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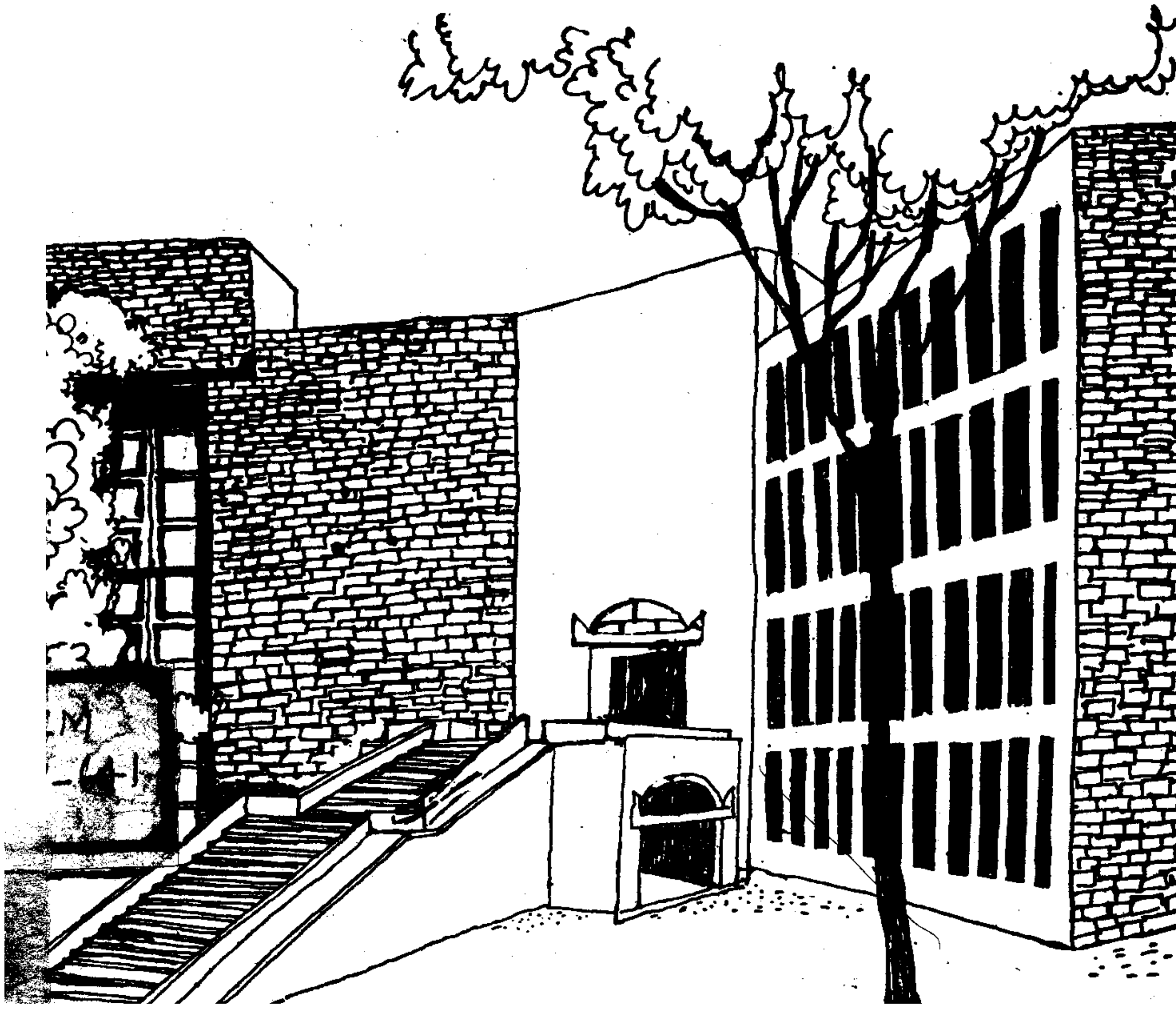

# INTEGRATED RURAL ENERGY SYSTEM : PLANNING AND ORGANIZATION

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# INTEGRATED RURAL ENERGY SYSTEM: PLANNING AND ORGANIZATION


## Abstract

This paper discusses the process and methodology for the integrated rural energy system (IRES) and organization of IRES. The planning includes methodology for estimation of village energy needs and energy resources, information and data on alternate energy systems available, model for optimal IRES selection for a village, installation and maintenance of IRES and strategies for and implications of energy resources development. Organizational issues considered include various interfaces among village organization and different agencies involved in implementation of IRES. The IRES planning and organization issues presented are supported and highlighted by the extensive studies conducted by the authors and their experience in IRES planning and organization.

## 1. Introduction

Concern of fast depleting conventional energy resources and pressures in 1970's created by Oil Squeeze bestirred the world to look for replenishable sources of energy. Experiments and development for renewable sources of energy such as solar, wind, tidal, biomass, etc. and corresponding technologies began. The role of renewable energy, techno-economic feasibility of these energy systems and optimal mix of these decentralized technologies in integrated energy system have been the issues under serious consideration by planners in India. The urgent need for increasing energy supply to rural population accounting for seventyfive per cent of India's population, specifically augumenting energy for domestic consumption, agriculture and rural industries has further raised concern for renewable and non-conventional energy system. The government policy in India has been to supply energy in rural areas in the form of diesel, kerosene, coal and electricity. Though the electricity policy has some success in laying transmission lines, the quantum of assured power supply and the rate of actual use of electricity in rural areas remain very low. Full electrification is still a distant dream and for villages distant from the electric grid and in remote areas, the efficiency and cost effectiveness of centralized energy system is questionable. Besides, electrification is far from energization of a village. More than eighty per cent of energy necessary in villages is for cooking only.

Some limitations of centralized energy generating systems are high capital investment, high transmission investment and high maintenance cost. This is not to deny that the centralized electricity system is perhaps the most versatile and efficient in end-use. However, in rural India, electricity is almost exclusively used for water pumping. Thus it leaves out important energy end-uses such as cooking, heating and lighting which form major portion of energy needs of a rural population.

The concept of decentralized energy generating systems is essentially small scale systems catering to the total energy needs of small group of people. The conventional energy forms are often costlier and difficult to supply due to remoteness and spread of rural areas whereas non-conventional forms such as solar, wind, biomass, have the definite advantages of local availability and at a zero price or at a very low cost. The decentralized systems based on non-conventional resources can be harnessed locally thus reducing drain on village surplus and can help build-up rural agro-industrial structure.

