ENERGY MANAGEMENT MODEL FOR RURAL AREAS

- A MULTIPLE CRITERIA DECISION

MAKING APPROACH

By

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Thesis Approved:

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PREFACE

This study is concerned with the application of Multiple Criteria Decision Making (MCDM) techniques like linear goal programming to rural energy management. The current research work was done using the Partitioning Algorithm for Goal Programming (PAGP) developed by Dr. Jeffrey Arthur and Dr. A.Ravindran while they were at Purdue University, Indiana. The primary objective of this study is develop a general purpose rural energy management model dealing with resource allocation subject to multiple goals and their priority ordering. The results of the study are used to generate basic guidelines for the decision maker in arriving at feasible solutions.

I am highly indebted to my thesis adviser, Dr. C. Patrick Koelling, whose encouragement, understanding and assistance made this study possible. His sound knowledge of the subject and friendly nature have inspired and sustained me throughout my association with him. My sincere thanks for all the help he extended to me.

I wish to thank Dr. R.G. Ramakumar of Electrical and Computer Engineering for suggesting this problem and serving as co-adviser on my committee. His constant guidance and long experience in the field of energy research has been very useful in making this study a success.

My thanks are also due to Dr. Philip M. Wolfe for being a member on the committee and for offering constructive criticism and suggestions. I am grateful to Dr. A. Ravindran, Chairman, Industrial Engineering

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Appreciation is expressed to the School of Indutrial Engineering and Management for extending an assistanship and funding the coumputer time. Sincere gratitude is due to Dr. Ronald D. Krenz of Economic Research Service, U.S. Department of Agriculture, Oklahoma State University for the job as Programmer/Analyst, which took care of my financial needs. Special thanks are due to Department of Agricultural Economics for permitting me to use their Radio Shack TRS80 microcomputer and Mrs. Valorie Gathright for word-processing this thesis.

On a personal note, I shall always be thankful to all my family members, relatives and friends who made my studies in this country a reality. I shall always be indebted to the personal sacrifices made by my father, mother, brother and sisters and the encouragement they gave to help me fulfil my ambitions.

Lastly I wish to thank all my friends and fellow students in Stillwater for making my stay a pleasant and lasting memory.

TABLE OF CONTENTS

Chapter Page

APPENDIXES

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

For the developing countries of the world in the continents of Asia, Africa, and South America the current times are the most challenging. With heavy populations, scant resources, widespread natural calamities like floods, drought and diseases etc., on the rampage, it is really a testing time for the governments in those countries. The current recession and unemployment have added to further the turmoil.

All reasonable solutions to alleviate these problems involve sharp increases both in the amount of energy consumed and in the efficiency of their use. The present decade has brought into focus the limited and geopolitical nature of the non-renewable energy sources of the world and the need to start the process of transferring the dependence, at least partly, onto renewable energy sources. Civilization has gone through a transfer of energy sources once already - from renewable energy sources to fossil fuels - as a consequence of the industrial revolution. This transfer was associated with the lowering of energy costs. However, the transfer that is in the making is going to increase energy costs considerably. The ramifications of this latest change in economic and socio-economic terms will be significant, global, and highly uneven.

For the nearly one billion people living in scatterred rural areas of the developing countries of the world, the consequences of the massive changes in the global energy scene have been utterly devastating.

The resolution of these global problems will be a very slow and painful process. Initial efforts must be concentrated in rural areas to improve the basic living environment and agricultural productivity, which, eventually will mitigate the exodus to urban slums - the most regressive of all the happenings in the developing countries of the world. This initial effort will require a phenomenal increase in the judicious use of energy in the rural areas (General Electric Company et al, 1963).

Most of the developing countries are poor in conventional fossil fuel resources and have to import them at the expense of their meager foreign exchange reserves. As such, solutions requiring increased consumption of fossil fuels can only make the situation worse. Introduction of nuclear technology on a large scale around the world has many ramifications and raises many unanswered questions regarding radiation safety, unauthorized recycling of spent fuel, etc. During the last 5 years, there has been a dramatic increase in interest in the utilization of renewable energy sources in the non-OPEC developing countries of the world. However, the absence (with some notable exceptions) of large and effective infra-structures dedicated to generating technological changes has posed a temporary barrier to the introduction of energy in rural areas.

Various nations of the Third World have started research and development programs for harnessing renewable energy sources like sun, wind, etc., using appropriate energy technologies. The main idea is to build energy farms for rural areas where the power from the national grid is not easily available.

These farms will make the villages at least partly self-sufficient in their energy needs and the advantages the villages accrue from this self-sufficiency are numerous. In countries like India where 80% of the population lives in villages, the upliftment of the rural scene is a strong indication of the nation's step towards progress. Recent studies conducted on the workings of rural energy farms have indicated that there are some areas of weakness which need to be given a new look. Firstly, the villagers have to be educated on the usage, care and maintenance of the equipment. This can enhance the lifetime of the equipment and also gives longer availability and trouble free service. The second point is the most important in the sense that the Rural Energy Management Committee (REMC), the hypothetical supervisory body, should have good information regarding the matching of resources/technologies with that of the village needs. This matching of needs is to be done in accordance with the priorities that the village may have, like meeting the daily basic living needs followed by agricultural and livestock needs, etc.

Using the newly developed Multiple Criteria Decision Making (MCDM) techniques such as Goal Programming, Multiobjective Linear Programming, Compromise Programming, etc., the analyst can model the rural energy scene to a certain degree of reality. Using this model, the REMC can match each resource with respective demands, subject to various goals and their priority ordering.

The current study views the above problem in an analytical fashion and tries to apply quantitative methods to search for a set of alternate solutions. This methodology is expected to reduce the entropy encountered by the REMC.

Statement of the Problem

This problem involves the matching of various renewable energy sources with that of various demands in a rural environment in a third world country.

In the hypothetical village, a rural energy farm is assumed to have facilities to generate biogas, bioalcohol, solar electricity, solar thermal energy, wind electricity and hydroelectricity. The rural demands are assumed to be only those required to satify the basic living needs viz. domestic (cooking, lighting, heating, and cooling) and community (lighting, heating, cooling, and communications).

It is required to aid the Rural Energy Management Committee (decision maker) by presenting solutions regarding the demand-resource allocation as and when required. That is, if the REMC has a preset goal to be achieved subject to various resources and demands and the goals are varying in nature, it is required to present an analytical solution methodology.

The primary objective of this study is to develop a general purpose rural energy management model which can serve as an efficient decision making aid. As can be seen in Fig. 1, the problem situation is an ideal case for the application of mathematical programming techniques and decision making aids with multiple criteria decision making approaches.

Significance of the Model

In the rural energy management model developed for this study, resources represent inputs and demands represent outputs. It is the purpose of the model to match them according to a set of priorities or goals. The renewable energy sources considered for the study are

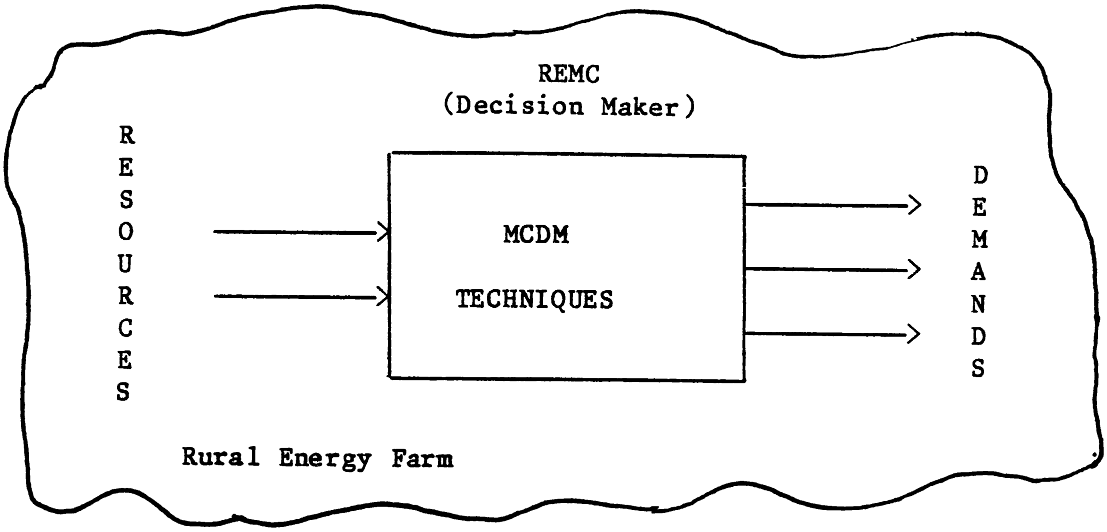

Figure 1. Rural Energy Scenario

electricity from solar cell arrays, solar thermal energy, biomass conversion to biogas and electricity, electricity from wind turbines, and hydro electricity. The availability of any one of these resources is highly stochastic in nature. For instance the wind speed can change dramatically over a few minutes, cloud cover can engulf a bright sun within the course of a sunny day or the water level in the stream supplying the hydro electricity may fluctuate widely on a seasonal basis.

On the other side, the demands also change widely depending on the season and the requirements. Added to this are the changing priorities regarding the matching of resources and demands. In such situations, the decision maker has to evaluate more than one scenario to arrive at a set of alternate solutions before he finally comes up with a single acceptable solution. In such circumstances, the MCDM techniques come in handy.

Limitations of the Model

The study of rural energy management and the resulting model generation limited by various factors. They are (1) the non-availability of pertinent data regarding the size, efficiency and capacity of community energy farms, as well as techno-economic factors and (2) very little published literature available on the mathematical modeling and analysis aspects regarding rural energy farms in the Third World.

The model is limited in its current study by considering only a certain number of energy resources and demands besides a small set of priorities. Although a wide choice of resources, demands, and goals exist, to ensure clarity, only a few are included in this study. The model is not made complex by considering the storage aspect that is inherent in any resource-demand problem. Similarly the stochastic nature of the energy environment has not been included in the current study. The shortage of pertinent data and literature were also limiting factors in thi research but however the data has been collected by extensive literature survey as well as personal interviews with local experts.

Though there are many mathematical modeling techniques available, this study is limited to only Linear Goal Programming. Even here the study is limited to Partitioning Algorithm (Arthur et al. 1980) and the one developed by Ignizio (1976).

Many assumptions were made wherever necessary in consultation with local experts and educated estimates were made to overcome the problem of non-availability of certain data.

Organization of the Research

The entire research problem was divided into 3 stages. Stage 1 deals with the definition of problem, literature survey, and collection of pertinent data. This includes a series of personal interviews with local experts. Stage 2 deals with the search for various alternatives for solving the problem, identification of one solution technique, and subsequent model building, validation, and testing. Stage 3 involves the analysis of data obtained from the model, interpretation of results, conclusions, further research areas, and recommendations.

Definition of Terms Used in MCDM

The following terms are adapted from Zeleny (1982):

Attributes: This term refers to descriptions of objective reality. They may be actual objective traits, or they may be subjectively assigned traits, but they are perceived as characteristics of objects in the "outside" world.

Example: Renewable energy

Objectives: Objectives are closely identifiable with a decision maker's needs and desires, they represent directions of improvement (Eg: maximizing or minimizing) or preference along individual attributes or complexes of attributes.

Example: Maximize profits

Goals: They are fully identifiable with a decision maker's needs and desires. They are **a priori** determined, specific values or levels defined in terms of either attributes or objectives.

Example: Achieving a profit of at least $1000

Criteria: Criteria are measures, rules, and standards that guide decision making. That is, criteria are all those attributes, objectives, or goals have been judged relevant in a given decision situation by a particular decision maker.

Multiple Criteria Decision Making (MCDM): It indicates a concern with the general claims of problems that involve multiple attributes, objectives, and goals.

Multiobjective Programming: It deals mostly with different objectives and does not attempt to regard them as inputs for forming higher level objective functions.

CHAPTER II

REVIEW OF LITERATURE

For the nearly two-thirds of humanity who live in the "Third World" countries in the continents of Asia, Africa, and South America, prospects for a 'full and happy life' today is are far away as ever. Troubled with population explosions, urban migrations, and perpetual penury, the prospect of hope is very bleak for them now. Their respective governments have been planning and executing various developmental activities. Most of them are aimed at strengthening the rural base by improving living conditions, increasing agricultural productivity, improving literacy, increasing the use of renewable energy sources, etc.

Ramakumar and Hughes (1981) in their study on energy sources and rural development found that educational institutions can play a vital role in the upliftment of rural areas. The success of systems introduced to harness renewable energy sources in the rural areas of developing countries will primarily depend upon two basic factors.

1. Development and availability of appropriate technologies, hardware, and design methodologies to match the resources to the needs.

2. Buildup of educational services and associated infrastructure necessary to properly maintain and utilize the systems that are already installed.

The current research problem is a direct outcome of factor 1 which says that the various resources that are available have to be matched with the demands. A good number of techniques are avaiable for converting renewable energy sources to directly usable forms such as electricity, thermal energy etc. But the problem in a rural energy farm is the matching of various energy types to the different village needs.

Ramakumar (1977) has investigated the techniacl and socio-economic aspects of solar energy and rural development in developing countries. In this paper he has given valuable estimates regarding the rural energy requirements to be taken as a guide to compute minimum energy requirements for various applications.

Ramakumar (1983) discusses small scale decentralized integrated renewable energy system for villages. Fig. 2 shows the overall schmatic of an integrated renewable energy system. In this approach, each of the energy conversion devices is dedicated to meet a specific need. While a wind energy system may be pumping water for storage in an overhead reservoir, photovoltaic arrays may be charging a small battery bank used to power educational and communications equipment, and a biogas facility might be supplying biogas for cooking. Thus the only "integration" that accrues is the integration of benefits at the user's end. After all, the objective is to supply the basic energy needs of remote rural communities in the most economic and appropriate manner.

There is very little literature available on the application of various techniques to solve the above problem. An attempt is made here to aid the decision maker (Rural Energy Management Committee) by using some of the MCDM techniques like Goal Programming and Group Decision-making.

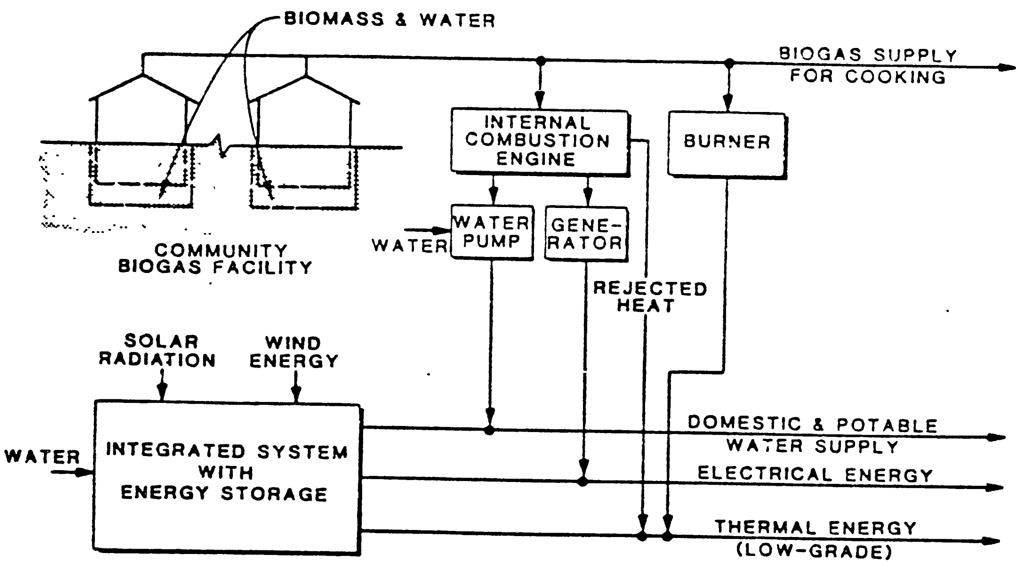

Figure 2. Schematic of an Integrated Renewable Energy System

The team of A. Charnes and W. W. Cooper (1961) is generally credited with the development of the goal programming method and has played a key role in introducing the method to industrial problems. This work found extensions into many areas, including accounting for control by Ijiri (1965). Lee (1972) has dealt in detail about various basic concepts and has applied goal programming to problems in production planning, financial decisions, academic planning, and medical care, to mention a few. Kendall, and Lee (1980) have applied the technique to the design of the operating policy of a blood bank. Ignizio (1976) deals with general formulation to linear integer, and nonlinear forms along with a computer code with cutting-plane option. Zeleny (1982) has a very detailed and expository articles on all the important MCDM techniques and has an extensive bibliography at the end. The process of decision making and its stages are also well explained here. Goicoechea et al; (1982) have very carefully analyzed and presented various applications of multiobjective decisions analysis for engineering and business. They trace the historical perspectives of multiobjective decision analysis to Harvard Water Program and various other early projects. The book contains ELECTRE computer program for handling multiobjective decision problems.

CHAPTER III

METHODS AND PROCEDURES

Introduction

In today's modern society, a multitude of complex resource - allocation problems are creating a difficult dichotomy on the part of planners and policy makers. In such problems there exists a need to formulate goals, develop alternative plans, and design criteria to be used in the selection of a plan. Once broad goals have been stated the need exists to cast these into detailed objectives and alternative plans must be designed to meet those objectives. In addition, measures of effectiveness or criteria must be formulated to evaluate and compare the performance of each plan.

Multiple Criteria Decision Making Techniques

Since the advent of operations research as a scientific approach to decision making, a variety of mathematical tools have been developed and applied to problems in engineering, business, government, economics, and the natural and social sciences. Decision making problem involves search for alternative solutions. To search for those alternative solutions, an array of systematic procedures or mathematical frameworks have been developed as evidenced by the substantial availability of text books, journal articles, and other published literature on linear programming, inventory control, dynamic programming, Bayesian inferences, and simulation techniques. These and many other techniques share a common feature: the formulation of a single criterion or objective function, and the optimization of that objective function subject to a set of prescribed constraints. As such, a large number of problems can be considered where it is of interest to do one of the following: maximize profits, maximize flow output, minimize costs, and so on.

In the last two decades, however, there has been an increased awareness for the need to identify and consider simultaneously several criteria in the analysis and solution of some problems. The current research problem deals with the matching of several energy resources to different demands in a village. Here, the decision maker will look into various goals like (i) meeting the daily demands, (ii) meeting the budget constraints, (iii) generating within the maximum and minimum limits, etc. For the decision maker all of them are important but with different priorities. Multiple goals of this nature can be solved by MCDM techniques like Linear Goal Programming.

Multiple criteria decision making techniques are Linear Multiobjective Programming, Goal Programming, Compromise Programming and Multiattribute Utility Theory (MAUT). Linear Multiobjective Programming deals with multiple objective functions for the same set of constraints by identifying all nondominated solutions. This is done by the Multicriterion Simplex Method (MSM) which is designed to locate nondominated corner points. Computer codes and advanced formulations can be found in Zeleny (1974,1975).

Compromise programming can be viewed as "an effort to approach or emulate the ideal solution as closely as possible" (Zeleny, 1982, pp.

315). In a technical sense, one measures the "goodness" of any compromise by its closeness to the ideal. Zeleny's (1973) introduction of the concept of "compromise solutions" was the seminal work in the area.

