

ENERGY SYSTEMS AND POLICY PLANNING:

A Multi-Level Optimization Approach

By

S.M. NAZRUL ISLAM

B.A. Hons., M.A. Econ. First Class (Raj.), M.A.
Econ. (McMaster), LL.B. (Dhaka).

DEPARTMENT OF ECONOMICS

To be conferred 1993

Thesis submitted in fulfilment of the requirements for the degree
of Doctor of Philosophy, The University of Tasmania, Australia.

JULY, 1992

DECLARATION

I do hereby declare that the thesis contains no material which has been accepted for the award of any higher degree or graduate diploma in any tertiary institution and that, to the best of my knowledge and belief the thesis contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

S. M. NAZRUL ISLAM

ABSTRACT

ENERGY SYSTEMS AND POLICY PLANNING:

A Multi-level Optimization Study

The objective of this study is to formulate an optimum multi-level energy plan that can resolve the underlying energy policy issues and options and can, thus, deal with the energy sector problems.

The main hypothesis of this study is that since there exists a multi-(two) level policy making system in the energy sector (government and private sector decision making), the formulation of a multi-level energy plan should take into account the choices and decisions of these decision makers. To accomplish this, an optimum multi-level energy plan should be developed within a framework of a multi - level optimization approach (MLO).

To support the hypothesis, a theoretical energy planning model/approach is developed within the framework of (1) the theory of economic policy planning; (2) policy systems analysis; and (3) multi-level programming (MLP) (an operational multi-level optimization method).

On the basis of this theoretical model, an Australian Energy Policy System Optimization Model (AEPSOM) has been developed.

The Parametric Programming Search (PPS) algorithm has been developed in order to provide an alternative algorithm for solving MLP which was adopted to solve AEPSOM.

The MLO model has been used to formulate an Australian multi-level energy plan. The results of this study suggest that a reformulation of existing Australian energy policies is needed.

This study also draws a conclusion that an MLO approach can provide an operational methodology and a framework for optimum multi-level energy planning.

ACKNOWLEDGMENTS

Firstly, I would like to express my sincere appreciation to the anonymous examiners of the previous drafts of the thesis and my supervisor Dr. B. Felmingham. Their comments have helped enormously to improve the present version of the thesis.

I also thank the following persons for their comments on either the whole or a part of the thesis: Dr. J. J. Todd, Dr. B. Heijdra, Dr. N. Groenewold, Dr. T. Heaps, Dr. S. Rahman, Dr. V. Candler, Dr. D. James, Dr. R. E. Marks, Prof. N. Idrus, Mr. T. Musgrove, Dr. Paul Hoole, Dr. M. R. Chambers, Prof. H. F. Campbell, Dr. M. Jaforullah, Dr. M. Nkasu, Prof. J. Falk, Mr. B. Louman, and Dr. R. Egudo.

My gratitude also goes to the persons who provided editorial, and computational assistance to this thesis as well as to the typists in Hobart and in Lae and to the artist for drawing the graphs.

Prof. M. White, Head of the Department of Business Studies, the University of Technology, encouraged me to complete the revision of the thesis timely. I am indebted to him. Thanks are also extended to the University of Technology for providing the facilities for preparing the final draft of the thesis.

Last, but not least, is my hearty gratitude to my family members who had to bear an enormous amount of suffering caused by my separation from them to undertake this study. I do not know

whether anything can compensate their loss and forbearance due to my absence from them during this study.

July, 1992

S.M. Nazrul Islam
University of Technology
Papua New Guinea

CONTENTS

	Page Numbers
i. ABSTRACT	i
ii. ACKNOWLEDGEMENTS	iii
iii. CONTENTS	vi
iv. LIST OF TABLES	xiv
v. LIST OF FIGURES	xvi
 CHAPTER ONE. INTRODUCTION	 1
1.1 ENERGY PLANNING: MULTI-LEVEL ENERGY PLANNING: ENERGY SYSTEM AND POLICY PLANNING	 1
1.2 OBJECTIVES OF THE RESEARCH	5
1.3 PROPOSED METHODOLOGY	6
1.3.1 The MLO Approach	7
1.3.2 Justifications for an MLO Approach	8
1.4 CONSTRAINTS OF THE STUDY	11
1.5 PLAN OF THE THESIS	12
 CHAPTER TWO. TOWARDS A MULTI-LEVEL OPTIMIZATION APPROACH TO MULTI-LEVEL ENERGY PLANNING	 14
2.1 INTRODUCTION	14
2.2 MODEL EVALUATION CRITERIA	14
2.3 EXISTING ENERGY SECTORAL OPTIMIZATION MODELS	19
2.3.1 Static Optimization Models	19
2.3.1.1 Mathematical Programming Models	19
2.3.1.2 General Equilibrium (GE) Energy Models	21
2.3.2 Dynamic Optimization Energy Models	25
2.3.3 Hybrid Models	27
2.4 EVALUATION OF EXISTING ENERGY APPROACHES	28

2.4.1	Limitations of Existing Energy Planning Models/Approaches	29
2.4.1.1	Inappropriateness of the Methodologies (related to criterion 1)	29
2.4.1.2	Non-specification of Energy Policy Planning Problem (related to criterion 2)	36
2.4.1.3	Inadequate Set of Results (related to criterion 3)	37
2.5	AN ALTERNATIVE MODELLING APPROACH: MULTI-LEVEL OPTIMIZATION OF ENERGY SYSTEMS AND ENERGY POLICY	37
2.5.1	Arguments for an MLP Approach	38
2.5.2	Elements of the MLO Approach	38
2.5.2.1	The Theory of Economic Policy Planning	39
2.5.2.1.1	Analytical Framework	39
2.5.2.1.2	Definition of an Optimum Economic Policy	41
2.5.2.2	Policy Systems Analysis	43
2.5.2.3	Multi-level Programming	45
2.6	A MULTI-LEVEL OPTIMIZATION ENERGY MODEL	50
2.6.1	An Illustrative Representation of the Model	50
2.6.2	A Discussion of the Model	52
 CHAPTER THREE. A MULTI-LEVEL OPTIMIZATION ENERGY PLANNING MODEL FOR AUSTRALIA		 53
3.1	INTRODUCTION	53
3.2	THE AUSTRALIAN ENERGY SECTOR: THE CONTEXT FOR ENERGY PLANNING AND MODELLING IN AUSTRALIA	54
3.2.1	Energy Resources: Supplies and Consumption	55
3.2.2	Prospects for the Energy Sector: Justifications and Initiations of Energy Policies and Modelling in Australia	56
3.2.2.1	Prospects for the Energy Sector	56
3.2.2.2	Why Energy Policies for Australia	57
3.2.2.3	Institutional Aspects	60

3.2.2.4	Energy Planning Modelling in Australia	61
3.3	THE AUSTRALIAN ENERGY PLANNING MODEL - AEPSOM: SOME PRELIMINARIES	63
3.4	AEPSOM: MODEL SPECIFICATION	70
3.4.1	A Policy Objective Function (P.O.F.)	71
3.4.1.1	Specification of Policy Objective Function	71
3.4.1.2	Alternative Methods of Specifying the Policy Objective Function	72
3.4.1.3	Functional Form	72
3.4.1.4	Variables in the Objective Function	76
3.4.1.4.1	The Objectives of the Australian Energy Policies	76
3.4.1.4.2	Quantification and Incorporation of the Energy Policy Objectives in the Model/Policy Objective Function	86
3.4.1.5	The Weights of the Policy Target Variables	87
3.4.1.6	Units of Measurements	91
3.4.1.7	The Policy Objective Function: Specification 1	91
3.4.1.8	The Policy Objective Function: Specification 2	92
3.4.1.9	The Policy Objective Function: The Economic Perspective	95
3.4.2	The Constraints of the Model	97
3.4.2.1	Policy Constraints	98
3.4.2.2	Behavioural Constraints: The Energy System Model	100
3.5	AEPSOM POLICY VARIABLES	111
3.6	AEPSOM: COMPLETE DESCRIPTION. MODEL SOLUTION OUTPUT AND DATA	113
3.6.1	A Complete Description of AEPSOM	113
3.6.2	Data	114
3.7	SUMMARY	115

CHAPTER FOUR. MLP SOLUTION ALGORITHM: THE PARAMETRIC PROGRAMMING SEARCH APPROACH.	116
4.1 INTRODUCTION	116
4.2 DEFINITIONS	118
4.3 PARAMETRIC PROGRAMMING SEARCH ALGORITHM	126
4.4 MLP SOLUTION BY THE PPS ALGORITHM	132
4.4.1 MLP Solution and its Proof	132
4.4.2 Economic Interpretations of MLP Solution by the PPS Algorithm	136
4.4.3 Mathematical Properties of the MLP Solution	138
4.5 AN ALTERNATIVE SPECIFICATION OF A MLP MODEL	140
4.6 SOME ISSUES IN USING THE PPS ALGORITHM	141
4.7 A SUMMARY OF THE ALGORITHM STEPS	148
4.8 SOFTWARE	150
4.9 USE OF PPS ALGORITHM IN DIFFERENT TYPES OF POLICY STUDIES	152
4.10 ADVANTAGES AND LIMITATIONS OF THE PPS ALGORITHM	152
4.10.1 Advantages	152
4.10.2 Limitations	154
4.11 SUMMARY AND CONCLUSION	155
 CHAPTER FIVE. THE RESULTS OF THE AUSTRALIAN ENERGY PLANNING MODEL	 157
5.1 INTRODUCTION	157
5.2 AEPSOM SOLUTIONS AND OUTPUT	157
5.2.1 Model	157
5.2.2 Solution	160
5.2.3 Optimum Solution	161
5.2.4 Output	162
5.2.5 Uses of Results for Energy Planning	163

5.2.6	Two Types of Model Specifications	168
5.2.7	Three Types of Units of Parametric Variations	168
5.2.8	Two types of Policy Studies	168
5.3	PRESENTATION AND DISCUSSIONS OF THE AEPSOM RESULTS	169
5.3.1	Some Elements of the Numerical Policy System	171
5.3.1.1	The Policy Objective Function	171
5.3.1.2	The Values of the Behavioural Objective Function	173
5.3.1.3	A Multi-level Policy System Analysis	176
5.3.2	Appropriateness of the AEPSOM Results	179
5.3.3	Taxes and Subsidies	181
5.3.4	Prices	181
5.3.5	Shadow Prices	188
5.3.6	Optimum Activities	188
5.3.7	Reduced Costs	190
5.4	SENSITIVITY ANALYSIS	195
5.5	RELIABILITY OF THE RESULTS: MODEL VALIDATION	203
5.6	CONCLUSION	213
CHAPTER SIX.	AN AUSTRALIAN OPTIMUM MULTI-LEVEL ENERGY PLAN	215
6.1	INTRODUCTION	215
6.2.	AN OPTIMUM ENERGY SYSTEM PLAN	216
6.3	OPTIMUM ENERGY POLICIES	219
6.3.1	Taxes and Subsidies	220
6.3.2	Pricing Policy	224
6.3.3	Depletion Policy	230
6.3.4	Exploration Policy	235
6.3.5	Conservation Policy	237
6.3.6	Education and Propaganda Policy	239

6.3.7	Research and Development Policy	241
6.3.8	Energy Technology Policy	243
6.4	AN ENERGY POLICY PLAN FOR AUSTRALIA	246
6.4.1	Australian Energy Policy Objectives	247
6.4.2	A Set of Optimum Energy Policy Instruments and Strategies	247
6.4.3	Effectiveness of Suggested Energy Policy Instruments and Strategies	249
6.5	CONCLUSION	254

CHAPTER SEVEN. MAJOR FINDINGS: SUMMARY, LIMITATIONS, AREAS FOR FURTHER RESEARCH AND CONCLUSIONS 255

7.1	SUMMARY AND OVERVIEW	255
7.1.1	Background: Problems, Issues and Policy Modelling	255
7.1.2	MLO Approach: Justification and Theoretical Formulation.	256
7.1.3	The Australian Model: AEPSOM	258
7.1.4	Solution Algorithm: The PPS Approach	260
7.1.5	Results: Validation Tests and Policy Implications	261
7.2	LIMITATIONS	262
7.3	AREAS FOR FURTHER RESEARCH	263
7.4	CONCLUSIONS	264

SELECTED BIBLIOGRAPHY 269

APPENDIXES

A. A SURVEY OF THE DEVELOPMENTS IN MLP: DIRECTIONS FOR FURTHER DEVELOPMENTS	281
A.1 CURRENT STATE OF MLP DEVELOPMENTS	289
A.1.1 Model Development and Application	289
A.1.2 Solution Algorithms	291
A.2 CRITICAL EVALUATION AND THE DIRECTIONS FOR FURTHER RESEARCH	294
B. SOME ADDITIONAL TOPICS OF THE PROPOSED MLO MODEL	296
B.1 SOME FEATURES OF THE PRESENT ENERGY PLANNING STUDY/APPROACH	296
B.2 CHARACTERISTICS OF MULTI-LEVEL DECISION MAKING: SOME ANALYTICAL RESULTS	301
C. AEPSOM DATA: SOURCES AND METHODS OF ESTIMATION	305
C.1 A DISCUSSION OF THE GENERAL ASPECTS	305
C.2 DATA FOR AEPSOM	305
C.2.1 Policy Objective Function	305
C.2.2 Policy and Budgetary Constraints	306
C.2.3 Behavioural Objective Function	306
C.2.4 The Behavioural Constraints	311
C.3 METHODS AND PRINCIPLES OF ESTIMATION AND/OR AGGREGATION OF DATA IN AEPSOM	314
D. SOME ADDITIONAL TOPICS ON THE PPS ALGORITHM	315
D.1 EXISTENCE AND UNIQUENESS PROBLEM	315
D.2 APPLICATION OF THE PPS ALGORITHM TO DIFFERENT TYPES OF MLP	318
D.2.1 Solution to a Resource Control MLP	319
D.2.2 Solution to a Price Control and Resource Control MLP	325
D.2.3 Solution to a Dynamic MLP	327
D.2.4 Solution to an MLP having a Non-linear Behavioural Model	329

D.3	A FORMULA FOR EXTENDING THE PARAMETRIC SEARCH	331
E.	THE POLICY PROGRAMME: THE FIRST SUB-PROGRAMME FOR FINDING AN MLP SOLUTION	333
F.	A COMPLETE LIST OF AEPSOM SOLUTIONS	338
F.1	A LIST OF MODEL SPECIFICATIONS AND SOLUTIONS	338
F.2	THE POLICY OBJECTIVE FUNCTION	347
G.	THE 1989-90 AEPSOM FOR SENSITIVITY STUDY	349
G.1	AEPSOM: 1989-90 - MODEL SPECIFICATION	349
G.1.1	Preliminaries	349
G.1.2	Specification of AEPSOM	349
G.1.3	Output of AEPSOM: 1989-90	354
G.2	DATA FOR AEPSOM: 1989-90	354
H.	PUBLICATIONS FROM THIS RESEARCH WORK	360

LIST OF TABLESPage numbers

Table 4.1	Determination of Optimum Mix of Taxes and Subsidies.	147
Table 5.1.	Optimum Model solutions.	170
Table 5.1.	(Appendix) List of Model Activities	.
Table 5.2.	Levels of Parametric Variations and the Values of the Policy Objective Functions.	172
Table 5.3.	Optimum Values of the Behavioural and Policy Objective Functions.	174
Table 5.4.	Different Values of θ and Three Objective Functions.	175
Table 5.5.A.	Optimum Mix and Levels of Taxes and Subsidies: 1979-80.	182
Table 5.5.B.	Existing and Optimum Set of $\pm T$.	183
Table 5.5.A.	(Appendix)	184
Table 5.6.A	Optimum Energy Prices in 1979-80 : Model No. 5	186
Table 5.6.B	Optimum Energy Prices in 1979-80 : Model No. 6	187
Table 5.7.A.	Proportion of Shadow Prices: 1979 - 1980.	189
Table 5.7.B	Shadow Prices Related to Different Demand Constraints (r)	189
Table 5.8.A	Optimum Activities: 1979-1980 (PJ).	191
Table 5.8.B	Optimum Activities: 1979-1980 (PJ).	192
Table 5.9.A	Reduced Costs: 1979-1980.	193
Table 5.9.B	Reduced Costs: 1989-1990.	194
Table 5.10	Different Weights to the Two Parts of P.O.F.(2).	201
Table 5.11.	Sensitivity of the Optimum Solution to Different Weights in the Policy Objective Function.	202
Table 5.12.	Comparison of Different Model Solutions	210

