

SYSTEMS PLANNING IN THE RURAL ENERGY SECTOR

by
C. SUBHASH

**A THESIS SUBMITTED IN FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY**



**Centre for Energy Studies
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
AUGUST, 1988**

C E R T I F I C A T E

This is to certify that the thesis entitled, ^{*} "PLANNING AND MANAGEMENT OF RURAL ENERGY SYSTEMS" which is being submitted by Mr.C.Subhash to the Indian Institute of Technology, Delhi for the award of the Degree of Doctor of Philosophy, is a record of bonafide research work carried out by him. He has worked under our supervision and has fulfilled the requirements for the submission of this thesis, which has attained the standard required for a Ph.D. degree of this Institute. The results presented in this thesis have not been submitted elsewhere for the award of any other degree or diploma.

<i>D.P. Kothari</i>	<i>V. Gautam</i>	<i>P.S. Satsangi</i>
(D.P.KOTHARI)	(V.GAUTAM)	(P.S.SATSANGI)
Professor	Professor	Professor
Centre for	Centre for	Dept. of Electrical
Energy Studies	Management Studies	Engineering

INDIAN INSTITUTE OF TECHNOLOGY, DELHI

NEW DELHI

August 4, 1988

* As suggested by the External Examiner, the thesis title has been changed to "SYSTEMS PLANNING IN THE RURAL ENERGY SECTOR".

To

R.S., P.S.S., & J.R.

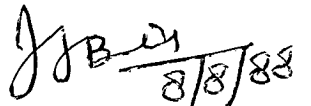
ACKNOWLEDGEMENTS

Words are just inadequate to express my deep gratitude for the sustained encouragement and invaluable guidance so readily provided by my supervisors Professors Dr.P.S.Satsangi, Dr.D.P.Kothari and Dr. V.Gautam, throughout the course of this work in showing this thesis the light of the day. They have indeed been more than generous in sparing their most valuable time by way of their stimulating discussions and useful guidance at every stage of this investigation.

I deem that it was my proud privilege to work with Professor PREM S.SATSANGI, a luminary and an internationally known authority in the area of Applied Systems Analysis. HE has been THE principal force behind this entire work. HIS vast experience and realistic approach towards the work in particular and life in general have been of immense help to me in perceiving new ideas in their proper perspectives.

I am also grateful to Mr L.M.Chelpa and Mr.A.Ramachandran for their physical and moral support particularly during the last phase of this work.

I shall be failing in my duty, if I do not record the support and encouragement provided by my mother Smt. Jamni Bai, wife Harsh, son Bhaskar and daughter Gaurvi throughout the course of this work.


C. Subhash

ABSTRACT

Systems thinking is holistic in nature and provides scope for integration of various techniques for analyzing large and complex systems. One of the prime perceived needs is to develop a viable and optimal perspective plan for a region such as the Fatehpur village-cluster in the Nainital district of U.P. from a basis of field survey studies.

Both quantitative and qualitative systems analysis techniques are required to investigate viable policy options in the context of rural energy systems at a micro-level with implications for macro policy planning.

It becomes imperative to study the emerging national scenarios also since the policy at the micro-level is directly influenced by the decisions at the macro-level. The research investigations reported in the thesis are therefore at both the levels, viz. (i) macro-level, and (ii) the micro-level of a village-cluster.

While the qualitative technique of Delphi study finds application in Energy Technology Characterizations for India, the secondary energy supply scenarios for India and the select rural village-clusters have been developed through the quantitative trend extrapolation technique. Also, the quantitative technique of Kalman filtering has been used to formulate and simulate a stochastic dynamic model of three sector energy-economy system of India. Energy-economy planning perspectives for the Fatehpur village-cluster are based on Leontief's input-output (I/O) framework at the level of six major sectors, viz. agriculture, livestock, industry, forestry, commerce and household.

Mixed integer programming technique has been successfully used for optimizing I/O coefficients for the horizon year as well as developing an integrated optimal energy plan for the Fatehpur village-cluster. Load forecasting and load scheduling has been attempted for the end-use of household cooking based on the concept of unit committment using a simple "merit order" approach.

Qualitative systems analysis techniques such as Idea Engineering, Fuzzy Sets, Delphi Study, Harva Method and Metagame Analysis find applications in the context of energy futures research investigations pertaining to the Fatehpur Village-cluster. The issues of policy implications and associated management strategy for implementation have been addressed in the context of perspective planning for energy for the selected region.