The concept of integrated rural energy system (IRES) is evolved out of the need to promote change from energy dependence to energy autonomy, from electrification to energisation, from inequitable to equitable distribution, from external control to self-reliance and above all from non-renewable to renewable energy sources. The problem posed in planning and organization for IRES at village level therefore is much multifaceted and includes: (i) estimation of an energy demand and energy resource availability for the village, (ii) selection of a cost optimal mix of energy generating technologies to meet energy needs of a village under the constraint of local energy resources, (iii) development of local energy resources, (iv) installation and maintenance of energy generating technologies, (v) organization at the village level for producing and consuming energy, and (vi) interface of village administration with relevant external agencies.

Rest of the paper presents the approach, process and issues in planning and organization of IRES. The presentation is based on extensive studies made by the authors for estimating village energy demands and to decide an optimal mix of centralized and decentralized energy systems to meet current and future energy needs (1) and for management of IRES (2).

## 2. Estimation of Village Energy Needs

Planning for IRES for a village begins with understanding and estimating energy needs. Energy needs of a village is generally estimated through a detailed village survey which is very time-consuming as well as costly process. As an alternative to this, there is a need to develop fairly accurate method for estimating the level of energy needs directly based on same physical parameters of the village. An approach for estimating village energy needs using appropriate non-energy paramters is presented below.

## 2.1 Energy Needs

Energy consumption in a village is a function of several variables which include population, number of households, cultivable area, irrigation requirement, etc. The purposes for which energy is needed in a village are:

(1) Cooking,

(2) Lighting,

(3) Agriculture,

(4) Rural Industries,

(5) Artisan uses, and

(6) Transportation.

The energy required can thus be classified into (a) motive power, (b) energy for thermal purposes, and (c) electrical energy. Human and animal energy is also extensively used in the villages.

The Gujarat Energy Development Agency (GEDA) had conducted a survey of a several villages to estimate the energy needs of rural population. A multiple regression method (1) estimated by using the village energy survey data conducted by GEDA for several villages is presented next. Once an accurate method is developed, village level energy needs may be estimated by using this method instead of costly and time-consuming surveys.

## 2.2 Multiple Regression Model

The regression model for village energy consumption presented ere is an equation where dependent variable is total energy consumption per capita per year and independent variables are the non-energy parameters of the village like, population, geographical area, number of households, etc. Thus, by knowing relevant physical non-energy characteristics of the village, its energy consumption per capita per year can be estimated. Since only a few villages had industries and artisan energy consumption was not uniformly available, the industry and artisan energy consumption has been excluded from the total energy consumption.

The variables which predict well the total consumption are:

| | | |
|---|---|---|
| $X_1$ | : | Village population |
| $X_2$ | : | Quantity of dung per day in Kg. |
| $X_3$ | : | Land under irrigation in hectares. |
| $X_4$ | : | Distance from the nearest town in Kms. |
| $X_5$ | : | Cultivable land in hectares. |
| $X_6$ | : | Number of households. |
| $X_7$ | : | Total land in hectares. |
| $X_8$ | : | Number of bullocks. |

The dependent variable was the total energy consumption in KCal - for cooking, lighting and agricultural purposes. Correlations for the set of GEDA survey data are shown below.

(a) For linear correlation

$$Y = 0.124313 \times 10^{7}.\ 781\, X_1 - 14X_2 + 3372X_3 + 19444X_4$$
$$- 3797X_5 + 3518X_6 + 1913X_7 + 4588X_8$$

(b) For log - log correlation

$$\text{Log } Y = 15.268 - 2 \text{ Log } X_1 + 0.353 \text{ Log}X_2 + 0.15 \text{ Log}X_3 - 0.092 \text{ Log}X_4 + 1.7 \text{ Log}X_5 + 1.6 \text{ Log}X_6 + 1.28 \text{ Log}X_7 + 0.68 \text{ Log}X_8$$

The results of the regression analysis indicate that the eight variables have a significant power ($R^2 = 0.96$), in predicting the energy consumption level of a village. In other words, with the data on these eight variables it is possible to work out fairly accurate estimates of the energy consumption level of the villages. It is also important to note that the data on these eight variables are easily and readily available for most of India's villages. However, it should be noted that for integrated energy system the aggregate energy consumption data need to be disaggregated into various end-use wise energy requirements in order to use the equations meaningfully for village level planning. This may be done by considering standard percentage of each end-use in aggregate demand or most accurately by developing multiple regression equations for each of the end-uses. It is only then that energy demand can be estimated meaningfully in individual village situation. In the absence of modelling approach, it would be necessary to conduct detailed survey for each village for planning for IRES.

## 3. Energy Systems

Supply of energy depends on available energy systems and energy resource. In India energy needs are met by both centralized and decentralized energy generating systems.

The energy generating systems can also be classified as conventional and non-conventional (e.g. electricity). Centralized energy systems have advantages of large scale production. However, they have disadvantage in terms of distribution costs especially to remote villages. Decentralized systems have advantage of local management of energy generation and little problems of distribution. Non-conventional sources of energy have advantage of using local resources, development of local economy and no drain on village surplus. The focus of IRES's is obviously decentralized, non-conventional energy sources. However, economic selection of energy systems in IRES must consider available centralized and conventional technologies also.

## 3.1 Centralized Energy Systems



Non-conventional centralized systems are yet to be proved economically viable for consideration in IRES. Major conventional energy system available is centralized electricity. As discussed earlier, although Indian Government's policy is to electrify all villages and there is some success in laying transmission lines. Full electrification is yet a distant dream. Also centralized electricity is mainly used for water pumping, while the most primary energy need in rural areas is for cooking and water heating for which electricity use cannot be thought of in foreseeable future. Extent of rural electrification and centralized electricity costs presented below are based on a study of centralized electricity generation in Gujarat State. Electricity generation in the state is mainly through thermal and hydel power stations, however, the state also purchases electricity from Tarapur Nuclear Plant in adjeacent state of Maharashtra.