Table C.1. Supply Costs of Energy.	306
Table C.2. Costs of Conversion Technologies.	307
Table C.3. Delivery Costs of Energy.	308
Table C.4. Boiler Costs.	309
Table C.5. Investment, and Operation and Maintenance Costs of Other Energy in the Manufacturing Industry Sector.	309
Table C.6. Heavy Mobile Plant Costs.	310
Table C.7. Investment, and Operation, and Maintenance Costs of the End-uses of Energy in the Transport Sector.	310
Table C.8. Investment, and Operation and Maintenance Costs of Energy uses in the Domestic Sector.	311
Table C.9. Energy End-Uses: 1979-80.	311
Table C.10. Efficiencies of Different Technologies.	312
Table C.11. Primary Energy Resources: 1979-80.	313
Table C.12. Capacities of Different Technologies 1979-80.	313
Table F.1.A A List of Model Specifications and Solutions - Base Solutions: (without policy constraints)	339
Table F.1.B Results: Single Level Model Solutions	340
Table F.1.C Results: Sensitivity Analysis: Existing $\pm T$.	341
Table F.1.D Results: Sensitivity Analysis: Optimum $\pm T$.	343
Table F.1.E Alternative Model Solutions : AEPsOM with Policy Constraints (Feasible Optimum Solution)	344
Table G.1. Increase in the Costs of Primary Energy.	355
Table G.2. Increases in the Costs of Conversion Technologies.	355
Table G.3. Cost of New Technologies.	355
Table G.4. Increases in the Cost of End-use Technologies.	356
Table G.5. End-uses of Energy 1989-90.	357
Table G.6. Efficiencies of Different Technologies: 1989-90.	358
Table G.7. Primary Energy Resources: 1989-90.	358
Table G.8. Capacities of Different Technologies	358

LIST OF FIGURES

	<u>Page Number</u>
Figure 3.1 Australian Energy System 1979-80.	102
Figure 4.1 Solution of a Parametric Programming Problem.	122
Figure 4.2 Choice of an Optimum Parametric Variation Level.	129
Figure 4.3 Search in the Entire Policy Behavioural Region.	144
Figure 5.1 Values of the Target Variables.	177
Figure D.1 PPS Algorithm Solution of Resource Control MLP.	322
Figure G.1 Australian Energy System 1989-90.	351

CHAPTER ONE

INTRODUCTION

1.1 ENERGY PLANNING: MULTI-LEVEL ENERGY PLANNING - ENERGY SYSTEM AND POLICY PLANNING

Events in the world energy¹ market since the beginning of the 1970s to the present time including the Iranian oil embargo and the dramatic oil price increases, and the heavy dependence of modern economies on energy have created an increased awareness of the economic consequences of energy problems such as imported inflation, unemployment, recession, the finite nature of fossil fuels, and national security (Mork [1981], Munasinghe and Schramm [1983], Webb and Ricketts [1980]). It has been argued that these energy problems are the manifestations of market failures (Griffin and Steele [1980]) in ensuring the allocation of resources in a socially desirable pattern.

A long standing result from classical economics is geared for the establishment of the thesis that a market economy through competitive equilibrium ensures the most efficient allocation of

1. Energy is the power to do things. In this study the following forms of energy : potential, kinetic, heat, chemical, electrical radiant, and nuclear which are produced from common sources such as crude oil, coal, natural gas, etc. are considered (Harder [1982]). Energy from such sources as human and animal muscles are not included.

resources¹ (Debreu [1959]) judged by the Pareto optimality criterion (Pareto [1971]): No one can be made better off without making some one worse off.

In reality markets may fail to allocate resources in an optimum manner (market failures). There are several reasons for which market failure may occur (Bator [1958]): externalities (economies and diseconomies), incomplete or non-existence of energy markets, existence of monopolistic elements, the public goods and merit goods character of energy, government ownership, and the existence of a social contract for fair distribution of income and wealth (Webb and Ricketts [1980]). These market failures provide an economic rationale for the formulation of energy plans².

For either pragmatic or ideological reasons, almost every nation has initiated the formulation of energy plans (Meier [1984], Stancescu [1985], and Munashinghe and Schramm, [1983]) to

1. A historical account of different views on the efficiency of different economic systems may be seen in Blaug [1985], Oser and Brue [1988].

2. Because of these market failures and the resultant problems in the energy sector, a number of issues and options has developed in the energy policy area. Some of these policy issues relate to short-term adjustments in the energy market (in the form of supply, demand, input and price controls), an appropriate pricing and depletion of energy resources, conservation of energy, inter-fuel substitution, energy import independence, determination of appropriate tax regime in the energy sector, long-term adjustment in the economy etc. (A comprehensive discussion on these issues and options and their resolution will be provided in Chapter Six.)

The development of these issues necessitates the formulation of an energy plan that can resolve these issues in the pursuit of solving energy problems.

accommodate energy problems. An energy plan¹ may involve energy (systems) planning² and/or policy (system) planning. Energy planning involving both energy systems and policy planning can be defined as multi-level (two-level) energy planning: The upper level of this plan involves the formulation of a set of government optimum energy policies (energy policy planning) while at lower level an optimum plan of the sector or economic agents is specified which is referred to as energy systems planning. Thus in a developed market economy context, multi-level energy planning generates (a) an energy policy plan of the government (a set of policies) and (b) an optimum energy system reflecting the optimum decisions of economic agents³.

While previous multi-level planning studies have considered the interrelationships between macro and sectoral planning problems, the present multi-level planning approach recognizes the existence of multi-level decision making within a sector. The relevance of previous multi-level procedures and the case for the

1. Energy planning may be defined as a process of influencing the energy sector resource allocation, directly or indirectly, by manipulation of the coefficients and variables of the energy system or by using a set of instruments such as taxes and subsidies, so that the energy sector performs in the directions consistent with the preferences of the policy makers.

In this study, energy policy and energy planning are used synonymously.

2. Energy systems planning refers to the determination of a set of energy sector activities (supplies, production, uses etc.) judged to be efficient by some criteria such as minimum cost, and maximum net social surplus (Munasinghe and Schramm [1983]). Energy policy planning involves the formulation of a set of optimum energy policies that will optimize the objective function of the policy makers (Tinbergen [1952]) and resolve the underlying policy issues.

3. Unless otherwise mentioned, energy planning will mean energy system planning or energy policy planning or both in this study.

present multi-level planning approach have been summarized as follows (Hazell and Norton [1986], p.321):

"In most cases of policy planning in market economies, macro and sector policy deliberations are not closely enough linked to benefit from such procedures. But at the sector level itself there is a two-level problem....The two levels are (1) the decentralized level of producer and consumer decisions..... and (2) the policy choice level, at which decisions are made on policy instruments."

The rationale for the formulation of multi-level energy planning follows from the real world market failures common in the energy sector, and the concern for the attainment of societal objectives. Government intervention in these conditions is justified as a means for achieving the efficient allocation of resources among other societal objectives. However major economic decisions in a market (mixed) economy are undertaken by individual economic agents, while government policy decisions influence the behaviour of economic agents. Therefore, an energy sector in a market economy is characterized by the existence of a two-level hierarchical decision making system. There are two types of decision makers: policy makers (the government) and the economic agents (producers and consumers). These decision makers attempt to optimize their goals (optimizing behaviour) subject to constraints and their decisions are interrelated. The goals of individual decision makers at various levels are rarely consonant, and intervention is usually justified by this inconsistency. The policy makers can control the actions of the economic agents by some direct controls, such as import control, price fixation etc., or indirect controls such as taxes and subsidies, and policies which encourage expenditures for research and development.

Decision making in the energy sector may be viewed as hierar-

chical. The policy makers (the upper level decision makers), announce their policy measures first. Then the economic agents in the energy sector (the lower level decision makers) choose their optimum actions. On the basis of the reactions of economic agents to policy announcements, the policy makers choose their optimum policy.

The overall performance of the energy sector (resource allocation and consumption) depends on the decisions of both these decision makers, and the achievement of the government's economic policy objectives depends on the reactions of the economic agents to the policy measures announced by the government. Therefore, decisions of the government and economic agents are interdependent in the following sense: optimum decision of any of them cannot be formulated separately; and a multi-level energy plan is appropriate since such a plan can incorporate the interdependent plans of different decision makers at different levels in the multi-level hierarchical policy system.

Models help the co-ordination of data necessary for energy planning, the construction of future scenarios, and the formulation of efficient and effective policy instruments (see James [1983], pp. 2-3). Because of the roles that models play in energy planning, it is now established practice to use a model to undertake any type of responsible energy planning study.

1.2 OBJECTIVES OF THE RESEARCH

The objective of this research is to formulate a multi-level (quantitative) optimum energy plan. In the process, this study

will endeavor to achieve the following sub-objectives:

(1) to evaluate the suitability of existing energy planning approaches/models for multi-level energy planning,

(2) to formulate a multi-level energy plan by adopting a multi-level optimization (MLO)¹ approach to energy planning (based on the structure of multi-level programming (MLP²), the theory of economic policy planning (Tinbergen, [1952]) and of policy system analysis (Mesarovic, et al. [1973])), and

(3) to explore the implication of this energy plan for a market economy.

1.3 PROPOSED METHODOLOGY

A multi-level optimization approach is developed to formulate a multi-level energy plan that can resolve the underlying policy issues and options and can provide a set of comprehensive energy policies. The essential elements of the approach and its justifications are discussed below.

1. For a definition of optimization see Skrapek et al. [1976]. MLO may be defined as a process of obtaining the optimum (choosing the best alternative/option) solution (maximum social welfare, minimum cost, etc.) to a problem involving several decision making sub-problems at different levels of decision making and represented by a mathematical model consisting of several sub-models related to different sub-problems.

2. The term 'MLO' relates to the general model structure, while MLP is a mathematical programming problem (emphasis is on solution algorithm) and multi-level planning refers to a plan which is the output of an MLO model. These different terms have been used to indicate different aspects of energy planning and modelling (Candler and Norton [1977]).

1.3.1 The MLO Approach

An MLO (bi-level) model can formally be represented as follows:¹

Optimize $W = w(\underline{T}, X)$ (a) - policy objective function

$\{T\}$

s.t. (1.1)

$g_1(\underline{T}, X) \leq R_1$ (b) - policy constraints

Optimize $C = c(\underline{T}, X)$ (c) - behavioural/energy

$\{X \mid T\}$ sectoral objective function

s.t.

$g_2(\underline{T}, X) \leq R_2$ (d) - behavioural/energy

sectoral constraints

$X \geq 0$ (e) - non-negativity constraints

where \underline{T} = a vector of variables controlled by the upper level
decision makers/policy makers,

X = a vector of variables controlled by the lower level
decision makers/energy producers and consumers.

For the policy studies, in the context of a multi-level

1. Detailed discussion about the constraints, variables and the optimization problem in (1.1) will be provided in Chapter Two (Section 2.5.) and Chapter Three.

hierarchical policy system, policy system analysis¹ provides the conceptual framework, the theory of economic policy planning offers the analytical and operational framework and MLP provides a methodology. Therefore, a policy system study needs to be developed within the framework of policy systems analysis, the theory of economic policy planning and MLP (Chapter Two).

Within the above modelling framework, an optimum energy planning model for Australia (AEPsOM) is developed. AEPsOM is a price control² MLP energy sector model, which incorporates the underlying energy policy objectives and instruments, and reflects the economic and technical characteristics of the energy sector.

To solve AEPsOM, the Parametric Programming Search (PPS) algorithm is developed. In this algorithm, the lower level problem is solved as a parametric programming problem. Alternative solutions generated by the parametric programme are searched to find the solution which optimizes the upper level objective function and satisfies the upper level constraints.

1.3.2 Justifications for an MLO Approach

It should first be stressed that the MLO approach is not

1. This study adopts a systems analysis/study of energy planning. The essential elements of this approach (Enthoven [1962]) are :

"a cycle of definition of objectives, design of alternative systems to achieve those objectives, evaluation of alternatives in terms of their effectiveness and costs, a questioning of the objectives, a questioning of the other assumptions underlying the analysis, the opening of new alternatives, the establishment of new objectives."

2. Different forms of MLP are defined in Chapter Two, Section 2.5.2.3.

the only methodology which can be adopted for energy planning. The MLO approach is proposed as an alternative approach to energy planning since it has several advantages as a methodology for formulating a particular type of multi-level energy plan characteristics of which are discussed in Appendix B. The real intention of this study has been to stimulate further discussion about the suitability of various types of models/approaches for energy planning rather than giving a definite verdict.

The justifications for adopting the proposed MLO approach to energy planning are summarized in the following paragraphs:

(a) Representation of the underlying policy system: In order to specify an optimum government policy in a multi-level policy system, an MLO approach is necessary since an MLO model can represent the characteristics and elements of the multi-level hierarchical policy system (the multi-level policy making system can be defined as an MLO model).

This is illustrated as follows: In the model (1.1), there are two objective functions and two sets of constraints (two optimization sub-models). These two optimization sub-models (policy model (equations 1.1.a to 1.1.b) and behavioural model (equations 1.1.c to 1.1.d)) represent the optimum decision making systems of the policy makers and economic agents. The policy makers optimize the policy objective function (maximization of social welfare, G.D.P. etc.) subject to the policy constraints (limits on taxes, budget deficit etc.). The economic agents optimize the behavioural objective function (minimization of total energy sector cost) subject to the energy sector constraints (demand, supply, and capacity constraints etc.).

The MLO model also captures the simultaneous interdependence

and interactions between these two types of decision makers. Goal interdependence implies that the attainment of the upper level objective is dependent on the achievement of the objective of the lower level, although the objectives of the two levels are generally different (conflicting objectives). In (1.1) the two objective functions (two sub-models) are interdependent through the variable \underline{T} which links both. The intervention of the authorities at the upper level on the lower level is also represented in the model by the policy instrument variable \underline{T} . The MLO model also clearly makes a distinction between the variables which are under control of the two types of decision makers: policy makers control \underline{T} (taxes and subsidies) while the economic agents control X (energy supply and uses).

The MLO model also represents the hierarchical structure of the policy system. In the MLO model, the upper level decision makers choose \underline{T} and then the decision makers at the lower level adjust their behaviour to optimize their decisions.

(b) Generation of a multi-level plan: In summary, an MLO model can generate a multi-level energy plan involving both an energy system plan and an energy policy plan.

(c) Formulation of a comprehensive and consistent energy policy plan: A further attribute is that of coordination. It has been stated before that government energy policies are sometimes incompatible, so a set of energy policies should be formulated in a comprehensive and integrated framework so that the consistency of these policies are ensured. Existing practice in energy modelling is to use econometric models to study energy-economic policies such as taxes and subsidies policies, while mathematical programming models are primarily used to study technology policies for

example conservation policy. The achievement of consistency between these receives a major emphasis here. For example, optimum energy resource allocation and technological patterns suggested by a single level mathematical programming model in a behavioural model of the energy sector may not remain optimum if government taxes and subsidies are introduced into the policy system. Alternatively, the consideration of the detailed technical structure of the energy sector may provide a different set of taxes and subsidies from that suggested by a macro-econometric model. Therefore, to formulate an appropriate multi-level energy plan, a methodology is needed which can be adapted to the formulation of both types of policies simultaneously. As an MLO model contains both taxes and subsidies and technical details of the energy sector (represented by T and X respectively in model (1.1)), an MLO model can be used to formulate a set of energy policies embracing energy economic and technology policies.

(d) Applied welfare economic applications: An MLO model can also be used to study some welfare issues related to energy planning such as the desirability of government intervention.

1.4 CONSTRAINTS ON THE STUDY

A major constraint relates to the interdisciplinary character of this study. The interdisciplinary character of energy system modelling requires the use of terms and concepts from different disciplines such as economics, mathematics, operations research, energy engineering and computer science. This has made

the present study relatively complex¹.

The recent origin of energy planning and MLP, non-availability of computer programme and dearth of literature on the topics of this thesis have also posed problems for the normal progress of the thesis beyond that generally encountered in a Ph.D. thesis.

1.5 PLAN OF THE THESIS

The thesis is organized in the following manner².

Chapter Two contains a survey of literature on existing overseas and Australian energy policy models. In addition, a discussion of the theoretical and conceptual foundations of an MLO energy planning model is provided and an approach to such energy planning is developed.

Chapter Three consists of a discussion of the specification of AEPSOM. The rationale for specifying the elements (as they are in the study) of AEPSOM and the sources of its data are also discussed in this chapter.

Chapter Four presents a discussion of the algorithmic ap-

1. Although central concepts and terms of this thesis have been defined at the appropriate places, because of the space restrictions all the concepts, ideas and terms from all these disciplines and used in this thesis have not been defined or elaborated in this work. However, references have been cited in the necessary cases.

2. Like any other optimization study, this study follows the different phases of an optimization study (Taha [1976]):

- (a) definition of the problem under study/the objective of the study (Chapter One/Two),
- (b) development of the relevant model (Chapter Three),
- (c) solution of the model (Chapter Four/Five),
- (d) validation of the model (Chapter Five),
- (e) application of the model results (Chapter Six).

proach adopted in this study (PPS algorithm) and the mathematical properties and evaluation of the PPS algorithm solution of an MLP model.

