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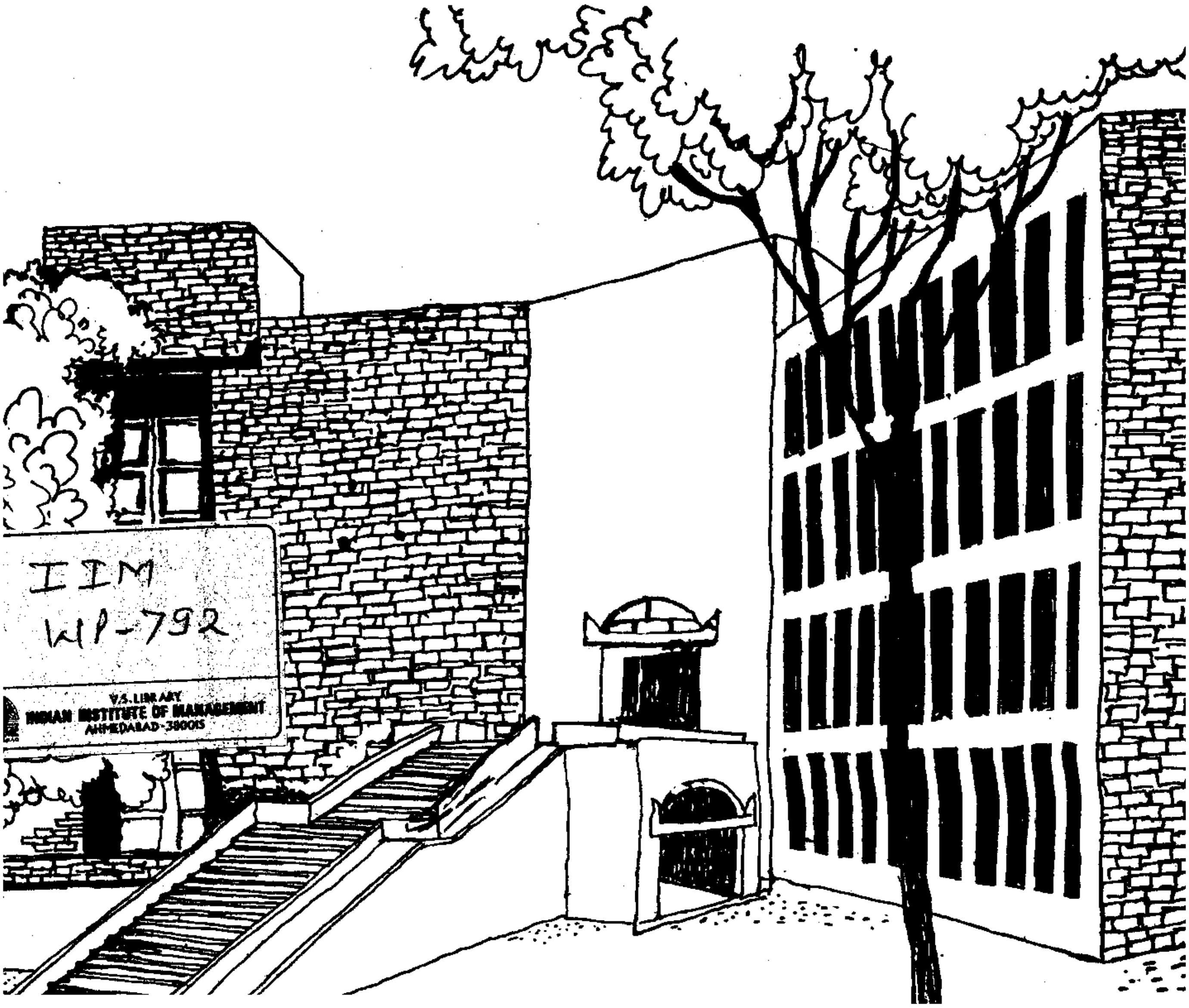

FRAMEWORK FOR INTEGRATED ENERGY PLANNING WITH APPLICATION IN INDIA

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W P No. 792
March 1989

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ABSTRACT

This paper presents a hierarchical framework for integrated energy planning and applications of the framework for planning at different levels. The proposed planning framework links macro level national and/or state(regional) energy planning with micro level block and village energy planning. Models are proposed for energy planning at national/state level, block level and village level. Real-life application of the models for energy planning at each level in India is presented. The models through appropriate interlinkages provide a wholistic framework for policy analysis and planning.

FRAMEWORK FOR INTEGRATED ENERGY PLANNING WITH APPLICATION IN INDIA

1.0 Introduction

As part of national planning exercises, the energy planning has been given specific attention by Central planners in India since long. Given the vastness of the country and diversity in stages of development and resource base, a macro level national energy plan need to be disaggregated at micro level. The ultimate implementation at the lowest level shall be for individual village. The disaggregation of national plan thus has to go through successive levels, viz. State level, district/taluka level and village level. The hierarchical planning linking macro to micro level has several advantages such as:

(i) it allows for incorporating regional specificities in energy supply-demand structure;

(ii) it specifies decisions to be made at different levels and their linkages with related levels;

(iii) it corresponds with the existing organisation structure (or evolves an effective organisation structure);

(iv) it facilitates implementation.

This paper presents a framework for integrated (hierarchical) energy planning and its application.

There is considerable available experience of energy planning at various levels (1), (2), (3), (4), (5), (6). The present paper discusses the linkages in disaggregation of the macro plan, the framework for planning at different levels, and some applications.

2. Macro planning at national/state level

A national level energy model for India should necessarily be supplemented by the regional (state) level models. This is essential since a large part of policy decisions on energy supply are presently being made centrally at the national level. Regional energy analysis integrated appropriately in the national energy planning would provide the necessary disaggregation for realistic planning and implementation. It was in response to this need of disaggregation and to capture the regional specificities in energy planning, the Advisory Board on Energy, Government of India, sponsored studies for developing regional energy model and analysis covering different states and together with a national model. As the exercise is recent and since it did not cover all states, necessary linkages between regional models and the national model are not explored. However, the state level models are also macro models and hence same methodology is used for national and state level planning. Our experiences of modeling and analysis for Gujarat state are reported next. The model is Linear Programming based and uses regional input-output (I-O) matrix as a starting point.

2.1 Regional Input-Output Transactions

Regional Input-Output table captures the sectoral inter-dependence, basic structure and broad technology in the economy. Since the level of technology, production structure and their rates of change vary considerably across regions in India, it is imperative to incorporate the spatial dimension explicitly into the planning model. This can be done most effectively only when regional I-O tables consistent and compatible with the national I-O table are estimated.

The estimates of regional input-output transactions for Gujarat are made by following the survey based method to generate first the I-O coefficient matrix. The whole regional economy of Gujarat State is classified into four broad categories: (A) Industry including electricity (30 sectors), (B) Agriculture and animal husbandry (8 sectors), (C) Fishing, Forestry and Mining (7 sectors). and (D) Supra-regional transactors and services (5 sectors). The classification of sectors into these four categories is based on the nature of data availability at the State level and the nature of the activity. In the case of supra-regional transactors and services, the national input-use coefficients are adopted like most other studies. With the help of the estimated gross output in each of the 50 sectors for the Gujarat State, we generate the input-output transactions in Gujarat for the year 1984-85 at current prices consistent and compatible with the national matrix.

In order to forecast the optimal energy requirements for the years 1989-90, 1994-95 and 1999-2000, we need to forecast final demand and gross output for each sector of the regional economy for each forecast year. Given the I-O matrix for the base year 1984-85, projections of regional inter- industry transactions for the forecast period are derived by projecting the final demand and corresponding estimates of gross output by sectors. Sector-wise final demand in the State economy are projected by using (a) sector-wise trends in final demand implicit in the Planning Commission's estimates relating to then national I-O transaction matrices for 1984-85 and 1989-90; and (b) time-trends in State domestic product by industry of originaly over the period 1960-61 to 1984-85.