The total electricity supply and sales in the state have been rising at a rate of 11% to 13% in the past six years. Hitherto power generation is contributed by thermal stations. The hydel power has shown decline in 1982-83 (half to one third of the past six years) and it shows ups and downs depending upon the rainfall. Diesel power generation was negligible and it was stopped in 1982-83 due to scarcity and price rise of oil. Gas turbine has erratic trend of power generation and its contribution in total supply is only 0.25% to 2.5%. Purchase from Tarapur has been about 9% to 12% for the last six years. The total electricity supply in Gujarat is approximately 25% to 35% higher than total sales, due to auxillary consumption (nearly 10%) and transmission and distribution losses (nearly 20%). Centralized electricity generation requires tremendous capital costs. At present capital investment for 1 MW capacity of thermal power station is considered to be Rs.10 million.

Electricity generation costs are shown in Table 1. There has been increase in cost of generation of thermal power due to scarcity and escalating cost of fuel, and increase in plant cost.

Table 2 shows the transmission cost. At present, there are 3600 Kms. of 220 KV lines, 3600 Kms. of 132 KV lines and 5600 Kms. of 66 KV lines in the state. The cost figures are for 1983.

While distribution cost details are not given here, the has been nearly 100 per cent increase in distribution cost ov the last five years.

Table 1

ELECTRICITY GENERATION COST

| Type of Generation | Cost in Paise for Kwh 77-78 | 78-79 | 79-80 | 80-81 | 82-83 | Estimated for Sikka Th. Power Project |
|---|---|---|---|---|---|---|
| I Thermal | 17.14 | 19.54 | 23.41 | 27.83 | | 43.92 |
| II Hydel | | | | | 10.00 | |

Table 2

COST OF TRANSMISSION LINE: 1982-83

| Type of Transmission | | Cost in Lakhs of Rs./Km. |
|---|---|---|
| 1) 66 KV lines | - S/C | 1.27 |
| | D/C | 2.45 |
| 2) 132 KV line | - S/C | 2.0 |
| | D/C | 3.32 |
| 3) 220 KV line | - S/C | 3.0 |
| | D/C | 5.34 |
| 4) Second Circuit Stringing of 220 KV line (in the same stand) | | 2.4 |
| 5) 400 KV line | - S/C | 7.0 |

As the new transmission and distribution (T&D) lines are laid every year, their losses increase, as power loss is also proportional to length of the line. Thus, there is increasing trend in T&D losses. There has been 26% increase in the T&D losses during the last 5 years.

When the load supercedes the supply, the system frequency goes down to meet the required demand and there is power loss due to it. This low frequency loss also shows increase (87%) over the last five years.

From the above figures, it can be seen that costs of electricity transmission are significantly high and hence for remote villages centralized electricity is uneconomical and hence it is all the more necessary to consider decentralized energy sources in IRES.

## 3.2 Decentralized Energy Systems

Both conventional and non-conventional decentralized energy systems are in use. The system description and cost estimates of these systems are given below.

### 3.2.1 Conventional Decentralized Energy Systems

Common conventional decentralized energy systems in use are:

1) Kerosene Stove:

This is the usual pressure stove which is kerosene as fuel.

2) Diesel Pumpset:

This is the usual diesel engine coupled with pumpset for lifting water for irrigation.

3) Diesel Genset:

This is the usual diesel engine coupled with gen set to produce electricity.

### 3.2.2 Non-conventional Decentralized Energy Systems

The available non-conventional decentralized energy systems are:

i) Solar concentrating Collector-cum-Steam Engine

In this system solar energy is focussed to the collector with the help of mirrors or lenses. The working fluid (e.g., water) heated by solar collectors is fed into the steam engine which either drives a pump directly or an electric generator.

ii) Solar Pond-cum-Vapour Engine

In the solar pond, salt is added to the water. Due to natural leeching of salts, the salt concentration increases with the pond's depth. This positive salt density gradient supresses convection and allows a temperature gradient to develop which leads to higher temperature difference between upper and lower portion of the pond, a vapour engine can be operated.

iii) Solar Photovoltaic System

Solar energy is converted directly into electricity in solar cells. During the day, theelectricity generated is stored in the rechargeable batteries. This is used in the night.

iv) Wind Pump

In this system the wind rotates the propellor. The rotary motion of propellor is converted into reciprocating motion with the help of crank mechanism which is used to drive reciprocating pumps.

v) Biomass Gasifier

In this system, producer gas is obtained by incomplete combustion of the biomass. This gas can run internal combustion engine. The biomass used could be crop residues, agricultural waste or wood from energy plantations. Gasifier engine can be coupled with pump for irrigation and with genset to produce electricity.

vi) Energy Plantation-cum-Wood Fired Boiler-cum-Steam Engine

Wood obtained from energy plantation is used here as fuel for boiler. The steam generated from the boiler runs the engine.

vii) Mini Hydel Power

The potential energy of water is converted to motive energy through water turbine. When the turbine is coupled with electric generator, it produces electricity.

viii) Biogas Plant

In this plant, the organic material like dung is fermented to produce methane gas which is used for cooking and for driving an engine (duel-fuel engine).

ix) Solar Cooker

This is basically a box like structure designed to efficiently convert incident solar radiation into heat.

x) Improved Wood Burning Chulha (Wood Burner)

In this chulha, the heat loss is reduced so that wood requirement is reduced considerably in comparison with traditional chulha.

xi) Solar Hot Water System

It consists of two units - heat absorption unit and hot water storage unit. It has fairly high solar thermal performance.

### 3.2.3 Cost of Energy Generating Systems

Capital cost, maintenance cost and variable cost of centralized and decentralized - conventional and non-conventional energy systems - are given in Table 3 below.

Table 3

COST OF ENERGY GENERATING SYSTEMS

| No. | Systems | Capital (fixed) cost in Rs. | Annual maintenance cost in Rs. | Variable cost in Rs./KWH |
|---|---|---|---|---|
| I. | Conventional Centralized Energy System | | | |
| 1. | Centralised electricity<br>5 KW<br>Module | <br>81000<br>1560 x* | <br>** | <br>0.26 |
| II. | Conventional Decentralized Energy System | | | |
| 1. | Normal Pressure Kerosene stove | 50 | 5 | 0.77 |
| 2. | Diesel Pumpset - 5 KW | 9680 | 900 | 1.22 |
| | 10 KW | 17340 | 1200 | 1.22 |
| 3. | Diesel Genset - 5 KW | 19880 | 1500 | 1.53 |
| | 10 KW | 35200 | 2500 | 1.53 |

.. contd.