Multiattribute Utility Theory (MAUT) evaluates utility functions intended to accurately express a decision maker's outcome preferences in terms of multiple attributes (Zeleny, 1982, pp. 409). The main purpose of MAUT is to establish a super objective, to "maximize the overall utility" and one of the most important tasks is to verify the independence of attributes. Keeney and Raiffa (1976) contains an excellent overview of MAUT.

Of the above four types, Goal Programming was selected as an appropriate technique to find the solution to the current problem. The Rural Energy Management Committee is the decision maker in the problem, and it has to evaluate the alternative energy sources against the possible demands which are prioritized. Linear goal programming has precisely the same goal priority structure and is ideally suited. The decision maker can change the priority ordering and take suitable decisions based on the results.

Goal Programming

Introduction

Lee (1972) has summarized the history of goal programming as follows. The origins of mathematical programming techniques go far back in mathematical history to the theories of linear and nonlinear equations and inequalities. However, George B. Dantzig is recognized as the father of linear programming. Dantzig's work was primarily in the search of techniques to solve logistics problems for miltary planning when he was employed by the United States Air Force in Washington, D.C., in the early 1940's. His research was encouraged by other scholars who were working on the same general subject: J. von Neumann, L. Hurwicz, and T.C. Koopmans. The original name given to the technique was "Programming of Interdependent Activities in a Linear Structure," and that was later shortened to "Linear Programming."

From 1948 on, many scholars have joined Dantzig in refining the technique and exploring the application potential of linear programming. However, the team of A. Charnes and W.W. Cooper has played a key role in introducing and applying the technique to industrial problems. They have published excellent expository journal articles as well as textbooks on linear programming.

As mentioned in the earlier chapter, Charnes and Cooper (1961) are attributed the development of the concepts behind goal programming. They provided the name of goal programming in their well-known book on linear programming published in 1961. The concept of goal programming first emerged as an issue for unsolvable linear programming problems. Charnes and Cooper explain:

> . . . Closely related to the analysis of contradictions in unsolvable problems is the issue which will be called "goal attainment." Management sometimes sets such goals, even when they are unattainable within the limits of available resources, for a variety of reasons. For example, such goals may be established to provide incentives or to judge accomplishments, or they may be used as a safeguard to ensure that long-run considerations are not obliterated by immediately attainable objectives, etc. Any constraint incorporated in the functional will be called a "goal." Whether goals are attainable or not, an objective may then be stated in which optimization gives a result which comes "as close as possible" to the indicated goals.(p.16)

The primary difficulty with linear programming is the unidimensionality of the objective function and the infeasibility. To overcome this difficulty, efforts have been made to convert various goals, costs, or value means into one criterion, namely utility. If this process could be effectively performed, the limitation of linear programming would undoubtedly be reduced. However, exact measurement of utility is not a simple matter. Hence, decision making through linear programming via utility function is only feasible in a theoretical sense.

Goal programming is a modification and extension of linear programming. The goal programming approach allows a simultaneous solution of a system of complex objectives rather than a single objective. In other words, goal programming is a technique that is capable of handling decision problems that deal with a single goal with multiple subgoals. In addition, the objective function of a goal programming model may be composed of non-homogeneous units of means, such as dollars, kWh of energy, rather than one type of unit.

Often multiple goals of management are in conflict or achievable only at the expense of other goals. Furthermore, these goals are incommensurable. Thus, the solution of the problem requires an establishment of a hierarchy of importance among these incompatible goals so that the low-order goals are considered only after the higher-order goals are satisfied or have reached the point beyond which no further improvements are desired. If one can provide an ordinal ranking of goals in terms of their contribution or importance and all goal constraints are linear relationship, the problem can be solved by goal programming. In goal programming, instead of trying to maximize or minimize the objective function directly as in linear programming, deviations between goals and what can be achieved within the given set of constraints are to be minimized.

In the linear-programming solution procedure, the values of the choice variables dictated by the objective function criterion tend to "drive" the values of the slack variables. Unlike linear programming, the goal-programming objective function does not contain choice variables. Instead, it contains the deviational variables that represent each type of goal or subgoal. The deviational variable is represented in two dimensions in the objective function, a positive and a negative deviation from each subgoal and/or constraint. Then, the objective function becomes the minimization of these deviations, based on the relative importance or priority assigned to them. The objective function, in effect, tends to cause the deviational variables to "drive" the values of the choice variables. It is, of course, possible to include the choice variables in the objective function if that is simpler or desirable in the decision problem.

The solution of a linear program is limited by quantification. Unless one can accurately quantify the relationship of the variable or cardinal numbers, the solution is only as good as the inputs. The distinguishing characteristic of goal programming is that it allows for an ordinary solution. The decision maker is usually required to determine the priority of the desired attainment of each goal or subgoal and rank them in ordinal sequence for decision analysis. The true value of goal programming is, therefore, the solution of problems involving multiple, conflicting goals according to the decision maker's priority structure.

Mathematical Formulation

The general linear goal programming problem with preemptive weights can be written as

$$\text{Minimize } Z = \sum_{i=1}^{b} P_i \; (W_i^- d_i^- + W_i^+ d_i^+)$$

$$\text{Subject to} \quad \chi \in X$$

$$F_i(\chi) - d_i^+ + d_i^- = T_i$$

$$d_i^+, d_i^- \geq 0 \qquad i = 1, 2, \ldots, p.$$

Where Z = objective function

P = priority factor where $P_i \ggg P_{i+1}$ which means that goal i has absolute priority over goal i+1

X = feasible region

χ = choice vector

$F_i(\chi)$ = ith objective function

T_i = target or right-hand side of goal i

W_i = weight of goal i

d_i^+ = positive deviation of goal i

d_i^- = negative deviation of goal i

Ranking and Weighting of Multiple Goals

Goals of the decision maker may simply be meeting a certain set of constraints. When all constraints and goals are completely identified in the model, the decision maker must analyze each goal in terms of whether over or under achievement of the goal is satisfactory or not. Based on this analysis he can analyze deviational variables to the regular and/or goal constraints. If overachievement is acceptable, positive deviation from the goal can be eliminated from the objective function. On the other hand, if underachievement of a certain goal is satisfactory, negative deviation would not be included in the objective function. If the exact achievement of the goal is desired, both negative and positive deviations must be represented in the objective function.

In order to achieve the ordinal solution, that is to achieve the goals according to their importance, negative and/or positive deviations about the goal must be ranked according to the "pre-emptive" priority factors. In this way, the lower order goals are considered only after higher order goals are achieved as desired.

Limitations

Some limitations are inherent to all quantitative tools, and some are attributable to the particular characteristics of individual techniques. Some of the limitations of goal programming that are attributable to the underlying assumptions of linear mathematical programming techniques are (i) proportionality, (ii) additivity, (iii) divisibility, and (iv) deterministic nature.

Partitioning Algorithm

In the partitioning algorithm the ordinal priority factor of the goal programming objective function can be used to partition the goal constraints of the problem, allowing a sequence of smaller subproblems to be solved in order to find a solution to the original problem.

The general model for the linear goal programming can be stated as

$$\text{minimize} \quad z = \sum_{k=1}^{p} P_k \sum_{i=1}^{m} (w_{ki}^- d_i^- + w_{ki}^+ d_i^+) \tag{1}$$

subject to

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &= f_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &= f_2 \\ \vdots \qquad\qquad\qquad \vdots \qquad & \quad \vdots \\ a_{l1}x_1 + a_{l2}x_2 + \cdots + a_{ln}x_n &= f_l \end{aligned} \tag{2}$$

$$\begin{aligned} e_{11}x_1 + e_{12}x_2 + \cdots + e_{1n}x_n + d_1^- - d_1^+ &= b_1 \\ e_{21}x_1 + e_{22}x_2 + \cdots + e_{2n}x_n + d_2^- - d_2^+ &= b_2 \\ \vdots \qquad\qquad\qquad \vdots \qquad\qquad & \quad \vdots \\ e_{m1}x_1 + e_{m2}x_2 + \cdots + e_{mn}x_n + d_m^- - d_m^+ &= b_m \end{aligned} \tag{3}$$

$$x_j \geq 0, \quad j = 1, 2, \ldots, n; \quad d_i^-, d_i^+ \geq 0, \quad i = 1, 2, \ldots, m, \tag{4}$$

where

- x_j — jth decision variable;
- a_{ij} — coefficient of x_j in the ith real constraint;
- f_i — required level for the ith real constraint;
- b_i — target for goal i;
- e_{ij} — coefficient of x_j in goal i;
- d_i^- — underachievement of goal i;
- d_i^+ — overachievement of goal i;
- p_k — kth ordinal priority factor ($P_k >>> P_{k+1}$);
- w_{ki}^- — weight assigned to d_i^- at priority P_k,
- w_{ki}^+ — weight assigned to d_i^+ at priority P_k.

The objective function (1) attempts to minimize the weighted sum of the deviational variables (d_i^- and d_i^+) at each priority. The set of constraints (2) describes the real constraints which must hold at any feasible solution; the set of goal constraints (3) relates the decision variables to the targets of the goals; and the conditions (4) give the standard nonnegativity restrictions on all variables.

Partitioning Procedure

The partitioning of the GP problem is accomplished by observing that for any goal constraint i one and only one of three things may occur:

(1) only d_i^- appears in the objective function,

(2) only d_i^+ appears in the objective function,

(3) both d_i^- and d_i^+ appear in the objective function.

In case (]) the partition would assign goal constraint i to the priority factor associated with d_i^-; in case (2) constraint i would be assigned to the priority factor associated with d_i^+; while in case (3) the partition would determine the higher order priority factor (in terms of the ordinal ranking) associated with either d_i^- or d_i^+ and constraint i would be assigned to that priority.

Let

$$C(k) = \{i \mid \text{constraint } i \text{ is assigned to priority factor } P_k\}, \qquad k = 1, \ldots, p.$$

Also, let k_i, denote the priority assigned to the deviational variables in constraint i. Then

$$k_i^- = \begin{cases} \text{priority } k \ni w_{ki}^- > 0, & \text{if any,} \\ +\infty, & \text{otherwise;} \end{cases}$$

$$k_i^+ = \begin{cases} \text{priority } k \ni w_{ki}^+ > 0, & \text{if any,} \\ +\infty, & \text{otherwise.} \end{cases}$$

Furthermore, define $k_i^* = \min(k_i^-, k_i^+)$. Then the partition can be represented by the mapping

$$P : \{1, 2, \ldots, m\} \rightarrow \bigcup_{k=1}^{p} C(k)$$

where

$$P(i) = C(k_i^*).$$

Algorithm

Many GP problems involve real constraints (where no deviations are allowed) along with the usual goal constraints. Since it is necessary to find a basic feasible solution to the real constraints before optimizing the goals, the partitioning algorithm performs a phase I simplex procedure on the real constraints before considering the goal constraints assigned to priority P_1.

The partitioning algorithm then solves subproblem S_1. The optimal tableau for this subproblem is examined for alternative optimal solutions. If none exist, it is not possible to optimize the goals of the lower priorities $P_2, P_3, \ldots, P_p$ (this is a direct consequence of the linear dependence between each pair of deviations, d_i^- and d_i^+). The algorithm substitutes the values of the decision variables $x_1, x_2, \ldots, x_n$ in the goal constraints assigned to $P_2, P_3, \ldots, P_p$ and calculates their levels of achievement. If alternative optimal solutions do exist, the next set of goal constraints C(2) (those assigned to priority P_2) and the corresponding terms in the objective function are added to S_1. At this time, the elimination procedure is used to delete all the nonbasic columns with a positive relative cost value c_js, and the optimization resumes. The algorithm terminates when a unique optimal solution is found to one of the subproblems or when all priorities have been included and optimized. A flowchart of the partitioning algorithm is given in Figure 4.

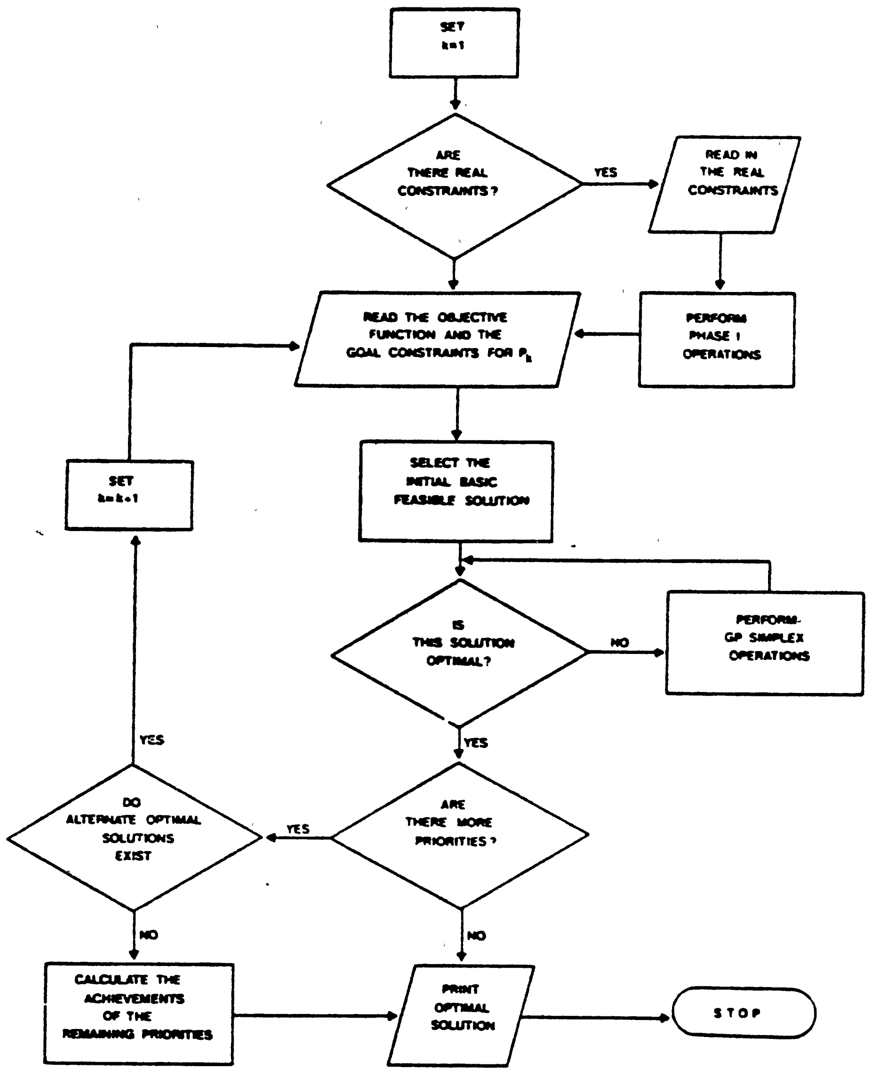

Figure 4. Flowchart of the Partitioning Algorithm

Model Description

In the current research work, a scenario is developed of a village in a Third World country which is remote from any national power grid. This village is assumed to contain 200 families of 5 members each (1000 persons total). Their energy demands are classified as (i) basic living needs (domestic and community), (ii) agricultural and livestock needs and (iii) industrial needs. However, for the sake of reducing the size of the problem only the basic living needs viz. domestic and community are taken into account.

To match these needs, the village is assumed to have a rural energy farm to harness the renewable energy sources (Fig. 3). This integrated energy farm works on a community basis. The entire village will contribute to it and share the energy. The various technologies used to harness the energy sources are (i) biomass conversion to biogas and bio-alcohol, (ii) conversion of this bio-alcohol through an internal combustion engine coupled to a generator into electricity, (iii) solar cell arrays to generate electricity, (iv) solar dish concentrators to collect thermal energy, (v) wind turbines to generate electricity, and vi) mini-hydro electric station to generate hydro electricity.

Estimates of rural energy consumption and needs vary widely (Reddy et al.1977; Smil, 1979). While some of this is due to their country-specific and site-specific nature, the primary reasons for the discrepancies are (i) assumptions made regarding efficiency of use, and (ii) the inclusion or exclusion of human labor, animal work, transportation needs, irrigation needs, and energy required for the small scale rural industries. Reasonably consistent figures can be obtained by considering only the useful (output) energy (excluding the

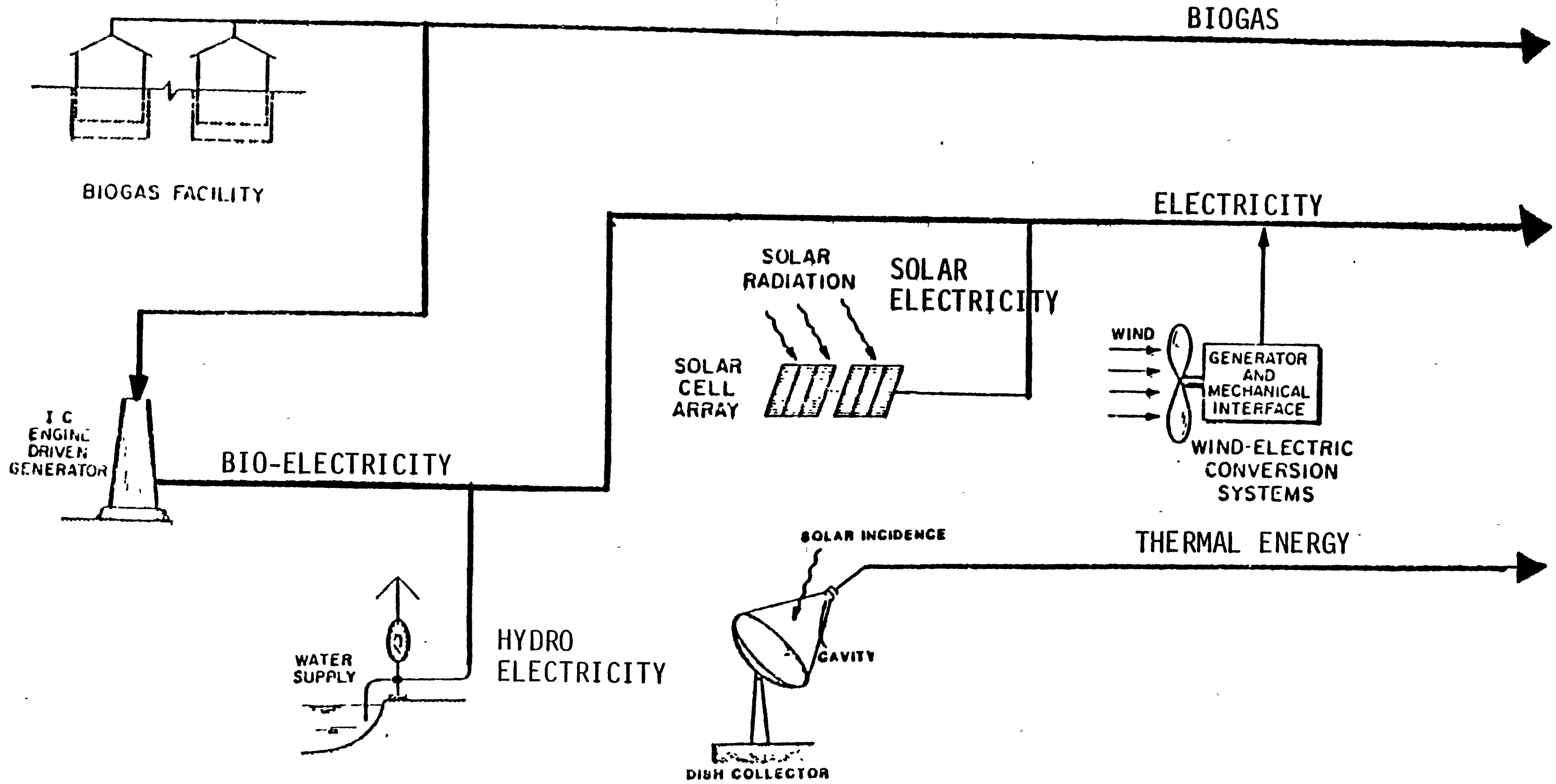

Figure 3. Schematic of a Rural Energy Farm to Harness Renewable Energy Sources

efficiency factor, which depends on the fuel and the mode of use) and by categorizing the needs.