2.2 REFERENCE ENERGY SYSTEM (RES)

2.1.1 RES Representation

An RES is a way of representing the activities and relationship of an energy system. It depicts energy flows from energy sources through energy conversion technologies to the end-use demand sectors [1],[2]. The RES network has three basic components - energy sources, energy products and energy end-use demand. Energy demand for each sector is independently assessed based on present use pattern, demographic data, sectoral development plans and targets. Conversion efficiencies of technologies at various stages of production, transmission. distribution and end-use system and energy resources availability are considered. Since energy resources are individually emphasised, the approach requires disaggregation of energy sectors from the existing level of representation in the usual input-output tables. Appendix I describes the disaggregated sectors definations.

2.2.2 CONSTRUCTING RES FOR A BASE YEAR (1984-85)

Construction of RES primarily require detailed data about energy supply, demand and the energy flow relationship for a year for which data are largely available. For the present study 1984-85 is taken as base year. For conventional energy sources such as coal, petroleum, electricity etc., data is available from appropriate state and central agencies. For non-conventional sources, data is obtained from state energy development agencies and other published sources. Base year energy demand for each product sector is derived from several sources, major source for the industry sector data is the data on quantity of fuel as input to various industry sectors collected by Central Statistical Organisation(CSO). For non-commercial energy sectors energy estimates are made using NCAER survey data[7] and other information collected from state agencies. Energy demand for the product sector is independently estimated based on the fuel use pattern for every product sector and taking into account conversion efficiencies of devices. Energy demand for domestic, municipal, agriculture, industry and transportation sectors are thus assessed. In fact, for each of these product sectors, energy demand is estimated independently. Using the energy flows from different energy sources to energy product sectors, RES for base year (1984-85) is constructed.

2.2.3 RES Projections For 1989-90,1994-95 & 1999-2000.

After validating the demand for energy products for base year 1984-85, the projections of demand for energy product sectors for 1989-90 , 1994-95 and 2000-2001 are made from base year demand. The projections in different sectors are based on the appropriate sectoral growth rates, demographic data, etc. Since 1984-85 demand is validated with actual consumptions, the procedure can be expected to give good demand forecast. In the case of 1989-90, actual growth rates in key sectors are checked and actual demand upto the recent time is considered for validation of demand projections. For example, consumption of electricity and petroleum products in different sectors is obtained for 1986-87 and the projections are validated with actual growth in consumption pattern. For 1994-95, and 1999-2000 projections are made from the 1989-90 energy demands. Growth rates used for industry, agriculture, transportation etc. are in correspondance with the growth rates suggested by input-output tables for these periods. Demand projections are made for various scenarios to understand policy implications.

Construction of RES for base year is the key to a meaningful analysis. Considerable and diverse data sources are used. Requisite data for the purpose do exist with the appropriate state agencies. Besides considerable published mertarial is available. However, certain assumptions are required where data gaps prevail and this must be done with utmost care so as to keep the data realistic. In case of state (regional) models, transportation data pose difficulties since inter and intra state movements have to be considered. In some other sectors too, national level data is easier to obtain than state level data and sometimes disaggregation from national level data has to be done with approprriate assumptions. This apart, appropriate cost data is most difficult to obtain especially for future scenarios. However, our experience is that meaningful RES can be constucted at regional level which can capture regional specificities.

2.3 A LINEAR PROGRAMMING(LP) MODEL

The RES is viewed as a network optimization problem in which energy flows are routed through a linear network in order to minimise the total energy cost subject to the requirement that all end-use demands are met. The problem formulation results in Linear Programming model. The model is similar to the Brookhaven model [1],[2]. However in our model, additional bounding constraints are incorporated to limit the extent of substistution.

There are 175 Decision variables.

X_s - Energy Source : 30 Variables

X_p - Energy product : 19 Variables

X_i - Energy Demand : 47 Variables

d_s^+ - Energy Export : 12 Variables

d_s^- - Energy Import : 12 Variables

X_{sp} - Energy flow : 55 Variables

The objective is to minimize total energy system costs while satisfying the demand for energy products and non-energy sectors. Costs for energy sources(C_s) considered include the production costs (in case of materials produced in the state), production and transportation costs for materials imported in the state and existing prices in case of non-commercial materials. For new capacities of energy sources (eg. electric power stations), fixed cost is appropriately allocated. Cost for energy products(C_p)

include both fixed costs and variable costs. Import and export of fuels is considered by incorporating import and export prices Pis and Pes.

2.3.1 LP Formulation

The LP formulation (175 variables and 255 constraints) for energy demand alalysis is as follows:

Min. : $C_sX_s + C_{sp}X_{sp} - P_{es}(d_s^{-}) + P_{is}(d_s^{+})$

S.T. : $A_{ss}X_s + I_{sp}X_{sp} + d_s^{-} - d_s^{+} = X_s <= G_s$ (60 constraints)

$A_{ps}X_s + A_{pi}X_i + Y_p = X_p$ (19 constraints)

$A_{is}X_s + A_{ii}X_i + Y_i = X_i$ (47 constraints)

$E_{sp}X_{sp} = X_p$ (19 constraints)

$L_{sp} <= E_{sp}X_{sp} <= U_{sp}$; (110 constraints)

$X , d_s^{-} , d_s^{+} >= 0$

where

Isp = Matrix (PxS) denoting 1 if sector S can supply P, else 0.

Gs = Annual Availability of Source.

Lsp & Usp = Lower & Upper bounds respectively on the end-use energy of sector p that can be provided by a source s.

Esp = Efficiency of the device using a source s to convert potential energy of the source into end-use energy for product sector p.

4 ANALYSIS FOR GUJARAT STATE

Analysis and results for all reference years are presented Here in details. The time frame used is upto 2000 AD, which is too far a future, and thus allows for construction of reasonable future scenarios and at the same time, this time horizon is far enough for meaningful planning and concrete policy interventions Table 1,2 and 3 summarise consumption of major fuels by energy product sectors for the four reference years.

2.4.1 A COMPARATIVE ANALYSIS OF BASE SCENARIOS FOR FOUR REFERENCE YEARS

From Tables 1,2 and 3 it can be seen that:

(i) Electricity generation is planned to increase rapidy (94% increase) during 8th Plan (1989-90 to 1994-95) period. If the power plants come up as per the GEB plans, then by 1994-95, Gujarat will have surplus power (880 MW surplus). However, due to considerable increases in thermal power plant capacity during 8th plan period, coal and natural gas consumption in the state is increasing substantially. In 1999-2000 AD, the State is expected to have nearly same consumption of electricity as the planned capacity. Electricity consumption in fifteen year period (1985-2000) is expected to triple.

(ii) Consumption of petroleum based fuels is expected to increase steadily, nearly doubling for Naphtha, FO and LSHS and increasing by 60 owexwbr for HSD in fifteen years.

(iii) In domestic sector consumption of electricity is increasing by four fold and kerosene consumption by about fifty percent in fifteen years.

(iv) Industry will remain to be the major consumer of electricity consuming about 60 percent of total in 2000 AD. Coal will be the major fuel for process heating but lignite will replace coal to some extent by 1995.