III. Decentralized Non-conventional Energy System

| | | | | |
|---|---|---|---|---|
| 1. | Concentrating collector-cum-steam engine - 5 KW | 325000 | 15000 | 0 |
| 2. | Solar Pond-cum-Vapour Engine - 5 KW | 312500 | 18000 | 0 |
| 3. | Solar Photovoltaic System - 5 KW | 600000 | 2600 | 0 |
| 4. | Wind Pump - 3.5 KW | 46240 | 800 | 0 |
| | - 10 KW | 74460 | 1200 | 0 |
| 5. | Biomass Gasifier-Pumpset - 5 KW | 20000 | 1100 | 0.62 |
| | 10 KW | 38000 | 1600 | 0.62 |
| | 25 KW | 75000 | 2400 | 0.62 |
| 6. | Biomass Gasifier-Genset - 5 KW | 28000 | 1800 | 0.78 |
| | 10 KW | 50000 | 2900 | 0.78 |
| | 25 KW | 93000 | 4000 | 0.78 |
| 7. | Energy plantation-cum-wood fired boiler-cum-steam engine - 5 KW | 217000 | 5000 | 2.4 |
| 8. | Hydel Power - 5 KW | 225000 | 25000 | 0 |
| 9. | i) Biogas Plant 5 $m^3$ | 8350 | 1100 | 0 |
| | 25 $m^3$ | 30400 | 3235 | 0 |
| | 60 $m^3$ | 65000 | 4490 | 0 |
| | 85 $m^3$ | 85000 | 6860 | 0 |
| | ii) Biogas Burner | 250 | 10 | 0 |
| | iii) Dual-Fuel Engine Pump for Biogas - 5 KW | 9680 | 1000 | 0.22 |
| | iv) Dual Fuel Genset for Biogas - 5 KW | 19880 | 1700 | 0.275 |
| | - 10 KW | 35200 | 2500 | 0.275 |
| | - 25 KW | 76400 | 3600 | 0.275 |
| 10. | Solar Cooker | 600 | 20 | 0 |
| 11. | Improved Wood Chulha | 200 | 10 | 0.35 |
| 12. | Solar Hot Water System 250 lts. per day capacity | 15300 | 1000 | 0 |

* "x" is the distance of the village for the grid.

** Maintenance cost for centralized electricity shall include power plant maintenance cost and transmission line maintenance costs. These figures per KW are not available.

## 4. Estimation of Energy Resources

Energy generating systems use energy resources for generating energy. Conventional resources such as diesel, kerosene, etc. are generally available to villages, however, at relatively higher prices. Many non-conventional systems e.g., biogas, gasifier, etc. require local resources. Before deciding the IRES, level of resource availability must be known. Mainly the two biomass resources - wood and dung must be assessed. Also, in the case of hydel systems water potential and for wind the wind potential must be known. Only under the constraint of available level of these resources, IRES selection could be made. As discussed in later section, long term strategy for IRES should also include energy resource development.

## 5. Optimal-Selection of IRES

A model for optimal selection of IRES proposed here attempts to satisfy energy needs of the village at minimum cost using available energy generating systems and resources. Centralised and decentralised and conventional and non-conventional energy systems may all be considered. The formulation of the problem results in mixed linear integer programming (MILP) model (3) (4). Both fixed and variable cost of the energy system are considered. Given the energy needs, resource availability, energy generating technologies and their costs, the model can be used to select IRES for a village and it also provides optimal allocation of energy from a energy systems to respective end-uses. Model assumptions and formulation is given below.

## 5.1 Model Assumptions

The model is based on following assumptions:

1. A year is divided into several time periods (summer, monsoon and winter) to account for different efficiencies of some energy systems and different energy demands for each end-use in different time period of a year. For example, solar cooker cannot operate in monsoon. Solar Hot Water System does run lower efficiency in monsoon and biogas plant has lower efficiency in winter.
2. Each energy system has specified capacity during a period.
3. For each energy system, the amount of raw materials used and variable costs are proportional to the amount of energy supplied. Variable costs are considered using market prices of resources.
4. Given the energy supplied by each energy system, the total cost and energy supplied are sums of costs and energy supplied by each source.
5. Annual fixed cost of the system is completed by considering appropriate depreciation, interest and maintenance cost.
6. Fixed cost of energy system is charged if and only if the system supplies positive amount of energy.
7. The demand for each end-use during each period must be satisfied.

## 5.2 Legend and variable and co-efficient definitions

| | | |
|---|---|---|
| $P$ | = | Number of primary energy systems |
| $i$ | = | Index Number for primary energy system - $i = 1 \ldots\ldots P$ |
| $n_i$ | = | Number of sizes of $i^{th}$ primary energy system |
| $j$ | = | Index number for sizes of each primary system. for $i^{th}$ primary system $j = 1,2,\ldots\ldots n_i$ |
| $d$ | = | Number of End-uses requiring energy. |
| $k$ | = | Index number for end-uses - $k = 1,2,\ldots\ldots d$ |
| $e$ | = | Number of time periods in a year. |
| $t$ | = | Index number for time period - $t=1,2,\ldots\ldots e$ |
| $q$ | = | Number of secondary energy systems |
| $l$ | = | Index number for secondary energy system - $l = 1,2,\ldots\ldots q$. |
| $m_l$ | = | Number of sizes of $l^{th}$ secondary energy system. |
| $s$ | = | Index number for sizes of each secondary system. For the $l^{th}$ secondary system - $s = 1,2,\ldots\ldots m_l$ |
| $h$ | = | Number of raw materials used by energy systems |
| $r$ | = | Index number of raw materials - $r = 1,2,\ldots\ldots h$ |
| $Y_{ij}$ | = | Number of units O 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. |
| $G_{ikt}$ | = | Variable cost of using a unit of energy from energy system i for end-use k in a period t. |

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

$U_{ijt}$ = Capacity of primary energy system of type i of size j 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:

### 5.3 Model Formulation

Minimize Annual Cost:

$$Z = \sum_i \sum_k \sum_t C_{ikt} X_{ikt} + \sum_i \sum_j F_{ij} Y_{ij} \sum_l \sum_s G_{ls} Z_{ls} \quad (1)$$

Subject to:

Primary Energy System Capacity Constraints

$$\sum_k X_{ikt} - \sum_j U_{ijt} Y_{ij} \leq O_t, \; i = 1,2,\ldots n; \; t = 1,2,\ldots e \quad \ldots\ldots \quad (2)$$