Chapter Five reports the essential results generated by AEPSOM and provides tests for the reliability of these results. This chapter also highlights some essential characteristics of multi-level decision making.

Chapter Six discusses the multi-level planning applications of the model: (a) it forecasts an optimum energy system, and (b) it prescribes an energy policy plan in the form of a set of optimum energy policies for Australia.

Chapter Seven consists of an overview of the main aspects of the study and discusses its limitations. This chapter also makes some recommendations for future research and ends with the main conclusions.

CHAPTER TWO

TOWARDS A MULTI-LEVEL OPTIMIZATION APPROACH TO MULTI-LEVEL ENERGY PLANNING

2.1 INTRODUCTION.

The objectives of this chapter are as follows: (1) to discuss the suitability of existing national sector-wide optimization models for the formulation of an optimum multi-level energy plan; and (2) to develop an alternative approach which will, possibly, be free from limitations of existing models.

The chapter is organized as follows: In Section 2.2, there is a discussion of the standard model validation criteria. Section 2.3 discusses existing energy planning models, while Section 2.4 evaluates existing models by some commonly used model validation criteria. Section 2.5 discusses the foundations of the new modelling approach and in Section 2.6, an MLO model of energy planning is developed. Additional information on the characteristics of the proposed MLO approach and some analytical principles of a decentralized energy-economic policy that the model can help formulate are given in Appendix B.

2.2 MODEL EVALUATION CRITERIA

In order to be able to investigate whether existing energy models are capable of providing an appropriate modelling framework

for multi-level energy planning, a critical survey of existing energy models in terms of some standard model validation criteria is necessary. However, it needs to be stated that the choice of a method is dependent on the uses of the model i.e., the objective of the modelling exercise. No method can be judged superior without reference to the underlying problems for which it is developed. For example, econometric methods are primarily used for quantitative estimation, analysis or prediction of some economic variables, while mathematical programming models are used mainly for optimum planning or forecasting. Econometric studies are based on historical data, while programming models use cross-sectional data and depend on equality and inequality constraints. In addition to the purpose (or use of the model) and nature of the study, several other factors such as the availability of data and computer programmes, and the size of information expected from the model after its implementation also influence the choice of an appropriate methodology.

In an optimization model, validation of the model (the determination of exactness of a model in representing a system (Taha [1976], p.11)) is an important step. Validation tests are performed to determine the appropriateness of the model and the reliability of the model results. There are three levels of validation tests (Kresge [1980]): descriptive, analytical and experimental. At the descriptive level, the following criteria are applied: (1) appropriateness of the model structure, (2) achievement of the objectives of the model, and (3) plausibility and usefulness of the results. At the analytical level some of the criteria which are applied are model documentation, implementation etc., while at the experimental level, audit by an inde-

pendent group and in-depth assessment are performed by undertaking sensitivity analysis and replication of results.

In this section, the validation tests at the descriptive level will be discussed to evaluate existing energy models. The following model evaluation criteria are applied:

(1) Appropriateness of the model structure in representing the underlying systems.

Multi-level energy planning requires modelling of the energy policy and energy system. As an energy policy system is characterized by a two-level optimum decision making/policy formulation process (discussed in Chapter One), formulation of policies by the government in such a policy environment is dependent on the decisions of economic agents. Therefore, in this context, energy planning involves the determination of optimum decisions of economic agents and optimum policies of the government simultaneously. This necessitates a multi-level optimization model representing two-level decision making for formulating an energy plan.

Further, the energy system involves many technological alternatives and capacity limitations. A methodology that can represent adequately the complex energy system operations is desirable. This requires that some of the constraints of an MLO energy model should reflect these types of relations of an energy system.

Finally, the present study is undertaken to address medium and long-term energy planning issues involving substantial structural changes in the energy system. Modelling of medium-term or long-term energy sector planning involving inequality constraints requires a mathematical programming methodology (if the study is an optimization study) since mathematical programming models can capture structural changes in a system (Folie and Ulph, [1977]).

The relationships in the multi-level optimization model can be estimated either econometrically or they can be specified on the basis of the technical structure of the energy sector involving inequality and non-negative constraints (modelled as a mathematical programming specification of the energy sector). The reasons for not applying econometric methods for energy sector planning may be summarized as follows (Norton and Schiefer, [1981] and Shumway and Chang [1977]): econometric methods can not be adopted in a multiproduct/activity and/or multi-regional environment since the degrees of freedom are usually inadequate; they are not applicable for policy planning in a situation characterized by fundamental structural and policy changes compared to the past period of statistical series or historical variation; econometric methods cannot include inequality constraints, such as the capacity constraint, which are important in energy sector planning; econometric models usually cannot provide much complementary information on the behaviour of the variables of a system model; econometric models are generally used for dealing with short-term energy policy issues (Folie and Ulph, [1977], not long-term energy planning problems.

For these reasons, a predominance of mathematical programming applied to energy planning is observed (Riaz, [1983]; Folie and Ulph, [1977]; Julius, [1981]).

(2) Achievement of the objectives of a study by the model.

As stated previously, if the purpose of this study is the formulation of an optimum multi-level energy plan, both economic and technological, then an explicit statement of the policy planning problems should be made. This requires the specification of the policy objectives and constraints, and a classification of the

policy variables as targets and instruments. Yotopoulos and Nugent ([1976], pp. 421-422) have stressed the importance of an identification of the policy targets and instruments in the following way:

"Perhaps the greatest shortcoming in planning to date has not been internal inconsistency, infeasibility, or suboptimality of the plans per se but rather the failure to link planning goals with practical and specific policy instruments, the utilization of which would ensure fulfillment of the planning goals."

(3) Plausibility, usefulness and adequacy of model results :

A set of results generated by a model has to be plausible. Also a comprehensive set of information of the energy system is necessary for an appropriate energy planning work. An energy plan involves, among other things, (a) pricing policy, (b) tax and subsidy policy, (c) depletion policy, (d) exploration and development policy, (e) conservation policy, (f) education and propaganda policy, (g) research and development policy, (h) an investment policy or plan, (i) technological policy, (j) equity policy, and (k) industrial policy. A methodology is required that generates information adequate for the formulation of a comprehensive set of energy policies containing as many of these elements as possible. Otherwise, consistencies cannot be tested.

The above arguments may be summarized as follows: for the formulation of an energy plan with emphasis on the economic and technical aspects of the energy sector in a market/mixed economy, a model that can represent a multi-level decision making process, which incorporates inequality constraints, and provides a comprehensive set of energy policies (economic and technological) is required. The modelling approach should be developed within a framework in which the energy planning problem, specifying targets and instruments, is explicitly described.

2.3 EXISTING ENERGY SECTOR OPTIMIZATION MODELS

Energy policy models can be classified on the basis of the methodology adopted in each type of model. These models can be classified as one of the following types: (1) Network/process models, (2) Mathematical programming models, (3) General equilibrium models, (4) Econometric models, (5) Dynamic optimization models, (6) Simulation models, and (7) Coupled/hybrid models.

Since this study leads to the formulation of an optimum energy plan, and as optimizing behaviour of decision makers is assumed in this study, only optimizing models or models which can represent such behaviour will be relevant for this survey. Since not all of the above types of energy models can be, or have been used for optimum energy planning, only the ones which can be, or have been used for this purpose will be discussed here. For discussion, these models have been regrouped as static optimization models, dynamic optimization models, and hybrid models.

2.3.1 Static Optimization Models

2.3.1.1 Mathematical Programming Models

Mathematical programming models are developed in order to identify an optimum energy system. The optimization criteria are contained in the objective function of the mathematical programming problem as:

$$C = f(X) \qquad (2.1.a)$$

where¹ X = a vector of instruments/activities in the model ($n \times 1$), as $X = (x_1, x_2, \dots, x_n)$.

The objectives of the problem are usually in the form of minimization of pollution, imports; or, maximization of output, employment, profit, net (social) surplus; or, sometimes, in forms which involve different objectives such as the minimization of cost, pollution, and the maximization of employment simultaneously.

Constraints in mathematical programming models are the structure of the energy system under study. A general representation of the structure of an energy system may be given as follows:

$$H(X) \geq R \quad (2.1.b)$$

where $H(X)$ = vectors of constraint functions ($m \times 1$);

R = vector of given constraint parameters ($m \times 1$).

The constraints in a programming model are usually the demand, supply, resource, capacity and pollution constraints and the intermediate energy balance equations in the present context.

The solution to mathematical programming models determines an optimum energy system - either in the normative or behavioural sense - and has been used to formulate an optimum energy policy and to analyse the sensitivity of the energy system to some changes in the economy. The result of mathematical programming models can be used to formulate energy policies of the (a) and (c) to (i) types stated above.

Some well known mathematical programming models include: the

1. Symbols used in different chapters have been defined separately in each chapter.

Brookhaven model set (Kydes [1978]), PILOT, DIES, EFOM, the Birmingham Energy Models, and CEC (see the following surveys: Hoffman and Wood [1976], Planco Inc [1979], Julius [1981], Rath-Nagel & Voss [1981] and Hildebrandt [undated])).

2.3.1.2 General Equilibrium (GE) Energy Models

These models are developed within the established tradition of general equilibrium analysis in economics. The modelling approach is based on the consideration of the simultaneous existence of equilibrium output and price in all sectors of an economy, which is achieved when demand and supply are equal in all the interdependent markets. GE models represent the relationships of demand and supply of primary inputs, intermediate products and final output in factor and commodity markets (Intriligator [1971]).

Numerical GE models which are used for formulating an optimum economic policy can be classified into three groups:

- (i) activity analysis general equilibrium models;
- (ii) Computable General Equilibrium (CGE) models;
- (iii) macroeconometric general equilibrium models.

(i) Activity Analysis Models

An activity analysis GE model can be developed by specifying an input-output model in an optimization framework (Intriligator [1971]). In an activity GE model, the objective function is usually specified to constitute either a problem of maximization of the output in different sectors of the economy or the final demand, or a problem of minimization of input costs. A standard

activity analysis GE model is as follows:

$$\begin{aligned}
 &\max W = \text{In}F \\
 &\{X, F\} \\
 &\text{s.t.} \\
 &(I - A)X - F \geq 0 \\
 &eX \leq L \quad (2.2) \\
 &kX \leq K \\
 &dX \leq R
 \end{aligned}$$

where: In = a vector of 1's ($1 \times n$) and I = identity matrix,
 X = a vector of outputs in different sectors ($n \times 1$),
 F = a vector of final demands ($n \times 1$),
 A = a matrix of the input-output coefficients ($n \times n$),
 e , k & d = vectors of employment, capital, and
energy coefficients ($1 \times n$),
 L , K & R = vectors of available working-age
population, capital and energy ($n \times 1$)
respectively.

A theoretical model in this line is Park and Kubursi (1982).
As far as the author knows, no numerical model has yet been developed.

The solution to this model provides an optimum allocation of resources i.e., an optimum output level and structure, and optimum input use levels and structure. Therefore, this type of model can be used to determine or plan the optimum allocation of resources in the economy. For the energy sector, these models can provide information necessary for formulating energy policies of the types: (a) and (e) to (j) stated above.

(ii) Computable General Equilibrium (CGE) Models

The tradition of 'computable general equilibrium' modelling goes back to Johansen's path-breaking work (Johansen [1960]). A general presentation of a CGE model is as follows:

$X = f(k, L)$ - Production function

$K = f(P_x, P_k, P_l)$ - Input demand function (capital)
(2.3)

$L = f(P_x, P_k, P_l)$ - Input demand function (labour)

$C = f(P_x, P_l)$ - Consumption function

$X = AX + C$ - Input-output model

where X = a vector of output in different sectors
($n \times 1$)

K, L = vectors of input demands in each sector
of the economy ($n \times 1$) and ($n \times 1$);

C = a vector of sectoral consumption ($n \times 1$);

A = a matrix of the input-output coefficients
($n \times n$);

P_x = a vector of output prices ($1 \times n$);

P_k, P_l = vectors of interest and wage rates
($1 \times n$) and ($1 \times n$).

The CGE model is represented by a set of simultaneous equations of demand and supply of inputs and outputs; inter-industry balances and aggregate macro-economic relationships.

A CGE model in reduced form may be represented as :

$$Y = f(X) \quad (2.4)$$

where Y = a vector of endogenous macroeconomic variables

X = a vector of exogenous macroeconomic variables

It can be reformulated as an optimum policy model by plugging in a policy objective function such as :

$$\begin{aligned} \text{Max } W &= f(X,Y) \\ \{X,Y\} & \\ \text{s.t.} & \\ Y &= f(X) \end{aligned} \quad (2.5)$$

Interpretation of the variables in this policy model is different from economic models. In a policy model, the endogenous and exogenous variables of an economic model are the instrument and target variables (Fox, Sengupta and Thorbecke [1973]).

The model can provide an optimum set of values for policy instruments. It is important to note that no optimization CGE model has yet been developed for the energy sector.

(iii) Macroeconometric General Equilibrium Energy Models

A Macroeconometric GE energy model in reduced form may be represented as :

$$Y = f(X) \quad (2.6)$$

where Y = a vector of endogenous macroeconomic variables

X = a vector of exogenous macroeconomic variables.

These models are simple extensions of macroeconometric models. In macroeconometric models, relationships between economic aggregates such as GDP, investment, saving, consumption, price level, money supply, and government expenditure are specified. The coefficients of the models are estimated econometrically. In macroeconometric GE energy models, the variables are defined

separately as energy and non-energy types. These models can be reformulated as optimum policy models as in (2.5).

Some examples of macroeconometric GE energy models are: Sweeny [1981], Hogan and Manne [1977], and Allen et al. [1976].

Solution to an optimization macroeconometric GE model provides a set of optimum values for energy policy instrument variables such as prices, taxes and subsidies, and investment.

2.3.2 Dynamic Optimization Energy Models

Dynamic energy modelling involves the problem of optimization of an energy system over a period of time (Intriligator [1971]). The optimization problem is evaluated in terms of an objective function (or performance index or integral), which is usually defined as:

$$J = \int_{t_0}^{t_T} I[X(t), U(t), t] dt \quad (2.7)$$

where $X(t)$ = a vector of state variables

$U(t)$ = a vector of control variables

t = time t_0, t_1, \dots, t_T

Dynamic energy systems, which are to be optimized, may be represented by a set of state equations:

$$\dot{X} = \frac{dX}{dt} = f(X(t), U(t), t) \quad (2.8)$$

$$\text{here } \frac{dX}{dt} = \frac{dx_1}{dt}, \frac{dx_2}{dt}, \dots, \frac{dx_n}{dt} \text{ for each } t = t_0, t_1, \dots, t_T.$$

The optimization problem is also subject to some initial

conditions and some terminal conditions on the state variables
(energy resource supplies and capacity levels).

$$X(t_0) = X_0 \quad \text{and} \quad X(t_T) = X_T \quad (2.9)$$

The feasible region or the boundary conditions of the control variables are specified, and the decision problem is to choose the optimum control trajectory from this feasible set:

$$U(t) \quad U^n \in E^n \quad (2.10)$$

Similarly the boundary conditions on the state variables are:

$$X(t) \quad X^n \in R^n \quad (2.11)$$

The dynamic optimization energy models can also be discrete time stepped. The discrete time stepped dynamic optimization problem can be considered as a mathematical programming problem (Intriligator [1971], p.303) of the following form:

$$\begin{aligned} \max J = & \sum_{t_0}^{t_T} I(X_t, U_t) \\ & \{X_t, U_t\} \quad (2.12) \\ \text{s.t.} \end{aligned}$$

$$X_{t+1} - X_{t0} = f(X_t, U_t)$$

$$X_t = X_0, \text{ given } U_t = U^n \in E^n$$

Basu's (1981) model is an example of an optimum control continuous model for the energy sector.

Solution of a dynamic optimization model mainly provides

information regarding prices, taxes and subsidies, optimum depletion rate, investments, and technological pattern in the energy sector.

2.3.3 Hybrid Models

In most large scale energy modelling, different types of models have been coupled with optimization models to formulate a comprehensive set of energy policies. When both the energy sectoral and macro-economic interrelationships are included in a hybrid model, various types of models such as input-output or macro-econometric and linear programming models are coupled in the hybrid model. In this hybrid-model, the values of the macro-economic variables from a macro-model are used in a linear programming model as the exogenous parameters, such as demand for energy in the different sectors; or the results of linear programming models (input-output coefficients in the energy sub-sectors), are used in an input-output model to predict consistent sectoral energy demand in the economy (Meier [1984]).