(v) More than two-thirds of HSD consumption in the state in 2000 AD will be for road transport sector. Goods transport sector will consume about 55 percent. HSD consumption for road

TABLE : 1

STATE : GUJARAT

ELECTRICITY GENERATION & CONSUMPTION - 1984-85 TO 1999-2000

ELECTRICITY

	1984-85	1989-90	1994-95	1999-2000
CAPACITY(MW)	3054	3891	7550	9532
GENARATION(MKWH)*	8049	11963	22697	28952
CONSUMPTION(MKWH)	9438	13724	19824	28483
EXPORT(IMPORT)(MKWH)	(1852)	(2298)	2873	469

* AFTER T&D AND AUXILLIARY CONSUMPTION LOSSES

TABLE : 2

STATE : GUJARAT

CONSUMPTION OF MAJOR FUELS - 1984-85 TO 1999-2000

MAJOR FUELS	1984-85	1989-90	1994-95	1999-2000
COAL(MT)	8980236	13585544	22184734	26298787
LIGNITE(MT)	1047467	1350000	3000000	4000000
NATURAL GAS(M.CU.M.)	673	884	1731	2676
HSD(MT)	981098	1187060	1301897	1526417
FO/LSHS(MT)	892311	1041548	1444096	1800730
NAPHTHA(MT)	585747	768758	988090	1133010

TABLE : 3

STATE : GUJARAT

CONSUMPTION OF MAJOR ENERGY SOURCE BY ENERGY PRODUCT SECTORS

DOMESTIC SECTOR				
ENERGY SORUCE	1984-85	1989-90	1994-95	1999-2000
ELECTRICITY(MKWH)	1098	1775	2923	4887
SKO(MT)	553705	647553	727163	862098
FIREWOOD(MT)	4142000	4142000	4142000	4142000
CROPWASTE(MT)	385440	462526	631000	808000
LPG(MT)	80467	110542	127000	140892
INDUSTRY SECTOR				
ELECTRICITY(MKWH)	6319	8811	12723	17438
COAL(MT)	3700415	4787263	5283334	6752472
LIGNITE(MT)	1047657	1350000	2947000	2947000
FO/LSHS(MT)	835647	1136330	1444096	1800730
ROAD TRANSPORT				
MS(MT)	246134	292995	337789	406883
HSD(MT)	616139	731110	890385	1032890
RAIL TRANSPORT				
HSD(MT)	69564	75504	88557	101164
ELECTRICITY(MKWH)	140	168	209	305
COAL(MT)	415601	443621	333318	166358
AGRICULTURE SECTOR				
ELECTRICITY(MKWH)	1619	2257	3226	4505
HSD(MT)	154926	200204	269955	330363
MUNICIPAL SECTOR				
ELECTRICITY(MKWH)	300	411	743	1348
ELECTRIC POWER SECTOR				
COAL(MT)	4656288	8123000	16314600	19100400
LIGNITE(MT)			1053000	1053000
NATURAL GAS(M.CU.M.)	273	319	735	1432
HSD(MT)	34200	46000	53000	62000

transport will increase by 65 percent in fifteen years.

(vi) For rail passenger transport, electricity will contribute 56 and HSD about 31 percent of needs. For rail goods transport, HSD will contribute to two-thirds of the movement. Contribution of coal in rail sector will decline to 13 for passenger and 5 percent for goods movement. Electricity consumption will more than double and HSD consumption will increase by about 70 percent during the fifteen.

(vii) For agriculture sector, electricity consumption will nearly triple and HSD consumption will double in fifteen year period.

(viii) Consumption of coal for electricity is increasing by nearly four fold and natural gas about five fold during fifteen year period.

(ix) For municipal sector, i.e. public water works and street lighting, electricity consumption will increase by more than four fold during the 1985-2000 period.

Above observations clearly suggest that coal will be the major source of energy as per the existing projections for electricity generation. As coal is brought from far distance (average lead of about 1000 km), load on railways will increases substantially. Projection for electrical power capacity are made as per the State electicity board plans, however in reality power projects are expected to be delayed at least for about two to three years. Uncertainty still prevails over the timely implementation of four 500 MW Narmada(coal) Thermal Power Projects. Similarly Gas availability for power is uncertain. Hence, for electrical power sector available capacity shall be lower than planned capacity. The results also suggest a major electrification of railway system.

Optimal energy cost for the Base Scenario for the four reference years at 1984-85 constant prices are as follows:

REFERENCE YEAR	1984-85	1989-90	1994-95	1999-2000
COST(Rs million)	23630	31980	50550	67810

As can be seen, energy costs are increasing rapidly and are tripling in fifteen years.

2.4.2 Scenario Analysis

The model is also used for scenario analysis. Major scenarios are consturcted for reference years 1994-95 and 1999-2000. Since model framework is already available, scenario analysis can be done readily. The advantage of scenario analysis is that the planners can understand the energy interaction under different situation and efficasy of their interventions can be readily assesed so as to make strategic dicisions.

3. Block/Taluka level planning

The national and state level planning decides major investments and provides the aggregate norms for planning at the block level. Long term decisions such as electric power availability, extent of electrification, coal availability, fuel prices, transport network, etc. are already made at macro level. The block level planning then considers first micro level decisions relevant for implementation of macro plan given the decisions of macro plan, energy needs and local resources at block level. The block level decisions may envisage certain decisions relevant at the block level, eg. wind farm for block energy needs. However, major investment decisions are not made at block level. In the context of Integrated Rural Energy Planning (IREP), a model is presented here for block level planning. In case of urban/industrial areas within the block, the model can be appropriately extended by including industry sectors as in case of state level model.

On the rural energy front, energy planning needs to consider varied options of energy - supply demand relationship. Unlike urban areas, a problem of rural energy is that, for the bulk of rural energy demand, local energy sources contribute substantially. However, their supply is limited and depleting - for example, as in the case of major local fuel firewood. While irrigation and lighting needs are best met by centralised electricity generation systems, in areas which are remotely situated, the cost of carrying electricity and the investment in infrastructure could be prohibitive. The problem, therefore, is how to consolidate integration of various energy supply sources for plugging the demand-supply gap in a manner that would minimise the implicit and explicit costs. Against this rural energy perspective, an Integrated Rural Energy Plan at the block level needs to be developed. Block level planning methodology and its application are discussed next.

3.1 Methodology

Methodological aspects in rural energy planning relates to two aspects; (i) collection of data, and (ii) framework for planning. A primary data collection in the present case was organised by purposively choosing five villages in the block from a list of all villages. These villages were selected on the basis of overall proximity to certain parametric values for each village to the valuesof these parameters at block level. A sample of five hundred households from these villages was chosen for detailed questionnaire survey. A seperate survey of all artisans and village industries in these villages was carriedout.

The planning framework consisted of (i) estimation of block level energy demand and resources from the sample data, and (ii) optimal decision on energy flows from a source via a device to an energy end-use. For future energy projections, appropriate growth rate in different energy end-use sectors was considered. Details of the planning framework are presented next.

3.2 Planning Framework

Block level planning framework includes estimation procedure and a linear programming decision model. For making block level projections for energy use pattern and resource availability average values calculated from the survey data are used. In all cases, the block level end-use consumption projections are worked out by sectors of consumptions. An advantage with this approach is that since end-use energy requirements worked out are free from efficiency considerations of devices, latter taking into account efficiencies of various devices,one can make projections of the physical quantities of each fuel required at the block level for the planning purpose. Energy consumption of various fuels used annually in various end use sectors is calculated in units shown in Table 4.

By using the survey data and the block level aggregate data, the block level projections are appropriately made sectorwise for the consumption pattern and source-wise for the availability of cash source. These estimates are developed for the base run for reference date April 1988. These estimates summarise the existing consumption pattern ; resources availabilities and energy flows. Additional options are introduced in the decision model later on for the planning purposes.

3.2.1 Decision Model

Once the energy demand and supply at the block level are estimated, the problem then is to make optimal decision regarding the energy flows at block level. The model approach is to determine optimal (minimumcost) flow pattern of energy, i.e. decision on the amount of energy supplied by an energy source through a device to an end-use energy need. Table 5 gives the energy sources (i), devices (j), and end-uses (needs) (k) considered in the present application. Table 6 gives the calorific valuesof various energy sources and Table 7 gives conversion efficiencies of devices. Table 8 gives approximate energy costs, i.e. cost of supplying one unit of end-use energy by a source via a device. The costs are computed considering both the variable costs as well as the apportioned fixed costs of the device. The problem formulation results in a linear programming model where the energy flow costs are assumed to be linear. The main constraints are that the end-use energy demand must be met and the energy source use shall not exceed the availability. Besides, some structural constraints are included based on the existing techno-economic situation of energy relationships. Details of model formulation are given next.