Secondary Energy System Capacity Constraints

$$\sum_{\varepsilon l} \sum_{k \varepsilon K} X_{ikt} - \sum_s V_{lst} Z_{ls} \leq 0, \; l = 1,2,\ldots q; \quad \ldots \quad (3)$$

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 $k \varepsilon K$ via secondary energy system l$\}$

Raw Materials availability constraints

$$\sum_i \sum_k a_{iktr} X_{ikt} \leq A_{rt}, \; r = 1,2,\ldots h, \; t = 1,2,\ldots e. \quad \ldots\ldots \quad (4)$$

Demand Constraints

$$\sum_i X_{kkt} \geq D_{kt} , \; k = 1,2,\ldots d, \quad t = 1,2,\ldots 0 \quad \ldots\ldots \quad (5)$$

Non-negativity and Integer Constraints

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

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

$$Z_{ls} \geq 0; \text{ and free integer}; \; l = 1,2,\ldots q; \; e = 1,2\ldots m_l \ \ldots(8)$$

5.4 Model Application

The model was used for optimal selection of IRES for four villages. Energy demand for such village (Table 4) and energy source availability (Table 5) were estimated earlier. Twenty seven energy system - size combinations were considered which were represented with twenty seven integer variables. Energy allocation required for two real variables. Extensive sensitivity analysis was performed to understand implications of various energy developmental strategies on IRES selection (3) (5) (6). Optimal IRES and energy allocation for four villages and costs thereof are given in Table 6, 7 and 8 respectively.

6. Development of Energy Resources: Potential and Strategies

Application of the described model to selection of IRES for four villages revealed that the low availability of local biomass resources restrict the selection of decentralized and non-conventional energy systems. For example, in most villages both wood and dung were completely used for optimal solution. It is thus obvious that the selection of IRES is influenced by the availability of energy resources and hence the long term strategies for planning for IRES must consider development of local energy resources.

Table 4

ANNUAL ENERGY REQUIREMENT IN (KWH) FOR FOUR VILLAGES

| End Use Type | Village 1 | Village 2 | Village 3 | Village 4 |
|---|---|---|---|---|
| Cooking | 210,000 (76.53)[a] | 435,000 (74.49) | 705,000 (73.55) | 1,411,200 (74.83) |
| Hot Water | 34,000 (12.39) | 75,840 (12.98) | 122,400 (12.77) | 245,400 (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) | 160,200 (8.51) |
| Total | 274,375 (100.00) | 584,010 (100.00) | 958,500 (100.00) | 1,883,300 (100.00) |

a) Figures in brackets represent percentage of total energy requirement for a particular village.

Table 5

ANNUAL AVAILABILITY OF RAW MATERIAL (IN KWH) AT 4 VILLAGES[a]

| Raw Material | Village 1 | Village 2 | Village 3 | Village 4 |
|---|---|---|---|---|
| Gobar | 187,000 | 281,000 | 437,000 | 313,000 |
| Wood | 1,400,000 | 562,000 | 605,000 | 2,907,000 |

a) The figures in this table represent the potential energy availability from a raw material. The actual energy availability at the demand level is then computed by considering efficiencies of the energy systems used.

Table 6

ENERGY SYSTEMS SELECTED FOR FOUR VILLAGES (NORMAL DATA)

| Energy Systems | Number of Systems Village 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **Primary System** | | | | |
| 1. Biogas Plant, 25 $M^3$ | - | - | 2 | - |
| 2. Biogas Plant, 85 $M^3$ | 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 7

ALLOCATION OF ENERGY FOR FOUR VILLAGES (NORMAL DATA)

| End-use | Energy Systems | Annual Energy Consumption (KWH) Village 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Cooking | Biogas | 89,340 | 1,53,410 | 2,26,710 | 1,68,500 |
| | Solar Cooker | 70,000 | 1,45,000 | 2,35,000 | 4,70,400 |
| | Wood Burner | 50,660 | 35,130 | 37,810 | 1,81,700 |
| | Kerosene stove | - | 1,01,460 | 2,05,480 | 5,90,600 |
| 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 | 6,675 | 5,670 | - | 10,200 |
| | Centralized Electricity | 15,000 | 60,000 | 89,100 | 1,50,000 |

Table 8

COSTS OBTAINED USING OPTIMAL SOLUTION FOR FOUR VILLAGES (RUPEES) (NORMAL DATA)

| Costs | Village 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1. Fixed (Capital) cost | 440,540 | 1,199,860 | 1,844,315 | 3,087,980 |
| 2. Total annual cost | 153,175 | 424,259 | 760,934 | 1,426,368 |
| 3. Annual variable cost | 43,040 | 124,297 | 245,855 | 654,373 |
| 4. Unit cost of energy (Rupees/KWh) | 0.588 | 0.726 | 0.737 | 0.757 |

An extensive study of impact of biomass availability on selection of IRES shows that if wood is made locally available, then it replaces use of kerosene for cooking and hot water energy needs. Gasifier based systems are still not preferred. However, if fifty per cent subsidy is given to gasifier systems, then they are preferred over conventional systems, i.e. diesel systems and centralized electricity. The unit energy cost to the village is reduced by about 12 to 15 per cent. Unrestricted dung availability has more significant impact on selection of IRES. Under this condition, it is most economical to use biogas based systems to supply most of the cooking and hot water needs and also biogas based dual-fuel engines are most economical for supplying irrigation and electricity needs. The unit energy cost to the village in this case reduces by nearly 35 to 40 per cent.

These results clearly suggest that there is a tremendous economic advantage in developing local biomass energy resources. Not only these resources reduce energy costs to the village, they have significant impact on non-renewable and decentralized energy. Long term planning for IRES must seriously consider development of these resources, e.g. energy plantation, developing alternate biomass as feed-stock to biogas plants.

## 7. Installation and Maintenance of IRES

Installation and maintenance of IRES forms very important part of IRES planning and organisations. The involvement of village people starts essentially with selection of site and continue during construction and installation of different energy systems. Interactions with outside agencies becomes more involved and frequent. Before installation, materials and equipment need transportation. Local labour is also needed. Regular maintenance of the energy systems thereafter ensures smooth running of the systems. This requires maintenance, personnel, tools, equipments and spares. Organisational functions related to installation and maintenance are outlined in later sections. Some specific issues concerning installation and maintenance of IRES are considered next.

