiplication of various exogenous data inputs, they can be changed by simply substituting new names in the program for those of less relevant traditional fuels. The following formula makes this flexibility clear:

$$TF_{a,tt} = RT_{a,tt} * (1 - NT_{a,tt})$$

where:

- TF = supply of a traditional fuel;
- RT = resources of a traditional energy form;
- NT = non-energy use factor for a traditional energy form;
- a = subscript denoting a traditional fuel (6 fuels); and
- tt = subscript denoting any year.

PROJECTING DEMAND

The MICROCOSM Model consists of ten energy product consuming sectors. These include the eight industrial sectors of commercial agriculture, the country's most important energy consuming manufacturing industry (agro-processing in Nepal), all other manufacturing, the fertilizer industry cottage industry power generation, transportation, commerce and services (including government), as well as the urban and rural domestic sectors.[7] The traditional sector is subsumed in the rural domestic sector as far as energy consumption is concerned. It is, however, considered separately as an economic sector (along with the eight industrial sectors, but excluding the two domestic ones).

Industrial Demand

For each fuel in each period, the consumption of each industrial sector is determined in appropriate units for that product. In the base year, the demands are exogenously determined. Thereafter, they are a function of the base year demand, the growth rate of the particular industry and the improvement in energy use efficiency for that industry. This improvement can be due to new equipment, an energy conservation program, etc. In summary:

$$IC_{aa,a,t+1} = IC_{aa,a,t} * (1 + EG_p) * (1 - EI_p)$$

where:

IC = demand for an energy product by an industrial sector;
EG = the growth rate of that sector;
EI = the energy efficiency improvement factor of that sector;
aa = subscript denoting industrial sector (8 sectors);
a = subscript denoting energy product (24 products);
t = subscript denoting base year; and
p = subscript denoting interval chosen in model implementation (6 intervals).

These product unit results are then endogenously converted to heat terms (petajoules) through simple multiplication by the appropriate constants in the model.

Domestic Demand

For each of the two domestic sectors (urban and rural), the demand for a particular energy product depends upon the exogenously specified per capita demand for that product in the base year, the population of that sector in a given year and the energy efficiency improvement of that sector. That is:

$$UC_{a,t+1} = PCU_{a,t} * PU_{t+1} * EEU_p$$

and:

$$RC_{a,t+1} = PCR_{a,t} * PR_{t+1} * EER_p$$

where:

UC = urban domestic demand for a product;
PCU = urban per capita demand for a product;
PU = urban population;
EEU = energy efficiency improvement factor of the urban domestic sector;
RC = rural domestic demand for a product;
PCR = rural per capita demand for a product;
PR = rural population;
EER = energy efficiency improvement factor of the rural domestic sector;
a = subscript denoting energy product (24 products);
t = subscript denoting base year; and
p = subscript denoting interval chosen in model implementation (6 intervals).

Naturally, most traditional fuel consumption in MICROCOSM should occur in the rural domestic sector which includes the subsistence part of the population.

Again, the product demands computed here are expressed in units. They are then endogenously converted to heat terms (petajoules) through simple multiplication by the appropriate conversion constants in the model.

SUPPLY/DEMAND BALANCES

The supply/demand balances in MICROCOSM are determined by simple arithmetic calculations of an accounting nature. At the end of each model time interval, the difference in the supply and demand for commercial energy products in heat terms (petajoules) is calculated, this difference is allocated to imports (or exports) and the results are displayed. An S/D (percent) ratio is also computed and shown. For traditional energy forms, the national heat gap due to product imbalance (if one exists) is listed separately.

ENERGY CONSUMPTION INDICATORS

These indicators are used along with the supply/demand balances to compare and evaluate various national energy policy options. The first, Gross Domestic Product, is expressed in local currency and developed endogenously during model operation. It is computed in the base year by summing the exogenously specified sectoral products as summarized below:

$$GDP_t = SPA_t + SAP_t + SPF_t + SPC_t + SPM_t + SPG_t + SPT_t + SPS_t + SPR_t$$

where:

- GDP = Gross Domestic Product;
- SPA = sectoral product of commercial agriculture;
- SAP = sectoral product of the agro-processing industry;
- SPC = sectoral product of cottage industry;
- SPM = sectoral product of other manufacturing;
- SPG = sectoral product of power generation;
- SPT = sectoral product of transportation;
- SPS = sectoral product of commerce and services (including government);
- SPR = product of traditional sector; and
- t = subscript denoting base year.