TABLE - 4

END-USE ENERGY AND UNITS

End-use	Unit
1. Cooking	MKCAL
2. Lighting	MLWHRS
3. Other Household Uses (via Appliances)	MKWH
4. Village Industry	MKWH
5. Artisan	MKCAL
6. Irrigation	MKWH
7. Land Preparation	MKCAL
8. Transportation :	
a) Passenger	PKMS x 10^3
b) Goods	TKMS x 10^3

TABLE - 5

ENERGY SOURCE, DEVICES AND END-USE NEEDS

(i) SOURCE	(j) DEVICE	(k) END-USE NEEDS
Local/conventional		
1. Firewood	1. Kerosene Stove	1. Domestic Cooking/Heat
2. Dung	2. Chulha	2. Domestic Lighting
3. Agriwaste	3. Biogas Pland and Burner	3. Other Domestic Uses (Appliances)
4. Animal Power		
Centralised/Commercial	4. LPG Burner	4. Village Industry
5. Kerosene	5. Solar Cooker	5. Artisans Work
6. LPG	6. Bulb	6. Irrigation
7. Electricity	7. Tubelight	7. Land Preparation/ Inter culture
8. Diesel	8. Kerosene Lamp	8. Threshing
9. Coal		
Non-commercial	9. Domestic Electrical Appliances	9. Goods Transportation
10. Solar	10. Brick Kiln	10. Passenger Transportat
11. Wind	11. Electrical Drives (for Industry)	
	12. Artisan's Devices	
	13. Diesel Engine and Pump	
	14. Electric Motor and Pump	
	15. Plough	
	16. Tractor	
	17. Bullock Cart	
	18. Wind Pump	

TABLE - 6

CALORIFIC VALUES OF ENERGY SOURCES

Energy Source	Calorific Value
1. Firewood	4730 KCAL/KG
2. Dung	2130 KCAL/KG
3. Agri Waste	3500 KCAL/KG
4. BIO-Gas	4770 KCAL/CuM.
5. Kerosene	11000 KCAL/KG
6. LPG	11950 KCAL/KG
7. Electricity	860 KCAL/Kwh
8. Diesel	10800 KCAL/KG

TABLE - 7

CONVERSION EFFICIENCIES OF DEVICES

DEVICE	EFFICIENCY
1. Kerosene Stove	55%
2. Chulha (Traditional)	12%
3. Chulha (improved)	18%
4. Biogas Burner	60%
5. LPG Burner	60%
6. Bulb (Incondescent Lamp)	22 lumen/watt
7. Flourescent Tube Light (40W)	64 lumen/watt
8. Flourescent Tube Light(slim - 36W)	70 lumen/watt
9. Kerosene Lamp	3.14 lumen hr/gm of kerosene
10. Pair of Bullocks	0.6 Kw
11. Diesel Engine	30%
12. Electric Drive	100%
13. Dung for Biogas Production	25 Kg wet dung/cuM of Biogas

TABLE - 8

ENERGY COSTS

COST OF ENERGY SOURCE

Source	Cost/Unit
Diesel	Rs. 4500/MT
LPG	Rs. 3800/MT
Kerosene	Rs. 3000/MT
Electricity	Rs. 1.20/kwh
Agri. Waste	Rs. 300/MT
Fuel Wood	Rs. 400/MT
Dung (dry)	Rs. 240/MT
Coal	Rs. 500/MT

3.2.2 Constants, Variables and Co-efficient Definition

i = Index number for Energy Source.

j = Index number for Conversion Devices

k = Index number for End-uses

A_i = Annual availability of Energy Source i

e_{ijk} = Conversion Efficiency of Device (j) to convert energy from source (i) to supply one unit of end-use demand (k).

D_k = Annual energy demand for end-use (k)

C_{ijk} = Cost of supplying one unit of end-use (k) energy demand by source (i) via device (j).

B_{ijk} = Capacity of Device (j) to produce a unit of end-use (k) energy annually using source (i).

B_j = Maximum Annual Capacity of Device (j)

$\underline{P}_{ijk}$, $\overline{P}_{ijk}$ = Lower and upper bound respectively on the proportion of end-use (k) energy demand, that can be met by the source (i) via device (j)

X_{ijk} = Amount of end-use energy demand supplied annually by an energy source (i) via device (j) for end-use (k)(in terms of end-use energy units).

X_{ik} = Amount of energy source (i) consumed for end-use (k) annually.

X_i = Amount of energy source ($\overset{i}{k}$) consumed annually.

Y_j = Annual capacity requirement of Device (j).

3.2.3 Model Formulation

Objective: Minimize total annual cost of supplying energy.

$$\text{Min:} \quad \sum_{i} \sum_{j} \sum_{k} C_{ijk} \; X_{ijk}$$

Subject to : **CONSTRAINTS**

(I) End-use Energy Demand to be met :

$$\sum_{i} \sum_{j} X_{ijk} \geqslant D_k \quad \forall_k$$

(II) Energy supply by a source to be within availability

a) Amount of energy source i used for end-use k annually (x_{ik}) :

$$\sum_{j} e_{jk} X_{ijk} = X_{ik} \qquad \forall i \text{ and } k$$

b) Amount of energy source i used annually (x_i) :

$$\sum_{k} X_{ik} = X_i \quad \forall_i$$

c) Amount of energy source i used annually to be within annual availability :

$$X_i \leqslant A_i \qquad \forall i$$

Supply constraints are not considered for diesel, solar and wind sources.

(III) Device Capacity

$$\sum_{i} \sum_{k} B_{ijk} X_{ijk} = Y_j B_j \quad \forall j$$

Total capacity requirements are computed only for major devices such as biogas plant, diesel engine, electric motor, tractor and wind pumps. For minor devices such as chulhas, stoves, etc. computation is made on the basis of households using the devices.

(IV) Structural Constraints:

These constraints impose limits on the change in structural relationship of energy flows. Existing energy flows in the block are a result of the existing techno-economic realities. For example, though electricity is most efficient and convenient source of energy for lighting, kerosene is used in substantial quantity for lighting due to different type of techno-economic causes. Thus, the structural constraints are considered to incorporate the existing techno-economic realities into the model. The specified bounds can be relaxed to understand the impact of restructuring the techno-economic relationship on the energy flows and energy costs.

$$\underline{P}_{ijk} \; D_k \leq X_{ijk} \leq \overline{P}_{ijk} \; D_k \qquad \forall \; i,j,k$$

$$(0 \leq \underline{P}_{ijk} \leq \overline{P}_{ijk} \leq 1)$$

(V) <u>Non-negativity Constraints</u>:

$$X_{ijk} \geq 0 \qquad \forall i,j,k$$

$$Y_j \geq 0 \qquad \forall j$$

The above formulation results in a Linear Programming model with Forty-nine (49) variables and Hundred and one (101) constraints. Using the estimated demand, costs, resource availability, and other relevant data, the program runs were made under different scenarios. Various scenarios and the results of Linear Programming runs are discussed next.

3.3 Application of Decision Model

This model is used to develope an integrated rural energy plan for a block in a Western Indian State. From the Block under consideration, 5 representative villages were selected from 190 villages in the block. From these villages, a representative sample or 515 households was chosen by using stratified random sampling approach. A detailed questionnaire covering all major energy consuming activities of the rural households was administered on the sample households and from this primary data on energy consumption pattern for these sample villages was obtained. This is given in Table 9. This data was then projected at the block level and on the basis of this future planning exercise for energy planning upto 1995 was carried out.