Some of the hybrid models in the energy sector are: BEEM (Behling et al. [1975], Hoffman and Jorgenson [1977], BES (deLucia and Jacoby [1982]), PIES (see Hogan and Weyant [1980]).

The output of a hybrid model consists of the outputs of the models included in the model suite. But the main objective for which the modelling work is undertaken is the development of an optimum energy system. If macroeconomic energy models (macroeconometric models or CGE models), formulated in an optimization framework, are combined with mathematical programming models, the hybrid model can provide a comprehensive set of energy policies.

Output of a hybrid model has also been used to formulate multi-level planning involving planning at the macro-economic level and planning at the sectoral level (Chapter One). Results of the macro-economic model/economy-wide model provide information for general economic planning, while the energy sector model provides information for an energy sectoral plan (energy system plan).

2.4 EVALUATION OF EXISTING ENERGY MODELLING APPROACHES

The first point that needs to be made is that not all of the energy sectoral optimization models mentioned above were developed for formulating optimum energy planning. Some of these models were developed for forecasting future energy systems or for analyzing the impact of different energy policies or technologies. This evaluation of the energy models is directed to all optimization models in the energy sector, since even the optimization models which have not been used to formulate optimum energy planning are applicable to energy planning.

Further, the present survey is not exhaustive. As the number of existing energy models is fairly large, all of them cannot be discussed individually. Therefore, limitations of different types of models (instead of individual models) are discussed. The limitations of a particular type of model are, to a large extent, valid for each model in that group.

In addition, extensive work on the methodological issues in sectoral modelling already exists. Candler, Fortuny-Amat, and McCarl [1981], McCarl and Spreen [1980], and Norton and Schiefer

[1980] have discussed the general limitations of sectoral single-level optimization models.

2.4.1 Limitations of Existing Energy Planning Models/Approaches

Limitations of the existing energy models are discussed here.

2.4.1.1 Inappropriateness of the methodologies (related to criterion 1)

The first limitation of existing energy models is the inappropriateness of the methodologies adopted in these models in representing the underlying systems (energy system and energy policy system).

(i) General Methodological Limitations of all Existing Models

Outcome of government policy is dependent on the reactions of economic agents to such policies i.e., government and economic agents decisions are inter-related. To formulate a multi-level energy plan in this policy environment, a model is needed which can represent decision making systems of both the government and economic agents simultaneously, and therefore, can generate both an energy system plan and an energy policy plan. Technically, an appropriate model should be a multi-level one for the reasons discussed in Chapter One. As existing optimization models contain one objective function and only one set of constraints, they are inappropriate in the representation of the two level decision making of the energy sector and in the formulation of a multi-level energy plan. Consequently, they will also generate results unsuited to this problem (policies or forecasts). Single-level energy models can not generate analytical and numerical results related to the characteristics of multi-level decision making.

Examples of such results derived from an MLO model may be seen in Appendix B and Chapter Five. Therefore, existing models are not developed within the appropriate methodological framework for multi-level energy planning.

As a basis of discussion, energy models may be classified as either positive or normative. A positive model represents the actual behaviour of the economic agents whereas a normative model represents the behaviour of economic agents as they ought to be.

For example, the following is a positive model which shows the cost minimization decision making of the energy suppliers:

$$\begin{aligned} \text{Min } C &= cX && \text{Behavioural objective function} \\ \{ X \} &&& \\ \text{s.t.} &&& (2.13) \\ S &= \{ X \mid AX \geq R; X \geq 0 \} \\ &&& - \text{Energy sectoral opportunity set} \end{aligned}$$

The variables and coefficients are the same as in (2.2). This type of energy model is frequently used in energy planning by conducting sensitivity analysis in investigating the impact of some changes in energy policies or technologies; it can also be used to investigate changes in demand and supply on the energy system. This information is then supplied to policy makers so that they can choose a set of energy policies which they perceive as consistent with their preferences.

As there is no policy objective function in these models, they cannot be used to formulate a set of optimum policies that provide the best strategy for policy makers considering all the possible alternatives. But when this type of model is used to

formulate an energy policy, some criteria are applied implicitly by the policy makers to enable them to choose the one they think is consistent with their preferences. As preference criteria are neither made explicit nor part of the model, the optimum policy cannot be identified by these models. Candler, Fortuny-Amat and McCarl ([1981], p. 521) state this limitation as follows:

" While models have been constructed to reflect the competitive behaviour of the decentralized decision makers ..., little attention has been given to a clear articulation of policy objectives or the acceptable range for policy variables...."

Positive models can be changed to normative models by incorporating a policy objective function in a model, instead of a behavioural objective function as follows:

$$\begin{aligned}
 &\text{Max } W = wX && \text{Policy objective function} \\
 &\{ X \} \\
 &\text{s.t.} && (2.14) \\
 &S = \{X \mid AX \geq R ; X \geq 0 \} && \text{Energy sectoral} \\
 &&& \text{opportunity set.}
 \end{aligned}$$

This type of policy model overlooks an important component of policy planning problems. Policy maker's decisions are not subject to the constraints of the energy sector. These constraints represent energy market equilibrium conditions and technological characteristics of the energy sector. Norton and Schiefer ([1980], p.207) also claim that such models do not represent adequately the policy problem (or even the descriptive problem).

In another type of normative use of optimization methods, the objective function of the type shown in (2.14) is retained, but some additional constraints are included in the model. These

additional constraints are specified to include the preferences of the policy makers. The following model is an example of such practice:

$$\text{Min } C = cX \quad - \text{Behavioural objective function}$$

$$\{X\} \quad (2.15)$$

s.t.

$$S = \{ X \mid AX \geq R ; L \leq X_p \leq P X, X_p \geq 0 \}$$

- Energy sectoral opportunity set and policy constraints.

X_p is the vector of variables directly controlled by the policy makers, L and P are the lower and upper limits of the constraints on X_p . The same objections which have been raised in connection with normative models such as (2.14) are also valid for the present type of formulation. In addition, in this specification it is impossible to know a priori whether there exists any solution to the model satisfying the policy constraints.

(ii) Methodological Limitations of Individual Models

On the basis of the above general limitations of single level optimization models, methodological limitations of each type of model can now be evaluated.

A. Mathematical Programming Energy Models

The limitations of mathematical programming models are evident from the discussion of the limitations of single level optimization models, since existing mathematical programming models are of the single level type. But mathematical programming methodology has several advantages for energy planning. It is operational and can include inequality constraints. It can also

capture multi-input, multi-activity, and multi-output economic and technological systems of the sector. Furthermore, it can capture future structural changes in the sector and also provide complementary information such as pollution levels produced in the energy sector.

B. General Equilibrium Models

All the methodological limitations of single level optimization models discussed above apply broadly to all general equilibrium models. Usually, the reaction functions in general equilibrium models are not decomposed into their relevant components which are the objective function of economic agents and constraints faced by them. Therefore, the policy reaction functions can not model the decision making of economic agents with its constituent components. And consequently, general equilibrium models cannot generate energy system plans, although they are useful in formulating energy policy plans.

To demonstrate this point, the three types of general equilibrium models are separately evaluated below.

Activity analysis GE models do not and cannot contain the decision making problems of economic agents as well as full details of an energy system (i.e. the energy sector constraints). Decision making problems of economic agents are suppressed in the input-output model. Also the energy sectoral decisions are influenced by many non-economic factors such as technical convenience, safety and efficiency which are not included in an activity analysis GE model. The existence of such phenomena as peak and off-peak demand, excess capacity and reserve capacity requires the relationships to be represented in inequality form. This type of

information is missing in an activity analysis GE model.

In the case of CGE models, the coefficients of CGE models are estimated econometrically. In some cases, the coefficients are derived from the national accounts system including the input-output models. In both these cases, however, the methodological structures of CGE models are the same. The problem with this type of CGE model is that reactions of individual economic agents to policy initiatives are represented by equations, such as the demand function for energy. The limitation of this type of functional representation of individual reactions in an energy policy study is that the decision criteria of the economic agents which are represented by an objective function of an optimization model are not explicitly shown in the policy model (CGE) structure. The decision problems of policy makers are shown explicitly, but decision principles of economic agents are shown by some equations without explicit representation of their decision making problem in the form of an optimization problem. In brief, CGE modelling does not provide the required multi-level dimension.

The other limitation of the CGE model (2.5) in optimum energy policy studies is that econometrically estimated demand and supply functions emphasize economic arguments such as prices and incomes, whereas energy demands and supplies depend on many technological factors. In a similar way to activity analysis GE models, CGE models do not contain detailed energy sector constraints, particularly none of a technical character.

Generally, the limitations of macro-econometric GE models are the same as those of all other GE models: inability to present energy policy systems and details of the energy sector.

Since all the GE models are single level optimization models, these models cannot represent the optimum energy policy formulation process. But, with regard to limitations imposed by a lack of detailed representation of the energy sector, it can be argued that some equations representing the energy system under study can be incorporated in a GE model by adding some additional relationships. For example if the following set of equations represent an energy system :

$$Y_e - f(X_e) = 0 \quad (2.16)$$

then a detailed GE model can be represented as :

$$\text{Max } W = f(X, Y, X_e, Y_e)$$

$$\{X, Y, X_e, Y_e\}$$

$$\text{s.t.}$$

$$Y = f(X) \quad (2.17)$$

$$Y_e - f(X_e) = 0$$

$$X, Y, X_e, Y_e \geq 0$$

where Y_e , X_e are vectors of the energy sector endogenous and exogenous variables, and X and Y are defined in (2.5).

The problem with the above type of presentation of an energy policy formulation system in a GE is that the energy system is being specified as a part of a macro-economic system and being evaluated (directly) in terms of the preference criteria of the policy makers. But, an energy system optimization problem needs to be evaluated in terms of the preferences of the individual economic agents as well. Therefore, though societal objectives are included in GE models, "there is no pretense of simulating the actual behaviour of economies" (Candler and Norton [1977], p.11), thus the model in (2.17) does not portray the two level decision

making problem at all.

C. Dynamic Optimization Models

These limitations of CGE models are also present in optimum control (continuous) models. Discrete dynamic optimization models possess the limitations of mathematical programming models. Candler and Norton ([1977], p 11) state the limitations of control models in the following way:

"Control theory utilizes an explicit usual econometric description of the underlying economic structure (feasible behavioural set). With the econometric description, the choice of instrument values is limited to that range of values which has been experienced during the period of historical observations. This restriction may be a strong one."

D. Hybrid Models

Hybrid models are constituted by various aspects of the models discussed above, each component of a hybrid model would have the limitations of each method. Generally, in existing hybrid models, preferences of the policy makers are not explicated and policy variables are not classified (ie, they fail to satisfy the second criterion). Again, hybrid models are not developed and solved as a single, integrated and interrelated MLO/policy model. Different levels of MLO problem are not treated simultaneously.

2.4.1.2 Non-specification of the energy policy planning problem (related to criterion 2)

There are conceptual problems in applying existing energy models for energy planning. First of all, preferences of policy makers are not made explicit and policy variables are not proper-

ly defined and classified to identify the underlying problems of policy planning. In some modelling studies, where the underlying energy policy targets and instruments have been stated, there is unprecise discussion of how these statements of policy problems relate to the preferences of policy makers. Also missing is a discussion of how some relevant quantitative information needed in a policy optimization study such as the classification of the policy variables and the specification of the weights in the policy objective function are obtained. Secondly, the elements of existing energy policy systems, for example multi-level hierarchical decision making systems, is not sufficiently incorporated. Therefore, existing models are not developed within the relevant conceptual, analytical, and operational framework.

A more appropriate energy planning structure, therefore, is the one in which the energy planning model includes the underlying policy preferences involving a classification of policy variables as target and instrument variables to provide a clear presentation of the existing policy planning problem and embedded within it the relevant systems: economic, energy and policy.

2.4.1.3 Inadequate set of results (related to criteria 3)

The third limitation of existing models is the inadequate nature of the results provided by these models. Existing energy models cannot provide a comprehensive set of energy policies.

2.5 AN ALTERNATIVE MODELLING APPROACH: MULTI-LEVEL OPTIMIZATION OF ENERGY SYSTEMS AND ENERGY POLICY

The limitations of existing energy planning approaches can be

overcome by adopting an MLO approach. The justifications and elements of this approach are discussed below.

2.5.1 Arguments for an MLO Approach:

The main justification for the proposed MLO model is that such models represent underlying policy problems accurately. As the energy sector policy system is characterized by what is called a 'multi-level (multi-goal) hierarchical policy system', undertaking an optimum multi-level planning study in the energy sector requires the adoption of a model which can represent the characteristics of the multi-level policy system. Since there are two optimization problems, an appropriate model should have two sub-optimization problems embedded in it.

2.5.2 Elements of the MLO Approach

To overcome the limitations of the existing models, it is necessary to develop the MLO approach on appropriate (a) theoretical, (b) conceptual and (c) methodological foundations which have been found to be lacking in existing models. This can be accomplished if the MLO approach is developed within the framework of the theory of economic policy planning, policy systems analysis and MLP.

It may, however, be mentioned that attempts for developing MLP models within an appropriate framework are not new. Fortuny-Amat [1979] has made clear the similarities between multi-level multi-goal policy systems and MLP, although he did not integrate or analyse his model results, analytically or numerically, in terms of multi-level multi-goal policy systems. Candler and Norton [1977] have made some reference to the theory of economic policy

planning, although their studies have not been fully and explicitly undertaken within the framework of the theory of economic policy planning. With this background, the present study has attempted to integrate MLP, policy systems analysis and the theory of economic policy planning in the energy sectoral context so that the integrated MLO approach may provide an improved methodology for and understanding of the policy formulation problem in the energy sector.

2.5.2.1 The Theory of Economic Policy Planning

2.5.2.1.1 Analytical Framework:

The first requirement of an appropriate modelling approach can be satisfied if an optimization energy model is developed within the framework of the theory of economic policy planning (Tinbergen [1952]). Fox, Sengupta, and Thorbecke ([1973], p.11) state that

"The theory of economic policy is concerned with the analysis of decision situations and policy problems, using that part of general economic theory which can be quantitatively applied to economic data in some operational sense."

Therefore, the theory of economic policy planning provides an analytical and operational framework for economic policy analysis and planning. It provides an analytical and operational framework for policy planning since it deals with the following aspects of policy planning: (a) The policy characterization problem (specification of a policy system model including the policy objective function, and a set of constraints of the system under study). (b) The policy selection problem (the classification of the variables of the policy model as the target and instrument variables). (c)

The policy steering problem (deviation of a set of optimum policies¹).

There are three elements in the theory of economic policy planning (i) a policy objective function, (ii) a policy model of the system under study (a set of policy constraints), and (iii) a classification of the variables, mainly as policy targets and instruments (Fox, Sengupta, and Thorbecke [1973]). The basic structure of the theory of economic policy planning has been extended in many directions and has been applied to different areas. The basic theoretical framework has been extended to develop the theory of economic policy planning within the framework of mathematical programming and optimum control. It has been applied to various areas of economics involving the policy formulation problem such as growth, development planning, stabilization, and sectoral policy and planning (Fox, Sengupta, and Thorbecke [1973]). This study attempts to apply it to energy planning.

Analytical strength of the theory of economic policy planning lies (a) in its emphasis on the explication of the preferences of the policy makers and the identification of target and instrument variables, and (b) in its analytical structure in which direct and causal relationships between the target and instrument variables are established and derived, both theoretically and numerically, and (c) in its ability to define and derive an optimum economic policy. Therefore, the theory of economic policy planning provides an appropriate analytical and operational framework for studying the underlying energy policy planning problem, and thus,

1. In this study, the energy policy characterization and selection problems will be discussed in Chapter Three, while the steering problem will be discussed in Chapter Five.

for the formulation of an optimum energy plan.

2.5.2.1.2 Definition of an Optimum Economic Policy:

An important reason for adopting the theory of economic policy planning is that it can define and help derive an optimum economic policy. At this point, therefore, it is needed to discuss the definition of an optimum policy and its derivation in the Tinbergen framework.

Generally an optimum policy is the "best" policy. It can be interpreted in two alternative ways: (1) Traditionally, an optimum policy is defined in terms of Pareto optimality criteria: A policy which can make no one better off without making someone worse off¹.

(2) Alternatively, an optimum policy may be defined as the policy which can attain the optimum value of the objectives of the policy makers. In terms of the Tinbergen approach, an optimum policy is the optimum value of a policy instrument (a set of

1. In terms of the results of the model (2.21), a set of policy instruments:

$$(\bar{G}, \bar{t}_1, \bar{t}_2, \bar{t}_3, \bar{Y}_p)$$

is Pareto efficient if

- (a) it is feasible,
- (b) no other feasible states (G, t_1, t_2, t_3, Y_p) exist so that

$$W(G, t_1, t_2, t_3, Y, X, Z) \geq W(\bar{G}, \bar{t}_1, \bar{t}_2, \bar{t}_3, \bar{Y}_p)$$

- (c) for at least one policy

$$W(g_j, t_{1j}, t_{2j}, t_{3j}, y_{pj}) \geq W(\bar{g}_j, \bar{t}_{1j}, \bar{t}_{2j}, \bar{t}_{3j}, \bar{y}_{pj})$$

tive function.