Both domestic and community environments have been included in computing the energy required to improve the basic living environment. In the domestic sector, cooking, lighting, heating, and cooling needs are considered. In the community sector street lighting, heating, cooling, and educational communication needs are considered.

Table I gives a list of all the resources, demands, and decision variables. These variables represent which demand is to be met by what different form of energy sources. It is assumed that the decision maker (REMC) has already established the likely resources for each of the demands.

Though the rural communities in the developing countries use very little electric energy, it is assumed that they are likely to use more in future as it is a very versatile and high grade energy form.

All the technologies used to derive the user-convenient energy form are assumed to be appropriate for a remote rural set-up. This means they have one or more of the following criteria as the main deciding factors (i) cheap and local availability, (ii) cost effectiveness and efficiency, (iii) reliability and high maintainability .

The biomass conversion units produce biogas and bio-alcohol. Biogas can be directly used for domestic cooking, heating, and lighting as well as community lighting and heating. The necessary inputs to the conversion units are usually available in agrarian societies where cattle are a part. The other product of the conversion units is bio-alcohol which can be used as a fuel to drive an internal combustion engine to generate electricity. This form of energy can be fed to the general bus

TABLE I

LIST OF DECISION VARIABLES

Demand \ Energy Form	Biomass Gas	Biomass Elect.	Solar Elect.	Solar Thermal	Wind Elect.	Hydro Elect.
Domestic						
Cooking	x_1	x_2	x_3	x_4	x_5	x_6
Lighting	x_7	x_8	x_9		x_{10}	x_{11}
Heating	x_{12}	x_{13}	x_{14}		x_{15}	x_{16}
Cooling		x_{17}	x_{18}		x_{19}	x_{20}
Community						
Lighting	x_{21}	x_{22}	x_{23}		x_{24}	x_{25}
Heating	x_{26}	x_{27}	x_{28}		x_{29}	x_{30}
Cooling		x_{31}	x_{32}		x_{33}	x_{34}
Communications		x_{35}	x_{36}		x_{37}	x_{38}

LEGEND: Elect. = Electricity

carrying electric energy. Solar cell array units will also feed the electric energy bus though the cost is somewhat prohibitive. Parabolic dish antennas collect solar radiation and can be used to cook food kept at their focal points. Wind energy can be transformed into a higher grade energy form like electricity by coupling a wind turbine to an electric generator. The problem with solar radiation and wind energies is that they are highly dependent upon seasons and are complementary. That is, when the sun shines bright in summer months, the winds are low and vice versa in the fall season. It is advantageous to have both types of energy plants for this reason. The mini hydro-electricity unit can be considered as a part of the total system to generate hydro electricity. It is assumed that the village has a small source of falling water whose potential energy can be used to turn a small water turbine connected to a generator. In cases where there is little or no running water, an overhead water tank can well do the job. But this requires pumping water into the tank which can be done by using the excess electricity (if available) to pump water into the tank. This can also be done by pumping water using a reciprocating pump driven by wind. All the above technologies have their own merits and demerits applicable in the current research. The cost of biogas used here is lowest ($0.05) followed by hydro-electricity ($0.08), bio electricity ($0.15), solar thermal ($0.18), wind electricity ($0.20), and solar electricity ($0.80). These costs are the per unit (kWh) costs and are used to calculate the total-expenditure. It is to be noted that the term "total expenditure" means only the energy costs and does not take into account all capital costs. A new dimension is added to the problem by incorporating an undesirability index. It means that for every form of energy, there is some amount of undesirability index attached, just as in the case of cost per kWh. The sum total of all such undesirability indice will add up to 1.0 as explained later under Data Collection.

The units for various energy forms is kilo Watt-hours (kWh) which is defined as 1000 Watts expended for 1 hour. These units are used wherever necessary in rest of the thesis.

Description of Goals

As mentioned in the problem statement, the decision maker (REMC) has to match the resources with the demands subject to a set of goals with a priority ordering. The goals considered for the model are (i) meet the daily demands, (ii) minimize the expenditure, (iii) minimize the undesirability index, (iv) minimize the overgeneration, and (v) minimize the undergeneration.

(i) Meet the Daily Demands. This goal means that the daily rural demands for domestic (cooking, lighting, heating, and cooling) and community (lighting, heating, cooling, and communications) are met. In other words, the goal constraint for each of the domestic and community demands should be greater than or equal to the desired level. That is, the positive deviations from the desired right hand side should be minimized in the objective function.

(ii) Minimize the Expenditure. This goal means that the total expenditure resulting from using various energy types calculated on a per unit basis should be minimized. The goal constraint in this case will be the sum total of the product of all the different types of energies and their respective costs per unit (kWh) should be less than or equal to some desired level. That is to say that the positive deviations from the desired right hand side needs to be minimized in the objective function.

(iii) Minimize the Undesirability Index. This goal means that the undesirability resulting from using various energy types should be minimized. The goal constraint in this case will be that the sum total of the product of all the different types of energies and their respective undesirability indices should be less than or equal to some desired level. In the objective function, the respective positive deviations from the desired right hand side are to be minimized.

(iv) Minimize the Overgeneration. This goal means that the total generation of various energy types should not exceed their respective maximum generation levels. The goal constraints for each of six different energy types have a desired right hand side signifying their maximum capacities. In the objective function, the positive deviations from this desired level are to be minimized.

(v) Minimize the Undergeneration. This goal means that the total generation of various energy types should be greater than or equal to their respective minimum generation levels. The goal constraints for each of the six energy types have a desired right hand side signifying their minimum capacities.

Data Collection

The pertinent energy data from the third world countries is not easily available. To overcome this problem extensive literature surveys and personal interviews with local experts were conducted and wherever necessary educated estimates were made.

Most of the basis for the following figures were taken from articles published by Dr. Ramakumar (1975, 1977, 1981, 1982) and personal interviews with him.

It is assumed that the hypothetical village consists of 200 families of 5 members each and all the calculations are kWh of energy/day. The demands considered were mainly two types, domestic and community, and the six renewable energy sources are (i) Biogas, (ii) Bio-electricity, (iii) Solar electricity, (iv) Solar thermal, (v) Wind electricity, and (vi) Hydro-électricity.

The domestic needs were limited to only four categories.

Cooking: Estimated at 1.0 kW for 2.5 hr a day per family of 5., distribution efficiency 70 percent.

$= 1.0 \times 2.5 \times 200 \times 0.7$

$= 350$ kWh

Lighting: Estimatd at 0.120 kW for 4 hr a day per family of 5., distribution efficiency 70 percent.

$= 0.120 \times 4 \times 200 \times 0.7$

$= 77.2$

$\simeq 75$ kWh

Heating: It is assumed that in a tropical climate there is no space heating and all the heating is used only to heat water for bathing purposes.

Estimated water consumption/head = 0.12 mtr^3/day

Say 50% of this water is for bathing

$= 0.05$ mtr^3/day/head

Say 50% of this water is to be heated

$= 0.03\ mtr^3/day/head$

Energy required to raise the temperature of this water through $20^{\circ}C$ with 60% efficiency

(1 calorie = 1.2×10^{-6} kWh)

$Q = M \times S \times (t_2 - t_1)$

$= 0.03 \times 10^6 \times 1 \times (20 - 0) \times 0.6 \times 1.2 \times 10^{-6}$

= 0.432 kWh/day/head

$\simeq$ 400 kWh

Cooling: It is assumed above 1/10th of the heating energy is required for cooling.

= 40 kWh.

The community needs were also limited to the following four categories:

Street Lighting: Estimated 50 lamps of 0.1 kW each for 4 hr per day; distribution efficiency 70 percent; for 250 people.

$= 50 \times 0.10 \times 4 \times 4 \times 0.70$

= 56 kWh

$\simeq$ 60 kWh

Heating: Estimated 12 heaters for 3 kW for 4 hr a day; distribution efficiency 70%.

$= 12 \times 3 \times 4 \times 0.7$

= 100.8 kWh

$\simeq$ 100 kWh

Cooling: Estimated to be 25% of heating

= 25 kWh

Communications: Estimated to be about 15 kWh

The resources are assumed to have upper and lower capacity limits termed as maximum generation and minimum generation respectively. Maximum generation capacity of any energy type is the maximum energy it can generate taking into account the conversion efficiencies as well as other applicable techno-economic factors. The minimum generation capacity is the bare minimum the plant has to generate to overcome set-up costs as well as other operational factors. For instance there will be a regular supply of biomass everyday which cannot be stored for long and has to be converted into usable energy form. This is also true for the hydro-electricity. But the other sources like solar radiation or wind are dependent upon the seasons and will not have any meaningful minimum generation capacity like the previous energy forms.

Table II lists all the resources as well as their minimum and maximum generation capacities (kWh). These figures were arrived at by the group decision process. The maximum and minimum levels are selected in such a way that the sum total of all the demands per day put together is less than the maximum level and greater than the minimum level.

Table II also gives the cost per kWh of energy. This cost has been arrived at by interviews with local experts. The figures shown may vary from country to country. However, care has been taken to maintain the relative cost ratios. These costs are used in the model to compute the total expenditure. It is to be noted that the term "total expenditure" only means the total cost of energy at the above rates per day.

The various capacities are arrived at by personal interviews with local experts. The minimum levels are set as 50% of the maximum levels.

TABLE II

LIST OF RESOURCES, DEMANDS AND OTHER INPUT DATA

RESOURCES

Energy Form	Generation Constraints Max (kWh)	Generation Constraints Min (kWh)	Cost/kWh ($)	Undesirability Index
Biomass				
Gas	1650	400	0.06	0.140
Elect.	800	240	0.15	0.204
Solar				
Elect.	100	0	0.80	0.215
Thermal	500	0	0.18	0.151
Wind				
Elect.	600	0	0.20	0.129
Hydro				
Elect.	1000	160	0.08	0.161

Elect. = Electricity
Hydro. = Hydro-Electricity

DEMANDS

Type	kWh (Minimum)
Domestic	
Cooking	350
Lighting	75
Heating	400
Cooling	40
Community	
Lighting	60
Heating	100
Cooling	25
Communication	15

The undesirability index is evaluated by the group decision making process. Hence, all the six different types of renewable energy sources are evaluated against ten criteria as shown in Table III. A value of 5 assigned to any energy type against any criteria is most desirable and a value of 1 vice-versa. Likewise all the energy types are given a number from 1 to 5 against each criteria. These numbers are arrived at by the group consensus process. The desirability (d) of each energy type is then computed as a fraction of the maximum possible value (=50). At this stage the undesirability can be computed as 1-d for each of the energy types. The undesirability index can be evaluated as a fraction of the total sum of the undesirabilities. The sum of the undesirability index of each energy type will add up to a maximum of 1.0.

Goal Programming Formulation

List of Decision Variables and Goals

x_1 = Domestic Cooking with Biogas

x_2 = Domestic Cooking with Bio-electricity

x_3 = Domestic Cooking with Solar Electricity

x_4 = Domestic Cooking with Solar Thermal

x_5 = Domestic Cooking with Wind Electricity

x_6 = Domestic Cooking with Hydro-electricity

x_7 = Domestic Lighting with Biogas

x_8 = Domestic Lighting with Bio-electricity

x_9 = Domestic Lighting with Solar Electricity

x_{10} = Domestic Lighting with Wind Electricity

x_{11} = Domestic Lighting with Hydro-electricity

TABLE III

UNDESIRABILITY INDEX EVALUATION

Criteria \ Alternatives	Bio Gas	Bio Elect.	Solar Elect.	Solar Ther.	Wind Elect.	Hydro Elect.
<u>Pollution</u>						
Water	3	3	5	5	4	2
Air	2	2	5	5	4	3
Noise	4	3	5	5	2	2
Availability	5	4	3	3	3	3
Maintainability	3	3	5	4	4	2
Reliability	4	3	4	4	3	5
Efficiency	4	2	2	3	3	5
Labor Intensity	5	5	2	3	3	3
Lost Effectiveness	4	3	2	2	2	5
Multipurposity	4	3	3	4	3	5
Column Sum (5 x 10 = 50 max)	37	31	36	38	30	35
Desirability = d = sum/50(max)	0.74	0.62	0.60	0.72	0.76	0.70
Undesirability = 1-d Row Sum (= 1.86)	0.26	0.38	0.40	0.28	0.24	0.30
Undesirability Index = 1-d/1.86	0.140	0.204	0.215	0.151	0.129	0.161

LEGEND: 5 most desirable
1 least desirable

x_{12} = Domestic Heating with Biogas

x_{13} = Domestic Heating with Bio-electricity

x_{14} = Domestic Heating with Solar Electricity

x_{15} = Domestic Heating with Wind Electricity

x_{16} = Domestic Heating with Hydro-electricity

x_{17} = Domestic Cooling with Bio-electricity

x_{18} = Domestic Cooling with Solar Electricity

x_{19} = Domestic Cooling with Wind Electricity

x_{20} = Domestic Cooling with Hydro-electricity

x_{21} = Community Lighting with Biogas

x_{22} = Community Lighting with Bio-electricity

x_{23} = Community Lighting with Solar Electricity

x_{24} = Community Lighting with Wind Electricity

x_{25} = Community Lighting with Hydro-electricity

x_{26} = Community Heating with Biogas

x_{27} = Community Heating with Bio-electricity

x_{28} = Community Heating with Solar Electricity

x_{29} = Community Heating with Wind Electricity

x_{30} = Community Heating with Hydro-electricity

x_{31} = Community Cooling with Bio-electricity

x_{32} = Community Cooling with Solar Electricity

x_{33} = Community Cooling with Wind Electricity

x_{34} = Community Cooling with Hydro-electricity

x_{35} = Community Communications with Bio-electricity

x_{36} = Community Communications with Solar Electricity

x_{37} = Community Communications with Wind Electricity

x_{38} = Community Communications with Hydro-electricity

The list of goals to be achieved is a follows:

(i) Meet the Daily Demands (kWh)

(ii) Minimize the Expenditure ($$)

(iii) Minimize the Undesirability Index

(iv) Minimize the Overgeneration (kWh)

(v) Minimize the Undergeneration (kWh)

The objective function has five priorities, one for each of the goals. These priorities can be changed according to the decision maker's requirements. To demostrate the model, the priorities are taken in the same order as above. In the first priority, the negative deviations from the goal of meeting the daily demands have to be minimized. In the second priority, the poisitive deviations from the goal of expenditure have to be minimized. In the third priority, the positive deviations from the goal of undesirability index have to be minimized. In the fourth priority, the positive deviations from the goal of overgeneration have to be minimized. In the fifth priority, the negative deviations from the goal of under generation have to be minimized.

Objective Function:

$$\text{Minimize } Z = P_1 \{d_1^- + d_2^- + d_3^- + d_4^- + d_5^- + d_6^- + d_7^- + d_8^-\}$$

$$+ P_2 \{d_9^+\}$$

$$+ P_3 \{d_{10}^+\}$$

$$+ P_4 \{d_{11}^+ + d_{12}^+ + d_{13}^+ + d_{14}^+ + d_{15}^+ + d_{16}^+\}$$

$$+ P_5 \{d_{17}^- + d_{18}^- + d_{19}^- + d_{20}^- + d_{21}^- + d_{22}^-\}$$

(i) Meet the Daily Demands (kWh)

Domestic

Cooking	$x_1 + x_2 + x_3 + x_4 + x_5 + x_6$	$+ d_1^- - d_1^+$	=	350 kWh
Lighting	$x_7 + x_8 + x_9 + x_{10} + x_{11}$	$+ d_2^- - d_2^+$	=	75 kWh
Heating	$x_{12} + x_{13} + x_{14} + x_{15} + x_{16}$	$+ d_3^- - d_3^+$	=	400 kWh
Cooling	$x_{17} + x_{18} + x_{19} + x_{20}$	$+ d_4^- - d_4^+$	=	40 kWh

Community

Lighting	$x_{21} + x_{22} + x_{23} + x_{24} + x_{25}$	$+ d_5^- - d_5^+$	=	60 kWh
Heating	$x_{26} + x_{27} + x_{28} + x_{29} + x_{30}$	$+ d_6^- - d_6^+$	=	100 kWh
Cooling	$x_{31} + x_{32} + x_{33} + x_{34}$	$+ d_7^- - d_7^+$	=	25 kWh
Communication	$x_{35} + x_{36} + x_{37} + x_{38}$	$+ d_8^- - d_8^+$	=	75 kWh

(ii) Minimize the Expenditure ($$)

$$0.06\{x_1 + x_7 + x_{12} + x_{21} + x_{26}\}$$

$$+ 0.15\{x_2 + x_8 + x_{13} + x_{17} + x_{22} + x_{27} + x_{31} + x_{35}\}$$

$$+ 0.80\{x_3 + x_9 + x_{14} + x_{18} + x_{23} + x_{28} + x_{32} + x_{36}\}$$

$$+ 0.18\{x_4\}$$

$$+ 0.20\{x_5 + x_{10} + x_{15} + x_{19} + x_{24} + x_{29} + x_{33} + x_{37}\}$$

$$+ 0.08\{x_6 + x_{11} + x_{16} + x_{20} + x_{25} + x_{30} + x_{34} + x_{38}\}$$

$$+ d_9^- - d_9^+ = \text{desired level}$$

(iii) Minimize the Undesirability Index

$$0.140\,\{x_1 + x_7 + x_{12} + x_{21} + x_{26}\}$$

$$+\,0.204\,\{x_2 + x_8 + x_{13} + x_{17} + x_{22} + x_{27} + x_{31} + x_{35}\}$$

$$+\,0.215\,\{x_3 + x_9 + x_{14} + x_{18} + x_{23} + x_{28} + x_{32} + x_{36}\}$$

$$+\,0.151\,\{x_4\}$$

$$+\,0.129\,\{x_5 + x_{10} + x_{15} + x_{19} + x_{24} + x_{29} + x_{33} + x_{37}\}$$

$$+\,0.161\,\{x_6 + x_{11} + x_{16} + x_{20} + x_{25} + x_{30} + x_{34} + x_{38}\}$$

$$+\,d_{10}^{-} - d_{10}^{+} = \text{desired level}$$

(iv) Minimize the Overgeneration (kWh)

Biogas

$$x_1 + x_7 + x_{12} + x_{21} + x_{26} + d_{11}^{-} - d_{11}^{+} = 2000 \text{ kWh}$$

Bio Elect.

$$x_2 + x_8 + x_{13} + x_{17} + x_{22} + x_{27} + x_{31} + x_{35} + d_{12}^{-} - d_{12}^{+} = 800 \text{ kWh}$$

Solar Elect.

$$x_3 + x_9 + x_{14} + x_{18} + x_{23} + x_{28} + x_{32} + x_{36} + d_{13}^{-} - d_{13}^{+} = 100 \text{ kWh}$$

Solar Thermal

$$x_4 + d_{14}^{-} - d_{14}^{+} = 500 \text{ kWh}$$

Wind Elect.

$$x_5 + x_{10} + x_{15} + x_{19} + x_{24} + x_{29} + x_{33} + x_{37} + d_{15}^{-} - d_{15}^{+} = 600 \text{ kWh}$$

Hydro Elect.

$$x_6 + x_{11} + x_{16} + x_{20} + x_{25} + x_{30} + x_{34} + x_{38} + d_{16}^{-} - d_{16}^{+} = 1000 \text{ kWh}$$

(v) Minimize the Undergeneration (kWh)

Biogas

$$x_1 + x_7 + x_{12} + x_{21} + x_{26} + d_{17}^- - d_{17}^+ = 400 \text{ kWh}$$

Bio Elect.

$$x_2 + x_8 + x_{13} + x_{17} + x_{22} + x_{27} + x_{31} + x_{35} + d_{18}^- - d_{18}^+ = 240 \text{ kWh}$$

Solar Elect.

$$x_3 + x_9 + x_{14} + x_{18} + x_{23} + x_{28} + x_{32} + x_{36} + d_{19}^- - d_{19}^+ = 0 \text{ kWh}$$

Solar Thermal

$$x_4 + d_{20}^- - d_{20}^+ = 0 \text{ kWh}$$

Wind Elect.

$$x_5 + x_{10} + x_{15} + x_{19} + x_{24} + x_{29} + x_{33} + x_{37} + d_{21}^- - d_{21}^+ = 0 \text{ kWh}$$

Hydro Elect.

$$x_6 + x_{11} + x_{16} + x_{20} + x_{25} + x_{30} + x_{34} + x_{38} + d_{22}^- - d_{22}^+ = 160 \text{ kWh}$$

CHAPTER IV

RESULTS AND DISCUSSION

The goal programming model was run using Partitioning Algorithm Program for Goal programming. This program was originally developed by Arthur and Ravindran (1980) and is suitably modified for current research. The modifications include re-dimensioning of certain arrays to handle the current problem, adding double precision features, developing new input- output formats to enhance user-friendlines and readability.