3.3.1 Scenario Approach

By using primary data on dung availability per cattle per day and secondary data on a number of cattle dung availability at block level is projected. For agriwaste, primary data on crop production from the sample survey with secondary data on land at block level is used to project agriwaste availability. Appropriate assumptions are made availability of other conventional and on-conventional energy sources. Accordingly, assumptions were made on future energy consumption pattern in various activities in the block. With these assumption,Scenario-1 was developed. In Scenario-1, no technological intervation was planned. In Scenario-2, technological intervention was introduced through consideration of some non-conventional and fuel efficient devices in various

TABLE : 9

ENERGY DEMAND-SUPPLY RELATIONSHIP(ANNUAL) 1987-88

	END-USE	SOURCE	UNIT	CONSUM-PTION	END-USE ENERGY	% END-USE DEMAND	POTENL ENERGY	% POTENL ENERGY	% SOURCE
1	COOKING (MKCL)	LPG	MT	0.08	0.6346	0.0715	1.0675	0.0100	100.000
		KEROSENE	MT	0.08	36.0500	4.1314	66.630	1.0000	27.530
		AGRIWASTE	MT	305.63	120.3846	14.4000	1000.705	17.0607	41.671
		FIREWOOD	MT	1080.00	887.40	78.5220	4002	70.2020	63.635
		DUNG(DRY)	MT	74.00	18.9144	2.1328	157.02	2.5677	22.408
		BIOGAS	'000 CU.M	1.00	5.070	0.5722	8.40	0.1346	100.000
2	LIGHTING (B.LU.HRS)	ELECTRICITY	MKWH	0.08	1.65536	97.0651	46.160	21.5402	36.024
		KEROSENE	MT	15.94	0.050054	2.3340	175.340	78.4510	72.404
3	HOUSEHOLD USES(MKWH)	ELECTRICITY	MKWH	0.01	0.0076	100.0000	0.01	100.0000	100.000
4	ARTISAN (MKCL)	FIREWOOD	MT	38.00	19.76	83.7150	141	78.5953	0.018
		COAL	MT	9.00	3.84	16.2850	38.4	21.4047	5.229
5	VILLAGE INDUSTRY (MKCL)	ELECTRICITY	MKWH	8.00	32.00	6.7901	32.38	0.9511	24.445
		COAL	MT	174.00	90.0	14.4612	506	20.2568	94.771
		FIREWOOD	MT	576.00	379.008	78.7487	2707.2	78.7920	0.346
6	IRRIGATION	ELECTRICITY	MKWH	0.0420	0.0420	100.0000	0.0420	100.0000	27.018
7	LAND PREP (MKWH)	ANI. POWER	MKWH	0.22	0.22	100.0000	0.22	100.0000	91.377
8	THRESHING (MKWH)	ELECTRICITY	MKWH	0.008	0.008	100.0000	0.008	100.0000	6.070
9	PASSENGER TRANSPORT (PKMS)	DIESEL	MT	1.44		31.29	15.58	60.48	98.552
		ANI. POWER	MKCL	10.18		68.71	10.18	39.52	5.019
10	GOODS TRANSPORT (TKMS)	DIESEL	MT	0.17		14.60	1.82	22.97	10.448
		ANI. POWER	MKCL	6.10		85.40	6.10	77.03	3.004

MKCL : MILLION KCALS
MT : METRIC TONS
MKWH : MILLION KILO WATT HOURS

activities. Thus, for the futuristic analysis for consumption pattern projected over seven years period, Scenario approach was used. This approach has several advantages. To begin with, it enables us to look at the future in a varied way rather than predicting just one future. Further, it forms the basis on which the differing views on future of different groups can be accomodated. Besides, it also helps in strategy formulation. Finally, it being a flexible approach is suited for analysing the impact of socio-economic and technological interventions on energy consumption pattern. The model was used to find optimal decisions under these Scenarios.

3.4 Comparative Analysis

Activity-wise comparisons between two scenarios indicated changes in fuel consumption only in the cooking activity. It was observed that conventional centralised electricity for lighting purpose received preference over the non-conventional photovoltic system. In irrigations gasifier was rejected by the model against electric motor operated pump sets. Table-10 gives the comparative cost analysis between two scenarios at optimality.

Prior to running Scenario-2, an LP run without any structural constraints was also considered. It was found that with existing cost structure the conventional energy sources were preferred over traditional and non-conventional sources. One aspect of the exercise is that, since a number of different fuels are already currently observed in various activities at the rural level, it is reasonable to put

TABLE - 10

COMPARATIVE ANALYSIS - SCENARIOS 1 & 2

Fuel	Unit	Consumption			Cost Difference
		Scenario-1	Scenario-2	Difference	
Firewood	MT	145629	104085	41544	6400248
Dung (dry)	MT	6563	3281	3282	787617
Kerosene	MT	2157	1889	268	586489
Biogas	'000cu.m.	160	2931	(2771)	(-1641166)
Solar Cooker	MKCL	-	2066	2066	-
Total		-	-	-	6133188

techno-economic and socio-cultural restrictions in the model. This consider that the existing techno-economic-social structure imposes certain constraints which need to be taken into account explicitly. For, if these constraints are not operating several fuels that are currently in use in various rural activities may not be used. On the basis of the comparative cost analysis, an aggregate plan was developed at block level. Detailed planning of installation of various devices and investment plan was developed. From this annual expenditure budgets over 5 year period under consideration was also developed.

4.0 Village Level Planning

Block level planning decides the energy consumption, resource utilazation and development intervention for entire block. However, ultimate implementation is at the village level. Thus, the microlevel planning is ultimately required for village level. Since number of villages are large, planning and implementation issues are complex, collection of data for village may be very difficult, time consuming and expensive. Hence, planning at village level needs special care and must be based on readily known parameters. Village level energy demand estimates can be done based on levels of population, ruralindustry etc. rather than detailed consumption data. Average of consumption at block level may be used in conjunction with overall village data to estimate end-usewise energy needs. Energy resource estimate can also be made at each village level based on aggregate data such as cattle population, crop production etc. in conjunction with block averages. However, in the ultimate analysis, planning has to be done at individual village level since there are many resources, technologies and alternatives, e.g. biogas supply etc. which can only be planned at the most decentralised level. In fact, the social economic dynamics and implementation needs may even require planning to consider energy options at household level. Planners thus have to exercise necessory care to prepare plan which is implementable. Since village is a considerably small umit for planning, planners can conceptualise the problems with relative case. However even at village level, formal model can provide better decision and considerably insight to planner for appropriate interventios. A model for village level selection of energy technologies is presented next. The application of model for optimal selection of energy technologies for four villages in Gujarat and policy evaluation for these four villags is presented next.