At the end of the first time interval, however, and at the end of succeeding intervals, GDP is also dependent upon population and annual sectoral growth. Thus:

$$GDP_{t+1} = SPA_t * (1 + PA_p) + SAP_t * (1 + AP_p) +$$

$$+ SPF_t * (1_p + FF_p) + SPC_t * (1 + CC_p) + SPM_t *$$

$$(1 + PM_p) + SPG_t * (1 + GG_p) + SPT_t * (1 + PT_p) +$$

$$SPS * (1_t + PS) + SPR_p * (PR_t - PR_{t+1}) \div PR_t)$$

where:

GDP = Gross Domestic Product;
SPA = sectoral product of commercial agriculture;
PA = sectoral growth rate of commercial agriculture;
SAP = sectoral product of the agro-processing industry;
AP = sectoral growth rate of the agro-processing industry;
SPF = sectoral product of the fertilizer industry;
FF = sectoral growth rate of the fertilizer industry;
SPC = sectoral product of cottage industry;
CC = sectoral growth rate of cottage industry;
SPM = sectoral product of other manufacturing;
PM = sectoral growth rate of other manufacturing;
SPG = sectoral product of power generation;
GG = sectoral growth rate of power generation;
SPT = sectoral product of transportation;
PT = sectoral product of commerce and services (including government);
SPS = sectoral product of commerce and services (including government);
PS = sectoral growth rate of commerce and services;
SPR = product of traditional sector;
PR = rural population;
t = subscript denoting base year; and
p = subscript denoting interval chosen in model implementation (6 intervals).

Gross Domestic Product growth per year is then calculated by dividing the GDP computed at the end of any interval by the number of years in that interval. Other indicators are developed by other simple arithmetic procedures. Product consumption per capita at the end of any interval is determined by dividing total product consumption for all energy product consuming sectors in that year by the population in that year; product consumption per unit of GDP is developed by dividing total product consumption in that year by GDP in that year; electricity consumption (kWh) per capita is computed by dividing the year's total electricity demanded by all energy product consuming sectors by the population in that year and electricity consumption per unit of GDP is found by the simple division of that year's total electricity demand by GDP in that year.

The relative growth of consumption to domestic product and population are also formulated in the model. Thus:

$$RGP_{t+1} = (TPD_{t+1} \div TPD_t) \div [(PU_{t+1} + PR_{t+1}) \div (PU_t + PR_t)]$$

$$RGO_{t+1} = (TPD_{t+1} \div TPD_t) \div (GDP_{t+1} \div GDP_t)$$

$$RGE_{t+1} = (TED_{t+1} \div TED_t) \div [(PU_{t+1} + PR_{t+1}) \div (PU_t + PR_t)]$$

$$RGG_{t+1} = (TED_{t+1} \div TED_t) \div (GDP_{t+1} \div GDP_t)$$

where:

RGP = relative growth of energy product consumption to population;
TPD = total energy product consumption;

PU = urban population;
PR = rural population;
RGO = relative growth of energy product consumption to Gross Domestic Product;
GDP = Gross Domestic Product;
RGE = relative growth of electricity consumption to population;
TED = total electricity consumption;
RGG = relative growth of electricity consumption to Gross Domestic Product; and
t = subscript denoting base year.

Primary energy imports are another important indicator. They are expressed in millions of dollars, the primary international trading currency. In the base year, the quantities of imports are specified by the user, as are their world market prices. Hence, these are simply multiplied and summed in the model. In subsequent years, however, the quantities are computed as previously discussed in the sections on commercial energy supplies. See particularly their treatment in petroleum products and natural gas products. The quantities thus determined are then, again, merely multiplied by the appropriate exogenously specified world market prices and summed in the model.

The indicator of energy product imports is also expressed in millions of dollars. For any product in any year, the difference between its domestic supply and demand (in units) is calculated, and the difference is multiplied by the relevant world market price which has been read into the model. These values are then summed. See sections and respectively for details of the energy product supply and demand calculations.

The final energy consumption indicator shows the per capita gap (or surplus) between the supply and demand for traditional energy in the economy. This is important because in the traditional sector where most people are engaged in subsistence agriculture, this gap is not normally closed by product substitution, but by a decline in energy consumption. Thus, the standard of living declines and illness, even starvation, increases. The indicator here is merely the expression of the national traditional energy gap (in heat terms) for all fuels in any year, calculated in section supply/demand balances divided by the total population in that year.