Over 25 different combinations of priority orderings were generated to test the model. Nine such major combinations are tabulated in Table IV. It can be seen from this table that for the trial #1, the total expenditure is $65.50 to meet all the demands fully and the undesirability index is 150.78 . The overgeneration goal of 0 kWh is met but the system has not met the undergeneration goal and 320 kWh of under generation is observed. These amounts are over the desired levels.

In trial #2 the undesirability goal has been placed as second priority and expenditure goal as third. It is very interesting to observe that the expenditure went up by about 225% to $213 and the undesirability index reduced by 9% (137.38). But this resulted in over generation by 465 kWh and further drop in the under generation levels. It can be seen from the respective output that all the demands

TABLE IV

SUMMARY OF SELECTED RESULTS

Trial #	Data Set Name	Priority Ordering	GOAL ACHIEVEMENT				
			1	2	3	4	5
1.	U12770A.F1.DATA	A - B - C - D - E	0.0	65.50	150.78	0.00	320.0
2.	U12770A.F2.DATA	A - C - B - D - E	0.0	137.38	213.00	465.00	800.0
3.	U12770A.F3.DATA	A - B - D - C - E	0.0	65.50	0.00	150.78	320.0
4.	U12770A.F4.DATA	A - D - B - C - E	0.0	0.00	65.50	150.78	320.0
5.	U12770A.F5.DATA	A - C - D - E - B	0.0	137.38	465.00	800.00	213.0
6.	U12770A.F6.DATA	B - C - A - D - E	0.0	0.00	1065.00	0.00	800.0
7.	U12770A.F7.DATA	C - B - A - D - E	0.0	0.00	1065.00	0.00	800.0
8.	U12770A.F8.DATA	D - B - C - A - E	0.0	0.00	0.00	1065.00	800.0
9.	U12770A.F9.DATA	E - B - C - A - D	0.0	72.80	130.72	265.00	0.0

LEGEND:
A - Meet the daily demands (kWh)
B - Minimize the expenditure ($$)
C - Minimize the undesirability index
D - Minimize the overgeneration (kWh)
E - Minimize the undergeneration (kWh)

(0.129). This resulted in exceeding its maximum capacity as well as in under utilizing the other energy types. This under utilization amounts to 800 kWh.

From trial #3, it is seen that by interchanging undesirability index and overgeneration goals effectively the same solution is obtained as of trial #1.

From trial #4 it is seen that interchanging of B, C, E, D did not change the solution from that of trail #1.

Trial #5 has the undesirability in second priority and expenditure in the fifth. The goal achievements are seen to be the same as that of trial #2.

Trial #6 & 7 have the expenditure and undesirability as the top priorities. It can be seen that while meeting the top two priorities, the third priority daily demands was not met at all. That is, the model made the expenditure goal zero thus not producing or meeting the demands.

Trial #8 has the overgeneration goal as top priority and under generation as the last priority. But with expenditure as the second priority which the model has met, the daily demand goal was not met at all. This is evident from the figure of 1065 kWh of under attainment for that goal. The under attainment of undergeneration goal reflected from the figure 800 kWh.

Trial #9 has undergeneration goal as the top priority and overgeneration as the last priority. Here the expenditure was met at $72.80 and undesirability goal at 130.72. This resulted in a positive deviation of 265 KWh (1065 - 800) in meeting daily demands goal and there was no overgeneration.

Sensitivity Analyis

A detailed sensitivity analysis was done on priority ordering A-B-C-D-E (Trial #1) by fixing the expenditure goal at $65.50 and varying the desired undesirability index as shown in Table V. It can be seen from Fig. 5 that the attainment of undesirability index is linear with a negative slope.

In the second stage, the desired level of the expenditure goal is varied from $65.50 to $213.0, and the resulting positive deviations from the desired undergeneration were plotted as shown in Table VI. It can be seen from Fig. 6 that the relationship between the variables is non-linear and from $140.50 and beyond it is linear. In the linear part of the curve, any amount of increase in expenditure will not further decrease the positive deviations in the undergeneration goal and 188.33 kWh is the lowest or minimum level attainable.

Further sensitivity analysis was done on combination E-D-A-C-B where expenditure goal and undesirability index goal are in fourth and fifth priority levels. The desired level of expenditure was fixed at $0.0, and level of undesirability index was varied from 137.38 to 937.38. The results are tabulated as shown in Table VII. It can be seen from Fig. 7 that when the undesirability index was changed from 137.38 to 151.38, the positive deviations for expenditure goal dropped from $213 to $65.00; for overgeneration goal, from 465 kWh to 0 kWh; and for undergeneration goal, from 800 kWh to 320 kWh. The values remained unchanged when undesirability index was changed beyond 151.38. It is interesting to note that the region between 137.38 to 151.38 is very sensitive and small changes at that level can drastically reduce certain levels. This part of the curve can be used for trade-off analysis.

TABLE V

SENSITIVITY ANALYSIS - 1

Trial #	Data Set Name	Desired Undesirability Index	Attained Positive Deviations
1	U12770A.C1.DATA	137.38	13.40
2	U12770A.C2.DATA	139.38	11.40
3	U12770A.C3.DATA	141.38	9.50
4	U12770A.C4.DATA	143.38	7.40
5	U12770A.C5.DATA	145.38	5.40
6	U12770A.C6.DATA	147.38	3.40
7	U12770A.C7.DATA	149.38	1.40
8	U12770A.C8.DATA	150.78	0.00

Note: The desired level of expenditure goal is fixed at $65.50.

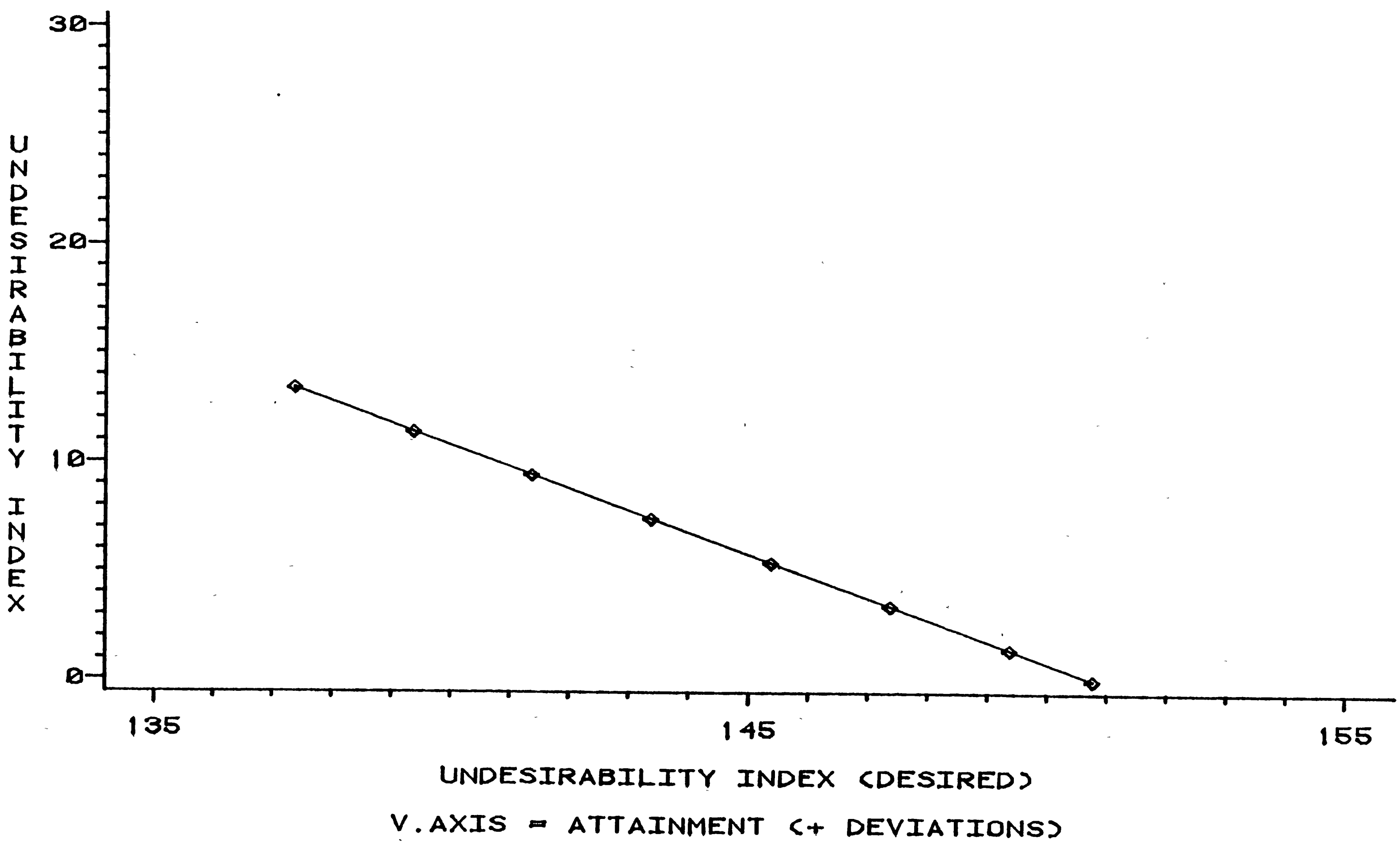

Figure 5. Sensitivity Analysis - 1

TABLE VI

SENSITIVITY ANALYSIS - 2

Trial #	Data Set Name	Desired Expenditure	Attained Under generation
1	U12770A.E1.DATA	$ 65.50	320.00 kWh
2	U12770A.E2.DATA	70.50	302.59
3	U12770A.E3.DATA	90.50	237.72
4	U12770A.E4.DATA	115.50	210.13
5	U12770A.E5.DATA	140.50	188.33
6	U12770A.E6.DATA	165.50	188.33
7	U12770A.E7.DATA	190.50	188.33
8	U12770A.E8.DATA	213.00	188.33

Note: The level of undesirability goal is fixed at 150.78

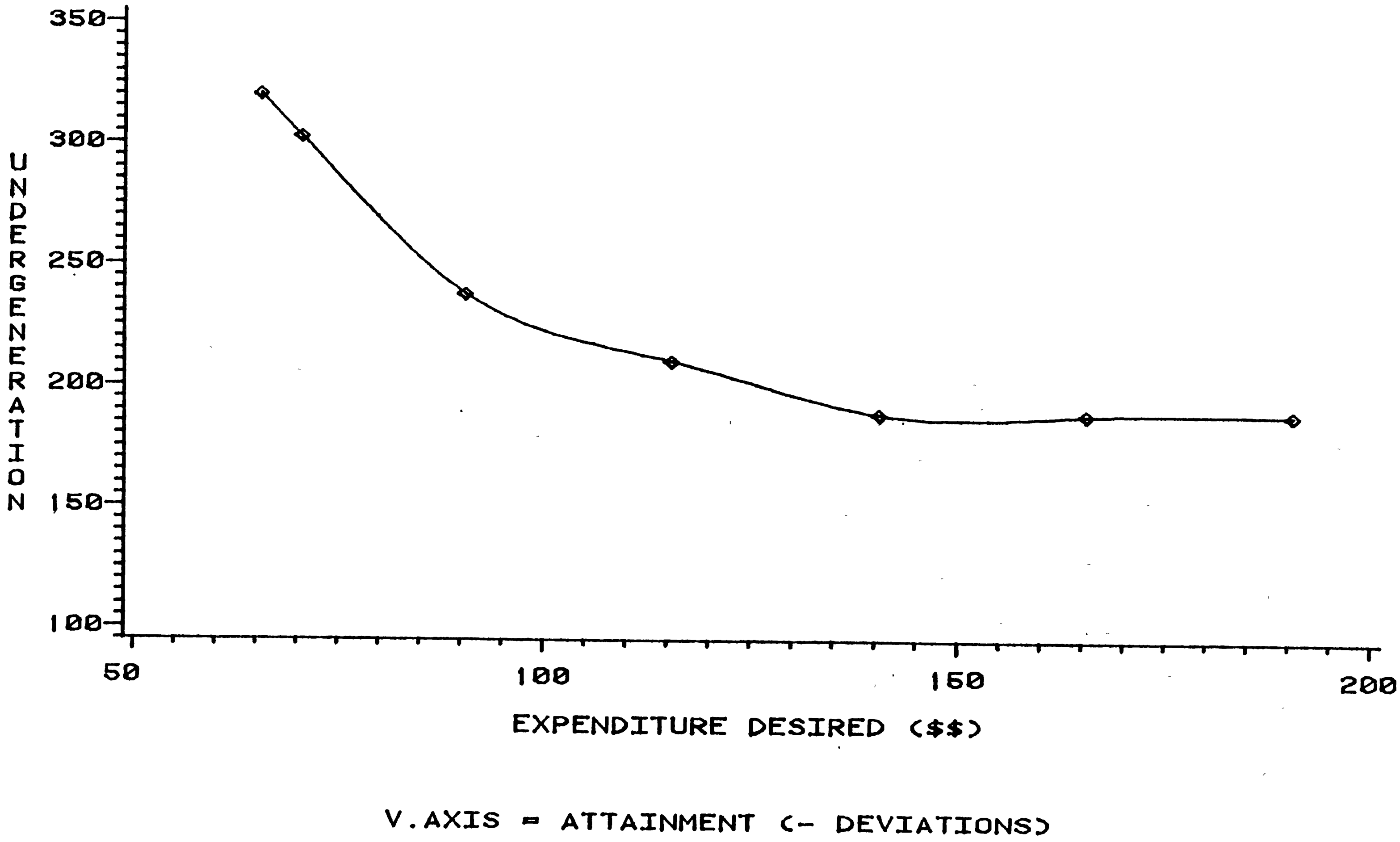

Figure 6. Sensitivity Analysis - 2

TABLE VII

SENSITIVITY ANALYSIS - 3

Trial		Desired		Attained			
#	Data Set Name	Expenditure ($$)	Undesirability Index	Undesirabi-lity Index	Expendi-ture($$)	Over gene-ration(kWh)	Under gene-ration(kWh)
1	U12770A.G1.DATA	0.00	000.00	137.38	213.00	465.00	800.00
2.	U12770A.G2.DATA	0.00	137.38	0.00	213.00	465.00	800.00
3.	U12770A.G3.DATA	0.00	138.38	0.00	200.34	374.55	709.55
4.	U12770A.G4.DATA	0.00	148.38	0.00	74.50	0.00	395.00
5.	U12770A.G5.DATA	0.00	149.38	0.00	70.75	0.00	363.75
6.	U12770A.G6.DATA	0.00	150.38	0.00	67.00	0.00	332.50
7.	U12770A.G7.DATA	0.00	151.38	0.00	65.00	0.00	320.00
8.	U12770A.G8.DATA	0.00	237.38	0.00	65.00	0.00	320.00
9.	U12770A.G9.DATA	0.00	937.38	0.00	65.00	0.00	320.00

Note: These runs were made with A-B-C-D-E combination.