4.1 Model for Selection of Energy Systems

The problem considered at village level is to select energy systems and distribute energy to multiple end uses with minimum cost. Energy demand for the location is considered to be aggregate of demands for four end-uses, namely (i) cooking, (ii) hot water, (iii) irrigation, and (iv) electricity. For each end-use, energy is supplied by various energy systems. Energy systems are classified in two types (i) primary energy systems which generate energy, and (ii) secondary energy systems which are required to transfer , in some cases, the energy produced by the primsry system to end-uses. Various energy systems are available in several discrete sizes. Primary energy systems used are:

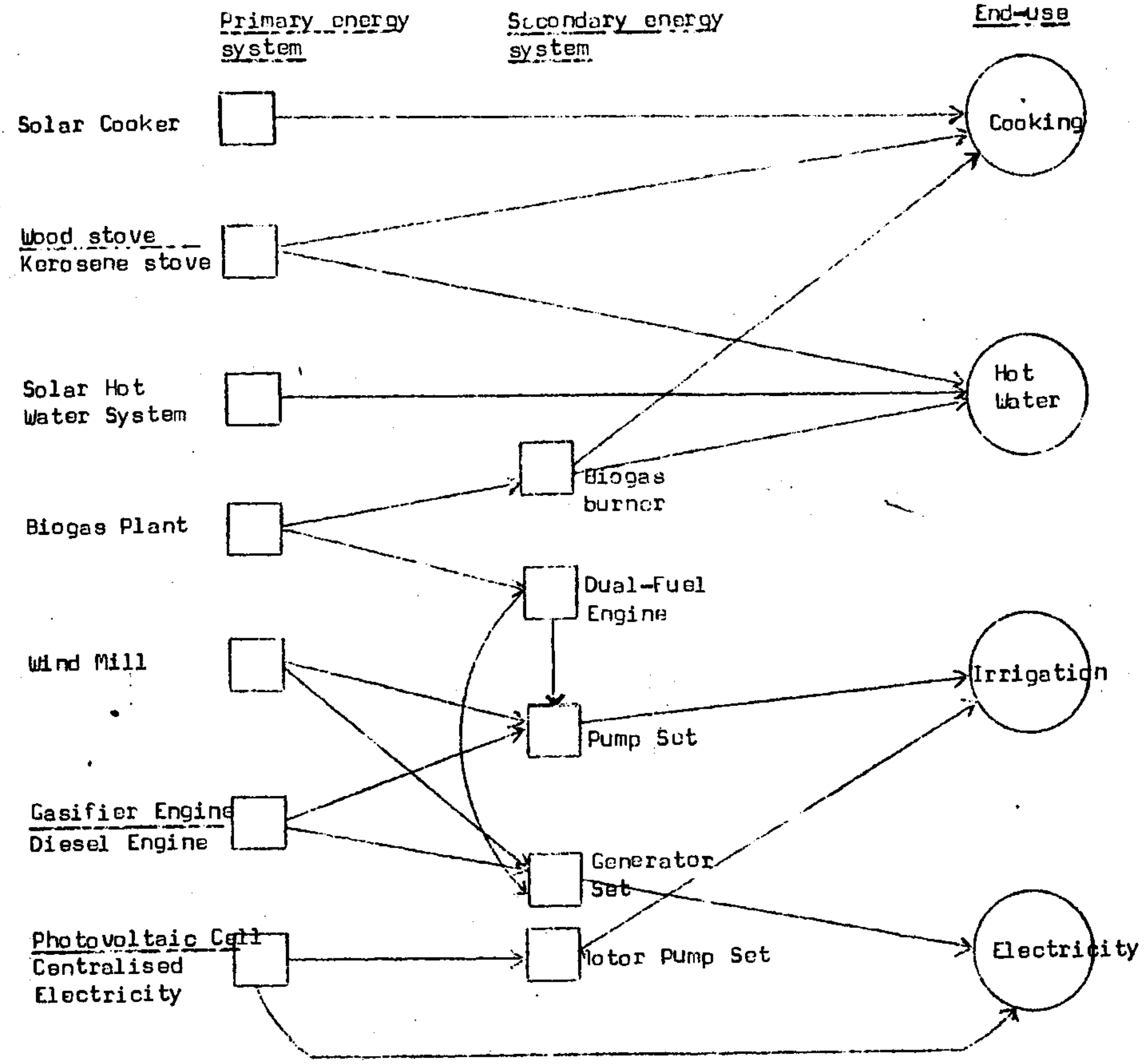
(1) Solar cooker, (2) Wood stove, (3) Kerosene stove, (4) Biogas plant, (5) Solar hot water systems, (6) Wind mill, (7) Diesel Engine, (8) Gasifier engine, (9) Photovoltaic cells, (10) Centralized Electricity (to the exent available).

Secondary energy systems used are: (1) Biogas burner, (2) Dual-Fuel engine, (3) Pumpset, (4) Generator set, (5) Motor pumpset.

Energy systems are available in discrete sizes, e.g. diesel engines are available in sizes 5 kilowatt (KW), 10 KW, 25 KW, etc. with higher sizes offering economies of scale. Each energy system of given size has a known fixed cost. Varaible costs of running the various energy systems are significantly differnt. Energy system efficiencies and demand for various end-uses are different during different periods in a year. For example, biogas system during winter months operates at sixty per cent of its normal efficiency during rest of the year. Similarly, irregation demand during monsoon season is different compared to rest of the year. Hence the model should accommodate several periods of a year. Also the model should include constraints on resqurces, especially local resource wood and gobar (i.e.dung or any other biomass usable as input to a biogas plant) which have restricted availability.

The problem modelled thus is to select primary and secondary energy systems of appropriate sizes to satisfy energy needs of a location in every time period using resources no more than available in a given time period and allocate energy to various end-uses in different time perioddddds so as to minimize total annual costs, i.e. the sum of annual fixed costs and variable costs. As the fixed and variable costs are involved, the problem is modelled similar to a fixed charge problem like location-allocation problem with Mixed Integer Linear Programming (MILP) formulation.

The reference energy system diflicting the energy flows is illustrated in Figure - 1.



Reference Energy(Generation and Distribution) System

Figure - 1

4.1.1 Model Formulation

Legend and Variable and co-efficient definations for the model are as under:

p = Number of primary energy systems.

i = Index number for primary energy system –
$i = 1,2,....,p$

n_i = Number of sizes of i^{th} primary energy system.

j = Index number for sizes of each primary system.
For i^{th} primary system $j = 1,2,....,n_i$.

d = Number of End-uses requiring energy.

k = Index number for end-uses – $k = 1,2,...,d$.

e = Number of time periods in a year

t = Index number for time period – $t = 1,2,...,e$.

q = Number of secondary energy systems.

l = Index number for secondary energy system –
$l = 1,2,...,q$.

m_l = Number of sizes of l^{th} secondary energy system.

s = Index number for sizes of each secondary system.
For the l^{th} secondary system – $s = 1,2,...,m_l$.

h = Number of raw materials used by energy systems.

r = Index number of raw materials - $r = 1, 2, \ldots, h$.

Y_{ij} = Number of units 0 primary energy system i of size j.

F_{ij} = Fixed cost (annual) of installing a primary energy system i of size j.

Z_{ls} = Number of units of secondary power system of type l and size s.

G_{ls} = Fixed cost (annual) of installing a secondary energy system of type l and size s.

x_{ikt} = Amount of energy supplied annually by a primary energy system i to end-use k in a period t.

C_{ikt} = Variable cost of using a unit of energy from energy system i for end-use k in time period t.

U_{ijt} = Capacity of primary energy system of type i of size j in time period t.

V_{lst} = Capacity of secondary energy system of type l of size s in time period t.

a_{iktr} = Raw material of type r required to supply a unit of energy by primary energy system i to end-use k in period t.

A_{rt} = Availability of raw material of type r in time period t.

D_{kt} = Energy demand of end-use k in period t.

The problem of optimal selection of energy system and allocation of energy to several end-uses is formulated as under:

4.1.2 Formulation

Minimize Annual Cost

$$Z = \sum_{i} \sum_{k} \sum_{t} C_{ikt} X_{ikt} + \sum_{i} \sum_{j} F_{ij} Y_{ij} + \sum_{l} \sum_{s} G_{ls} Z_{ls} \qquad \text{.....} (1)$$

Subject to:

Primary Energy System capacity constraints

$$\sum_{k} X_{ikt} - \sum_{j} U_{ijt} Y_{ij} \leq 0; \quad i = 1,2,\ldots,n; \quad t = 1,2,\ldots,e \qquad \text{.....} (2)$$

Secondary Energy System capacity constraints

$$\sum_{i \in I} \sum_{k \in K} X_{ikt} - \sum_{s} V_{lst} Z_{ls} \leq 0; \quad l = 1,2,\ldots,q; \quad t = 1,2,\ldots,e. \qquad \text{.....} (3)$$

Where

$K = \{ k : k =$ all indices of end-uses which can be supplied by a secondary system $l \}$.