In the theory of economic policy planning, the problem of the formulation of the optimum economic policy¹ is stated as follows:

$$\text{Min } WL = W(x-\bar{x}, u-u^*) = (x-\bar{x})^T Q (x-\bar{x}) + (u-u^*)^T R (u-u^*)$$

$$\{ u \} \quad Q \geq 0, R \geq 0$$

$$\text{s.t. } Ax + Cz = Bu + Dw \quad - \text{ a macroeconomic model}$$

where

(2.18)

x : $N \times 1$; N endogenous target variables

\bar{x} : $N \times 1$; N desired levels of the target variables

z : $R \times 1$; R endogenous non target variables

u : $K \times 1$; K exogenous instruments

u^* : $K \times 1$; K desired levels of the instrument variables

W : $J \times 1$; J exogenous data

and the dimensions of the coefficient matrix are:

A : $(N + R) \times N$;

C : $(N + R) \times R$;

B : $(N + R) \times K$;

D : $(N + R) \times J$;

In many applied works, the macroeconomic model is defined as follows:

$$AX = Bu + D$$

A set of optimum policies can be formulated by solving the model as a classical optimization model (steering problem):

$$\tilde{u} = (M^T Q M + R)^{-1} (Ru^* + M^T Q Y) \quad (2.19)$$

1. This section is adapted from Preston & Pagan [1982], Chapter 1 which shows the characterization and selection problems.

where $M = A^{-1}B$ and $Y = X - A^{-1}D$

The classical optimization model presented above is most commonly used in the theory of economic policy planning. However, as it was stated above, other forms are used in formulating optimum economic policy. In the present study, the theory of economic policy planning is embedded in MLP. In an MLP model, an optimum policy is identified by the optimum solution of MLP (characteristics of an MLP optimum solution are discussed in Chapter Four (mathematical properties) and Chapter Five (economic properties). Therefore, an optimum policy is defined in the present study as the policy (a set of instrument variables) which attains the optimum value of the policy objective function of the MLP model and corresponds to the optimum solution of the MLP model.

2.5.2.2 Policy Systems Analysis

Policy system analysis refers to the organization and analysis of the various elements of the policy formulation process existing in an environment.

One important type of policy system is what is called a multi-level multi-goal system, two characteristics of which are : goal inter-dependence or interactions among different levels of goal seeking, and intervention by one level on the other level (Mesarovic et al. [1973]).

Interdependence or interaction between the different goals implies that achievement of one level's objective is dependent on the achievement of one of the other level's objectives.

Two types of interdependence exist: direct and indirect. In the case of direct interdependence,

depend explicitly upon the outputs and behaviour of the casual systems" (Ibid Mesarovic et al., p. 301).

In the case of indirect interdependence,

"goals of a given higher level unit may explicitly depend only upon the goals of the lower level units and implicitly upon the performance of the basic casual system" (Ibid Mesarovic et al., p. 301).

Intervention is another characteristic of the multi-goal multi-level policy system. The authorities of the upper level usually intervene on the lower level. Two types of intervention exist: direct and indirect. In the case of direct intervention, the casual sub-system is partly controlled by the upper level along with the control of the lower level. In case of indirect intervention, the upper level cannot directly control the decision of the lower level - but can modify the behaviour of the lower level by adopting a set of appropriate instruments. In this case, the decision making on the upper level's part is to choose the best method of modifying or influencing the behaviour of the lower level decision makers.

The justification for developing an MLO approach within the framework of policy systems analysis is that it provides a conceptual framework for policy planning studies. The adoption of the conceptual framework is useful since it will allow extensive use of formal concepts and analytical or quantitative techniques in policy planning studies (Mesarovic et al. [1973], p. 294). It is revealed that the development of the MLO approach within the framework of policy systems analysis helps systematic and improved study of the policy making system in the energy sector.

Generally, policy system analysis is developed theoretically or conceptually. This study develops a numerical policy system analysis for the energy sector (Chapter Five).

2.5.2.3 Multi-level Programming

Since a multi-level multi-goal policy system exists in the energy sector, a methodology that can represent that policy system is required. This methodological requirement is satisfied by multi-level programming (MLP). The following discussion demonstrates this point.

MLP consists of a series of nested optimization problems at different levels (Candler and Norton [1977], Bialas and Karwan [1980]). An MLP model involving two levels of optimization is represented¹ as follows:

$$\begin{array}{ll}
 \text{Opt. } W = w(X_0, \pm T) & \text{Policy objective function}^2 \\
 \{X_1, \pm T\} & \\
 \text{s.t.} & \\
 X_0 = g_0(X_1, X_2) & \text{Definitions of Target Variables} \\
 g_1(X_0, X_1, \pm T) = R_1 & \text{Policy constraints} \\
 \text{Opt. } C = f(X_2, \pm T) & \text{Behavioural objective function} \\
 \{X_2 \mid \pm T, X_1\} & (2.20) \\
 \text{s.t.} & \\
 g_2(X_1, X_2) \geq R_2 & \text{Behavioural constraints} \\
 X_0, X_1, X_2 \geq 0 &
 \end{array}$$

where X_0 = vector of policy target variables ($1 \times n_1$) such

1. This bi-level programming problem is a special case of MLP. In this study only bi-level programming problems (models and solution algorithms) have been considered. However, the term MLP has been used to represent bi-level programmes since some statements, arguments and conclusions made in this study have general MLP implications.

2. The mathematical properties of the functions and feasible regions of an MLP model will be discussed in Chapter Four.

as energy conservation,

X_1 = vector of resource control policy instrument variables ($1 \times n_2$),

\underline{T} = vector of price control policy instrument variables (taxes and subsidies) ($m \times 1$),

X_2 = vector of behavioural variables ($1 \times n_2$) such as supply, production, and end-uses of energy,

R_1 = vector of right hand side policy constraints ($n_1 \times 1$) for example total sectoral budget allocation,

R_2 = vector of right hand side behavioural constraints ($n_2 \times 1$) - constant values as supply of resources, demand for energy, capacity limits.

w = policy objective function containing policy objectives such as conservation of energy,

f = behavioural objective function representing criteria such as cost minimization or social surplus maximization,

g_0 = functions defining the policy target variables.

g_1 = policy constraints in the form of budget constraint, limits on the changes on taxes and subsidies, and import control,

g_2 = behavioural constraints such as energy supply and demand constraints,

$$n = n_1 + n_2$$

The MLP given by (2.20) consists of two sub-optimization problems: the policy problem (upper level problem) and behavioural problem (lower level problem). The two sub-optimization problems have two objective functions: the policy objective function

and the behavioural objective function. There are two types of constraints: the policy constraints and the constraints on the behaviour of individual economic agents. There are three types of feasible regions which are searched to find the policy optimum. The feasible regions are: the policy feasible region generated by the policy constraints, and the policy target and instrument variables; the behavioural feasible region generated by the behavioural constraints; and the policy-behavioural feasible region generated by the reaction functions through the interactions of policy instruments, behavioural variables and policy target variables. The variables of an MLP model can be classified into three types: policy target variables, policy instrument variables and behavioural variables which are related to the behaviour of economic agents.

MLP can be of one of the following types: price control, resource control, and price and resource control. In a price control MLP model, the upper level decision makers control the behaviour of the lower level decision makers through ($\pm T$) prices, taxes, and subsidies while in a resource control MLP, the control is through the allocation of resources (X_1)¹. In price and resource control MLP, both prices and resources are controlled by the policy makers.

Advantages of MLP for studying policy planning problems are made explicit in the following statement by Candler and Norton ([1977] p. 40) (next page):

1. Examples of each type of MLP will be provided in Chapter Four.

"The separation of the policy problem into two components, the policy sub-problem proper and the behavioural (or 'forecasting') sub-problem, has long been accepted as a rational approach. However, this approach has not often been implemented systematically. We hope that multi-level programming is a step in this direction."

An MLP problem has two objective functions and two sets of constraints. So, MLP can represent exactly the features of multi-goal, multi-level, hierarchical policy systems. The MLP model in (2.20) resembles a multi-goal multi-level policy system. This has been discussed by Fortuny-Amat ([1979], Section 4.5, pp.34-39). In the MLP model, the policy makers have some targets or goals (X_0) which they try to achieve by directly or indirectly controlling the decisions of economic agents (producers and consumers of energy) through the instrument variables ($\pm T, X_1$). These two types of decision makers optimize their respective objectives f_1 and f_2 , therefore, there are two separate domains of control which are inter-related by the reaction functions (g_0). While policy makers control $\pm T, X_1$, economic agents control X_2 . The MLP model, therefore, represents the multi-goal, multi(two)-level policy making system, and thus, can fit within the conceptual framework of policy systems analysis. Consequently, an MLP Model can provide some useful information regarding the characteristics of the multi-level decision making both analytical (as shown in Appendix B) and numerical (as shown in Section 5.3). An MLP model also can represent the technical characteristics of an energy system since the constraints of an MLP model can be in inequality form. Consequently, an MLP model satisfies the validation criterion (1): can represent the system under study. Moreover, the elements of the theory of economic policy planning can be incorporated in an MLP model. In the above MLP modelling framework, there is a policy objective function; the varia-

bles can be classified as: X_0 = the target variables, $\pm T$, X_1 = the instrument variables, and X_2 = irrelevant variables (behavioural variables, in this study); and a model is (2.20). Therefore, MLP can represent and incorporate the elements of energy policy systems, and can also accommodate the elements of the theory of economic policy planning and can thus incorporate the underlying policy planning problem adequately and appropriately. So an MLO model satisfies the validation criteria 2. Since MLP is an optimization technique developed within a mathematical programming framework containing economic variables such as taxes and subsidies and a detailed technical structure of the energy sector, MLP can provide information adequate for formulating a comprehensive set of energy policies (Chapter Five). As MLP is an operational method, it satisfies the model validation criterion (3) and it can be used for a comprehensive and integrated quantitative energy planning study of a country¹.

Justifications for an MLO Approach : A Summary, To summarize, an MLO energy plan developed within the above mentioned framework can overcome the limitations of existing energy planning approaches: it can represent the underlying energy policy system and therefore, generates an energy system plan and an energy policy plan simultaneously, can contain an explicit statement of the energy policy planning problem and can provide a comprehensive set of energy policies. Therefore, an MLO approach can be considered an appropriate modelling framework for multi-level energy planning. Although MLP has been applied to other areas and sectors of the economy (Candler, Fortuny-Amat, & McCarl [1981]), MLP has not yet been applied for energy planning. So the present study will, probably, be the first multi-level optimization study in the energy sector.

It may, however, be mentioned that this study in its process of developing an energy sector MLP model will attempt to make some extensions in the MLP literature - in model specification (Chapter Three), policy applications (Chapter Five) and solutions algorithm (Chapter Four). Justifications for making efforts for these extensions may reveal from the survey of the current state of MLP models provided in Appendix A.

2.6 A MULTI-LEVEL OPTIMIZATION ENERGY MODEL

2.6.1 An Illustrative Representation of the Model

Within the conceptual, analytical and methodological framework proposed above, and considering the current level of development of MLP, the following abstract and illustrative representation of an multi-level energy planning model¹ is specified:

$$\begin{aligned}
 &\text{Max } W = wG && \text{(a) Policy objective function}^2 \\
 &\quad \{ G, \pm T_1, \pm T_2, \pm T_3, Y_p \} \\
 &\quad \text{s.t.} && (2.21) \\
 &\quad T_1 \leq \{ \pm T_1, \pm T_2, \pm T_3 \} \leq T_p && \text{(b) Policy constraints (price control)} \\
 &\quad G = I_1 Y + I_2 X + I_3 Z && \text{(c) Equations defining energy targets} \\
 &\quad Y_p \leq Y_c && \text{(d) Policy constraints: resource control} \\
 &\text{Min } C = (c_1 \pm T_1)Y + (c_2 \pm T_2)X + (c_3 \pm T_3)Z \\
 &\quad \{ Y, X, Z \mid G, \pm T_1, \pm T_2, \pm T_3, Y_p \} \\
 &&& \text{(e) Behavioural objective function} \\
 &\quad \text{s.t.} \\
 &\quad Z > D && \text{(f) Energy demand constraints} \\
 &\quad Z = aX && \text{(g) Intermediate energy balances} \\
 &\quad X = bY && \text{(h) Supply balances}
 \end{aligned}$$

1. The model specified here is a static partial equilibrium model. To show the possibility for extension of the model, a general equilibrium dynamic MLO energy planning model is presented in Appendix B.

2. In this specification of the policy objective function, the policy instruments have not been included. However policy instrument ($\pm T$) will be included in the policy objective function in the subsequent specifications of MLO models (Chapters Three and Four).

$$Y + Y_p \leq \bar{Y}$$

(i) Supply constraints

$$X \leq \bar{X}$$

(j) Capacity constraints

$$G, Y, X, Z, Y_p \geq 0$$

(k) Non-negative constraints

where¹

w = vector of the coefficients of the policy objective

functions (1 x m₁),

G = energy target variable vector (k x 1),

Y, X, Z = vectors of primary energy, secondary energy and
end-uses of energy: (1 x 1), (n x 1), and (p x 1),I₁, I₂, I₃ = matrices the elements of which are either 1 or 0, $\pm T_1, \pm T_2, \pm T_3$ = vectors of tax and subsidy related to Y,

X, and Z: (1 x 1), (n x 1), and (p x 1),

Y_p = amount of Y that is directly controlled by the policy
makers (sub-vector of Y), T_1, T_p = lower and upper limits on $\pm T$,

D = the vector of given end-uses of energy (p x 1),

 \bar{Y}, \bar{X} = total supplies and capacities of fuels (1 x 1) and (n x 1),

a, b = matrices of technical coefficients (1 x n) and (n x 1).

The above model is a partial equilibrium energy sectoral MLO model which should be used for formulating medium or long term energy plans. The characteristics of the modelling approach and the analytical characteristics that the model (2.21) can demonstrate are stated in Appendix B.

1. A description of the economic and analytical characteristics of this type of MLO energy planning model will be given in Chapter Three.

2.6.2 A Discussion of the Model

In this model, the government's choice is to determine a set of policy instruments and strategies including taxes, subsidies, prices, government expenditures, etc. which will optimize the policy objective function involving the minimization of the use of energy, crude oil and imported oil. The government's choice is constrained by the limits on the variation of taxes and subsidies and by the condition that net government revenue should be positive. The behavioural model represents the choice problem of economic agents in the form of the choice (for production and consumption) of the set of energy activities which can be provided at the minimum cost given the government choice of a set of energy policy instruments and strategies. The decisions of economic agents are subject to the energy resource supply, capacity and demand constraints.

CHAPTER THREE

A MULTI-LEVEL OPTIMIZATION ENERGY PLANNING MODEL FOR AUSTRALIA

3.1 INTRODUCTION

From the discussion in the previous chapter it is now apparent that an energy model needs to be based on the foundations of the theory of economic policy, policy system analysis and on the methodology of MLP: The model should be developed within the general framework proposed in the last chapter. Therefore, the model will be a partial equilibrium energy sectoral micro-economic planning model, explicitly based on the MLO approach (Appendix B).

The objective of this chapter is to develop a numerical multi-level optimization/ multi-level energy planning model for Australia. The model is a static one year model and named as the Australian Energy Policy System Optimization Model¹: AEPSOM.

The structure of this chapter is as follows: Section 3.2 provides a brief discussion of the Australian energy sector to prepare a background for the specification of AEPSOM. Section 3.3 presents some preliminary information about AEPSOM to provide a general context of AEPSOM. Within this energy sector conceptual and methodological context, Section 3.4 specifies the detailed structure, variables, relationships and coefficients of

1. Although the model is a multi-level energy planning model, it is named as the Australian Energy Policy System Optimization Model since the emphasis of this model is on the optimization of the policy system.

AEPSOM. Section 3.5 presents a classification of the energy policy variables. Section 3.6 describes briefly the data used in the model and Section 3.7 summarizes the contents of the chapter.

3.2 THE AUSTRALIAN ENERGY SECTOR: THE CONTEXT FOR ENERGY

PLANNING AND MODELLING IN AUSTRALIA

The process of transformation of the Australian economy from a predominantly agricultural towards a modern manufacturing one is clearly characterized by the increased importance of the energy sector in the micro-economic structure of the economy. This is explained by the fundamental and pervasive role of energy in the modern production and consumption processes in an industrialized economy. The role that the energy sector plays in the Australian economy is clearly indicated by the higher energy-GDP ratio (Folie and Ulph [1982]), and by the substantial contribution of the energy sector to GDP, employment, capital expenditure, government revenue and export earnings (Department of National Development [1979], Department of Primary Industries and Energy [1988]).