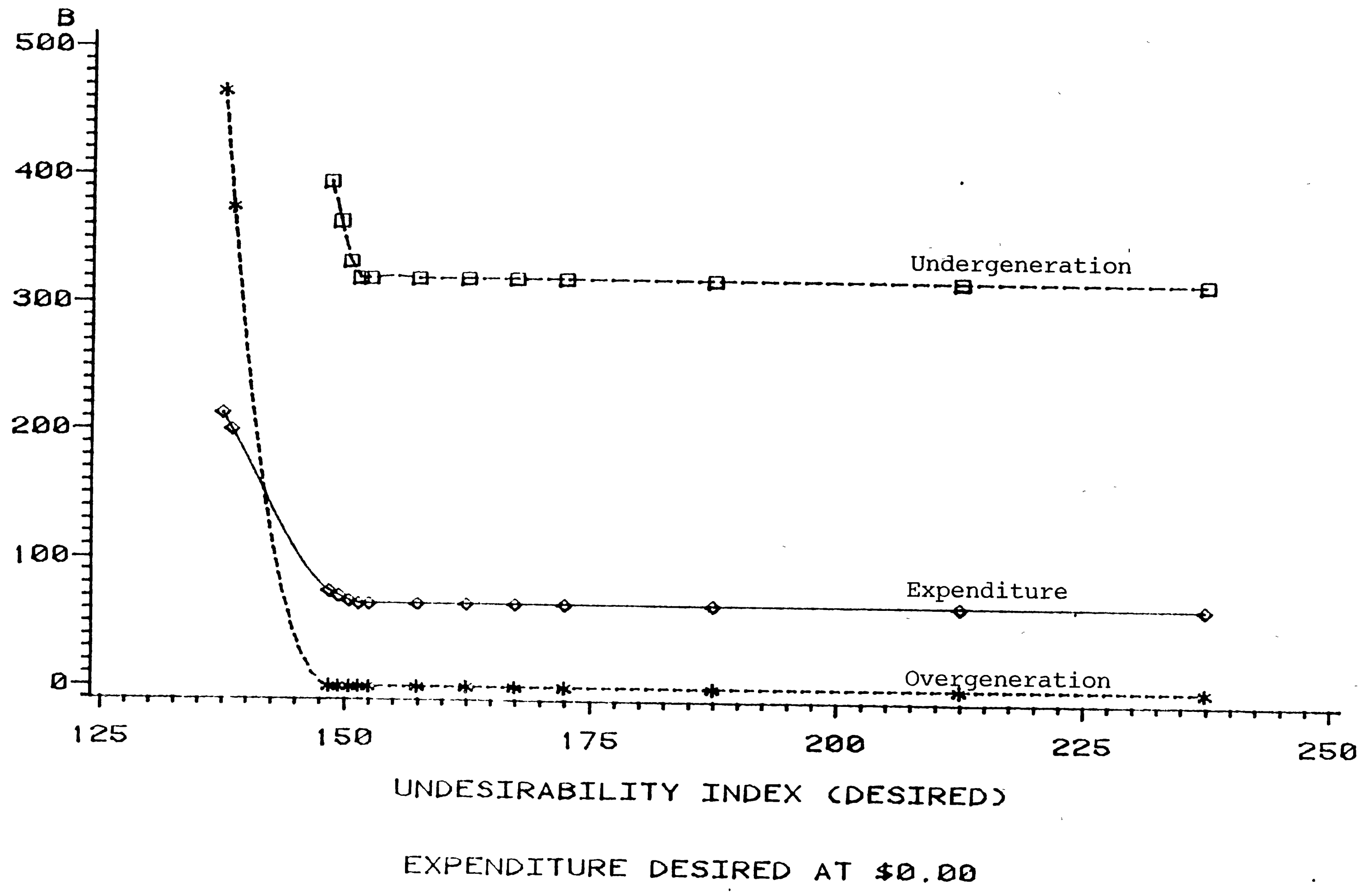

Figure 7. Sensitivity Analysis - 3

Model Validation

Validation task consists of determining that the mathematical model is a reasonable representation of the system. Validating a linear programming model is generally more difficult than a simulation model.

A common method of testing the validity of a model is to compare its performance with some past data available for the actual system. The model will be valid if under similar conditions of inputs, it can reproduce the past performance of the system. The problem in the current research is that there is no such previous model or data available to compare with. In effect, this current model may become a basis to compare with for future models.

In situations like above where previous history is not available, one can apply the techniques of fare vaildity as follows. The goal programming formulation has been done following the well established rules and concepts in the field. The computer algorithm that was adapted was developed by experts in the field and was tested for much bigger and complex problems than the current problem. The structural aspects of the formulation were tested for inconsistencies as well as logic errors.

For combinations involving the expenditure and undesirability index goal in the fourth and fifth priorities, the program was found to be cycling. Several data sets were run using the combination E-B-A-C-B and varying the desired level of expenditure from $80 to $100 while keeping the undesirability index level at 100 constantly. The results were tabulated as shown in Table VIII.

The reasons for this may be explained as due to machine cycling (Gauss, 1979) and/or the very nature of the goal programming formulation. Machine cycling occurs due to the method the computer

TABLE VIII

TEST RUNS FOR DETECTING CYCLING

Trial #	Data Set Name	Desired Expenditure	Desired Undesirability Index	Attained Undesirability Index	Remarks
1	U12770A.R1.DATA	85	100	–	Cycling for all values of expenditure < $89.00
2.	U12770A.R2.DATA	89	100	67.80	$1.00 increase in expenditure would decrease the undesirability index by .08
3.	U12770A.R3.DATA	90	100	67.72	
4.	U12770A.R4.DATA	100	100	66.93	Some amount of bio-electricity and wind electricity were used.

Note: These runs were made with E-D-A-C-B combination.

handles the numbers while accumulating, rounding-off or truncating to mention a few. It can be inferred from Gauss (1979) that this type of computer cycling is inherent in the machine and is not uncommon to hypothetical problems as like the current research. The second reason is due to the way the problem has been formulated under goal programming. The goal programming model tries to meet the top priority goal first, and with remaining resources the immediately next goal and continues until all goals are met as far as possible. When the expenditure goal is set at $0.0 level and has a priority of 4, it has no resources to meet the demands at $0.0 level. The same logic holds good when the undesirability index level is set at 0.0 and has priority of 5. Under the above circumstances, there are no resources available to meet two goals at those desired levels. Hence the model starts cycling. This problem has been overcome by making the respective right-hand ideas have values greater than 0. Table VIII gives the details of the different right-hand sides and the results. It is found from this exercise that when the expenditure goal is set at $89. and the undesirability goal set at 100, there is no cycling and these are the minimum numbers.

It can be concluded from the above analysis and explanation that the model does cycle when certain combinations are attempted, and a logical analysis of the combination and choosing the correct right-hand sides would eliminate it.

The model was tested on well over 100 different combinations varying the priority orderings as well as values of the right hand sides and variables. The results were found to be logical and no structural inadequancies were found.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The current research is aimed at the application of mathematical programming techniques to the energy management problems. It can be summarized from the results obtained, a successful model can be built and tested as a decision aiding tool in a complex situation like rural energy management.

The area of energy management has been a testing field for various mathematical modelling techniques. This research will add a new dimension to the existing research by the way of application of Linear Goal Programming techniques.

It is evident from results, that the decision maker (REMC) can change its priorities and arrive at the optimal resource allocation levels.

It can be concluded from this research that a well structured analytical model can be built for a rural energy management situation and it provides the desired solutions. It will be a very versatile decision aid in multiple criteria problems. The program is very flexible and can handle a variety of problems. The program can address many issues that were not explicitly considered in the item.

This research opens up many new areas of research and improvements. This current model is limited to a hypothetical situation only. But many more real world situations can be easily modeled and solved with this program. The following are some of the important recommendations regarding this research.

(1) attempts should be made to collect more meaningful data

(2) incorporating the torage aspect will add reality

(3) as the resources are stochastic in nature, a simulation model for that will further enhance its utility

(4) this model can be modified to design the energy plants efficiently

(5) besides goal programming, other MCDM techniques can be used to get improved solution.

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APPENDIXES

APPENDIX A

USER DOCUMENTATION FOR THE GOAL PROGRAMMING CODE - PAGP

USER DOCUMENTATION FOR THE GOAL PROGRAMMING CODE - PAGP

Purpose

PAGP solves the linear goal programming (GP) by the partitioning algorithm developed by Arthur and Ravindran (1980). The GP problem is allowed to have real constraints along with the usual goal constraints. The partitioning algorithm is easy to use, more efficient, and requires less core than the existing goal programming codes. The program uses much of the notation and structure developed by Ignizio (1976).

Problem Structure

The user's goal programming problem should be restructured if necessary to conform with the following format:

1. The constraints should be arrange in such a way that all the real constraints of the problem appear first, followed by the goal constraints.

2. Every goal constraint must be expressed in terms of the decision variables (i.e., no goal decomposition (Charnes, A. et al., 1975) is allowed).

Input Format

The following is the order and format of the data cards:

Card Type	Description	Format
1	TSO data set name	2A4
	Example: A1.DATA	
2	Total number of priorities - NPRIT Number of decision variables - NVAR Number of real constraints - NRCON	3I5
	Example: 5 38 0	
3	Number of goal constraints assigned to each priority - NC(K), K = 1, 2, . . . , NPRIT	10I5
	Example: 8 1 1 6 6 (Priority P1 has 8 goal constraints P2 & P3 1 each and P4 & P5 6 each)	
4	For each priority K (K = 1, . . . , NPRIT) one card is needed which gives the subscript of the goal constraints (i.e. subscript of the deviational variables for each goal constraint) assigned to priority P_k	12A4/9I5
	Note: If there are no goal constraints assigned to to P_k, no type 4 card is necessary	
	Example: MEET DAILY RURAL DEMANDS (KWH) 1 2 3 4 5 6 7 8	
5	Description of the demands	8A4
	Example: COOKING 350.	
6	Description of the resources	12A4
	Example: BIOGAS 2000. 1000. 0.10 0.140	

Card Type		Description	Format
	Note:	Card types 1, 5, & 6 are tailor made for this problem	
7		Description of variables	15A4
	Example:	1. DOMESTIC COOKING WITH BIOGAS	
8		Number of terms (deviational variables) assigned to each priority in the objective function. NTOF (K), K = 1, 2, . . . , NPRIT	10I5
	Example:	8 1 1 6 6	
9		For each real constraint, one card is needed with the right hand side value followed by the coefficients of all the decision variables (x_j). If NVAR > 7, another card is to be used	8F10.0
	Note:	If NRCON = 0 in card type 1, no card type 9 is necessary	
10		For each goal constraint assigned to priority P1, read in the right hand side constant and the coefficients of all the decision variables (x_j). If NVAR > 7, another card is to be used. The coefficients of the deviational variables d_1^+ and d_1^- (which are always equal to -1 and +1) are added automatically by the program.	8F10.0
11		The following cards are required for each deviational variable assigned to priority P1.	2I5, F10.0

Example:

000.000	.140	.204	.215	.151	.129	.161	.140
.204	.215	.129	.161	.140	.204	.215	.129
.161	.204	.215	.129	.161	.140	.204	.215
.129	.161	.140	.204	.215	.129	.161	.204
.215	.129	.161	.204	.215	.129	.161	
10 3	1.						

Note: Card types 10 & 11 are needed for all the priorities

Explanation of the Output

Page 1 is the title page, tailor made for current research problem. However, it can be modified to user's requirement.

Page 2 is the Input Summary - I which gives the input data set name on TSO account besides the number of priorities and the number of variables. Various goals according to their priority order as well as positive or negative deviations that need to be minimized, units and any desired level they were fixed at will also appear. It is to be noted that the term "total-expenditure" here means only to the sum of the product of per unit cost of each type of energy and number of such units used for each type of demand.

Page 3 is the Input Summary - II which is tailor made for this problem. The first half of the page gives the details of the various demands and their quantities. The second half gives the various resource types and their generation capacities (maximum and minimum), cost/kWh and undesirability index.

Page 4 is the Output Summary - I which gives in which subproblem the GP simplex optimization ended and the number of constraints in final tableau. The second part of the output gives each subscript along with the variable name and its value in the solution matrix.

Page 5 is the Output Summary - II where each of the goals and their achievements appear in the priority structure given in the input. If any one of the goals is fixed to a certain amount, it is also shown in the output. If the achievement column is 0.00, it means that the goal is fully met with. Any other values mean that the goal has either under attained or over attained the derived level.

Page 6 is the continuation of Output Summary - II where for each priority, all the goals and their detailed under or over achievements are known. Again, 0.00 in any achievement column means that it is fully met with and any other value in either column could be interpreted over or under attainment of the derived level.

Page 7 is the Output Summary - III which gives details for each of the variables, the subscript number, variable name, optimal value (XOPT) in the final solution. This table also gives the same information asin the Output Summary-II under AOPT, POSDEV and NEGDEV. That is each subscript number is to be read as goal number and AOPT as the achievement (for each of the priorities), POSDEV as the over achievement and NEGDEV as the under achievement of the derived levels. In the current problem AOPT is to be red for priorities 1 to 5 (under SUBSCRIPT) and POSDEV and NEGDEV from 1 to 22 (under SUBSCRIPT).