$I = \{ i : i =$ all indices of primary energy system which can supply to a corresponding $k \in K$ via secondary energy system $l \}$.

Raw Materials availability constraints

$$\sum_{i} \sum_{k} a_{iktr} X_{ikt} \le A_{rt}; \quad r = 1,2,\ldots,h; \quad t = 1,2,\ldots,e. \qquad \ldots\ldots (4)$$

Demand Constraints:

$$\sum_{i} X_{ikt} \ge D_{kt}; \; k = 1,2,\ldots, d; \quad t = 1,2,\ldots, e. \qquad \ldots\ldots (5)$$

Non-negativity and Integer Constraints:

$$X_{ikt} \ge 0; \quad i = 1,2,\ldots,m; \quad k = 1,2,\ldots,d; \quad t = 1,2,\ldots,e. \qquad \ldots\ldots (6)$$

$$Y_{ij} \ge 0; \text{ and free integer; } \quad i = 1,2,\ldots,n; \quad j = 1,2,\ldots,n_i. \qquad \ldots\ldots (7)$$

$$Z_{ls} \ge 0; \text{ and free integer; } \quad l = 1,2,\ldots, q; \text{ and } s = 1,2,\ldots, m_l. \qquad (8)$$

4.2 Application of Model For Four Villeges

The model is used for optimal selection of energy system for four villeges in Gujarat. The annual energy needs for different end-uses are estimated [8] and are given in Table 11. Raw material availability for local bioman resources is given in Table 12. Various sizes of energy systems available for selection are considered, e.g., biogas plants of sizes 5,25,60 and 80 cum are considered.

TABLE 11

Annual Energy Requirement (in KWH) for four villages

Village End Use Type	1	2	3	4
Cooking	2,10,000 (76.53)	4,35,000 (74.49)	7,05,000 (73.55)	14,11,200 (74.83)
Hot Water	34,000 (12.39)	75,840 (12.98)	1,22,400 (12.77)	2,45,400 (13.03)
Irrigation	8,700 (3.19)	7,500 (1.28)	42,000 (4.38)	66,500 (3.53)
Electricity	21,675 (7.89)	65,670 (11.25)	89,100 (9.30)	1,60,200 (8.51)
Total	2,74,375 (100.00)	5,84,010 (100.00)	9,58,500 (100.00)	18,83,300 (100.00)

Note: Figures in brackets represents percentage of total energy requirement for a village.

Table-12

Annual Raw Materials Availability (in KWH) at Four Villages*

Raw Material \ Village	1	2	3	4
Gobar	1,87,000	2,81,000	4,37,000	3,13,000
Wood	14,00,000	5,62,000	6,05,000	29,07,000

*The figures in this table represent the potential energy availability from a raw material.

4.2.1 Analysis of Optimal Results

Optimal Energy System selection, energy allocation, and costs under existing data (normal data) for the four villeges are projected in tables 13 to 16.

In the optimal solution for four villages under existing conditions (normal data). It was also found that local biomass resources (gobar and wood) were completely used up (i.e. the constraint relating to these resources had no slack at optimality) except in village 1. the wood constraint had some slack becaus energy plantation were being raised and hence, wood was available in abundance. Scarcity of local biomass resources leads to use of costly fuels like kerosene and diesel. Using kerosene results in a substantial increase in unit variable cost of energy for villages 2,3 and 4 compared to village 1 where kerosene is not used. For the same reason, the unit variable cost of cooking energy for village 1 is substantially lower than for the other three. The results with normal data thus indicate the following:

1. Local availability of biomass resources like gobar and wood result in substantial reduction in energy costs to a village.

Table-13

Energy Systems selected for Four Villages (Normal Data)

	Energy Systems	Number of Systems			
		Village 1	2	3	4
	PRIMARY SYSTEM				
1	Biogas Plant, $25M^3$	-	-	2	-
2	Biogas Plant, $85M^3$	1	2	2	2
3	Solar Cooker	102	309	419	754
4	Solar Hot Water Panels	7	17	28	56
5	Wood Burner	102	309	419	754
6	Kerosene stove	-	309	419	754
7	Diesel Pumpset, 5 KW	-	-	1	-
8	Diesel Pumpset, 10 KW	1	1	4	7
9	Diesel Genset, 5 KW	-	1	-	-
10	Diesel Genset, 10 KW	1	-	-	1
11	Centralized Electricity, 5 KW	1	4	6	10
	SECONDARY SYSTEM				
1	Biogas - Burner	102	309	419	754

Table-14

Allocation of Energy for Four Village (Normal Data)

Enduse	Energy Systems	Annual Energy Consumption (KWH) Village 1	2	3	4
Cooking	Biogas	89,340	1,53,411	2,26,710	1,68,520
	Solar Cooker	70,000	1,45,000	2,35,000	4,70,400
	Wood Burner	50,657	35,124	37,812	1,81,690
	Kerosene Stove	--	1,01,461	2,05,474	5,90,610
Hot Water	Solar Hot Water Panels	35,000	83,400	1,36,800	2,73,800
	Wood Burner	1,600	--	--	--
	Kerosene Stove	--	530	--	200
Irrigation	Diesel Pumpset	8,700	7,500	42,000	66,600
Electricity	Diesel Genset	6,690	5,700	--	10,200
	Centralized Electricity	15,000	60,000	89,100	1,50,000

Table-15

Costs due to Optimal Solution for Four Villages (Rs.) (Normal Data)

Costs \ Village	1	2	3	4
1 Fixed (Capital) Cost	440540	1199860	1844315	3087980
2 Total Annual Cost	153175	424259	706934	1426368
3 Annual Variable Cost	43040	124297	245855	654373
4 Unit Cost of energy (Rs./KWH)	0.558	0.726	0.737	0.757

Table-16
End-usewise Unit Variable Costs (Rs. /KWH) (Normal Data)

Village/ End-use	1	2	3	4
1. Cooking	0.084	0.208	0.243	0.367
2. Hot Water	0.015	0.005	0.000	0.001
3. Irrigation	1.220	1.220	1.220	1.220
4. Electricity	0.650	0.370	0.260	0.341

2. Although both gobar and wood can provide energy for irrigation as well as electricity by using dual-fuel engines, their current restricted availability limits them to meeting only a fraction of the cooking energy needs.

3. Use of solar energy for cooking (solar cookers) and hot water (solar hot water panels) is economical due to zero variable cost and low fixed costs.

It is thus obvious that an increase in the availability of biomass can result in substantial energy cost savings. Hence, development efforts for energy plantation, improved gobar collection and promotion of alternate biomass (agriculture waste, water hyacinth, etc.) for biogas plants and subsidy for biomass utilizing devices deserve consideration. The analysis above asume certain biomass availability and costs. However policy interventions can result in alternate scenarios of bioman availability some such proposals are considered for analysis.

1. Relaxing the wood availability constraint. This proposal considers the impact of fuel plantations.

2. Relaxing the wood availability constraint and subsidizing gasifier by 50 percent. This proposal examines the impact of partially subsidizing the gasifier specifically to determine whether or not the the partially subsidy can help promote the economical use of gasifiers.

3. Relaxing gobar availability constraints. This proposal studies the impact of development efforts for alternate biomass resources for biogas plants.

The results and impacyts of these proposals are discussed below.

.2.2. IMPACT OF RELAXING THE WOOD AVAILABILITY CONSTRAINT

Comparison of the results obtained under this proposal with those obtained under normal data assumption suggest the following changes in energy system selection, allocation of energy, and costs.