### 7.1 Construction

Several technologies, e.g. biogas plant, require extensive construction in the village. This requires trained construction personnel. Some of whom may come for construction from outside. Village masons and labourers are also required. Transportation of materials and sometimes substitution of some of the construction materials by local materials are also very important. This requires some initiative and ingenuity on the part of implementing agency personnel. Management during this phase is essentially on project basis.

## 7.2 Equipment Installation

Many energy technologies require installing equipment, e.g. gasifier, solar hot water systems, etc., are directly brought from outside or require only minor assembly at the village. Small and simple systems such as solar cooker are given to individual households and their transportation and installation pose little problem except user education. However, for more complex systems such as gasifier pumpsets or gensets, the installation of equipment involves transporting heavy equipment, site preparation, physical installations at the site, trouble-shooting, and training of personnel for operating the systems.

## 7.3 Installation of Distribution Lines

Energy systems such as biogas, electricity, etc. require distribution to individual household. Installation of distribution lines require clear planning of distribution network, e.g. underground or overground network, extent of distribution, etc. Physical installation of pipes, wiring, etc. require local participation and some trained personnel such as plumbers and electricians.

## 7.4 Trouble-shooting

Most technologies, especially several non-conventional technologies which are not yet highly standardised, require trouble-shooting before start-up. Technical personnel knowledgeable about the energy systems are required at this stage. This is the transition form physical installation to operation stage.

### 7.5 Maintenance Personnel and Organisation

For smoothe operation of the IRES, proper maintenance is essential. Most important issue in maintenance at village level is the adequate manpower for maintenance. Local persons must be trained for maintenance. Also for maintenance of IRES, it may not be necessary to keep several specialised maintenance personnel. It would be more appropriate to have one or few persons with versatile skills in trouble-shooting and repairs with few semi-trained helpers.

### 7.6 Maintenance Tools and Spares

Maintenance require specialised tools, equipment spares. It is essential to keep these in adequate number in stores as it is difficult to acquire these at the village at the time of energy system failure, and may cause considerably down time and inconvenience. Proper inventory policy must be designed for periodical purchasing of the consumable spares.

### 7.7 Manpower Training and User Education

During implementation stage, training of local personnel to operate, maintain, supervise and manage the energy systems are very important. Appropriate training programmes should be offered. User education is also important in the success of IRES. The user education may involve proper use of accessories and knowledge of pricing arrangements both for raw materials supplied by them and energy charges.

## 8. Organisation for IRES

IRES requires organisation of village community to participate in planning, installation, maintenance and operation of IRES. For this purpose, the concept of integrated rural energy centre (IREC) is developed. The IREC is the focal point for IRES management. The organisational requirements for IRES is discussed in next subsection. IREC concept is already being tested in Khandia village where India's first IREC is established. Besides Khandia, in four other villages of Gujarat, IREC are planned. The organisational requirements, structure and process described here are based on the actual interactions being formed in these IRECs among village organisation and various agencies in IRES management. The four economical interfaces to be considered by IREC are:

i) Between resource endowment of a village and the nergy generating systems of the centre.

This is important as much as the locally available resources determine the type, scale and economy of the energy generating systems, particularly for those resources which are necessary as raw material input for energy conversion.

ii) Between energy generating systems of the Centre and the end-use-wise energy demand in the village.

This interrelationship is crucial for matching energy supply and demand and also for assessing the gap, if any, in order to plan for alternative optimal strategies to fill up the gap between supply and demand.

iii) Between the village community and the Centre.

It is the active participation by the whole village community both as organiser of production of energy as well as consumer of energy, which will ensure the sustained efficient operation of the IREC. This means that there should be commonly agreed policies and principles within the village community for day-to-day operational management of the energy systems, harnessing raw-material as inputs for energy conversion and distribution of energy output and a regular maintenance of the energy generating systems. In other words, IREC is not merely a technologically and end-use wise integrated system, but should also be actuallized as organically integrated into the socio-cultural life of the village community.

iv) Between the village community and the relevant external agencies.

There should be one or more external agencies involved in a particular IREC providing capital investment (grant or loan), technical services (installation and maintenance of the equipments) economics administration of the Centre and other follow-up services. These external agencies could be government organisations, non-government voluntary organisations or even private enterprise. The relationship between these external agencies and the village community should have to be negotiated for a mutually agreed economic-administrative arrangements in which the roles and responsibilities of each side are clearly spelt out.

## 8.1 Organisational Functions

Since self-reliance and decentralisation are the major considerations in promoting IRES and for establishing IREC, it is imperative that an adequate administrative and economic arrangements should be evolved at the village level itself so that the revenue generated pays for operational as well as maintenance costs. What are the organisational functions in these administrative-economic arrangements? There are clearly eight distinct organisational functions in the management of IRES.

1) To identify the appropriate village sites; assess the resource-endowment and the socio-economic characteristics of the selected sites; survey the existing energy consumption needs and project the future demand; and lastly, select the optimal mix of energy generating technologies for meeting the energy demand.

2) To motivate the villagers to actively participate in the planning, installing and management of IRECs.

3) To install the energy generating systems in the village sites and ensure technologically smooth operation of the systems.

4) To arrange for sustained supply of biomass as inputs for energy conversion.

5) To organise trained manpower for IREC for everyday operation of the IRES.

6) To arrange an operating system for payment of wages, fees and charges for biomass supply, as well as, collection of revenue from the consumers on a commonly agreed upon rates and schedules.

7) To arrange for a suitable technical linkage for follow-up maintenance and monitoring services.

8) To plan for replacement and addition of energy systems and expand IRES to meet expanding future energy needs.

## 8.2 Organisational Structure

Of the eight distinct organisational functions, the first three and to some extent the last one in the above mentioned list are largely the responsibilities of some external agencies or organisations, while the rest of the functions are to be performed largely by some kind of participating community organisation in the village sites. Alternatively, the whole operation and management of IRES could be conceived as a commercially viable energy-utility service to be run as an enterprise by entrepreneurs or some entrepreneurial organisations. In the latter case, all the eight organisational functions are to be performed by the entrepreneur or entrepreneurial organisation in close collaboration with the beneficiaries. However,considering the existing stage of development of IRES, the second alternative seems to be extremely difficult to come by except in some specific situations. Thus, the organisational alternative which needs to be operationalised in specific IRES sites would be the first one as described above. To illustrate, three key nodal points in the Gujarat organisational structure are: Gujarat Energy Development Agency (GEDA), Implementing Agency for IRES and Village Organisation. Besides, the department of non-conventional energy sources of Government of India, New Delhi, provides finances and over all policy. The organisational interfaces for this alternative are specified in Figure 1.