In the following sub-section, some aspects of the Australian energy sector such as the supply of and demand for energy resources, energy related problems in the economy, and the initiation of energy policies are discussed to justify the undertaking of an energy policy study for Australia. In view of the indispensable role of a model in energy policy studies, this discussion will also provide the background for an Australian energy model.

3.2.1 Energy Resources: Supplies and Consumption

Australia is well-endowed with most fossil fuels: coal, natural gas, uranium and oil shales. The major constraint on the Australian energy supply system is the inadequacy of oil reserves. It has a moderate hydro-electricity supply and a large biomass and solar energy potential, although its potential for other renewable energy sources such as wind, wave, ocean, and geothermal energy is considered conservatively.

In Australia, the demonstrated economic recoverable black coal reserve is 31.0 gigatonnes which, at the 1983 production rate, is expected to last for about 300 years. Australia's brown coal reserve is higher than its black coal reserve: a reserve of 37.4 gigatonnes is expected to last for about 1,000 years. Other non-renewable energy reserves are also substantial: the natural gas reserve, which is mainly located offshore, is sufficient for 55 years, and the uranium supply is good for 15.3% of the total supply of recoverable fossil fuel (Department of Resources and Energy [1983]).

Australia's oil reserve can last only until 2000 A.D - its reserve, including condensate and LPG, is only 1.0% of the total recoverable energy resources of Australia. The possible supply of fuel from biomass is about 461 petajoules, although biomass fuels such as methanol, ethanol and seed oils are found costly compared to oil products (Stewart et al. [1979]).

Like any other country, energy consumption in Australia is shaped by its industrial, economic, demographic and geographic characteristics. Australian primary energy consumption in 1979-80 was 51.2 Million Tonnes of Oil Equivalent (MTOE) almost all of which was supplied from commercial energy sources. Total energy

consumption has also grown historically to facilitate the increased development activities in the country. For example, over the period of 1977-78 and 1981-82, total energy demand has increased at the annual rate of 2.1 percent (Department of Resources and Energy [1983]).

The Australian economy depends heavily on liquid fuels, particularly for meeting its transport needs. Demand for different fuels in 1979-80 in MTOE was as follows: oil: 32.1 (44.40%), coal: 28.1 (38.87%), natural gas: 8.8 (12.17%), hydro-electricity: 1.2 (1.66%), and other fuels (bagasse and wood): 2.4 (3.32%) (Department of National Development and Energy [1981]).

Australia is among the 5 net energy exporting OECD countries. Export of energy consists of black coal, uranium, coke and some petroleum products. Total export of energy in 1979-80 was 217.7 MTOE. One of the major characteristics of the Australian energy system is the dependence on imported oil. Total import of energy - crude oil and petroleum products - was 14.2 MTOE in 1979-80 which was 49.76% of the total production of domestic crude oil and 30.5% of the total oil demand in the same year (Department of National Development and Energy [1982]).

3.2.2 Prospects of The Energy Sector: Justifications and Initiation of Energy Policies and Modelling in Australia

3.2.2.1 Prospects of the Energy Sector

The government forecasts for the energy production and consumption are as follows (Department of National Development and Energy [1981]): Total domestic energy production in 1989-90 will be 258.5 MTOE - a 256.7% increase in ten years. Total net energy

consumption will be 64.1 MTOE. Australia will be a net exporter of energy: the total import of energy will be equal to 8.1 MTOE, which is lower than the total export of energy: 171.3. However, the country's oil imports are expected to increase because of its dwindling reserves of oil¹.

In the past, Australia experienced the adverse macro-economic effects of past events in the world energy market, in particular the three oil price shocks of 1973, 1979, and 1990 in the form of inflation, unemployment and recession (The effects of the first two price shocks are discussed in Vincent, et al. [1980]).

3.2.2.2 Why Energy Policies for Australia?

The survey of the Australian energy sector in the previous section highlights its salient characteristics: Australia is well endowed with major energy resources except crude oil; it is a net exporter of energy although heavily dependent on imported oil to meet the domestic need for liquid fuel; it is expected that Australia will remain dependent on imported oil for some decades. The question is now: Does the Australian situation warrant the formulation and implementation of energy policies? The answer to this question in general has been discussed in Chapter One. Although the answer was not straight forward, the existence of market failures in the energy sector was the justification for government intervention in this sector. Australian writers are

1. The dependence of the Australian economy on oil (liquid fuel) is caused by such factors as the present transport system and nonexistence of natural oil substitutes as shale oil, tar sands and oil from coal or natural gas. And since the domestic production of crude oil is not expected to increase enough to meet the domestic needs for oil, the dependency on the imported oil will remain or even increase in the future.

divided on the subject: one group believes in the infallible power of the market in solving all the problems in the energy sector (Hocking [1975], Tengrove [1986]), while another group advocates government intervention in the form of deliberate energy policies to solve the energy related problems and to correct for market failures (Folie and Ulph [1979], Gruen and Hillman [1981]).

The justifications¹ for energy policies in Australia suggested by the second group are based on the following arguments: The Australian reserves of crude oil will be exhausted in the near future, uncertainty about the required supply of oil and its price, possible macro-economic problems in the form of inflation, unemployment, recession and the balance of payment deficit caused by the oil supply embargoes or price increases of 1973, 1979 and 1990, the merit-good character of energy, and the inefficient operation of the energy market (Folie and Ulph [1979], Gruen and Hillman [1981]). The following statement may show the importance of a set of energy policies/energy management in Australia. Allan Powell has stated (quoted in Lloyds (ed.) [1984], p. 323) that

"Even a lucky country cannot afford to squander the resources with which it is barely endowed".

Hall [1984] has argued more directly and strongly for a set of energy policies for Australia.

Because of the existence of market failures and the possibil-

1. Saddler [1981] has discussed and examined in detail the views of both groups on the formulation of energy policies in the context of energy problems in Australia from their broad socio-economic - technical perspectives and suggested the formulation of energy policies for the provision, distribution and utilization of energy resources.

ity of exhaustion of oil in Australia, a certain amount of government intervention is viewed as essential: Interventions designed to correct energy market failures, specifically to provide information and to ensure greater distribution of the income arising from the energy sector. This view is consistent with the government's attitude towards public intervention in the energy sector (Department of National Development and Energy [1979], p.4, Department of Resources and Energy [1984], and Department of Primary Industries and Energy [1988]).

The formal initiation of energy policy activities goes back as far as 1972 when the Department of Minerals and Energy was set up. There was no policy document until the publication of "Australian Energy Policy - A Review" by the Department of National Development in 1979. From then onward, national energy policy has become more comprehensive and integrated, although not to the desired extent.

Since Australian energy policies are still at the formative phase, some issues related to the objectives, strategies and instruments of energy policies are being discussed. Such issues relate to the selection of appropriate energy policy objectives, such as the question of whether import independence should be an objective of Australian energy policies (Folie and Ulph [1979]). There are other issues that relate to the choice of appropriate energy policy strategies and instruments. For example, the question of suitability of stockpiling or broader adjustment in the macro-economy for facing any possible oil shortage has received careful consideration. These issues of Australian energy policies will be given due treatment in the appropriate places: issues related to policy objectives in Section 3.4.1, issues related to

strategies and instruments in Chapter Six.

3.2.2.3 Institutional Aspects

Politically, Australia is a federation with a high degree of delegation of power between the Commonwealth and State Governments.

In situ on-shore and off-shore minerals are owned by the Crown, except for uranium in the Northern Territory. The Commonwealth government controls the price of oil and the allocation of leases for exploration of oil, coal and natural gas. The State Governments produce and supply electricity and determine its price.

The private sector supplies or produces coal, oil, natural gas, wood, uranium and solar energy. The prices of these fuels are determined by the individual suppliers or producers except oil. Consumers make their decisions about end-uses of different fuels.

The economic agents have greater freedom in making their optimum decisions independently. Their decisions are, as is revealed from above discussions, affected by some government actions. The behaviour of economic agents are subject to the influence of the following government quantitative policies and strategies: taxes and subsidies, price control, government expenditures for research and development etc, and exploration, conservation and technology policy strategies.

The role of energy markets (decisions of economic agents) in Australia has been stated as follows (quoted in 'Department of National Development [1979], p. 4):

"Quite clearly, the Commonwealth Government's role should not be to attempt to indicate the precise future path along which energy producers and consumers should move. It is however, necessary to set the scene within

which the private sector and Government instrumentalities can operate with confidence, while as far as practicable, i.e. given our other objectives, allowing the forces of the market to allocate our available resources of manpower, capital and technology.

The thrust of the Australian energy policies is stated in the following (Department of National Development, p. 4) :

"There are circumstances where market forces will not achieve the Government's objectives. The Government has used taxes and subsidies to encourage conservation, advance production of new sources of energy and intensify exploration and development of oil and gas fields."

From the above analysis, it may appear that in Australia there exists a multi-level (two-level) policy system characterized by the presence of government and economic agents in policy making processes. The major form of government intervention in the decision making of economic agents is the control of energy prices.

3.2.2.4 Energy Planning Modelling in Australia

It should be mentioned here that the existence of these problems and their resolution require the formulation of a set of energy policies. To undertake such policy studies, energy modelling has started in Australia.

Energy modelling activities in Australia are relatively new. An initial study in this area is the work of the National Energy Advisory Committee (NEAC) (1978). The need for, and scope of energy modelling in Australia has been discussed in NEAC (1978). Four types of models were proposed in the energy model suit: Reference Energy System (RES), the Brookhaven Energy System Optimization Model (BESOM/ AUSTESOM), an input-output model, and a Hudson-Jorgenson type model (DRI/CRES/UNSW model).

RES was necessary to develop the data base and structure for an optimization model-BESOM (or Australian version, AUSTESOM). But instead of a static optimization model BESOM, a dynamic optimization model (MARKAL) has been formulated by CSIRO (Musgrove et al. [1983]). MARKAL is a special version of DESOM.

An input-output model named MERG has also been developed by James [1984]. Development of a Hudson-Jorgenson type of model named CRES/UNSW model was attempted (Folie and Ulph [1976]), but was not implemented. An independent modelling work is GESOM (Schuyers [1979]), which is an application of BESOM to Australia. This model has been coupled with the IMP macro-model (Brain and Schuyers [1981]). Another hybrid model is MERG-MARKAL (James et al. [1986]).

Strictly speaking, MARKAL and GESOM are the only two optimization models which belong to the type of energy models considered in this study. These are mathematical programming models whose characteristics have already been discussed above.

Australian energy models belong to one or other category of the models mentioned in the model survey in Chapter Two. A classification of Australian models is as follows:

(a) Mathematical Programming Model:

- MARKAL
- GESOM

(b) Input-Output Model:

- MERG

(c) Hybrid Model

- IMP macro model + GESOM
- MERG + MARKAL

The limitations of different types of energy models discussed in

Chapter Two apply to the different types of Australian models. Since the general counterparts of the Australian models have been evaluated separately, a general statement can be made that the Australian energy models also do not satisfy the model evaluation criteria. Therefore, there is a need for developing an alternative energy model in Australia, similar to the one proposed in Chapter Two.

3.3 THE AUSTRALIAN ENERGY PLANNING MODEL - AEPSOM: SOME PRELIMINARIES

(a) Abstract Presentation of AEPSOM

An abstract presentation of the structure of the model¹ to be specified in this section is given here, and can be used as reference in the subsequent discussion. Two alternative specifications of the model are provided: in the first specification, budget constraints are included in the policy model ($\pm T$ is not in the policy objective function), while in the second specification, $\pm T$ (budgetary implications of policies) is included in the policy objective function (budget constraints are not in the model).

Specification 1

$$\text{Min WL} = wG$$

(a) Policy objective function

$$\{\pm T\}$$

s.t.

$$G = I_1Y + I_2X + I_3Z$$

(b) Definitional equations

1. This model is similar to the model (2.21) in Chapter Two. But this model is a price control MLP model, while the model (2.21) is a price and resources control MLP model.

$$\begin{aligned}
& T_1 \leq \pm T \leq T_p && \text{(c) Policy constraints} \\
& \{(+T_1)Y + (+T_2)X + (+T_3)Z\} - \{(-T_1)Y + \\
& \quad (-T_2)X + (-T_3)Z\} \geq 0 && \text{(d) Budget constraints} \\
& \text{Min } C = (c_1 \pm T_1)Y + (c_2 \pm T_2)X + (c_3 \pm T_3)Z \\
& \quad \{Y, X, Z \mid \pm T\} && \text{(e) Behavioural objective function} \\
& \text{s.t.} && (3.1) \\
& \quad Z \geq D && \text{(f) Demand constraint} \\
& \quad Z = aX && \text{(g) Intermediate energy balance constraints} \\
& \quad X = bY && \text{(h) Energy supply balance constraints} \\
& \quad Y \leq \bar{Y} && \text{(i) Resource constraints} \\
& \quad X \leq \bar{X} && \text{(j) Capacity constraints} \\
& \quad G, Y, X, Z \geq 0 && \text{(k) Non-negativity constraints}
\end{aligned}$$

where:

WL = the value of P.O.F.,

w = vector of coefficients of the policy objective,
function (i x e)

G = vector of energy target variables (e x 1),

Y = a vector of primary energy (p x 1),

X = a vector of energy products (n x 1),

Z = a vector of end-uses of the energy products (m x 1),

D = a vector of end-uses in various sectors (q x 1),

c_1, c_2, c_3 = costs for supplying, converting and using
energy {(p x 1), (n x 1), (m x 1)},

$\pm T = \{\pm T_1, \pm T_2, \pm T_3\}$ = vector of different taxes

and subsidies {Sub-vectors $\pm T_1, \pm T_2, \pm T_3$ = (p x 1),
(n x 1), (m x 1)} (+T = taxes, -T = subsidies; lower

case t 's are the elements),

a, b = matrices of technological coefficients $\{(m \times n),$
 $(n \times p)\}$,

I 's = identity matrices the elements of which are either
 1 or 0,

T_1 = lower level of $\pm T$,

T_p = upper level of $\pm T$.

Specification 2.

$$\text{Min WL} = wG -$$

$$[\{(+T_1)Y + (+T_2)X + (+T_3)Z\} - \{(-T_1)Y + (-T_2)X + (-T_3)Z\}]$$

$\{\pm T\}$

(a) Policy Objective Function
 (P.O.F.2)

s.t.

$$G = I_1Y + I_2X + I_3Z \quad \text{(b) Definitional equations}$$

$$T_1 \leq \pm T \leq T_p \quad \text{(c) Policy constraints}$$

(3.2)

$$\text{Min } C = (c_1 \pm T_1)Y + (c_2 \pm T_2)X + (c_3 \pm T_3)Z$$

$\{Y, X, Z \mid \pm T\}$

(d) Behavioural objective
 function

s.t.

$$Z \geq D$$

(e) Demand constraint

$$Z = aX$$

(f) Intermediate energy balance
 constraints

$$X = bY$$

(g) Energy supply balance
 constraints

$$Y \leq \bar{Y}$$

(h) Resource constraints

$$X \leq \bar{X}$$

(i) Capacity constraints

$$G, Y, X, Z \geq 0$$

(j) Non-negativity constraints

(b) A Discussion of the Model

Model (3.1) is a price control MLP in which the policy makers at the upper level of the hierarchical structure intervene in the behaviour of the energy producers and consumers by taxes and subsidies ($\pm T$)¹. Policy makers are only interested in the policy target and instrument variables (G and $\pm T$). The policy optimization problem involves the minimization of the policy objective function consisting of target variables such as energy import, total energy use etc. subject to such constraints as policy constraints and budget constraints. The policy constraint imposes limits on the changes of taxes and subsidies, while the budget constraint requires that the government budget (taxes and subsidies) in the energy sector should be balanced or surplus.

The behavioural model is a cost minimization linear programming model in which the economic agents choose variables : Y , X , and Z after $\pm T$ is announced by the policy makers. The objective function of the behavioural model (3.1.e) consists of total costs for supplying, producing and using energy plus taxes minus subsidies. Marginal costs of various types of energy are constant irrespective of the levels of input and output, however rela-

1. The government influences indirectly the economy. Decisions in the energy sector are indirectly controlled by the government through taxes and subsidies ($\pm T$), prices, government expenditures, education and propaganda, and the supply of technical information.

tive prices influence resource allocation in the energy sector since in the model, price is equal to cost \pm taxes/subsidies which is endogenous in the model (see equation 3.1.e). The equations 3.1.f to 3.1.j (relationships, variables and technical coefficients (a and b)) represent the characteristics of the underlying energy system, modelled as different types of constraints on the demand for energy, maximum possible energy supply and capacity utilization etc.