Changes in Energy Systems and Energy Allocations

1. Village 1 has no change in energy system selection, allocation, or costs when the wood constraint is relaxed because it has large amounts of wood available, even under normal condition. This was evident because with normal data this village had considerable slack in the wood constraint.
2. For the other three villages, the use of kerosene for cooking and hot water demands is replaced by wood when the wood constraint is relaxed.
3. For irrigation and electricity demands, even when the wood constraint is relaxed, there is no changes in

system selection and energy allocations. The gasifier-based systems are not selected, even if wood is freely available.

Cost Savings

Comparing costs under relaxed wood availability with those under normal data shows the following cost savings and energy costs.

. Annual Cost Savings and Unit Costs (Rs/kWh) for Each Village under the Relaxed Wood Constraint

	Village			
	1	2	3	4
Annual cost Savings (Rs.)	0	52,226	57,434	257,565
Unit cost (Rs./kWh)	0.558	0.637	0.636	0.620

4.2.3. IMPACT OF RELAXING THE WOOD AVAILABILITY AND SUBSIDIZING GASIFIER

If, in addition to relaxing wood constraints, the gasifier is subsidized by 50 percent, significant changes result. These are observed in the selection of energy systems and the allocation of energy for irrigation and electricity in some villages.

Changes in Energy System and Energy Allocation

First, no changes are observed in villages 1 and 2 in energy system selection and energy allocation for irrigation demand. Irrigation demand is very low for these two villages and at such low energy demand levels gasifier pumpsets are not cost effective. This is because of their higher capital (fixed) costs (even when a subsidy is given) in comparision with the fixed cost of diesel pumpsets.

Second, in Villages 3 and 4 where the irrigation demands are substantially higher than in villages 1 and 2, gasifier pumpsets will replace diesel pumpsets selected under earlier data assumption. Thus most irrigation demands are met by gasifier pumpsets when they are subsidized by 50 percent.

Third, in all four villages, the entire electricity demand is met by gasifier gensets, replacing centralized electricity as well as the diesel gensets used under earlier data assumption.

Finally, a fifty percent gasifier subsidy can effectively help select gasifier based systems if wood is freely available.

IMPACT OF RELAXING THE GOBAR AVAILABILITY

When raw material for biogas plants is unconstrained, substantial changes are observed in the selection of energy systems, allocation of energy, and costs compared to using normal data.

Changes in Energy System Selection and Energy Allocation

1. Cooking demand is met mostly through biogas, while solar cookers and wood burners are also used to some extent. Kerosene is completely eliminated.

2. To meet most of the hot water demand, solar hot water panels replace biogas.
3. To meet irrigation and electricity demands, all other systems are eliminated. Only biogas-based dual-fuel engines are used, coupled with pumps for irrigation and generator sets for electricity.

Thus, if biomass is freely available for use in biogas Plants, it is optimal to supply most of the village energy needs through biogas-based systems.

Cost Savings

Comparision of costs under the assumption of free availability of gobar with those under normal data shows the following cost savings and unit energy costs.

Table

Annual Cost Saving and Unit Costs (Rs/kWh) for Each village When the Gobar Constraint is relaxed

	Village			
	1	2	3	4
Annual cost Savings (Rs.)	31,202	144,695	251,455	581,953
Unit cost (Rs./kWh)	0.444	0.475	0.475	0.448

Sensitivity to parameters such as wood price, range of subsider on the gasifer system, diesel price, electricity price etc were also carried out.

5.0 Discussion

Hierarchical planning framework linking macro i.e. national/state level energy planning with micro, i.e. block and village level energy planning is presented above. Just as macro level plans need disaggregation to micro level for effective implementation, aggregation of micro level plans in different villages and blocks must match with macro plan targets. The process of successful planning and implementation thus is interactive and not one sided. Energy demands must be estimated at disaggregated level, while the supply requires planning at aggregate levels. The aggregation in macro planning generalises the energy demand-supply relations, while the disaggregation in micro planning captures regional/local specificities. The hierarchical approach thus facilitates linkage of macro and micro level planning. At each level, models for optimal decisions are proposed. At each level decisions are different and the lower level planning has to be done under the overall targets of higher level decisions. However, higher level plan decisions must be realistic to be achieved by micro level supply-demand specificities and possibilities. Interaction of micro and macro planning thus needs wholistic approach. Appropriate organisation structure is needed to translate planning decisions into actual implementation. In various energy planning applications discussed in the paper, it can be seen that the suggested models not only provide a plan at each level but a policy framework. The advantage of models is that policy interventions can be evaluated under different scenarios for arriving at an appropriate plan. The success of the proposed energy planning framework depends on linkages between various levels of planning hierarcy through information flows and organisational concatanations.

Appendix I

Disaggregated Sectors Defination

Energy sources energy product and energy (end-use) demand sectors are broadly classified as follows :

Energy Sources(S):

1. Electricity - hydel , thermal, nuclear, diesel and natural gas.
2. Coal and lignite - coking coal,noncoking coal, hard coke,soft coke,lignite.
3. Crude and petroleum products - Crude, MS, LPG, NAPTHA, ATF, SKO,HSD, LDO, FO, LSHS, and other petroleum products
4. Natural gas
5. Non commercial energy sources - firewood, cropwaste, charcoal, dung, biogas, solar, wind, and animal power

Energy Products(P):

1. Demestic sector - lighting, cooking and other uses.
2. Municipal sector - street lighting, public water works
3. Industry sector - process heating, electric drive ore reduction, and ind.lighting
4. Transportion sector- road, rail and air Person Kilometers (PKMS) and Tonne Kilometers(TKMS)

5. Agricultural sector- irrigation, harvesting, thrashing
and land preparation

Energy Demand(I):

Energy demand(end-use) sectors are taken directly from the I-O matrix used by the Planning Commission. The expanded matrix with emphasis on energy sectors represents a departure from the conventional input-output analysis. First, energy sector outputs are expressed in terms of physical units. Second, outputs of energy supply and conversion sectors are distributed to energy demand sectors via "dummy" energy product sectors.

The coefficients matrix A is artificially partitioned as:

$$A = \begin{array}{cccc} \text{Energy Supply (S)} & \text{Energy Product (P)} & \text{Energy Demand (I)} & \\ \hline \text{Ass} & \text{Asp} & 0 & \text{Energy Supply} \\ \hline \text{Aps} & 0 & \text{Api} & \text{Energy Product} \\ \hline \text{Ais} & 0 & \text{Aii} & \text{Energy Demand} \\ \hline \end{array}$$

Where,

Ass: input-output coefficients describing sales of the output of one energy supply sector to another energy supply sector. Conversion losses are excluded since all coefficients are calculated on the basis of delivered energy.

Asp: input-output coefficients describing how distributed energy products are converted to end-use forms. They contain end-use conversion efficiencies embodied in the RES.

Asi: 0 implying that energy supplies are not used directly by energy demand sectors; energy is distributed to the energy demand sectors via energy product sectors.

Aps: Input-output coefficients describing how energy products are used by the energy supplying industries. Auxillary consumptions are accounted for in Ass.

App: 0 implying that energy products are not used to produce energy products.

Api: input-output coefficients describing how energy products - final energy forms - are used by energy demand sectors. This submatrix describes the ways end-use energy forms are used in the energy demand sectors.

Ais: input-output coefficients describing the uses of non-energy materials and services by the energy industry. An example of this would be requirements for machinery for oil drilling or coal mining.

Aip: 0 implying that energy product-sectors equipment require no material or service inputs. This is because they are pseudo-sectors and not real producing sectors.

Aii: Input-output coefficients describing how non-energy products are used in the energy demand sectors. Coefficients in this submatrix are enumerated in purely monetary terms. Aii is equivalent to the A matrix of the conventional input-output framework.

Note that input - output coefficients in the S and P sectors are in physical units . For example, electricity is expressed in MU(million units), petroleum products are expressed in MT(metric tons), etc. Only the input-output coefficients in the I sector are in monetary values.

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