

**A LINEAR GOAL PROGRAMMING MODEL FOR URBAN
ENERGY - ECONOMY - ENVIRONMENT INTERACTION IN
THE CITY OF DELHI**

by
RANJAN KUMAR BOSE
Department of Mathematics

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



**to the
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
APRIL 1990**

To my parents,

To my wife, and my brothers

CERTIFICATE


*This is to certify that the thesis entitled "A Linear Goal Programming Model for Urban Energy-Economy-Environment Interaction in the city of Delhi", which is being submitted by **Mr. Ranjan Kumar Bose** for the award of the degree, Doctor of Philosophy in Mathematics, to the Indian Institute of Technology, Delhi, is a record of bonafide research work carried out by him under our guidance and supervision.*

The thesis has reached the standard fulfilling the requirement of the regulation relating to the degree. The results obtained in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

Department of Mathematics
Indian Institute of Technology
Hauz Khas, New Delhi - 110 016

April 1990


N.S. Kambo


A. Nagabhushanam

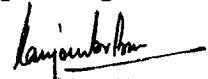
Acknowledgements

I take this opportunity to express my deep sense of gratitude to Prof. N.S.Kambo and Mr. A.Nagabhushanam for their constructive guidance, supervision and encouragement throughout this work. I am equally grateful to Dr. B.R.Handa for his enthusiastic cooperation, useful discussions and offer critical comments and suggestions at various stages.

I gratefully acknowledge Dr. R.K.Pachauri, Director, Tata Energy Research Institute (TERI), New Delhi, for suggesting me the subject of this thesis and for providing me necessary research facilities and support in TERI. He was always willing to discuss the problems and helped in evolving conceptual framework of the model. I am grateful to my colleagues in TERI during the course of this study for their friendly association. In particular, I wish to express my sincere thanks to my colleagues Mr. M.Karuppasamy for helping me in computer programming, Ms. S.Sengupta for editorial comments and Mr. T.P.Sankar who worked diligently in typing the report.

I will be failing in my duties if I don't gratefully acknowledge my parents and brothers who were the motivating source of inspiration and encouragement during the period of this work.

Finally, a special acknowledgement should be made to my wife, Lopa, for her continued help and encouragement in completing this work.


Ranjan Kumar Bose

CONTENTS

	Page
LIST OF TABLES	viii
LIST OF FIGURES	xiii
SYNOPSIS	xiv
CHAPTER 1 : INTRODUCTION	1
1.1 Background	1
1.2 Multiobjective Programming Approach for Sustainable Urban Energy Systems	7
1.3 Scope and Objectives of the Study	8
CHAPTER 2 : ENERGY SYSTEM MODELS - A METHODOLOGICAL OVERVIEW	11
2.1 Methods for Developing Energy Models	12
2.2 Review of Energy Studies	16
2.2.1 Energy models in the industrialized countries	16
2.2.2 Energy models in India	21
2.2.3 Urban energy studies	24
CHAPTER 3 : METHODOLOGY	27
3.1 Goal Programming	28
3.1.1 Goal formulations	30
3.1.2 Ranking or prioritizing multiple goals	31
3.1.3 Weighting within a priority Level	33

	Page
3.1.4 Mathematical structure of a general linear goal programming model	36
3.1.5 Steps in linear goal programming formulation and solution	37
3.2 Reference Energy System	38
3.3 Energy - Economy - Environment Interaction - An Energy Optimization Model for Delhi	39
3.4 The Mathematical Model	44
3.4.1 Constraints	52
3.4.2 Linear goal programming framework	56
3.4.3 Goal formulations	57
3.4.4 Prioritization of goal classes	60
3.4.5 Objective weighting within priority grouping	62
3.4.6 Objective function	63
CHAPTER 4 : DATABASE	69
4.1 Energy Units and Conversion Factors	70
4.2 Sectoral Energy Demand Analysis (EDA) - Method and Estimation	71
4.2.1 EDA in the domestic sector	71
4.2.2 EDA in the transport sector	92
4.2.3 EDA in the industrial sector	100
4.2.4 EDA in the services and commercial sector	108
4.3 Fuel Availability in Delhi	112

	Page
4.4 Energy Use and Environmental Effects : Atmospheric Air Pollution in Delhi	114
4.4.1 Estimation of pollutant loading	115
CHAPTER 5 : RESULTS OF SCENARIOS	132
5.1 Structure of the Data Input	134
5.2 Scenario Results	135
CHAPTER 6 : DISCUSSION AND CONCLUSIONS	176
6.1 Annual Mix of Fuels Across Scenarios	180
6.1.1 G_5 at P_2 and G_6 at P_3	186
6.1.2 G_6 at P_2 and G_5 at P_3	187
6.1.3 G_5 at P_2 and G_4 at P_3	189
6.1.4 G_4 at P_2 and G_5 at P_3	190
6.2 A Comparative Analysis Across Scenarios	191
6.2.1 Method of combined ranking across scenarios	191
6.3 Data Limitations	196
6.4 Practical Use of the Study Results	197
REFERENCES	201
APPENDIX I : A FORTRAN program for solving a LGP	212
APPENDIX II : Household schedule	224
APPENDIX III : Parameters of aspiration level	227

	Page
APPENDIX IV : Decision variables	228
APPENDIX V : Specifications of the data input	230
APPENDIX VI : Structure of the data input for Scenario 1	234
APPENDIX VII : Computer output of Scenario 1	256
 VITAE	 261