The primary inputs in the production processes are the primary fuels which are either converted into secondary energy or are transported to the end-users for final uses. Activities in the model represent the flows of energy from the stage of supply of primary energy to the end uses. The energy inputs and outputs are perfectly divisible. The quantities of inputs and outputs in case of conversion activities are in fixed proportions. Substitutability among primary energy, energy products, and end-uses of energy (inter-fuel substitution) exists. The linear production function of the multi-input, multi-activity and multi-output type (Naylor and Vernon [1969], Chapter Eight) exists in the energy sector. The production function embedded may be written as $Q(Z,X,Y) = 0$, where Z , X , Y = vectors of energy end-uses, energy products and primary energy.

Capital and labour inputs are not endogenous variables in the model. Therefore, the inter-factor substitution possibility is not specified in the model¹. Only capital supply is con-

1. The inter-factor (labour, capital, energy and raw materials) substitutability has been a major focus of the econometric studies on the aggregate relationships between macroeconomic activity and energy use (Julius [1981] contains a survey). Different degrees

strained. The supply of labour is not constrained (due to availability of sufficient labour to supply the required amount of energy). Demand for energy in each sector of the economy is given exogenously.

As the demand for energy and the supply of inputs are exogenous in the model, this is a partial equilibrium energy sector model.

In summation, the MLP model (3.1) (or (3.2)) is a mathematical definition of the constituent components of the multi-level decision making system in the form of two objective functions and two sets of constraints. The programming problem embedded in the model is to determine the optimum values of the decision variables of both levels of decision makers.

(c) Foundations

(1) The above model is a price control non-linear MLP (price control bi-level programming) model. The model consists of two optimization problems, the policy optimization problem and

...Continued...

of substitutability are assumed and specified in different types of production functions (for example Cobb-Douglas, CES and translog production functions (Berndt and Wood [1979])). Findings of these studies have been used to predict the aggregate energy use or other energy macroeconomic relationships in the economy. It may, however, be mentioned that in mathematical programming energy models, the emphasis has been on the inter-fuel (coal, natural gas, oil etc), substitutability. This is so because most of the mathematical programming energy models are developed to capture the technical details and processes of the energy sector in which case inter-fuel substitution appears to be more important than inter-factor substitution. Relative merits and demerits of mathematical and econometric models were discussed in Chapter Two. It was stressed that which method should be adopted in a study depends on the objective, nature and uses of the model. Approaches and assumptions made in this study to undertake a specific type of energy planning study require the adaptation of an MLP model in which inter-fuel substitution appears to be a dominating issue.

the energy systems optimization problem, which are as follows:

(Specification 1):

(i) Policy Optimization Problem

$$\begin{array}{ll} \text{Min } WL = wG & \text{(a) Policy objective function} \\ \{+T\} & \text{(3.3.a)} \end{array}$$

s.t.

$$G = I_1Y + I_2X + I_3Z \quad \text{(b) Definitional equations}$$

$$T_1 \leq \pm T \leq T_p \quad \text{(c) Policy constraints}$$

$$\{(+T_1)Y + (+T_2)X + (+T_3)Z\} - \{(-T_1)Y + (-T_2)X + (-T_3)Z\} \geq 0$$

(d) Budget constraints

$$G, Y, X, Z \geq 0 \quad \text{(e) Non-negativity constraints}$$

(ii) Energy Systems Optimization Problem

$$\text{Min } C = (c_1)Y + (c_2)X + (c_3)Z$$

$$\{Y, X, Z\} \quad \text{(a) Behavioural objective function}$$

s.t.

$$Z \geq \bar{D} \quad \text{(b) Demand constraint} \quad \text{(3.3.b)}$$

$$Z = aX \quad \text{(c) Intermediate energy balance constraints}$$

$$X = bY \quad \text{(d) Energy supply balance constraints}$$

$$Y \leq \bar{Y} \quad \text{(e) Resource constraints}$$

$$X \leq \bar{X} \quad \text{(f) Capacity constraints}$$

$$Y, X, Z \geq 0 \quad \text{(g) Non-negativity constraints}$$

(2) The model has the three elements of the theory of economic policy: (a) a policy objective function (equation 3.1a), (b) a set of constraints to represent the energy technology,

policy and economic systems under study, (c) a classification of the variables:

G = the target variables

$+T$ = the instrument variables

Y, X, Z = the behavioural variables.

(3) AEPSOM is specified within the conceptual framework of policy systems analysis. There are several goals (G) that the policy makers (such as energy conservation) and economic agents (such as cost minimization) try to achieve. Goals of the two level decision makers are inter-dependent. The existing policy system has a hierarchical character, i.e. the upper level decision makers (policy makers) influence the behaviour of economic agents by indirect intervention ($+T$). This two-level decision problem is interactive - simultaneously interdependent. The attainment of economic agents' objective is dependent on the selection of taxes and subsidies by the government. The fulfillment of the government objective is also dependent on the outcome of economic agents' behaviour: the attainment of the optimum value of the policy objective function is determined by the choice of energy activities by the economic agents.

Therefore, the model contains the characteristics of a multi-goal (G), multi(two)-level, hierarchical policy system.

3.4 AEPSOM: MODEL SPECIFICATION

The elements of AEPSOM will be specified as follows: The policy objective function in Section 3.4.1, and the constraints

in Section 3.4.2.

3.4.1 A Policy Objective Function (P.O.F.)

The policy objective function¹ of AEPSOM represents the value judgments of Australian policy makers about the allocation of energy resources. So it provides the criteria for the evaluation of policy alternatives.

3.4.1.1 Specification of Policy Objective Function:

The specification of a policy objective function is partly a political exercise. The political philosophy of the policy makers will largely determine the nature of the policy objective function. Economic conditions also influence the specification of a policy objective function.

A policy objective function in an energy sector planning model should contain the existing energy policy objectives and preferences regarding the allocation of resources and the distribution of income. It should be mentioned here that the policy objective function may take the form of what an economist or a planner thinks it should be on the basis of his own arguments and preferences. Alternatively, it may manifest only the preferences

1. In spite of the Arrow impossibility theorem (Arrow [1951]), which rules out the possibility of specifying a social welfare function without violating one or more of the five acceptable axioms of social preferences, economists' endeavor to construct and analyse social welfare functions has proceeded steadily. One development in the mechanism of the specification of the social welfare function has been suggested by Downs (1957). In this approach it is assumed that the social preference is revealed through the political process of voting i.e., the individuals' preferences are signaled to the government policy makers by their vote in favour of the party elected. Therefore, the policy objective function is used as a proxy for the social welfare function. And this is how Tinbergen viewed the social welfare function (Tinbergen [1952]).

of the current policy makers. In the present study, the latter approach has been followed.

To establish a policy objective function, the following information is necessary:

- (1) the functional form,
- (2) the variables appearing in the function,
- (3) the weights attached to each variable,
- (4) the units of measurement of the variables.

3.4.1.2 Alternative Methods of specifying the Policy

Objective Function

The alternative approaches for revealing the preferences of policy makers are: direct interview, indirect interview, imaginary interview, inference from planning documents, and the revealed preference method (Johansen [1974]). Because of the problems associated with the interview methods such as the non-availability of enough appropriate information to specify analytically and numerically a policy objective function (by either of the first three methods), an approach that consists of some elements of the last two methods has been adopted. Thus the adopted method of establishing the policy objective function requires one to study the policy documents and to make inferences from the actions of policy makers.

3.4.1.3 Functional Form

The methods for establishing the policy objective function stated above have been applied to specify the functional form of the policy objective function. Frisch has adopted the direct interview method (Johansen [1974]), van Eijk and Sandee [1959]

adopted an imaginary interview method, while Fox, Sengupta and Thorbecke ([1973], Chapter 15) used the methods of inferences drawn from published documents and revealed preferences to specify the functional form of the policy objective function in their studies. For the reasons stated above, the methods of inferences from the policy documents and revealed preferences were used in the present study.

A policy objective function can take many economically acceptable functional forms (Frish [1976]) such as: linear, quadratic, cubic, log, log-inverse etc. Quadratic and linear forms are most commonly used in macro-economic and sectoral policy studies (Fox, Sengupta and Thorbecke [1973]).

For example, in Theil's macro-econometric studies of optimum policy formulation in which some desirable values of the targets and instruments can be identified, a quadratic policy objective function involving the squared deviations of the desired and actual values is specified. An alternative approach is what is termed as the multi-target policy objective function (linear or non-linear). In van Eijk and Sandee's [1959] approach to the multi-target policy objective function, no macro-economic fixed targets were identified; a linear function involving macro target variables such as GDP, employment, inflation and the balance of payment was found to be appropriate.

In most of the MLP literature so far, relatively simpler policy objective functions have been specified because of the computational problem of an MLP model. In all large or medium scale real applications of MLP models, a linear policy objective function has been specified (see Candler and Norton [1977], Bischoff et al. [1982] and Fortuny-Amat [1979]). For example Candler

and Norton [1977] have specified a linear policy objective function involving the following agricultural sector policy target variables: employment, farm income, the level of wheat production and the size of government budget. The policy objective function was maximized by the programming problem.

Relative superiority of different functional forms has been disputed by economists (Yotopoulos and Nugent [1976]), without any definite agreement.

Theil's quadratic welfare function has gained wide application in macroeconomic policy studies. The justifications for adopting Theil's quadratic function have been stated as follows (Fox, Sengupta and Thorbecke [1973], p. 192):

"It is not necessary to believe that the preference functions of policy makers are necessarily and precisely quadratic forms; we may simply use quadratic forms as reasonable approximations to the true preference functions over limited ranges on either side of the desired values of the instrument variables. The justification for using quadratic preference functions, says Theil, is analogous to that for using minimum-variance estimation in statistics and mean-square error minimization in engineering, which derived their popularity mainly from considerations of mathematical convenience. A more profound argument in favour of quadratic preference functions is that this form allows us to have decreasing 'marginal rates of substitution' between the various instrument variables and non-controlled variables."

Theil's quadratic function has several disadvantages. Since in this approach the specified objective is to minimize the sum of the weighted squares of deviations of instruments and targets from a desired level (the fixed target variables), it is necessary to implement this approach to determine some fixed values of the target variables. One problem of the determination of the fixed values of targets by an analyst is that it may be arbitrary, unless these values are determined by the policy makers.

In Australia, no effort has so far been devoted to determine the target values of energy conservation, oil use, oil import, etc., by either academics or government. Therefore, the specification of Theil's quadratic welfare function will be arbitrary because of the arbitrary character of the targets to be determined.

Another drawback of Theil's approach has been stated by Yotopoulos and Nugent ([1976] p. 423) as:

"Moreover, this specification has the unfortunate characteristics of treating as equally undesirable positive and negative deviations from the fixed targets".

Finally, although Theil's approach has mathematical convenience (for which it has gained wider application in macro-economic policy studies), a linear multi-target policy objective function also has mathematical and computational convenience in mathematical programming models.

For all these reasons, a multi-target policy objective function (linear or non-linear) is being advocated here. A multi-target policy objective function approach is a flexible and commonly accepted approach (Yotopoulos and Nugent [1976] and Fox, Sengupta and Thorbecke [1973]). This has been argued by Yotopoulos and Nugent ([1976], p.423) as follows:

"Some of the short-comings of Theil's quadratic objective function can be overcome by specifying a somewhat more general objective function, that is, a complete multi-target social welfare function, each different goal being weighted by its relative importance from the point of view of the decision makers."

The conclusion is that a multi-target (linear or non-linear) policy objective function may be considered as a suitable functional form for energy policy planning studies, particularly in a

study where an MLP or mathematical programming model is used.

Therefore, a multi-target policy objective function of the following form is specified:

$$W = F(w_1x_1, w_2x_2, \dots, w_nx_n) \quad (3.4)$$

where: w's are the weights of the policy target variables

x's are the policy target variables.

This is a general presentation of the policy objective function. Specific presentations of the two specifications of policy objective functions will be given in (3.5) and (3.18).

3.4.1.4 Variables in the Objective Function

3.4.1.4.1. The Objectives of the Australian Energy Policies:

The study method ((a) the study of the energy policy documents and (b) inferences from the revealed preferences of the policy makers) has been adopted in order to identify the relevant variables appearing in the policy objective function (the policy target variables).

Many governments adopted energy policies before the Australian government did so. Australia did not initiate any formal energy policies until the establishment of the Department of Energy in 1972. Since that time several government energy policy statements and documents have been published to highlight the salient features of Australian energy policies.

It was stated before that in the absence of any market failures, a perfectly competitive economy can attain an optimum allocation of resources in the energy sector. But because of the occurrence of market failures, manifested in several energy

problems (stated in Chapter One), government policies have been designed to correct these market failures and to solve these energy problems. All these policies are aimed at the efficient use of the energy resources, the determination of efficient prices, and the provision of some social goods (research and development). Furthermore energy policy objectives also embrace the need for an equitable distribution of benefits accruing in the energy sector. In 1977, the objectives of the Australian energy policies were as follows (Anthony [1977]):

"to move crude oil prices in the direction of international levels; for the average rate of growth of energy consumption, particularly in liquid fuels, to be restrained; the highest degree of self-sufficiency in liquid fuels consistent with the broadly economic utilization of energy reserves; that economic oil and gas reserves be developed; to encourage individual major energy projects to meet overseas demand for energy minerals where those projects are economical and will provide an adequate return to Australia; and that energy research and development (R&D) be substantially increased."

The emphasis of Australian energy policy has remained unchanged since 1977. For example in 1979 (ESCAP [1979]), the policy objectives were stated as follows: to reduce energy consumption, specially in liquid fuels, attain the highest degree of self-sufficiency, increase energy reserves, encourage exports and increase research and development. In 1986, Tengrove [1986] stated that in general government policies are designed 'to increase security of supply, to encourage industrial development, to alter distribution of income and to reduce the rate at which resources are depleted.' Similar objectives are also stated in Department of Resources and Energy (undated, probably 1984) and Department of

Primary Industries and Energy (1988).¹

Therefore, it can be stated that inspite of the changes in the government in power and changes in the energy sector, both locally and globally, the following energy policy objectives have been common to all the above energy policy development initiatives: (a) security of energy supply, (b) conservation of energy, (c) (specially) conservation of oil, (d) efficiency in energy supply, production and uses, (e) the development of the export energy sector, and (f) equity in the opportunities generated in the sector.

The above emphasis of the energy policy is not restricted to Australia. Countries of similar economic and energy sectoral backgrounds have pursued the same types of energy policy objectives (International Energy Agency [1986]). Generally, Australia and other western industrialized countries have a common set of energy policies designed to achieve the objectives specified.

The citation of the historical and cross-country energy policy experiences alone is not enough to justify the identification of a set of energy policies for a country. An analysis of the energy sector problems and prospects for its developments, Australian and global, in the context of the overall macro-economy is necessary to justify the individual energy policy objectives relevant for a country.

Such an analysis is provided below.

1. For an account of the evolution of the Australian energy policies, see Marks [1986].

(A) The Security of Supply/Import Independence

The Arab oil embargoes have created a world wide sense of oil supply insecurity due to the expected non-availability of oil that may be caused by any further embargoes in the future. The problem has several interpretations (Griffin and Steele, [1980]). The most common one is that the non-secured oil supply is a national security problem. Oil embargoes are motivated by nationalistic policies, and, therefore, oil exporting countries may prohibit oil exports for political reasons. This creates a political dependency of the oil importing countries, and may threaten their national sovereignty. Another interpretation of the problem is that though the non-secured oil supply problem may not appear to threaten national security of the oil importing countries, it may, however, create serious macro-economic problems in the form of unemployment, inflation, the balance of payment deficit, and recession due to oil supply shortages or oil price hikes, and may threaten the country's economic welfare.

Whatever the exact interpretation of the problem may be, the situation had certainly created a market failure - the market can not internalize the expected cost of an oil supply embargo. Therefore, a deliberate policy response from the government is necessary to deal with this problem.

At this stage a clear statement about what is meant by the terms "the security of energy supplies" is necessary for the subsequent discussion on the topic. The Department of Primary Industries and Energy [1988] defines it as follows:

"...it is more a concept of relative assurance and dependability of overall energy supplies in foreseeable circumstances"...

As has already been discussed in Section 3.2.1 although

Australia has vast reserves of coal, natural gas and uranium, making it a net exporter of energy, the country's indigenous reserves of crude oil and condensate will decline over the coming decade. This, together with the fact that no major discoveries have been made in recent years, will make Australia dependent on imported oil, in spite of the recent downward trend in the use of oil in Australia. "Hence a principal concern in energy security is to maintain a satisfactory supply of liquid fuels in the longer term" (Department of Primary Industries and Energy [1988]).