APPENDIX B

LISTING OF COMPUTER PROGRAM

```
C        PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C ******************************************************************
C ****
C ****
C ****
C **** PAGP (THE PARTITIONING ALGORITHM FOR GOAL PROGRAMMING) IS
C **** DESIGNED TO SOLVE THE LINEAR GOAL PROGRAMMING PROBLEMS.  THE
C **** ALGORITHM PARTITIONS THE GOAL CONSTRAINTS OF THE PROBLEM
C **** ACCORDING TO THE HIGHEST PRIORITY ASSIGNED TO EITHER DEVIATIONAL
C **** VARIABLE (D- OR D+) IN EACH GOAL   THE ALGORITHM IS THUS ABLE TO
C **** SOLVE A SEQUENCE OF SMALLER PROBLEMS IN ORDER TO FIND A SOLUTION
C **** TO THE ORIGINAL PROBLEM.
C ****
C ****
C ******************************************************************
C ****
C ****
C **** MUCH OF THE NOTATION AND STRUCTURE OF THE PAGP CODE IS TAKEN
C **** (WITH THE AUTHOR'S PERMISSION) FROM THE LINEAR GOAL PROGRAMMING
C **** CODE GIVEN IN 'GOAL PROGRAMMING AND EXTENSIONS' JAMES P IGNIZIO
C ****
C ******************************************************************
C ****
C ****
C **** THE CODE FOR PAGP USES THE FOLLOWING ARRAYS-
C ****
C ****          TE(NROW,NCOL) : THE COEFFICIENT OF THE VARIABLE IN
C ****                          COLUMN NCOL IN THE CONSTRAINT IN ROW NROW
C ****
C ****          TT(NP,NCOL)   : THE WEIGHT OF THE VARIABLE IN COLUMN NCOL
C ****                          AT PRIORITY NP
C ****
C ****          TB(NROW)      : THE RIGHT HAND SIDE CONSTANT OF THE
C ****                          CONSTRAINT IN ROW NROW
C ****
C ****          TL(NROW,NP)   : THE WEIGHT ASSIGNED TO THE BASIC VARIABLE
C ****                          IN ROW NROW AT PRIORITY NP
C ****
C ****          TI(NP,NCOL)   : THE RELATIVE WEIGHT OF THE VARIABLE IN
C ****                          COLUMN NCOL AT PRIORITY NP
C ****
C ****          TA(NP)        : THE TOTAL DEVIATION FROM THE GOALS AT
C ****                          PRIORITY NP
C ****
C ****          NC(NP)        : THE NUMBER OF GOAL CONSTRAINTS ASSIGNED
C ****                          TO PRIORITY NP BY THE PARTITION
C ****
C ****          NCON(I,NP)    : THE SUBSCRIPT OF THE I-TH CONSTRAINT
C ****                          ASSIGNED TO PRIORITY NP (I=1,.  ,NC(NP))
C ****
C ****          NTOF(NP)      : THE NUMBER OF TERMS IN THE OBJECTIVE
C ****                          FUNCTION AT PRIORITY NP

C ****
C ****          IND(NCOL)     : 1, IF THE VARIABLE IN COLUMN NCOL IS
C ****                          ELIGIBLE TO ENTER THE BASIS
C ****                        : 0, OTHERWISE
C ****
C ****          JROW(NROW,1)  : THE TYPE OF BASIC VARIABLE IN ROW NROW,
C ****                          WHERE TYPE IS GIVEN BELOW
C ****
C ****                                    TYPE       JROW(     1)
C ****                                    ****       ***********
C ****                                     X              2
C ****                                     D+             3
C ****                                     D-             4
C ****
C ****          JROW(NROW,2)  : THE SUBSCRIPT OF THE BASIC VARIABLE IN
C ****                          ROW NROW
C ****
C ****          JCOL(NCOL,1)  : THE TYPE OF VARIABLE IN COLUMN NCOL
C ****                          (TYPE IS DEFINED AS ABOVE)
C ****
C ****          JCOL(NCOL,2)  : THE SUBSCRIPT OF THE VARIABLE IN
C ****                          COLUMN NCOL
C ****
C ****
C ******************************************************************
C ****
C ****
C **** AS PRESENTLY DIMENSIONED, THE PAGP CODE CAN SOLVE PROBLEMS WITH
C **** UP TO 80 CONSTRAINTS (BOTH REAL + GOAL CONSTRAINTS), 125
C **** VARIABLES (DECISION + DEVIATIONAL VARIABLES), AND 10 PRIORITIES
C ****
C ****
C ******************************************************************
C ****
C ****
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(80),TE(80,125),TL(80,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(80,2),NVAR,NPRIT,IND(125)
      COMMON /PHASE1/ W,NRCON,NDVR
      COMMON /CHNG/ NCON(80,10),NTOF(10)
C ******************************************************************
C *******         THIS PART OF THE PROGRAM IS SPECIALLY MADE FOR
C *******              THE CURRENT THESIS WORK   - PRASAD         ******
C ******************************************************************
C *******      GOALS(5,12) : 5 GOALS IN 12A4 FORMAT
C *******      DEMND(10,8) : 8 DEMANDSIN 8A4 FORMAT +  2 TITLES    *****
C *******      RESOR(8,15) : 8 RESOURCES IN 15A4 FORMAT + 2 TITLES *****
C *******      VARIAB(50,15) : 50 UPTO VARIABLES IN 13A4 FORMAT    *****
C *******   NOTE: INPUT CARDS SHOULD COME IN THE ABOVE SEQUENCE    *****
C ******************************************************************
      COMMON /PRASAD/ GOALS(5,12),DEMND(10,8),RESOR(8,15),VARIAB(50,15)
      INTEGER ALTST
      WRITE(6,300)
      WRITE(6,303)
```

```
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,302)
      WRITE(6,303)
      WRITE(6,304)
      WRITE(6,303)
      WRITE(6,305)
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,306)
      WRITE(6,303)
      WRITE(6,3061)
      WRITE(6,303)
      WRITE(6,3062)
      WRITE(6,303)
      WRITE(6,307)
      WRITE(6,303)
      WRITE(6,308)
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,309)
      WRITE(6,303)
      WRITE(6,310)
      WRITE(6,303)
      WRITE(6,311)
      WRITE(6,303)
      WRITE(6,312)
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,303)
      WRITE(6,299)
C **** READ IN PROBLEM DATA
C ****
C **** NPRIT=THE TOTAL NUMBER OF PRIORITIES
C ****
C **** NVAR=THE TOTAL NUMBER OF DECISION VARIABLES(INCLUDING SLACK AND
C ****        SURPLUS VARIABLES BUT EXCLUDING ARTIFICIAL VARIABLES FOR THE
C ****        REAL CONSTRAINTS)
C ****
C **** NRCON=THE NUMBER OF REAL CONSTRAINTS
C
      READ (5,1200) NAME1,NAME2
1200  FORMAT (2A4)
      READ (5,120) NPRIT,NVAR,NRCON
      READ (5,121) (NC(NP),NP=1,NPRIT)
      DO 101 NP=1,NPRIT
         IF (NC(NP).EQ.0) GO TO 101
         NCTMP=NC(NP)
C ********************************************************************
C *********************  READ IN THE GOALS    *************************
C ********************************************************************
         READ (5,122) (GOALS(NP,K),K=1,12),(NCON(N,NP),N=1,NCTMP)

  101 CONTINUE
C ********************************************************************
C *********************  READ IN THE DEMANDS   ************************
C ********************************************************************
       DO 45 ID=1,10
         READ (5,1212) (DEMND(ID,J),J=1,8)
  45  CONTINUE
1212  FORMAT(8A4)
C ********************************************************************
C *********************  READ IN THE RESOURCES  ***********************
C ********************************************************************
       DO 46 IJ=1,8
         READ (5,1213) (RESOR(IJ,M),M=1,15)
  46  CONTINUE
1213  FORMAT(15A4)
C ********************************************************************
C *************  WRITE OUT THE INPUT SUMMARY- I  *********************
C ********************************************************************
      WRITE (6,300)
      WRITE (6,303)
      WRITE (6,303)
      WRITE (6,399) NAME1,NAME2
      WRITE (6,303)
      WRITE (6,401) NPRIT,NVAR
      WRITE (6,303)
      WRITE (6,303)
      WRITE (6,303)
      WRITE (6,402)
      WRITE (6,303)
         DO 500 I = 1,NPRIT
            WRITE (6,403) I,(GOALS(I,K),K=1,12)
            WRITE (6,303)
500      CONTINUE
      WRITE (6,303)
      WRITE (6,303)
      WRITE (6,404)
      WRITE (6,303)
      WRITE (6,405)
      WRITE (6,303)
      WRITE (6,303)
      WRITE (6,299)
C ********************************************************************
C *************  WRITE OUT THE INPUT SUMMARY- II  ********************
C ********************************************************************
      WRITE (6,298)
      WRITE (6,503)
      WRITE (6,503)
      WRITE (6,400)
      WRITE (6,503)
      WRITE (6,3001)
      WRITE (6,503)
3001  FORMAT (T34,'**', T63,'DEMANDS (KWH)',T101,'**'/T34,'**',T63,
     $13('_'),T101,'**')
      WRITE (6,503)
```

```
      WRITE (6,503)
            DO 47 ID=1,10
               WRITE (6,3002) (DEMND(ID,J),J=1,8)
3002           FORMAT (T34,'**',T58,8A4,T101,'**')
      WRITE (6,503)
  47        CONTINUE
      WRITE (6,503)
      WRITE (6,599)
      WRITE (6,503)
      WRITE (8,3003)
      WRITE (8,503)
3003  FORMAT (T34,'**', T65,'RESOURCES ',T101,'**'/T34,'**',T65,
     59('_'),T101,'**')
      WRITE (6,503)
             DO 48 IJ=1,8
                WRITE (6,3004) (RESOR(IJ,M),M=1,15)
3004            FORMAT (T34,'**',T38,15A4,T101,'**')
      WRITE (8,503)
  48         CONTINUE
      WRITE (6,503)
      WRITE (6,503)
      WRITE (6,599)
C *******************************************************************
C ******************  READ IN THE VARIABLES   ************************
C *******************************************************************
      DO 200 J=1,NVAR
      READ (5,201) (VARIAB(J,K),K=1,13)
 200  CONTINUE
 201  FORMAT(15A4)
      READ (5,121) (NTOF(NP),NP=1,NPRIT)
C
C **** INITIALIZE SUBPROBLEM DIMENSIONS AND COLUMN INDICATORS.
C ****
C **** NCOLI=THE NUMBER OF COLUMNS IN THE CURRENT WORKING TABLEAU
C ****
C **** NROWI=THE NUMBER OF ROWS IN THE CURRENT WORKING TABLEAU
C ****
C **** NPRIC=THE PRIORITY CURRENTLY BEING OPTIMIZED
C ****
C **** ZERO THE TE, TL, TT, AND TI ARRAYS
C
      NCOLI=0
      NROWI=0
      NPRIC=0
      DO 104 NCR=1,125
         IND(NCR)=1
         DO 102 NR=1,60
  102    TE(NR,NCR)=0.
         DO 103 NP=1,10
            TI(NP,NCR)=0.
  103    TT(NP,NCR)=0.
  104 CONTINUE
      DO 105 NR=1,60
      DO 105 NP=1,10

  105 TL(NR,NP)=0
C
C **** CHECK FOR REAL CONSTRAINTS.
C
      IF (NRCON.EQ.0) GO TO 106
      CALL PHSE1
      IF (NDVR LE.0) GO TO 116
      IF (W.GT 0.) GO TO 117
C
C **** THE PARTITIONING ALGORITHM BEGINS
C
  106 NPRIC=NPRIC+1
      IF (NPRIC EQ 1 AND.NRCON EQ 0) GO TO 107
      GO TO 108
  107 CALL READ1
      GO TO 109
  108 CALL READ2
  109 CALL CINDX
      CALL TEST (NEVC,NDVR)
C
C **** IF NEVC IS LESS THAN ZERO, THE SUBPROBLEM IS OPTIMIZED
C
      IF (NEVC.LE 0) GO TO 110
C
C **** IF NDVR IS LESS THAN ZERO, NO MINIMUM POSITIVE RATIO WAS FOUND.
C
      IF (NDVR.LE.0) GO TO 116
      CALL PERM (NEVC,NDVR)
      GO TO 109
C
C **** IF THERE ARE NO MORE PRIORITIES, TOTAL PROBLEM IS OPTIMIZED
C **** PRINT THE OPTIMAL SOLUTION
C
  110 IF (NPRIC EQ.NPRIT) GO TO 115
C
C **** SINCE THERE ARE MORE PRIORITIES, MOVE ON TO THE NEXT SUBPROBLEM
C **** IF THERE ARE ALTERNATE SOLUTIONS.  FIRST, ELIMINATE THOSE
C **** COLUMNS WHICH CAN NOT ENTER THE BASIS.  IF THERE ARE NO
C **** ALTERNATE SOLUTIONS, PRINT THE UNIQUE OPTIMAL SOLUTION.
C
      ALTST=0
      DO 112 NCR=1,NCOLI
         IF (IND(NCR).EQ.0) GO TO 112
         IF (TI(NPRIC,NCR).GT.0 ) GO TO 112
         DO 111 NR=1,NROWI
            IF (JROW(NR,1) EQ.JCOL(NCR,1) AND.JROW(NR,2) EQ.JCOL(NCR,2))
     1      GO TO 112
  111    CONTINUE
         ALTST=1
  112 CONTINUE
C
C **** IF ALTST=1, THERE ARE ALTERNATE SOLUTIONS.
C
      IF (ALTST.EQ.1) GO TO 113
```

```
      GO TO 115
C
C **** ELIMINATE THOSE COLUMNS WITH A POSITIVE RELATIVE COST AT
C **** PRIORITY NPRIC
C
  113 DO 114 NCR=1,NCOLI
  114 IF (TI(NPRIC,NCR).GT.0 ) IND(NCR)=0
      GO TO 106
C
C **** THE OPTIMIZATION IS OVER. PRINT OUT THE FINAL SOLUTION
C
  115 CALL POUT
      GO TO 119
  116 WRITE (6,123) NPRIC
      GO TO 119
  117 WRITE (6,124) W
      WRITE (6,125)
      DO 118 NR=1,NROWI
         WRITE (6,126) JROW(NR,1),JROW(NR,2),TB(NR)
  118 CONTINUE
  119 STOP
C
  120 FORMAT (3I5)
  121 FORMAT (10I5)
  122 FORMAT (12A4/9I5)
  123 FORMAT (/  40H   THE PROGRAM TERMINATED ON SUBPROBLEM ,I4, 42H  NO
     1 MINIMUM POSITIVE RATIO COULD BE FOUND)
  124 FORMAT (/  65H  THE PROGRAM TERMINATED IN PHASE 1 WITH OBJECTIVE F
     1UNCTION VALUE,F15.4)
  125 FORMAT (/  55H  THE OPTIMAL SOLUTION TO THE PHASE 1 PROBLEM IS
     1    //   6H  TYPE,2X,  3HSUB,8X,  5HVALUE)
  126 FORMAT (2I5,F15.4)
298    FORMAT(1H1,2(/),T34,69('*'))
299    FORMAT(T37,63('*'))
599    FORMAT(T34,69('*'))
300    FORMAT(1H1,10(/),T37,63('*'))
CO1    FORMAT(////T37,'**',T98,'**')
302    FORMAT(1X,T37,'**',T49,'ENERGY MANAGEMENT MODEL FOR RURAL AREAS',
     $T98,'**')
303    FORMAT(T37,'**',T98,'**')
503    FORMAT(T34,'**',T101,'**')
304    FORMAT(T37,'**',T53,'- A MULTIPLE CRITERIA DECISION',T98,'**')
305    FORMAT(T37,'**',T60,'MAKING APPROACH',T98,'**')
306    FORMAT(T37,'**',T51,'MASTER',3H'S ,'THESIS BY · M.V L. PRASAD',
     $T98,'**')
3061   FORMAT(T37,'**',T51,'THESIS ADVISORS : DR. C.P  KOELLING',
     $T98,'**')
3062   FORMAT(T37,'**',T69,'DR. R.G. RAMAKUMAR',T98,'**'/T37,'**',T98,'**
     $'/T37,'**',T69,'DR. P.M. WOLFE',T98,'**')
307    FORMAT(T37,'**',T46,'SCHOOL OF INDUSTRIAL ENGINEERING & MANAG',
     $'EMENT',T98,'**')
308 -  FORMAT(T37,'**',T44,'OKLAHOMA STATE UNIVERSITY, STILLWATER,',
     $' OK 74078',T98,'**')
309    FORMAT(T37,'**',T47,'THIS PROGRAM HAS BEEN DEVELOPED AROUND',


     $' THE',T98,'**')
310    FORMAT(T37,'**',T43,'PARTITIONING ALGORITHM (GOAL PROGRAMMING) ',
     $'DEVELOPED',T98,'**')
311    FORMAT(T37,'**',T48,' BY DR. JEFFREY ARTHUR & DR  A RAVINDRAN',
     $T98,'**')
312    FORMAT(T37,'**',T62,'DECEMBER 1983 ',T98,'**')
399    FORMAT (T37,'**',T61,'INPUT  SUMMARY-I',T98,'**'/T37,'**',T61,
     $ 16('_'),T98,'**'/T37,'**',T98,'**'/T37,'**',T57,
     $'DATASET:U12770A.',2A4,T98,'**')
400    FORMAT (T34,'**',T61,'INPUT  SUMMARY-II',T101,'**'/T34,'**',T61,
     $ 17('_'),T101,'**')
401    FORMAT (T37,'**',T57,'NUMBER OF PRIORITIES = ',I2,T98,'**'/
     $ T37,'**',T57,'NUMBER OF VARIABLES   = ',I2,T98,'**')
402    FORMAT (T37,'**',T41,'PRIORITY',T65,'DESCRIPTION',T98,'**',/
     $ T37,'**',T41,8('_'),T65,11('_'),T98,'**')
403    FORMAT (T37,'**',T43,I2,T47,12A4,T98,'**')
404    FORMAT (T37,'**',T46,'LEGEND:',T98,'**'/T37,'**',T46,6('_'),T98,'*
     $*'/T37,'**',T55,'D+ = POSITIVE DEVIATIONS',T98,'**'/T37,'**',T55,'
     $D- = NEGATIVE DEVIATIONS',T98,'**')
405    FORMAT (T37,'**',T46,'THESE PRIORITY ORDERINGS CAN BE ',
     $ 'CHANGED AROUND',T98,'**')
C
       END
```

```
C *****
C ********************************************************************
C                                   SUBROUTINE PHSE1
C ********************************************************************
C *****
      SUBROUTINE PHSE1
C
C **** SUBROUTINE PHSE1 READS IN ANY REAL CONSTRAINTS AND PERFORMS A
C **** PHASE 1 SIMPLEX PROCEDURE IN ORDER TO FIND AN INITIAL BASIC
C **** FEASIBLE SOLUTION.
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(60),TE(60,125),TL(60,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(60,2),NVAR,NPRIT,IND(125)
      COMMON /PHASE1/ W,NRCON,NDVR
      DIMENSION C(125), CR(125), CB(60)
C
C **** SET COLUMN AND ROW HEADINGS
C
      DO 101 NV=1,NVAR
         JCOL(NV,1)=2
  101 JCOL(NV,2)=NV
      DO 102 NR=1,NRCON
         JROW(NR,1)=1
         JROW(NR,2)=NR
         NAR=NVAR+NR
         JCOL(NAR,1)=1
  102 JCOL(NAR,2)=NR
C
C **** READ IN COEFFICIENTS AND RHS OF REAL CONSTRAINTS
C
      DO 103 NR=1,NRCON
         READ (5,118) TB(NR),(TE(NR,NV),NV=1,NVAR)
  103 CONTINUE
C
C **** PUT IDENTITY MATRIX IN FOR ARTIFICIAL VARIABLES
C
      DO 104 NR=1,NRCON
         NAR=NVAR+NR
  104 TE(NR,NAR)=1.
C
C **** SET C(J)=0 FOR ALL DECISION VARIABLES AND C(J)=1 FOR ALL
C **** ARTIFICIAL VARIABLES
C
      DO 105 NV=1,NVAR
  105 C(NV)=0.
      DO 106 NR=1,NRCON
         CB(NR)=1.
         NAR=NVAR+NR
  106 C(NAR)=1.
C
C **** CALCULATE RELATIVE COST COEFFICIENTS CR(.)
C
      NCOL=NVAR+NRCON

  107 DO 108 NV=1,NCOL
         CR(NV)=C(NV)
      DO 108 NR=1,NRCON
  108 CR(NV)=CR(NV)-CB(NR)*TE(NR,NV)
C
C **** CHECK FOR OPTIMALITY
C
      VEVC=0.
      NEVC=0
      DO 109 NCO=1,NCOL
         NV=NCO
         IF (CR(NV) GE.0.) GO TO 109
         IF (CR(NV) GE VEVC) GO TO 109
         VEVC=CR(NV)
         NEVC=NV
  109 CONTINUE
C
C **** IF NEVC=0, PHASE 1 IS OPTIMIZED   CALCULATE OBJECTIVE FUNCTION
C
      IF (NEVC EQ 0) GO TO 115
C
C **** DETERMINE DEPARTING VARIABLES ROW
C
      NDVR=0
      VDVR=10.0E+20
      DO 111 NRI=1,NRCON
         NR=NRI
         IF (TE(NR,NEVC).LE.0.) GO TO 111
         V=TB(NR)/TE(NR,NEVC)
         IF (NDVR EQ.0) GO TO 110
         IF (V-VDVR) 110,110,111
  110    VDVR=V
         NDVR=NR
  111 CONTINUE
C
C **** IF NDVR=0, MINIMUM RATIO RULE FAILED.  RETURN.
C
      IF (NDVR.EQ.0) RETURN
C
C **** PERFORM THE PIVOT   REPLACE HEADINGS AND COST COEFFICIENT
C
      JROW(NDVR,1)=JCOL(NEVC,1)
      JROW(NDVR,2)=JCOL(NEVC,2)
      CB(NDVR)=C(NEVC)
C
C **** COMPUTE NEW TE ARRAY
C
      PIV=TE(NDVR,NEVC)
      PIB=TB(NDVR)
      DO 113 NR=1,NRCON