8.3 <u>Role of the Organisations</u>

In the organisational network suggested in Figure 1, different organisations have definite roles which are described below.

8.3.1 <u>GEDA</u>

The role of GEDA as the over all planning and overseeing model agency initiating the IRES programme in the State is obvious. Right from the site selection and planning for the energy technology mix according to survey data to installation, operation and monitoring, GEDA's responsibilities and roles will

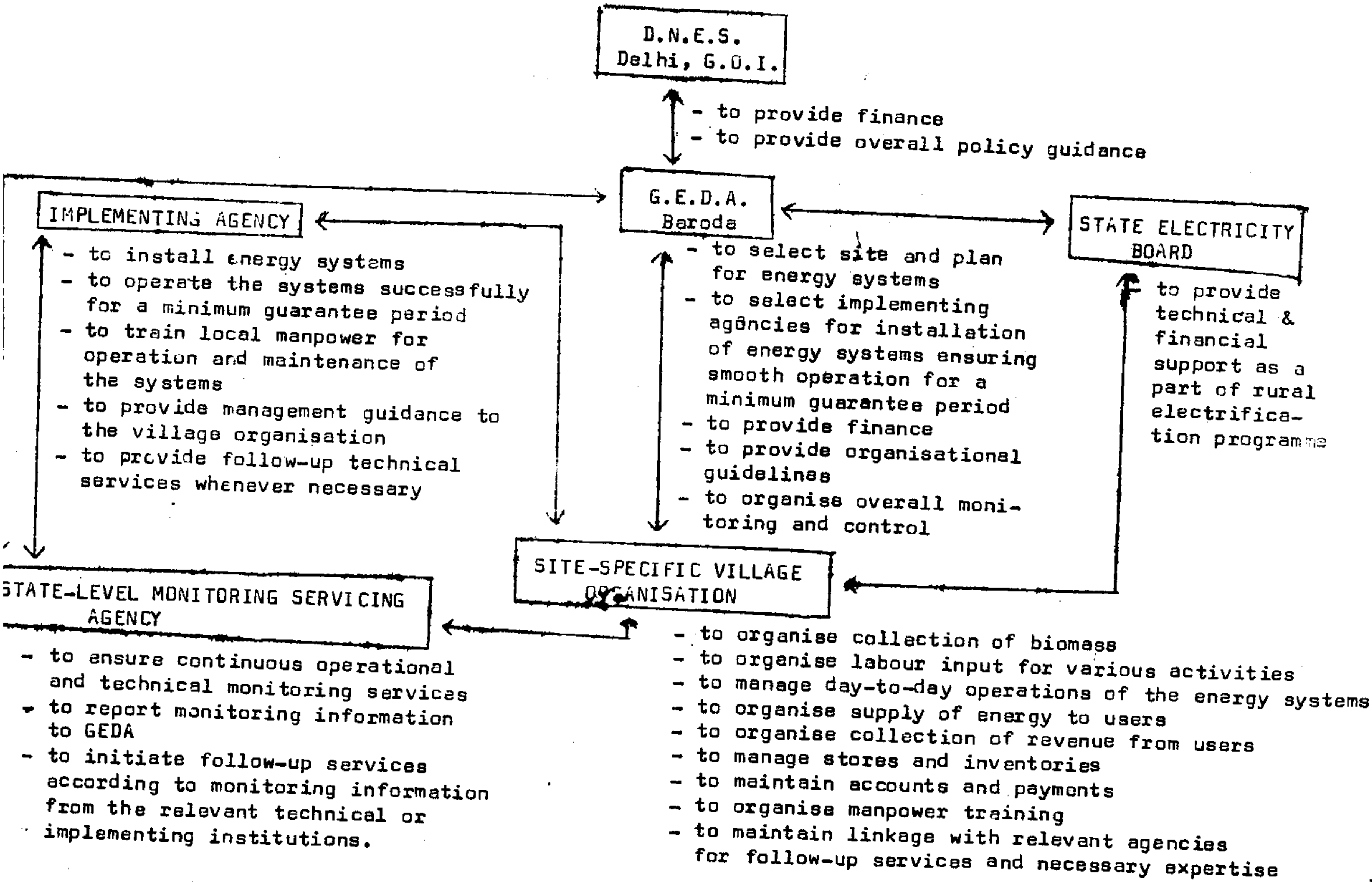


FIG.1: ORGANISATIONAL STRUCTURE

continue to be supreme. It is a different matter if GEDA accomplishes all these tasks on its own using its internal resources or gets some of these tasks accomplished through some reliable and competent organisation. In fact, many of these tasks may not be possible to be undertaken directly by GEDA, considering the constraints of relevant manpower requirements, exclusive time required to be spent and the necessary administrative and overhead costs to be incurred. The tasks like village surveys, installations of energy systems and extension work among the villagers are beyond the capability and scope of GEDA to undertake directly. GEDA's responsibility, is therefore, to get these tasks performed by engaging suitable external agencies including the existing voluntary organisations involved in developmental activities.

8.3.2 Implementing Agency

The second important nodal point is the Implementing Agency. It would be ideal if the Implementing Agency has equally strong capabilities in energy generating technologies as well as in community development activities in the rural areas. There are very few organisations or agencies having such a combination of capabilities. It is therefore unlikely to have such ideal implementing agency in all site-specific situations. Hence, the necessity to involve a local development agency - Government (IRDP for example) or voluntary organisation - in the whole process of implementation along with a technical institution or organisations. This is particularly so when the tasks of motivating the villagers and evolving a suitable village organisation are crucial for the success of IRES. For, the role of the Implementing Agency is not merely to instal energy generating systems and to operate it successfully and smoothly for a minimum guarantee period before handing over to a suitable organisation, but its equally important role is also to train local manpower, provide guidelines for overall management of the systems, follow-up services and assisting the local organisation to develop capabilities.