TABLE OF CONTENTS

CERTIFICATE
ACKNOWLEDGEMENTS
ABSTRACT

	page no.
CHAPTER-I	
I INTRODUCTION ...	1-32
I.1 Context of Need ...	1
I.2 Historical Perspective ...	5
I.3 State-of-the-Art of Energy Modelling ...	7
I.4 Energy Surveys ...	11
I.5 Pertinent Review of Literature ...	15
I.6 Salient Features of the Rural Economy of the Fatehpur village cluster ...	21
CHAPTER-II	
II ENERGY TECHNOLOGY CHARACTERIZATIONS ...	33-44
II.1 Introduction ...	33
II.2 Details of the Delphi Study ...	35
II.3 Results ...	39
II.4 Conclusions ...	41
CHAPTER-III	
III SECONDARY ENERGY SUPPLY SCENARIOS ...	45-59
III.1 Introduction ...	45
III.2 Approach ...	47
III.3 Methodology ...	47
III.4 Data ...	49
III.5 Scenario Constructs ...	49
III.6 Discussion ...	53
III.7 Conclusions ...	54

CHAPTER-IV

IV	STOCHASTIC MODELLING OF AN INTER- CONNECTED NATIONAL ENERGY-ECONOMY SYSTEM	...	60-85
IV.1	Introduction	...	60
IV.2	Kalman Filtering Technique	...	63
IV.3	Parameter Estimation Using Kalman Filter	...	66
IV.4	Extended Kalman Filter	...	68
IV.5	Dynamic Input-Output Economic Models	...	70
IV.6	Data Collection	...	72
IV.7	Discussion of Results	...	76
IV.8	Conclusions	...	80

CHAPTER-V

V	ENERGY DEMAND FORECAST FOR THE FATEHPUR VILLAGE CLUSTER	...	86-100
V.1	Introduction	...	86
V.2	Forecasting Methodology	...	87
V.2.1	Technological Constraints	...	88
V.2.2	Supply Demand Constraints	...	88
V.2.3	Objective Function	...	89
V.2.4	Optimal Input-Output Coefficients	...	89
V.3	Energy Demand Forecast for the Productive Sectors of the Economy	...	91
V.4	Domestic Energy Demand Forecast	...	91
V.5	Energy Demand Forecast by End-use	...	92
V.6	Conclusions	...	94

CHAPTER-VI

VI	QUALITATIVE SYSTEMS ANALYSIS IN PLANNING OF RURAL ENERGY SYSTEMS	...	101-138
VI.1	Introduction	...	101
VI.2	Idea Engineering Approach	...	103

VI.3	Fuzzy Set Analysis	...	106
VI.3.1	Data Collection	...	107
VI.3.2	Methodology and Analysis	...	108
VI.4	Harva Scenario Building Studies	...	112
VI.4.1	Team 1	...	113
VI.4.2	Team 2	...	116
VI.4.3	Team 3	...	119
VI.4.4	Team 4	...	122
VI.5	Two-Round Delphi Study	...	125
VI.5.1	Population	...	126
VI.5.2	Energy Demand	...	126
VI.5.3	Energy Supply	...	128
VI.5.4	Ecological Environment	...	132
VI.5.5	Miscellaneous Aspects	...	133
VI.6	Conclusions	...	134

CHAPTER-VII

VII	ENERGY MODEL COMPARISONS	...	139-158
VII.1	Introduction	...	139
VII.2	Idea Engineering Approach	...	140
VII.3	Harva Scenario Building Studies	...	142
VII.4	Delphi Study	...	142
VII.5	Fuzzy Set Analysis	...	143
VII.6	Metagame Analysis	...	146
VII.7	Conclusions	...	153

CHAPTER-VIII

VIII	LONG-TERM PROGRAMMING MODEL FOR INTEGRATED RURAL ENERGY PLANNING AND TECHNO-ECONOMIC FEASIBILITY ANALYSIS	...	159-191
VIII.1	Introduction	...	159
VIII.2	Programming Structure	...	162
VIII.3	Data for the Model	...	165
VIII.3.1	Energy Demand Projection	...	165
VIII.3.2	Energy Supply Scenario	...	166

VIII.3.3	Energy Technology		
	Characterizations	...	170
VIII.4	Optimization Model Results	...	171
VIII.5	Techno-Economic Feasibility		
	Analysis	...	173
VIII.6	Conclusions	...	178
CHAPTER-IX			
IX	CONCLUSIONS AND FURTHER SCOPE OF		
	RESEARCH	...	192-202
IX.1	Introduction	...	192
IX.2	Conclusions	...	192
IX.3	Further Scope of Research	...	201
REFERENCES		...	203-209
APPENDICES		...	210-248
APPENDIX-1.	Delphi Technique	...	210
APPENDIX-2.	Delphi Questionnaire for Energy		
	Technology Characterizations	...	213
APPENDIX-3.	List of Participants in Delphi		
	Energy Technology Characterizations		
	Study	...	221
APPENDIX-4.	Select Energy Technology Characteristics		
	Used by Sarma (1986)	...	230
APPENDIX-5.	Optimal 'A' matrix for different ob.fn.	...	231
APPENDIX-6.	List of Harva Team Participants	...	232
APPENDIX-7.	Delphi Questionnaire	...	233
APPENDIX-8.	Metagame Analysis:		
	The Cookie Conflict	...	242
APPENDIX-9.	Response sheet for Fuzzy Set Analysis	...	248
ANNEXURE-I	Rural Energy Survey Methodology	...	249
ANNEXURE-II	Household Schedule	...	267
ANNEXURE-III	Location and Background of Nainital	...	274