         IF (NR.EQ.NDVR) GO TO 113
         IF (DABS(TE(NR,NEVC)).LE.0.0005) GO TO 113
         PIX=TE(NR,NEVC)/PIV
         TB(NR)=FIX(TB(NR)-PIX*PIB)
```

```
            DO 112 NV=1,NCOL
  112       TE(NR,NV)=FIX(TE(NR,NV)-TE(NOVR,NV)*PIX)
  113 CONTINUE
      TB(NOVR)=FIX(PIB/PIV)
      DO 114 NV=1,NCOL
  114 TE(NOVR,NV)=FIX(TE(NOVR,NV)/PIV)
C
C **** END OF PIVOT OPERATIONS   PROCEED TO NEXT ITERATION.
C
      GO TO 107
C
C **** CALCULATE W, THE PHASE-1 OBJECTIVE FUNCTION.
C
  115 W=0.
      DO 116 NR=1,NRCON
  116 W=W+TB(NR)*CB(NR)
C
C **** INITIALIZE THOSE PORTIONS OF THE TABLEAU ASSIGNED TO THE
C **** ARTIFICIAL VARIABLES
C
      DO 117 NR=1,NRCON
      DO 117 NV=1,NCOL
         IF (NV LE.NVAR) GO TO 117
         TE(NR,NV)=0.
  117 CONTINUE
C
C **** UPDATE NCOLI AND NROWI PARAMETERS.
C
      NROWI=NRCON
      NCOLI=NVAR
      RETURN
C
  118 FORMAT (8F10.0)
C *************
C 999 FORMAT (1X,'THE RHS AND X-J COEFFS. OF THE REAL CONST =',8F10.3)
C *************
C
      END
```

```
C *****
C *******************************************************************
C                              SUBROUTINE READ1
C *******************************************************************
C *****
      SUBROUTINE READ1
C
C **** SUBROUTINE READ1 READS IN THE GOAL CONSTRAINTS AND OBJECTIVE
C **** FUNCTION TERMS ASSIGNED TO PRIORITY ONE
C **** SUBROUTINE READ1 IS NOT USED IF REAL CONSTRAINTS ARE PRESENT
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(60),TE(60,125),TL(60,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(60,2),NVAR,NPRIT,IND(125)
      COMMON /CHNG/ NCON(60,10),NTOF(10)
C
C **** SET COLUMN AND ROW HEADINGS
C
      DO 101 NV=1,NVAR
         JCOL(NV,1)=2
  101 JCOL(NV,2)=NV
      NC11=NC(1)
      DO 102 NCR=1,NC11
         NC1=NVAR+2*NCR-1
         NC2=NVAR+2*NCR
         JCOL(NC1,1)=4
         JCOL(NC1,2)=NCON(NCR,1)
         JCOL(NC2,1)=3
         JCOL(NC2,2)=NCON(NCR,1)
         JROW(NCR,1)=4
  102 JROW(NCR,2)=NCON(NCR,1)
C
C **** READ IN THE GOAL CONSTRAINTS ASSIGNED TO PRIORITY 1
C
      NC1=NC(1)
      DO 103 NCR=1,NC1
         NV1=NVAR+2*NCR-1
         NV2=NVAR+2*NCR
         READ (5,105) TB(NCR),(TE(NCR,NV),NV=1,NVAR)
C
C **** PUT +1 IN FOR D- AND -1 IN FOR D+
C
         TE(NCR,NV1)=1
         TE(NCR,NV2)=-1
  103 CONTINUE
      NCOLI=NV2
      NROWI=NC(1)
C
C **** READ IN THE OBJECTIVE FUNCTION TERMS FOR PRIORITY 1
C
      NT1=NTOF(1)
      DO 104 NT=1,NT1
         READ (5,106) ISUB,ITYPE,WGHT
         CALL PLACE (ISUB,ITYPE,WGHT)
```

```
  104 CONTINUE
      RETURN
C
  105 FORMAT (8F10 0)
  106 FORMAT (2I5,F10 0)
C
      END
```

```
C *****
C *******************************************************************
C                           SUBROUTINE READ2
C *******************************************************************
C *****
      SUBROUTINE READ2
C
C **** SUBROUTINE READ2 READS IN THE GOAL CONSTRAINTS AND OBJECTIVE
C **** FUNCTION TERMS ASSIGNED TO PRIORITY NPRIC
C **** SUBROUTINE READ2 IS ALSO USED TO READ IN THE FIRST PRIORITY GOAL
C **** CONSTRAINTS AND OBJECTIVE FUNCTION TERMS IF REAL CONSTRAINTS ARE
C **** PRESENT
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(60),TE(60,125),TL(60,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(60,2),NVAR,NPRIT,IND(125)
      COMMON /CHNG/ NCON(60,10),NTOF(10)
      IF (NC(NPRIC) EO O) GO TO 107
C
C **** READ IN THE COEFFICIENTS OF THE X'S
C
      NCTMP=NC(NPRIC)
      DO 106 NRI=1,NCTMP
         NR=NRI+NROWI
         NC1=NCOLI+2*NRI-1
         NC2=NCOLI+2*NRI
         JCOL(NC1,1)=4
         JCOL(NC1,2)=NCON(NRI,NPRIC)
         JCOL(NC2,1)=3
         JCOL(NC2,2)=NCON(NRI,NPRIC)
         READ (5,108) TB(NR),(TE(NR,NV),NV=1,NVAR)
         TE(NR,NC1)=1
         TE(NR,NC2)=-1.
C
C **** PERFORM THE ROW REDUCTION.
C
         DO 102 NRC=1,NROWI
            IF (JROW(NRC,1).NE.2) GO TO 102
            J=JROW(NRC,2)
            TB(NR)=TB(NR)-TE(NR,J)*TB(NRC)
            DO 101 NCR=1,NC2
               IF (NCR.EQ.J) GO TO 101
               TE(NR,NCR)=TE(NR,NCR)-TE(NR,J)*TE(NRC,NCR)
  101       CONTINUE
            TE(NR,J)=0.
  102    CONTINUE
C
C **** DETERMINE.THE DEVIATIONAL VARIABLE TO ENTER THE BASIS.
C
         IF (TB(NR)) 103,105,105
C
C **** SINCE TB IS LESS THAN ZERO, MULTIPLY THE ROW BY -1 AND ENTER D+
C **** IN THE BASIS.
C
```

```
  103     DO 104 NCR=1,NC2
  104     TE(NR,NCR)=-TE(NR,NCR)
          TB(NR)=-TB(NR)
          JROW(NR,1)=3
          JROW(NR,2)=NCON(NRI,NPRIC)
          GO TO 106
C
C **** SINCE TB IS GREATER THAN OR EQUAL TO ZERO ENTER D- IN THE BASIS.
C
  105     JROW(NR,1)=4
          JROW(NR,2)=NCON(NRI,NPRIC)
  106 CONTINUE
C
C **** INCREASE THE PARAMETERS NCOLI AND NROWI.
C
      NCOLI=NC2
      NROWI=NR
C
C **** READ IN THE OBJECTIVE FUNCTION TERMS FOR PRIORITY NPRIC.
C
  107 NTTMP=NTOF(NPRIC)
      DO 108 NT=1,NTTMP
         READ (5,110) ISUB,ITYPE,WGHT
         CALL PLACE (ISUB,ITYPE,WGHT)
  108 CONTINUE
      RETURN
C
  109 FORMAT (8F10.0)
  110 FORMAT (2I5,F10.0)
C
      END
```

```
C *****
C ******************************************************************
C                  SUBROUTINE PLACE (ISUB,ITYPE,WGHT)
C ******************************************************************
C *****
      SUBROUTINE PLACE (ISUB,ITYPE,WGHT)
C
C **** SUBROUTINE PLACE PUTS THE OBJECTIVE FUNCTION WEIGHTS FOR THE
C **** DEVIATION VARIABLES AT THE CURRENT PRIORITY LEVEL (NPRIC) IN THE
C **** CORRECT POSITIONS IN THE AUGMENTED TABLEAU.
C ****
C **** ISUB=THE SUBSCRIPT OF THE DEVIATIONAL VARIABLE
C ****
C **** ITYPE=3, IF POSITIVE DEVIATIONAL VARIABLE (D+)
C ****       4, IF NEGATIVE DEVIATIONAL VARIABLE (D-)
C ****
C **** WGHT=THE CARDINAL WEIGHT OF THIS DEVIATIONAL VARIABLE AT THE
C ****        CURRENT PRIORITY LEVEL
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(80),TE(80,125),TL(80,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(80,2),NVAR,NPRIT,IND(125)
      COMMON /CHNG/ NCON(80,10),NTOF(10)
C
C **** PLACE THE WEIGHT IN THE PROPER COLUMN IN THE TOP STUB.
C
      NC1=NVAR+1
      DO 101 NCR=NC1,NCOLI
         IF (JCOL(NCR,1).EQ.ITYPE.AND.JCOL(NCR,2).EQ.ISUB) GO TO 102
  101 CONTINUE
  102 TT(NPRIC,NCR)=WGHT
C
C **** PLACE THE WEIGHT IN THE PROPER ROW IN THE LEFT STUB
C
      DO 103 NR=1,NROWI
         IF (JROW(NR,1).EQ.ITYPE.AND.JROW(NR,2).EQ.ISUB) GO TO 104
  103 CONTINUE
      GO TO 105
  104 TL(NR,NPRIC)=WGHT
  105 CONTINUE
      RETURN
C
      END
```

```
C *****
C *******************************************************************
C                              SUBROUTINE CINOX
C *******************************************************************
C *****
C
      SUBROUTINE CINOX
C **** SUBROUTINE CINOX COMPUTES THE RELATIVE COST COEFFICIENTS FOR EACH
C **** VARIABLE IN THE CURRENT TABLEAU(THE TI(     ,  . ) ARRAY) AND THE
C **** OBJECTIVE FUNCTION VALUE(THE TA(.) ARRAY) AT THE CURRENT
C **** PRIORITY(NPRIC)
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(80),TE(80,125),TL(80,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(80,2),NVAR,NPRIT,IND(125)
C
C **** COMPUTE TA(NPRIC) AND TI(NPRIC,NC)   NC=1,. . ,NCOLI
C
      TA(NPRIC)=0.
      DO 101 NR=1,NROWI
  101 TA(NPRIC)=TA(NPRIC)+TB(NR)*TL(NR,NPRIC)
      DO 102 NCR=1,NCOLI
         TI(NPRIC,NCR)=TT(NPRIC,NCR)
      DO 102 NR=1,NROWI
  102 TI(NPRIC,NCR)=TI(NPRIC,NCR)-TE(NR,NCR)*TL(NR,NPRIC)
      RETURN
C
      END
C *****
C *******************************************************************
C                         SUBROUTINE TEST (NEVC,NOVR)
C *******************************************************************
C *****
C
      SUBROUTINE TEST (NEVC,NOVR)
C **** SUBROUTINE TEST DETERMINES THE NEXT ENTERING VARIABLE'S COLUMN
C **** (NEVC) AND THE NEXT DEPARTING VARIABLE'S ROW(NOVR)   IF NO
C **** FURTHER OPTIMIZATION IS POSSIBLE, THE VALUE NEVC=0 IS RETURNED.
C **** IF NOVR=0 IS RETURNED, NO MINIMUM POSITIVE RATIO COULD BE FOUND
C **** IN THE CURRENT PIVOT OPERATION,I.E , ALL OF THE COEFFICIENTS
C **** TE( . ,NEVC) ARE NONPOSITIVE.
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(80),TE(80,125),TL(80,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(80,2),NVAR,NPRIT,IND(125)
      NOVR=0
      NEVC=0
      VEVC=0.
      VOVR=10.0E+20
C
C **** DETERMINE ENTERING VARIABLE'S COLUMN.
C
      DO 101 NCR=1,NCOLI
         IF (TI(NPRIC,NCR).GE.0.) GO TO 101

         IF (IND(NCR).EQ.0) GO TO 101
         IF (TI(NPRIC,NCR).GE.VEVC) GO TO 101
         NEVC=NCR
         VEVC=TI(NPRIC,NCR)
  101 CONTINUE
C
C **** IF NEVC=0, SUBPROBLEM NPRIC IS OPTIMIZED. RETURN.
C
      IF (NEVC.EQ.0) RETURN
C
C **** DETERMINE DEPARTING VARIABLE'S ROW
C
      DO 105 NR=1,NROWI
         IF (TE(NR,NEVC) LE 0 ) GO TO 105
         V=TB(NR)/TE(NR,NEVC)
         IF (NOVR.EQ.0) GO TO 104
         IF (V-VOVR) 104,102,105
  102    DO 103 NP=1,NPRIC
            IF (TL(NR,NP)-TL(NOVR,NP)) 105,103,104
  103    CONTINUE
  104    VOVR=V
         NOVR=NR
  105 CONTINUE
      RETURN
C
      END
```

```
C *****
C ******************************************************************
C                           SUBROUTINE PERM (NEVC,NDVR)
C ******************************************************************
C *****
C
      SUBROUTINE PERM (NEVC,NDVR)
C **** SUBROUTINE PERM PERFORMS THE PIVOT OPERATION USING THE PIVOT
C **** ELEMENT IN COLUMN NEVC AND ROW NDVR AND COMPUTES THE NEW TABLEAU
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(60),TE(60,125),TL(60,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(60,2),NVAR,NPRIT,IND(125)
C
C **** REPLACE HEADING FOR ROW NDVR.
C
      JROW(NDVR,1)=JCOL(NEVC,1)
      JROW(NDVR,2)=JCOL(NEVC,2)
C
C **** REPLACE TL VECTOR FOR ROW NDVR
C
      DO 101 NP=1,NPRIC
  101 TL(NDVR,NP)=TT(NP,NEVC)
C
C **** COMPUTE NEW TE ARRAY
C
      PIV=TE(NDVR,NEVC)
      PIB=TB(NDVR)
      DO 103 NR=1,NROWI
         IF (NR.EQ.NDVR) GO TO 103
         IF (DABS(TE(NR,NEVC)).LE.0.0005) GO TO 103
         PIX=TE(NR,NEVC)/PIV
         TB(NR)=FIX(TB(NR)-PIX*PIB)
         DO 102 NCR=1,NCOLI
  102    TE(NR,NCR)=FIX(TE(NR,NCR)-TE(NDVR,NCR)*PIX)
  103 CONTINUE
      TB(NDVR)=FIX(PIB/PIV)
      DO 104 NCR=1,NCOLI
  104 TE(NDVR,NCR)=FIX(TE(NDVR,NCR)/PIV)
      RETURN
C
      END
```

```
C *****
C ******************************************************************
C                      DOUBLE PRECISION FUNCTION FIX(Z)
C ******************************************************************
C *****
C
      DOUBLE PRECISION FUNCTION FIX(Z)
C **** FUNCTION FIX BRINGS FLOATING POINT VALUES THAT ARE WITHIN 1 E-3
C **** OF AN INTEGER TO THAT INTEGER.
C
      IMPLICIT REAL*8(A-H,O-Z)
      FIX=DINT(Z+DSIGN( 5D+0,Z))
      IF (DABS(FIX-Z) GT  1 D-3) FIX=Z
      RETURN
C
      END
```

```
C *****
C ***************************************************************
C                         SUBROUTINE POUT
C ***************************************************************
C *****
C
      SUBROUTINE POUT
C **** SUBROUTINE POUT PREPARES AND PRINTS THE SOLUTION INFORMATION
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON TT(10,125),TB(80),TE(80,125),TL(80,10),TA(10),TI(10,125),JC
     1OL(125,2),NCOLI,NROWI,NPRIC,NC(10),JROW(80,2),NVAR,NPRIT,IND(125)
      COMMON /CHNG/ NCON(80,10),NTOF(10)
      COMMON /PRASAD/ GOALS(5,12),DEMND(10,8),RESOR(8,15),VARIAB(50,15)
      DIMENSION WOUT(125,4), RLHS(80,10), WM(80), WP(80)
      DIMENSION DIFF(80)
C ************************
C1313  FORMAT (//10X,7A4)
C ************************
      WRITE (6,123) NPRIC,NROWI
C
C **** OUTPUT ARRAY IS ZEROED.
C
      DO 101 I=1,125
      DO 101 J=1,4
  101 WOUT(I,J)=0.
C
C **** OUTPUT ARRAY IS FILLED.
C
      DO 102 NP=1,NPRIC
  102 WOUT(NP,1)=FIX(TA(NP))
      DO 103 NR=1,NROWI
         I1=JROW(NR,1)
         I2=JROW(NR,2)
  103 WOUT(I2,I1)=FIX(TB(NR))
C
C **** IF ALL PRIORITIES HAVE BEEN INCLUDED, PRINT OPTIMAL SOLUTION.
C **** IF NOT, WE MUST CALCULATE VALUES FOR REMAINING TA'S AND D- AND D+
C
      IF (NPRIC.GE.NPRIT) GO TO 114
      NP1=NPRIC+1
      DO 113 NP=NP1,NPRIT
         TA(NP)=0.
         IF (NC(NP).EQ.0) GO TO 106
C
C **** READ IN THE GOAL CONSTRAINTS ASSIGNED TO PRIORITY NP
C
         NCTMP=NC(NP)
         DO 105 NCI=1,NCTMP
            NR=NROWI+NCI
            READ (5,124) TB(NR),(TE(NR,NV),NV=1,NVAR)
            RLHS(NCI,NP)=0.
            DO 104 NV=1,NVAR
  104       RLHS(NCI,NP)=RLHS(NCI,NP)+TE(NR,NV)*WOUT(NV,2)


            DIFF(NCI)=TB(NR)-RLHS(NCI,NP)
  105    CONTINUE
C
C **** READ THE OBJECTIVE FUNCTION TERMS FOR PRIORITY NP
C
  106    NTTMP=NTOF(NP)
         DO 112 NT=1,NTTMP
            READ (5,125) ISUB,ITYPE,WGHT
            IF (NC(NP).EQ.0) GO TO 111
            NCTMP=NC(NP)
            DO 110 NCI=1,NCTMP
               IF (ISUB.NE.NCON(NCI,NP)) GO TO 110
               IF (DIFF(NCI)) 107,108,109
  107          IF (ITYPE.NE.3) GO TO 110
              WOUT(ISUB,3)=-DIFF(NCI)
  108          GO TO 110
  109          IF (ITYPE.NE 4) GO TO 110
              WOUT(ISUB,4)=DIFF(NCI)
  110       CONTINUE
  111       TA(NP)=TA(NP)+WGHT*WOUT(ISUB,ITYPE)
  112    CONTINUE
         NROWI=NROWI+NC(NP)
C
C **** FILL IN THE OUTPUT VALUE FOR ATTAINMENT OF PRIORITY NP
C
         WOUT(NP,1)=FIX(TA(NP))
  113 CONTINUE
C
C **** PRINT OPTIMAL SOLUTION
C
  114 WRITE (6,127)
      DO 115 NV=1,NVAR
         WRITE (6,128) (VARIAB(NV,K),K=1,13),NV,WOUT(NV,2)
        IF (NV  EQ  15) WRITE(6,140)
  115 CONTINUE
      WRITE (6,126)
      WRITE (6,131)
      DO 117 NP=1,NPRIT
         WRITE (6,132) NP,(GOALS(NP,K),K=1,12),WOUT(NP,1)
  117 CONTINUE
      WRITE (6,129)
      DO 116 NP=1,NPRIT
         IF (NC(NP).EQ.0) GO TO 116
         NCTMP=NC(NP)
      DO 139 NCO=1,NCTMP
         N=NCON(NCO,NP)
         WRITE (6,130) NP,N,WOUT(N,3),WOUT(N,4)
  139 CONTINUE
  116 CONTINUE
      WRITE (6,126)
      WRITE (6,133)
      WRITE (6,134)
      I=MAX0(NPRIT,NVAR,NROWI)
      DO 121 K=1,I
```

```
      IF(K EQ  16) WRITE(6,141)
        IF (K.GT NPRIT) GO TO 119
        IF (K GT NVAR) GO TO 118
        WRITE (6,135) (VARIAB(K,J),J=1,13),(WOUT(K,J),J=1,4)
        GO TO 121
 118    WRITE (6,136) (VARIAB(K,J),J=1,13),WOUT(K,1),(WOUT(K,J),J=3,4)
        GO TO 121
 119    IF (K.GT NVAR) GO TO 120
        WRITE (6,137) (VARIAB(K,J),J=1,13),(WOUT(K,J),J=2,4)
        GO TO 121
 120    WRITE (6,138) (VARIAB(K,J),J=1,13),(WOUT(K,J),J=3,4)
 121 CONTINUE
     WRITE (6,142)
     RETURN
C
 123 FORMAT (1H1,5(/),T42,54('*')/T42,'**',T94,'**'/T42,'**',
    $ T61,'OUTPUT  SUMMARY I',T94,'**'/T42,'**',T94,'**'/T42,'**',
    $ T48,'THE OPTIMIZATION ENDED ON SUBPROBLEM  : ',I2,T94,'**'/T42,
    $ '**',T94,'**'/T42,'**',T48,'NUMBER OF CONSTRAINTS IN FINAL ',
    $ 'TABLEAU : ', I2,T94,'**'/T42,'**',T94,'**'/T42,54('*') )
 124 FORMAT (8F10.0)
 125 FORMAT (2I5,F10.0)
 126 FORMAT (//,T10,120(1H*))
 127 FORMAT (3(/),T55,'THE OPTIMAL SOLUTION FOR THE '/T55,29('_')//,
    * T52,'DECISION VARIABLES X(J) IS GIVEN BY',/T52,35('_'),
    * //,T35,'SUBSCRIPT',T60,'VARIABLE NAME',T96,'SOLUTION',
    * /T35,9('_'),T60,13('_'),T96,8('_')//)
 128 FORMAT (1H0,T39,13A4,T91,2HX(,I3,2H)=,F10.2)
 129 FORMAT (1H1,6(/),T115,'    CONTD...',2(/),T58,'THE GOAL ACHIEVE',
    $'MENTS ARE',/T56,28('_'),3(/),T40,'PRIORITY',T50,'GOAL NUMBER',
    $T63,'OVER ACHIEVEMENT',T81,'UNDER ACHIEVEMENT',/T40,
    $8('_'),T50,11('_'),T63,16('_'),T81,17('_')/)
 130 FORMAT (/T43,I2,T55,I2,T66,F10.2,T85,F10.2)
 131 FORMAT (1H1,6(/),T54,29('*')/T54,'**',T81,'**' /T54,'**',T59,
    $'OUTPUT  SUMMARY  II',T81,'**'/T54,'**',T81,'**'/T54,29('*'),5(/),
    $ T54,'THE PRIORITY ACHIEVEMENTS ARE',/T54,29('_'),4(/),T38,
    $ 'PRIORITY',T66,'TYPE',T97,'ACHIEVEMENT'/T38,8('_'),T66,4('_'),
    $ T97,11('_')//)
 132 FORMAT (//T41,I2,T47,12A4,T97,F9.2)
 133 FORMAT (1H1,5(/),T54,29('*')/T54,'**',T81,'**'/T54,'**',T59,
    $'OUTPUT  SUMMARY III',T81,'**'/T54,'**',T81,'**'/T54,29('*'))
 134 FORMAT (1H0,3(/),T11,'SUBSCRIPT',T35,'VARIABLE NAME',T77,'AOPT',
    $T90,'X OPT',T104,'POS DEV',T119,'NEG DEV'/T11,9('_'),T35,
    $13('_'),T77,5('_'),T90,5('_'),T104,7('_'),T119,7('_')//)
 135 FORMAT (/T15,13A4,T71,F10.2,T85,F10.2,T101,F10.2,T115,F10.2)
 136 FORMAT (/T15,13A4,T71,F10.2,T101,F10.2,T115,F10.2)
 137 FORMAT (/T15,13A4,T85,F10.2,T101,F10.2,T115,F10.2)
 138 FORMAT (/T15,13A4,T101,F10.2,T115,F10.2)
 140 FORMAT (//T115,'    CONTD...'/
    $ 1H1,6(/),T115,'    CONTD...',3(/),T34,'SUBSCRIPT',T60,
    $'VARIABLE NAME',T96,'SOLUTION'/T34,9('_'),T60,13('_'),T96,
    $8('_'),2(/))
 141 FORMAT(//T115,'    CONTD...'/
    $1H1,//T115,'    CONTD...',3(/),T11,'SUBSCRIPT',T35,'VARIABLE NAME',

    $T90,'X OPT',T104,'POS DEV',T119,'NEG DEV'/
    $T11,9('_'),T35,13('_'),T90,5('_'),T104,7('_'),
    $ T119,7('_')///)
 142  FORMAT(//T10,50('*'),'    END OF OUTPUTS    ',T80,50('*'))
      END
```