### 8.3.3 Village Organisation

As mentioned before, this should be the most important organisation in the whole network. The success of IREC largely depends on the capability and viability of a suitable village organisation for day-to-day management of IRES. In fact, the village organisation may be conceived as a participating entrepreneur in the management of IREC as an energy utility enterprise. In this sense, the role of the village organisation is almost akin to the second organisational alternative discussed earlier in which an entrepreneur or an entrepreneurial organisation performs all the eight essential functions in the management of IRES.

What should be the relevant structure and form of the village organisation? There would be several alternatives depending on the location-specific situations. While it may not be worthwhile to suggest a generalised blue-print, it is important to specify the basic structural and functional principles of such organisation. Structurally, this organisation should truly represent all sections of the village society - both as producers as well as consumers of energy - with close interface with GEDA and the Implementing Agency. Functionally, it has to perform all the day-to-day managerial and operational activities including liaison with GEDA and the Implementing Agency. In other words, what it ideally requires is an exclusive organisational entity at the village level devoting full time attention to IREC, rather than an additional function or appendage of an existing organisation. While the ultimate aim should be to form an exclusive registered body or a cooperative (e.g. energy associations, or users cooperative), it may be worthwhile, depending on location-specific situations, to initiate the process of organisation building through some of the existing organisations. Thus, an active and interested Village Panchayat or a Cooperative or a local Voluntary Organisation, could be the starting point as the organisational forum. Over a period, as the IRES becomes more complex, both functionally and technologically, an exclusive separate organisational entity (e.g. users cooperative) may be deliberately engineered as a spin-off or an exclusively separate division be created within the existing umbrella organisation (e.g. Panchayat, etc.)

8.3.4 Monitoring/Servicing Agency

Regular monitoring and follow-up services are the important management inputs for successful operation of the decentralised

IRECs. While monitoring is the overall responsibility of GEDA and the existing local technical institutions or the technical Implementing Agency could be linked up for necessary follow-up services, we still suggest a separate monitoring/servicing agency at the State level. There are mainly two reasons for such a suggestion: one, it might be too much strain on its limited manpower and time for a state level nodal agency like GEDA to undertake regular and continuous performance monitoring at all the IREC sites in Gujarat. This would be particularly true when the number of IRECs become larger and dispersed all over the States and mostly located in remote level rural areas. Second, it would be equally time consuming for the available manpower at GEDA to ensure necessary follow-up services through either the Implementing Agency or a local technical institutions. As the number of IRECs increase, it would be less costly and managerially more efficient to have a capable external agency to undertake the task. Hence, we suggest for a separate monitoring/servicing agency at the state level under the overall sponsorship of the state level nodal agency. It would, however, be ideal if such an agency has the capability for both monitoring and providing necessary follow-up services.

## 9. Operation and Administration of IRES

Operation and administration of IRES concern issues of smooth operation of IRES, i.e. production and distribution of energy, procurement of energy resources, stores and inventory management and administration of accounts, deciding prices and control of IRES.

## 9.1 Operation of IRES

Operation of IRES involve running the energy systems to produce energy and distribute energy for consumption. Operation of each energy system requires allocation of work to workers assigned with IREC, collecting energy resources such as dung, wood, etc., keeping inventory of centralized energy resources such as kerosene, diesel, etc., managing the resources to run the systems and collecting charges from user etc. The operation of IRES thus involve managing several activities. For smooth operation of IRES, maintenance function must be properly integrated with operational policies. IREC can be very effective as a single unit for managing operations, resources, stores, maintenance and distribution of energy and finances.

## 9.2 Economic Administration of IRES

The ultimate objective of management of IRES is to get maximum benefits from available financial and other resources. Also the economic administration must consider policies not only for maintaining but also for energy systems, their replacement using internally generated revenues. In other words, IRES management should not only be techno-economically viable and self-sustaining but also should provide energy to the rural beneficiaries at affordable prices at the same time generating resources for replacement and development of energy systems for meeting future enhanced energy needs. As the availability and costs of local resources are site specific, no uniform pricing of the inputs and outputs could be recommended for all situations. It should be decided according to location-specific situations. There could be two ways to decide the pricing of energy output in IREC. One way could be to ensure economic viability for each of the energy generating system individually. The other way would be to consider the economic viability of the IRES as a whole. In the latter case a particular energy generating system may be loosing but this can be made up by other energy systems and thereby making the IRES viable. The pricing should also consider future energy requirements and produce internal resources to sustain and grow IRES to meet expanding future energy needs.

10. Managing IRES for future Energy Needs

The energy needs in Indian villages are bound to increase in future. IRES management must consider this and device alternative plans and strategies for meeting expanding future energy needs. IRES planning must consider desired and not only devised demand. Thus IRES management must be seen from a long term strategic view point and not only from immediate needs. The main issues of concern in this context are:

1) Estimating future cost and price trends of different energy technologies (e.g. costs of non-conventional systems such as photovoltaic systems are likely to reduce substantially).

2) Developing local energy resources such as biomass.

3) Planning for replacement and addition of energy systems to enhance consumption for betterment of life.

4) Creating village level organisation for managing complex energy technologies and multiple functions.

5) Managing IRES growth for development of village economy, ecological balance and betterment of all sections in a village.

At this stage of development, these complex functions are as yet can not be managed by village level organisation. However, in a long run with the development and consolidation of IREC, these village level organisations can be developed to play significant roles in strategic long term planning for IRES. The basic functions of IRES management would still be quite similar to the IREC management issues discussed. For example, (i) estimation of energy demand and resources will need further demand projections and for this demand forecasting models can be useful, (ii) for IRES selection same model with dynamic multi-period variation of the basic model discussed earlier can be used, (iii) for cost estimation of energy systems, technological forecasting would be required, (iv) for growth planning of IRES, appropriate financial policies would be required, and (v) for developing biomass resources, proper economic planning of energy plantation etc. will be required. Annual variable cost of energy plantation for 50 hectare plantation is estimated at Rs.30000/-. The economic implication of these plantation for IRES would be tremendous and must be exploited in long term strategies. IRES planning and organisation, thus, must be viewed (i) dynamically i.e. in their development and growth, (ii) interrelatedly, i.e.

in connection with changing external situation such as changes in technologies and their costs, government policies, etc., (iii) <u>strategically</u>, i.e. with long term perspective and not only from short term operational view point, and (iv) <u>integrally</u>, i.e. forming coherant policies for economic viability, ecological balance and strengthening of existing socio-economic-cultural process and for the betterment of entire community.

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