SUPPLY EXPANSION IMPACTS

Input Parameters

The expansion of a country's energy supply infrastructure can be studied using MICROCOSM. Its impacts in terms of foreign exchange expenditures and domestic capital costs, as well as in the present value dollar terms of operation and maintenance and of total investment (including side effects), are displayed in model output. This feature allows analysts not only to compare the energy effects of various policy options, but also to evaluate their supply side costs in a general way.

More specifically, MICROCOSM allows the user to evaluate various supply expansion projects or programs (multiple projects). Thirteen types of projects may be grouped into an almost limitless array of programs. Projects for Nepal include constructing six types of electric power plants (hydro, small hydro, coal, fuel oil, diesel and natural gas), developing five different forms of primary energy (petroleum, natural gas, coal, peat and wood) and investing in energy efficiency improvements. Parametric assumptions for the construction of each project are developed outside the model. Some are specified per relevant unit for each project (that is, for a Megawatt of installed capacity for a power plant, for 10^3 metric tons for coal production, for 10^9 cubic feet for natural gas production, etc.). These parameters include foreign exchange requirements, the domestic capital needed, the percent of total investment represented by operation and maintenance costs and the amount of the relevant energy product required in operation by an installed Megawatt of electrical generating capacity.

Other parameters are also specified. The construction period and useful life for a project must be included, as must the total quantity (in dollar terms) of any side effect, plus the number of years from the inception date until that side effect takes place. The analyst develops a program simply by deciding the appropriate size for each project in the program and the inception date for the project. The inception date states when construction begins (this is required to be at the start of one of the six intervals), and it is assumed there is no project output until the end of the construction period. That is, output is maximum and constant once a project is on line.

Once a program is specified and a simulation run, energy supply is expanded through the construction of the new facilities. However, no consideration is given to the retirement of the physical stock of facilities that already exists in the base year. This must be handled by the analyst (if relevant) by reducing various capacities appearing among model inputs. For the new facilities, on the other hand, useful project lives have been determined by the user so the model will endogenously eliminate this physical stock as it ages.

Present Value Calculations

To develop the current or nominal values for the foreign exchange and domestic capital components of project and program investment, the input values for the relevant units of projects are multiplied by their scale in units. While these results are displayed, the model allows for more sophisticated project program and policy evaluation through the present value comparison of costs. The standard formula for present value is used, and all projects are discounted in dollar terms to year zero as in World Bank analysis. Thus:

$$PV_{\$,\emptyset} = \sum_{j=i}^{j=n} \frac{Cj}{(1+i)}$$

with:

- PV = present value;
- j = years i ..... n;
- i = discount rate (exogenously specified);
- Cj = current or nominal cost in \$ or \$ equivalent of local currency in year j;
- \$ = subscript denoting dollar; and
- ϕ = subscript denoting year zero.

The present value of a project includes the discounted investment costs (of both foreign exchange and local currency), operation and maintenance costs and positive and/or negative side effects. The sum of these for all projects constitutes the total present value of the entire energy supply expansion program.

Present Value Assumptions

A number of assumptions are important to these calculations and should be well understood in comparing different programs.

First, the projects are evaluated only for the length of the planning period relevant to the particular implementation of MICROCOSM. That is, the period for discounting is equal to the length of an interval times six (the number of intervals). If, for example, an interval is five years, as is most commonly the case, the planning period is thirty years. Consequently, the residual or salvage value of a project must be considered. The residual value is defined here as the worth of the project beyond the end of the planning period. If considered in the analysis, it would overestimate the value of the project in the planning period of concern. Thus, MICROCOSM discounts the salvage value of all projects from the end of the planning period.

Second, investment costs are discounted from the mid-point of the construction period and assumed to be zero after the project is in operation.

Third, operation and maintenance costs are constant annual amounts (in current dollars) over the entire life of the project once construction is over and the project is on line.

Finally, all side effects are considered as a lump sum component of project present value. That is, they are assumed to occur in the year specified as a program input (i.e., number of years from inception date to side effects) and discounted to year zero.

FINAL COMMENTS

While this paper has concentrated on the conceptual basis and methodology of the MICROCOSM energy sector simulation model that has been demonstrated in Nepal, some final remarks on its use are important for its evaluation. MICROCOSM is a simplified system dynamics model with an accounting framework, and it projects supply and demand based on user determined data assumptions It uses linear and growth equations, and computes deficits or surpluses by ordinary arithmetic. It is a simple model, and in this simplicity lie its strength and utility.