APPENDIX C

SAMPLE LISTING OF USER INPUT DATA

```
E1 DATA
     5    38     0
     8     1     1     6     6
MEET DAILY RURAL DEMANDS (KWH) (D-)
     1     2     3     4     5     6     7     8
MINIMIZE TOTAL EXPENDITURE(D+) DESIRED($85 50)
     9
MINIMIZE UNDESIRABILITY INDEX(D+) FIXED(150.78)
    10
MINIMIZE OVER GENERATION (KWH) (D+)
    11    12    13    14    15    16
MINIMIZE UNDER GENERATION (KWH) (D-)
    17    18    19    20    21    22
DOMESTIC            (KWH)
  COOKING            350.
  LIGHTING            75
  HEATING            400.
  COOLING             40
COMMUNITY           (KWH)
  LIGHTING            60
  HEATING            100
  COOLING             25.
  COMMUNICATIONS      15.
```

TYPE	MAX.GEN (KWH)	MIN GEN (KWH)	COST/KWH ($S)	UNDESIRABI -LITY INDEX
BIOGAS	2000.	400.	0.06	0.140
BIO-ELECTRICITY	800	240	0.15	0.204
SOLAR ELECTRICITY	100.	000	0.80	0 215
SOLAR THERMAL	500.	000.	0.18	0.151
WIND ELECTRICITY	800.	00.	0.20	0.129
HYDRO-ELECTRICITY	1000.	160.	0.08	0 161

```
 1.  DOMESTIC COOKING    WITH BIOGAS
 2.  DOMESTIC COOKING    WITH BIO-ELECTRICITY
 3.  DOMESTIC COOKING    WITH SOLAR ELECTRICITY
 4.  DOMESTIC COOKING    WITH SOLAR THERMAL
 5.  DOMESTIC COOKING    WITH WIND ELECTRICITY
 6.  DOMESTIC COOKING    WITH HYDRO-ELECTRICITY
 7.  DOMESTIC LIGHTING   WITH BIOGAS
 8.  DOMESTIC LIGHTING   WITH BIO-ELECTRICITY
 9.  DOMESTIC LIGHTING   WITH SOLAR ELECTRICITY
10.  DOMESTIC LIGHTING   WITH WIND ELECTRICITY
11.  DOMESTIC LIGHTING   WITH HYDRO-ELECTRICITY
12   DOMESTIC HEATING    WITH BIOGAS
13.  DOMESTIC HEATING    WITH BIO-ELECTRICITY
14.  DOMESTIC HEATING    WITH SOLAR ELECTRICITY
15.  DOMESTIC HEATING    WITH WIND ELECTRICITY
16.  DOMESTIC HEATING    WITH HYDRO-ELECTRICITY
17.  DOMESTIC COOLING    WITH BIO-ELECTRICITY
18.  DOMESTIC COOLING    WITH SOLAR ELECTRICITY
19   DOMESTIC COOLING    WITH WIND ELECTRICITY
20.  DOMESTIC COOLING    WITH HYDRO-ELECTRICITY
21   COMMUNITY LIGHTING  WITH BIOGAS

22   COMMUNITY LIGHTING  WITH BIO-ELECTRICITY
23   COMMUNITY LIGHTING  WITH SOLAR ELECTRICITY
24   COMMUNITY LIGHTING  WITH WIND ELECTRICITY
25   COMMUNITY LIGHTING  WITH HYDRO-ELECTRICITY
26.  COMMUNITY HEATING   WITH BIOGAS
27   COMMUNITY HEATING   WITH BIO-ELECTRICITY
28.  COMMUNITY HEATING   WITH SOLAR ELECTRICITY
29   COMMUNITY HEATING   WITH WIND ELECTRICITY
30.  COMMUNITY HEATING   WITH HYDRO-ELECTRICITY
31   COMMUNITY COOLING   WITH BIO-ELECTRICITY
32.  COMMUNITY COOLING   WITH SOLAR ELECTRICITY
33.  COMMUNITY COOLING   WITH WIND ELECTRICITY
34   COMMUNITY COOLING   WITH HYDRO-ELECTRICITY
35.  COMMUNITY COMMNS    WITH BIOGAS
36   COMMUNITY COMMNS    WITH SOLAR ELECTRICITY
37.  COMMUNITY COMMNS.   WITH WIND ELECTRICITY
38.  COMMUNITY COMMNS    WITH HYDRO-ELECTRICITY
    8     1     1     6     6
   350.       1         1         1         1         1         1


   75
    1       1         1         1                                     1


  400.
    1                                       1.        1         1         1


   40
            1         1.        1         1


   60

    1       1.                                        1         1         1
  100


                      1         1         1         1         1
   25.


    1       1         1                                               1
   15
```

```
                    1    1    1    1
1  4      1
2  4      1
3  4      1
4  4      1
5  4      1
6  4      1
7  4      1
8  4      1
65.50    .06    .15    80    18    .20    08    .06
15       80     20     08    06    15     80    .20
.08      15     80     .20   08    .06    15    80
.20      08     06     .15   80    .20    .08   15
.80      20     08     15    80    .20    .08
5  3     1
150.780  140    204    215   151   129    161   140
204      215    129    161   140   204    215   129
161      204    215    129   161   140    204   215
129      161    140    204   215   129    161   204
215      129    161    204   215   129    .161
10  3    1
2000.    1
                             1                 1
                                   1
                1.
800.            1.
1.
                                   1
         1                               1
                       1.                      1.
                       1.
100.                   1.
         1.                              1.
                1.                             1.
                             1.
1.                           1.
500.                         1
800.
                                   1.
                1.                             1.
                       1.
1.                                 1
         1.                        1.
1000.                                    1
                       1.
1                            1
         1.                              1
                1.                       1
11  3    1
12  3    1
13  3    1
14  3    1
15  3    1
16  3    1
400.     1
                             1                 1
                                   1
                1
240             1
1
                                   1
         1                               1
                       1                       1
                       1
0000                   1
         1
                1                        1     1
1                            1
000                          1
                             1
00.                                1.
                1                              1
1.                     1
         1                         1
180                                1
                                         1
1                      1     1
         1
                1                        1
17  4    1.                              1
18  4    1
19  4    1
20  4    1
21  4    1
22  4    1.
```

APPENDIX D

SAMPLE COMPUTER OUTPUT

INPUT SUMMARY-I

DATASET·U12770A.F1 DATA

NUMBER OF PRIORITIES : 5
NUMBER OF VARIABLES : 38

PRIORITY	DESCRIPTION
1	MEET DAILY RURAL DEMANDS (KWH) (D-)
2	MINIMIZE TOTAL EXPENDITURE ($S)(D+) FIXED($000)
3	MINIMIZE UNDESIRABILITY INDEX (D+) FIXED(0000)
4	MINIMIZE OVER GENERATION (KWH) (D+)
5	MINIMIZE UNDER GENERATION (KWH) (D-)

LEGEND:

D+ : POSITIVE DEVIATIONS
D- : NEGATIVE DEVIATIONS

THESE PRIORITY ORDERINGS CAN BE CHANGED AROUND

INPUT SUMMARY-II

DEMANDS (KWH)

DOMESTIC	(KWH)
COOKING	350
LIGHTING	75
HEATING	400
COOLING	40
COMMUNITY	(KWH)
LIGHTING	60
HEATING	100
COOLING	25
COMMUNICATIONS	15

RESOURCES

TYPE	MAX.GEN (KWH)	MIN.GEN (KWH)	COST/KWH ($S)	UNDESIRABI -LITY INDEX
BIOGAS	2000	400.	0.06	0.140
BIO-ELECTRICITY	800	240	0.15	0.204
SOLAR ELECTRICITY	100.	000	0.80	0 215
SOLAR THERMAL	500.	000	0.18	0 151
WIND ELECTRICITY	800	00	0.20	0 129
HYDRO-ELECTRICITY	1000	160	0.08	0 161

```
****************************************************
**                                                **
**                OUTPUT  SUMMARY I               **
**                                                **
**   THE OPTIMIZATION ENDED ON SUBPROBLEM  :  2   **
**                                                **
**   NUMBER OF CONSTRAINTS IN FINAL TABLEAU :  9  **
**                                                **
****************************************************
```

THE OPTIMAL SOLUTION FOR THE

DECISION VARIABLES X(J) IS GIVEN BY

SUBSCRIPT	VARIABLE NAME		SOLUTION
1.	DOMESTIC COOKING WITH BIOGAS	X(1)=	350 00
2.	DOMESTIC COOKING WITH BIO-ELECTRICITY	X(2)=	0.00
3.	DOMESTIC COOKING WITH SOLAR ELECTRICITY	X(3)=	0.00
4.	DOMESTIC COOKING WITH SOLAR THERMAL	X(4)=	0.00
5.	DOMESTIC COOKING WITH WIND ELECTRICITY	X(5)=	0.00
6.	DOMESTIC COOKING WITH HYDRO-ELECTRICITY	X(6)=	0.00
7	DOMESTIC LIGHTING WITH BIOGAS	X(7)=	75 00
8.	DOMESTIC LIGHTING WITH BIO-ELECTRICITY	X(8)=	0.00
9.	DOMESTIC LIGHTING WITH SOLAR ELECTRICITY	X(9)=	0 00
10.	DOMESTIC LIGHTING WITH WIND ELECTRICITY	X(10)=	0 00
11.	DOMESTIC LIGHTING WITH HYDRO-ELECTRICITY	X(11)=	0 00
12.	DOMESTIC HEATING WITH BIOGAS	X(12)=	400.00
13.	DOMESTIC HEATING WITH BIO-ELECTRICITY	X(13)=	0 00
14.	DOMESTIC HEATING WITH SOLAR ELECTRICITY	X(14)=	0 00
15	DOMESTIC HEATING WITH WIND ELECTRICITY	X(15)=	0 00
16	DOMESTIC HEATING WITH HYDRO-ELECTRICITY	X(16)=	0 00
17	DOMESTIC COOLING WITH BIO-ELECTRICITY	X(17)=	0 00
18	DOMESTIC COOLING WITH SOLAR ELECTRICITY	X(18)=	0 00
19	DOMESTIC COOLING WITH WIND ELECTRICITY	X(19)=	0 00
20	DOMESTIC COOLING WITH HYDRO-ELECTRICITY	X(20)=	40 00
21	COMMUNITY LIGHTING WITH BIOGAS	X(21)=	60 00
22	COMMUNITY LIGHTING WITH BIO-ELECTRICITY	X(22)=	0 00
23	COMMUNITY LIGHTING WITH SOLAR ELECTRICITY	X(23)=	0 00
24	COMMUNITY LIGHTING WITH WIND ELECTRICITY	X(24)=	0 00
25	COMMUNITY LIGHTING WITH HYDRO-ELECTRICITY	X(25)=	0 00
26	COMMUNITY HEATING WITH BIOGAS	X(26)=	100 00
27	COMMUNITY HEATING WITH BIO-ELECTRICITY	X(27)=	0 00
28	COMMUNITY HEATING WITH SOLAR ELECTRICITY	X(28)=	0 00
29	COMMUNITY HEATING WITH WIND ELECTRICITY	X(29)=	0 00
30	COMMUNITY HEATING WITH HYDRO-ELECTRICITY	X(30)=	0.00
31	COMMUNITY COOLING WITH BIO-ELECTRICITY	X(31)=	0 00
32	COMMUNITY COOLING WITH SOLAR ELECTRICITY	X(32)=	0 00
33	COMMUNITY COOLING WITH WIND ELECTRICITY	X(33)=	0 00
34	COMMUNITY COOLING WITH HYDRO-ELECTRICITY	X(34)=	25 00
35.	COMMUNITY COMMNS WITH BIOGAS	X(35)=	0 00
36	COMMUNITY COMMNS. WITH SOLAR ELECTRICITY	X(36)=	0 00
37	COMMUNITY COMMNS. WITH WIND ELECTRICITY	X(37)=	0 00
38	COMMUNITY COMMNS. WITH HYDRO-ELECTRICITY	X(38)=	15.00

OUTPUT SUMMARY II

THE PRIORITY ACHIEVEMENTS ARE

PRIORITY	TYPE	ACHIEVEMENT
1	MEET DAILY RURAL DEMANDS (KWH) (D-)	0 00
2	MINIMIZE TOTAL EXPENDITURE ($$)(D+) FIXED($000)	65.50
3	MINIMIZE UNDESIRABILITY INDEX (D+) FIXED(0000)	150 78
4	MINIMIZE OVER GENERATION (KWH) (D+)	0.00
5	MINIMIZE UNDER GENERATION (KWH) (D-)	320 00

THE GOAL ACHIEVEMENTS ARE

PRIORITY	GOAL NUMBER	OVER ACHIEVEMENT	UNDER ACHIEVEMENT
1	1	0 00	0 00
1	2	0 00	0 00
1	3	0 00	0 00
1	4	0 00	0 00
1	5	0 00	0 00
1	6	0 00	0 00
1	7	0 00	0 00
1	8	0 00	0 00
2	9	65 50	0.00
3	10	150 78	0 00
4	11	0 00	0 00
4	12	0 00	0.00
4	13	0 00	0 00
4	14	0 00	0 00
4	15	0.00	0 00
4	16	0 00	0 00
5	17	0 00	0 00
5	18	0 00	240.00
5	19	0.00	0 00
5	20	0.00	0.00
5	21	0 00	0 00
5	22	0 00	80 00

OUTPUT SUMMARY III

SUBSCRIPT	VARIABLE NAME	X OPT	POS DEV	NEG DEV
1	DOMESTIC COOKING WITH BIOGAS	350 00	0 00	0 00
2	DOMESTIC COOKING WITH BIO-ELECTRICITY	0.00	0 00	0.00
3	DOMESTIC COOKING WITH SOLAR ELECTRICITY	0.00	0.00	0.00
4	DOMESTIC COOKING WITH SOLAR THERMAL	0 00	0 00	0.00
5	DOMESTIC COOKING WITH WIND ELECTRICITY	0.00	0.00	0 00
6	DOMESTIC COOKING WITH HYDRO-ELECTRICITY	0.00	0 00	0.00
7	DOMESTIC LIGHTING WITH BIOGAS	75.00	0.00	0.00
8.	DOMESTIC LIGHTING WITH BIO-ELECTRICITY	0 00	0.00	0.00
9	DOMESTIC LIGHTING WITH SOLAR ELECTRICITY	0.00	65.50	0.00
10	DOMESTIC LIGHTING WITH WIND ELECTRICITY	0 00	150.75	0.00
11	DOMESTIC LIGHTING WITH HYDRO-ELECTRICITY	0 00	0.00	0.00
12	DOMESTIC HEATING WITH BIOGAS	400.00	0.00	0.00
13	DOMESTIC HEATING WITH BIO-ELECTRICITY	0.00	0.00	0.00
14	DOMESTIC HEATING WITH SOLAR ELECTRICITY	0 00	0 00	0 00
15	DOMESTIC HEATING WITH WIND ELECTRICITY	0.00	0 00	0 00
16	DOMESTIC HEATING WITH HYDRO-ELECTRICITY	0 00	0.00	0 00
17	DOMESTIC COOLING WITH BIO-ELECTRICITY	0 00	0 00	0 00
18.	DOMESTIC COOLING WITH SOLAR ELECTRICITY	0 00	0 00	240.00
19	DOMESTIC COOLING WITH WIND ELECTRICITY	0 00	0 00	0 00
20	DOMESTIC COOLING WITH HYDRO-ELECTRICITY	40 00	0 00	0 00
21	COMMUNITY LIGHTING WITH BIOGAS	60 00	0 00	0 00
22	COMMUNITY LIGHTING WITH BIO-ELECTRICITY	0 00	0 00	80 00
23.	COMMUNITY LIGHTING WITH SOLAR ELECTRICITY	0 00	0 00	0 00
24	COMMUNITY LIGHTING WITH WIND ELECTRICITY	0 00	0 00	0 00
25	COMMUNITY LIGHTING WITH HYDRO-ELECTRICITY	0 00	0 00	0 00
26	COMMUNITY HEATING WITH BIOGAS	100 00	0 00	0 00
27	COMMUNITY HEATING WITH BIO-ELECTRICITY	0 00	0 00	0 00
28	COMMUNITY HEATING WITH SOLAR ELECTRICITY	0 00	0 00	0 00
29	COMMUNITY HEATING WITH WIND ELECTRICITY	0 00	0 00	0 00
30.	COMMUNITY HEATING WITH HYDRO-ELECTRICITY	0 00	0 00	0.00
31	COMMUNITY COOLING WITH BIO-ELECTRICITY	0 00	0 00	0.00
32.	COMMUNITY COOLING WITH SOLAR ELECTRICITY	0 00	0 00	0 00
33	COMMUNITY COOLING WITH WIND ELECTRICITY	0 00	0 00	0 00
34	COMMUNITY COOLING WITH HYDRO-ELECTRICITY	25 00	0 00	0 00
35	COMMUNITY COMMNS WITH BIOGAS	0 00	0 00	0 00
36.	COMMUNITY COMMNS. WITH SOLAR ELECTRICITY	0 00	0 00	0.00
37.	COMMUNITY COMMNS WITH WIND ELECTRICITY	0' 00	0 00	0 00
38.	COMMUNITY COMMNS. WITH HYDRO-ELECTRICITY	15 00	0.00	0 00

VITA 2

Mushti Visweswara Lakshminarayana Prasad

Candidate for the Degree of

Master of Science

Thesis: ENERGY MANAGEMENT MODEL FOR RURAL AREAS - A MULTIPLE CRITERIA DECISION MAKING APPROACH

Major Field: Industrial Engineering and Management

Biographical:

Personal Data: Born in Hospet, Bellary district, Karnataka (India), April 8, 1955, the son of Sri Mushti Ramakrishna Rao and Srimati Subbalakshmi.

Education: Basic schooling at Children's Montessori School, Vijayawada, A.P; passed S.S.C from Saint Mary's High School, Secunderabad, A.P, 1969; passed Intermediate from Railway Junior College, Secunderabad, 1971; received Bachelor of Engineering in Electronics & Communications Engineering from Manipal Institute of Technology, University of Mysore, 1977; completed the requirements for the degree of Master of Science at Oklahoma State University in May, 1984.

Professional Experience: Systems Engineer, Indian Space Research Organization, Sriharikota, India, 1978-81; graduate teaching assistant, School of Industrial Engineering and Management, Oklahoma State University, 1982; Systems analyst/Programmer, Economic Research and Statistical Analysis Service, U.S. Department of Agriculture, Oklahoma State University, 1983.

Professional Organizations: Student member- American Institute of Industrial Engineers; American Institute of Decision Sciences; Institute of Electrical and Electronic Engineers.