LIST OF TABLES

<u>Table No.</u>		<u>.page no.</u>
1.1	Select Particulars of the Fatehpur village-cluster.	... 31
1.2	Domestic energy consumption in the Fatehpur village-cluster in 1980-81.	... 31
2.1	Energy Technologies Selected for Characterization	... 42
2.2	Energy Technology Characterization Summary Format	... 43
2.3	Second-Round Delphi Characterization Summary	... 44
3.1	Secondary Energy Supply scenarios.	... 56
3.2	Low Supply Scenario for Select Rural Clusters...	57
3.3	High Supply Scenario for the Select Rural Clusters.	... 58
3.4	Comparison of Electricity Supply Scenario with the Demand Projections of other Studies	... 59
4.1	Time series of GNP and the final demand vectors of ROE, NRE, and RE sectors.	... 82
4.2	Gross output vector of the three sector economy of India.	... 83
4.3	Changes in the coefficients of I/O matrix 'A'	... 84
4.4	Changes in the coefficients of capital coefficient matrix 'B'.	... 84
5.1	The input-output coefficient matrix 'A' for the Fatehpur village-cluster.	... 96
5.2	The optimal 'A' matrix for the year 2001.	... 97
5.3	Sector energy demand scenario for the year 2001.	... 98
5.4	Base year (1981) domestic energy consumption pattern for the Fatehpur village-cluster.	... 99
5.5	Energy demand scenarios for the domestic sector of Fatehpur village-cluster.	... 99

5.6	End-use-wise energy demand scenarios for the Fatehpur village-cluster for the year 2001	...	100
6.1	Base year (1981) energy consumption by the Household sector of the Fatehpur village-cluster in TCR.	...	135
6.2	Future Energy Demand Scenarios for the year 2001 assuming a population gr. rate of 2.1%	...	135
6.3	Energy Supply Scenarios (ESS) for the Fatehpur village-cluster to the year 2001.	...	136
6.4	Comparative Fuzzy Set Ranks of ESS for six different procedures of Aggregation.	...	138
7.1	Cases studied by various Futures Scanning methodologies.	...	154
7.2	State-of-the-art Indices for the Base Year	...	155
7.3	State-of-the-art Indices for the Target Year	...	155
7.4	Number of questions in the Delphi Studies.	...	156
7.5	Aggregate Matrix by Pessimistic Aggregation	...	157
7.6	Cost effectiveness ratios (CERS) for the Matrix in Table 7.5.	...	157
7.7	Composition of Energy Supply Scenarios.	...	158
8.1	Realistic optative energy demand scenario by end-use for the Fatehpur village-cluster for the year 2001.	...	179
8.2	Selected preferred secondary energy supply scenario for the Fatehpur village-cluster for the year 2001.	...	179
8.3	Selected preferred scenario of renewable energy supply for the target year 2001 for the Fatehpur village-cluster.	...	179
8.4	Energy Technology Variable Cost Characterizations.	...	180
8.5	Energy Technology Fixed Cost Characterizations	...	181
8.6	Energy Technology Characterizations: Annual Energy Flows.	...	182

8.7	Optimal technology mix for the Fatehpur village-cluster for the year 2001.	...	183
8.8	Feasible plan for the introduction of different Appliances for the end-use of Cooking.	...	184
8.9	Average Consumption of fuels in cooking Appliances in Fatehpur in 1981.	...	184
8.10	Anticipated consumption of fuels in cooking Appliances in 2001.	...	184
8.11	Daily Cooking Load for the Fatehpur village-cluster in the Base year 1981.	...	185
8.12	Daily Cooking Load for the Fatehpur village-cluster for the Target year 2001.	...	186
8.13	Operational cost per unit (kWhs) output of various cooking devices in Fatehpur.	...	187

.....

LIST OF GRAPHS

Graph-1	Time-series graph of GNP(197-71) ...	82a
Graph-2	Final Demand Vector of ROE ...	82a
Graph-3	Final Demand Vector of NRE ...	82b
Graph-4	Final Demand Vector of RE ...	82b

LIST OF FIGURES

<u>Figure No.</u>		page no.
1.	Energy Related Flow Diagram for the Fatehpur village-cluster (1981).	... 32
2.	Flow Diagram of Kalman-Bucy Filter for Discrete Time.	... 85
3.	Base year (Summer) Household Cooking Daily Load Curve in kWh output (1981).	... 188
4.	Base year (Winter) Household Cooking Daily Load Curve in kWh output (1981).	... 189
5.	Target year (Summer) Household Cooking Daily Load Curve in kWh output for 2001 A.D.	... 190
6.	Target year (Winter) Household Cooking Daily Load Curve in kWh output for 2001 A.D.	... 191

.....