MICROCOSM was designed specifically for use in developing countries where the permanent staff of energy sector planning agencies is often unable to use the large, complex, sophisticated and expensive models developed by consultants from Europe or America. An attempt was made to devise a simple tool to extend the possibilities for policy analysis and integrated energy planning in such agencies, while assuring that neither the data requirements nor the knowledge necessary to operate the model would be unrealistically extensive. Certainly, some analytical and computational power has been sacrificed in doing this, but no previous experience or training with computers is required to operate the model.

In developing countries, complex tools, however brilliantly formulated and constructed, often remain unused once completed, while simple tools like MICROCOSM can be quite effective in assisting analysts and policy makers with their difficult tasks. MICROCOSM's modest goal is to provide such help in the energy sector.

FOOTNOTES

1. For an elaborate treatment of various energy modeling approaches, see David J. Edelman, "Recent Energy Models: A Review of Methodologies", Journal of Environmental Systems, Vol. 7, No. 3, 197[illegible]-78, pp. 279-292.

2. The logic and application of the MICROCOSM model system has been discussed earlier in "The Conceptual Model and Methodology of MICROCOSM - a Tool for Energy Sector Policy Analysis and Training in a Developing Country", prepared with Dr. Donald M. Manson for the 8th Conference on Energy Systems Modeling, Swiss Federal Institute of Technology, Lausanne, July 4-5, 1985.

   The author has previously applied this methodology with Dr. Donald M. Manson and Dr. R. Neil Byron to the forestry sector in Bangladesh. The work was completed in Dhaka and three field reports were produced. These are:

   i. User's Guide to the Bangladesh Forestry Sector Simulation;

   ii. Technical Manual for the Bangladesh Forestry Sector Simulation: Volume I, Model Description; and

   iii. Technical Manual for the Bangladesh Forestry Sector Simulation: Volume II, BASIC Program Description.

   All these reports were published by UNDP/FAO Project BGD/78/010 - Supply and Demand for Forest Products and Future Development Strategies - for the Planning Commission of Bangladesh in November 1983. The work was summarized as "The Bangladesh Forestry Sector Simulation", International Journal for Development Technology, Vol. 3, 1985, pp. 5-18.

Dr. Edelman has, in addition, employed this approach to study the developmental impact of increased crude oil expenditures. See "A Macroeconomic Policy Simulation of the Energy Crisis and the Development of Low-Income Countries" in Manas Chatterji (ed.), Energy and Environment in the Developing Countries, London: John Wiley and Sons, 1981), pp. 167-192.

Thus, if Nepal were to build an oil refinery, its output would be considered to be composed of domestic products even though the petroleum would be imported.

It is recognized that a country like Nepal may have or import two forms of coal even though MICROCOSM allows for only one type. An analyst could allow for this second form by substituting it for peat, the supply and demand of which are computed in the same manner as for coal, but which is not found or used in Nepal. This is accomplished simply by typing a new name wherever peat appears in the computer program. A good computer programmer, of course, could allow for an additional form of coal by more sophisticated means.

These figures were supplied to the author by the Supply and Demand of Forest Products and Future Development Strategies Project (UNDP/FAO, BGD/78/010) in Dhaka, Bangladesh, November 1983. Figures for Nepal could be expected to be quite similar.

New and renewable forms of energy are often grouped with traditional energy. These normally include solar energy, wind energy, biotechnology, etc. While they have been excluded from the model due to computer space limitations, the additional complexity they would require of the model, and their current relative lack of importance, a particular technology might be substituted for another commercial energy product, e.g., peat, should it become important. It is the author's belief that such energy is properly considered commercial, in that the technology to produce it is normally purchased. In addition, even in the rural sectors of developing countries where many advocates feel these forms of energy are potentially most appropriate and most economic (although this has never been proven), the technologies are usually acquired by the relatively rich.

According to the Joint UNDP/World Bank Energy Sector Assessment Mission to Nepal in 1983, 70 percent of the country's industrial output involves agro-processing while textiles, apparel and leather account for 14 percent and forest products 8 percent. See World Bank Report No. 4474 - NEP, Nepal: Issues and Options in the Energy Sector, August 1983, p. 23.