Therefore, the concept of "the security of energy supply" has been interpreted in the Australian context in the form of the security of supply of liquid fuels (oil) (Folie and Ulph [1979]).

The conceptual difficulty with the phrase "the security of supply of oil" is that it is subject to different interpretations, since the security of the oil supply can be achieved by pursuing several strategies such as: the reduction in oil import, self-sufficiency of indigenous oil supply through increased supply of domestic oil, general adjustments in the macro-economy to increase the level of self-sufficiency in oil (through oil conservation, macro-economic policy adjustments etc.), stock piling, and diversification of energy supply and increase in the supply of oil substitutes (Folie and Ulph [1979], Department of Primary Industries and Energy [1988]).

Because of the uncertainty in the possibility of increased domestic oil production in Australia in the near future, and of the possible non-effectiveness of other options in the short term, and due to the possible problems associated with the dependency of the importation of oil (inflation, embargo etc.), the emphasis of the issue of the security of liquid fuel supply in Australia has

been on the reduction of oil import, as an interpretation of the issue as well as as a policy response or objective. Therefore, a reduction in the importation of oil has become an explicit energy policy objective in Australia.

The issue is also related to the conservation of oil (Department of Primary Industries and Energy [1988]). This is discussed below (next page).

(B) Conservation of Energy

The principal concern of the developed countries is the security of an adequate energy (oil) supply. This cannot adequately be addressed by only limiting oil imports, complementary strategies are also necessary. Because of the expected ultimate global exhaustion of fossil fuel, concern for inter-generational equity in the distribution of depletable energy resources, uncertainty about the future viable backstop technology and pollution from the energy industries, it is now increasingly felt that energy conservation should be specified as an energy policy objective, at least as a by-product of the concern for the security of an adequate energy supply. The Department of Primary Industries and Energy [1988 p. 4] states it in the following form:

"... energy security in the broadest sense will be best served by pursuing, within a realistic economic framework, an adaptive strategy incorporating....energy conservation."

Energy conservation is defined as an acceptable or feasible reduction in the present consumption of energy (Griffin and Steele [1980], P. 213). Since the past history of economic development shows that there is a positive correlation between energy use and economic development, the rationale for energy conservation has

been debated. The advocates of energy conservation base their arguments on (1) what is called the energy theory of value (Webb and Ricketts, [1980]) (which implies that only energy has value), and (2) external consumption and production diseconomies (pollution etc.). However, the other position has aptly been summarized by Griffin and Steele ([1980], P. 226) as follows:

"...even though energy conservation is feasible, its desirability, when couched in terms of aggregate energy, is not obvious. Arbitrarily minimizing energy/GNP values will lead to much higher production costs and a loss in economic welfare".

This leads us to interpret energy conservation in terms of control of wastage, increased process (single or combined) efficiencies and fuel specific energy conservation through inter-fuel substitution. In this sense, the conservation of specific fuels may lead to welfare gains caused by supply security, reduction in pollutions, and the efficient allocation of energy resources.

In Australia, energy conservation has been adopted as an explicit energy policy objective, in a similar manner as in other OECD countries (Endersbee et al. [1980], Folie and Ulph [1982], ESCAP [1979], Department of Primary Industries and Energy [1988], Department of National Development and Energy [1979]). Regard has also been paid to the welfare and economic growth issues in the formulation of the Australian energy conservation policy. It was clearly stated in government policy documents. For example ESCAP [1979], P. 70) states that:

"An important constraint upon the Government's energy conservation programme was that it should not detract from the attainment of socially desirable objectives such as economic growth and the welfare of the population"

Therefore, energy conservation strategies in Australia consist of minimizing the use of energy in the economy by eliminat-

ing energy waste, by improving the efficiency of energy supply, production and end-use methods, and through the development of an efficient energy system (mix of various energy forms).

(C) Conservation of Oil

The case for fuel specific energy conservation is strong. It is argued that because of (i) market failures due to externalities, and government intervention creating differences between social and market costs and benefits, and, (ii) national security considerations, fuel specific energy conservation would increase social welfare (Griffin and Steele [1980]). As a result of this argument, conservation of oil, the fuel with a high national security risk, has been the major fuel specific energy conservation policy strategy in many OECD countries as well as in Australia (International Energy Agency [1986]).

In terms of the proven energy reserves and future energy demand, Australia is in a better position than many other OECD countries. However, its domestic oil reserve is low. Since the energy supply is very dependent on liquid fuels, it is forecasted that the country's dependency on oil, specially imported oil, will increase over time. This situation has resulted in a serious concern for consuming oil. In some cases, the conservation of oil is seen as a separate policy objective. For example in the Department of Primary Industries and Energy ([1988] p. 66) an objective of the Australian energy policy is stated as follows:

"Putting more effort into conservation/efficient use of petroleum products."

In some other cases, the objective of conservation of oil has been specified as part of the general conservation strategy. In

ESCAP ([1979], P.68) it is mentioned that one of the government energy policy objectives would be:

"To restrain the average rate of growth of energy consumption, particularly in liquid fuel."

Therefore, one of Australian energy policy objectives is to minimize the use of oil in the economy.

(D) Efficient Utilization of Energy Resources

Efficient utilization of energy resources involves the minimum cost supply of the energy demand in the economy. Efficiency can be achieved by adopting cost minimizing production, transportation and end-use processes and by avoiding waste. An appropriate energy price structure is fundamental in this process of efficiently allocating resources. As efficient allocation and utilization of energy resources are more imperative than that of any other resources because of the limited supply of the major energy fuels, this objective has received considerable attention.

(E) Maximization of Government Revenue:

In Australia, the energy sector contributes significantly to the government budget: revenue from indirect taxes including royalties was \$m 4729 in 1981-82 (Department of Primary Industries and Energy [1988]). The possibility of increased government tax earning in the energy sector has risen with the advent of large scale mining in the economy and the introduction of the import parity pricing of crude oil. The government is aware of this potential of the energy sector and a government policy has been to maximize the contribution. This is reflected in the government decision to introduce resource rent tax - a tax to siphon off the surplus rent generated in the energy sector - which should be

utilized for the development of the sector and the community.

Further discussion on the justifications for the revenue maximization objective of the government is provided in Section 3.4.1.9.

(F) Development of the Export Energy Sector

Following what is called the export-led growth strategy, Australia has adopted a policy of increasing its exports, specially its mineral (including energy) exports, inspite of the problem indicated by Gregory [1984]¹. Because of Australia's balance of payment deficit and its international competitiveness in coal and liquid natural gas (LNG), the Australian economy can gain substantially by developing the export energy sector. To help realize this potential, one of the objectives of the Australian energy policy has been the development of the export energy sector (Department of Primary Industries and Energy [1988]).

(G) Equity

Equity considerations of the energy sectoral resource allocation utilization and development have also been dominating in Australia (Gruen and Hillman [1981], Saddler [1981], Tengrove et al. [1986]).² The objective has been "to seek an equitable sharing of the benefits of energy resources development amongst the

1. Gregory thesis states that exports of minerals in a primary commodity exporting country may deindustrialize the country instead of industrializing it.

2. Scepticism in the market determined equity in income and property in the energy/resources sector has been an important issue in Post-Keynesian economics (Eichner(ed.) [1979]).

Australian Community" (Department of Resources and Energy (1984), P.47).

Since an optimum allocation of resources can be determined for every given distribution of income and wealth, and because of the problem of the incorporation of the efficiency and equity objectives in one model, it is generally argued that in policy studies these two objectives should be studied separately (Griffin and Steele [1980]).

The present study is primarily concerned with the allocative implications of energy policies. Therefore, the equity objective has not been included in this model.

3.4.1.4.2 Quantification and Incorporation of the Energy Policy

Objectives in the Model/Policy objective Function

The international trade sector will not be explicitly specified in the model, thus the objective of the development of the export energy sector can not be specified in variable form in the policy objective function. However, constraints will be specified in the energy sector model to ensure that the given foreign demand for Australian energy is satisfied by the domestic production of energy (see equation 3.8).

The objective of the efficient utilization of energy resources will be taken care of by the energy sectoral behavioural model since the energy sector behavioural model will be specified as a cost minimizing linear programming model.

The remaining objectives of Australian energy policy namely reduction of oil imports, reduction in the use of oil, conservation of energy and the maximization of net revenue will be incorporated in the policy objective function. These objectives will

be represented by the following target variables (quantities): oil import (Ie_1) total use of oil ($CNo = R_2 + Ie_1$) and total use of energy ($TCe = R_1 + \dots + R_6 + Ie_1$) (p. 102), and $\{(+T) - (-T)\}$.

In the first type of specification the first three target variables will be included. In the second type of specification, all the four target variables will be included.

3.4.1.5 The Weights of the Policy Target Variables

(A) Mechanism for the Specification of the Weights

Specification of weights of policy target variables (the coefficient of the policy objective function) from the quantitative information obtained through the revelation of the preferences of policy makers is a difficult task, since hardly any information is available for this purpose (Fox, Sengupta, and Thorbecke [1973]). Two approaches are usually adopted to specify the weights of the target variables. The first approach is to derive the weights as accurately as possible through one or several methods for the specification of the preferences of policy makers (Johansen [1974]). The second approach involves the derivation of a set of weights as a working set from the quantitative information gathered from published documents and announcements of policy makers, and later evaluating the sensitivity of the optimum solution of the policy model to changes in the coefficients of the policy objective function, in order to determine the robustness of the weights used in the initial specification. In AEPSOM, the second approach has been adopted.

(B) Past Examples

Several past efforts for determining the weights of the policy objective function are worth mentioning here.

(i) In Theil's quadratic welfare function approach (Theil [1970]), a quadratic function of the deviation between the desired and the actual values of the target and instrument variables is minimized. Therefore there is no need for specifying the weights of the target variables.

(ii) Frisch [1976] used a method based on direct interview of the policy makers to extract enough quantitative information about the coefficients in the policy objective function.

(iii) Another approach involves the determination of weights of the policy objective function from studies of the underlying policy environment (for example Van Eijk and Sandee [1959]). In this approach, an analysis of policy statements, actions, and published documents provide information on the initial specification of weights, although the weights are subsequently changed to study the sensitivity of the optimum solution to these changes. If the optimum solution is not very sensitive to the alternative sets of weights, then the initial set of weights can be considered to be appropriate.

(iv) In some policy studies, the coefficients of the policy objective function can be obtained from the economic system under study. For example, if the policy objective function is in a form that represents the social surplus (consumer's surplus plus producer's surplus) the coefficients of the policy objective function can be obtained from the model under study.

(v) In the MLP policy studies, the issue of the selection of appropriate weights has not received any serious attention, proba-

bly because of the fact that attention has mainly been paid to the computational problems and other fundamental problems associated with the mathematical properties of MLP such as existence, uniqueness and global optimality of the MLP solution (Chapter Four; Candler and Norton [1977]).

Candler and Norton [1977] have adopted a method similar to van Eijk and Sandee [1959]. In that study the selection of the weights of the variables in the policy objective function was somehow arbitrary, although some motivation for the initial specifications was given. A sensitivity analysis was conducted to study the effects of the changes of the coefficient in the policy objective function on the optimum solution. In other MLP studies, either there is no need for specifying weights because of the nature of the policy objective function (for example, maximization of net benefit) as in Sparrow et al. [1979] or in some other studies (Fortuny-Amat [1979]) the weights have been purely arbitrary.

(C) Weights in AEPSOM

No quantitative information about the relative importance of the various Australian energy policy objectives is available from the government or from academic publications in this area. Therefore, the specification of the weights in the policy objective function in the present study is mainly based on past experience in this area, professional judgment, and partly on the revealed preferences of the policy makers.

Of the three policy objectives to be included in the policy objective function (1), reduction in oil import may appear to be more important than the other two objectives because of its direct

implications in terms of national security. But the objective of reduction of oil import may lose some weight if oil can be imported from a friendly country or oil use can be reduced by diversifying the domestic energy sector. The other two policy objectives may appear to be of equal weight i.e., conservation of oil and conservation of total energy are of equal concern.

Because of the apparent equal importance of the three policy objectives and since no information about the relative weights of different policy objectives is available, it is maintained that these three target variables will have equal weight in the policy objective function. This means that one unit reduction in the import of oil is equally important to the policy makers as one unit reduction in the total use of energy or oil. However, one unit reduction in oil import will be three times more important than one unit reduction in the use, say, of natural gas, since oil import is appearing three times in the three target variables. Similarly the reduction in oil use will get two times more weight than the reduction in the use of natural gas.

Attaching equal weights to all target variables may appear as a simplification of the exercise of the specification of the policy objective function. However, as it was stated above, literature in this area in energy economics has not yet developed unlike macroeconomics where relative prioritization of target variables is merely a duplication job (Fox, Sengupta and Thorbecke [1973]). The problems of relative prioritization of targets have been discussed by Griffin and Steele ([1981], p.342) and they have expressed their concern as follows:

"How, then, does one assess the success or failure of an energy policy - weighting all goals as equal and computing a batting average?"

Also, as it was mentioned above, in existing MLP literature, weights of the policy objective function have, so far, been simple (one).

Sensitivity analysis will, however, be conducted to study effects of the changes in weights on the optimum solution to the model to test the robustness of the initial specification of the weights (Chapter Five).

The specification of the weights of the policy objective function 2 will be discussed in Section 3.4.1.9.

3.4.1.6 Units of Measurements

The policy target variables (physical variables) in Specification 1 are measured in petajoules, while in Specification 2 they (physical and monetary variables) are measured in petajoules and million Australian \$ (respectively).

3.4.1.7 The Policy Objective Function: Specification 1

In Specification 1, a linear policy objective function has been adopted. A linear policy objective function is based on the assumption of separability and additivity of the target variables. The specification of a linear policy objective in economic policy studies (macro-economic, planning, and sectoral) is an established practice specially in development and sectoral planning (see Fox, Sengupta and Thorbecke, [1973], Chapters 7, 13, and 15). Although the linear policy objective function has the characteristics of separability and adaptivity, these characteristics do not yet appear to be inconsistent with the nature of policy preferences in the energy sector. For example, energy policy targets such as the reduction of energy imports and conservation

are not highly inter-dependent.

The policy objective function 1 of AEPSOM is specified (in the AES symbols discussed below) as:

$$\text{P.O.F.}(1): \text{WL} = \text{wG} = \text{Ie}_1 + \text{CNo} + \text{Tce} \quad (3.5)$$

where WL = the value of the policy objective function .

The policy objective function which shows the level of the values of all the target variables is the policy criterion in the Australian energy sector.

3.4.1.8 The Policy Objective Function: Specification 2

It has been mentioned that at the present level of development, most large or medium scale MLP models have linear policy objective functions (Candler and Norton [1977]). An alternative form of the policy objective function is also specified in AEPSOM to test the model solution's sensitivity to a more complex and, probably, more realistic policy objective function. In Specification 2 a multi-criteria approach (Gal [1979]) to the policy objective function is adopted.

Cherniavsky ([1981] p. 399) has summarized the essence of energy modelling incorporating a multi-criteria objective function as: The purpose of multi-objective analysis is to identify and quantify the trade-offs between different social objectives, and to aid policy makers in formulating decisions which achieve the best possible compromise between conflicting goals.

In this approach, several conflicting or incompatible goals are specified, some of these goals may be measured in different units (petajoules, money, environmental damage etc.).

There are three methods which are generally adopted for specifying or solving a multi-criteria model: a) generating tech-

niques, (b) utility function approach, and c) interactive methods. In the first method, the objective functions are ordered according to some decreasing preference by the modeller. In the utility function approach, all objective functions are collapsed to form a single function by giving different weights to different objectives. In the third method, information about the preference ordering is obtained interactively from policy makers. Cherniavsky [1981] has reported the experimental results of trying the three above mentioned solution techniques in the Brookhaven model. It was not possible to establish the superiority of any method in any absolute sense. The conclusion was that the choice of solution technique should depend, to a large extent, on "the suitability of the method to the structure of the problem" (Cherniavsky, op. cit. p. 416).

Cherniavsky [1981] has provided a survey of multi-criteria modelling of the energy sector. In energy planning, the Brookhaven Model (BESOM) is one good example of adopting multi-criteria policy objective functions (Chapter Two; Kydes [1978]). In BESOM the following objective functions (in alternative combinations) were adopted: total annual energy system cost, investment requirements, total crude oil use, oil import, total energy use, environmental effect index, total use of nuclear fuel.

The solution technique adopted in the PPS algorithm is the utility function method. In this method various objective functions are collapsed into a single objective function by relating those functions by some weights attached to each of them. Following the utility function method approach, the policy objective function 2 of AEPsOM is specified as follows (a general presentation): $P.O.F.2: a \text{ (Part 1)} + b \text{ (Part 2)}$.

For specifying weights firstly, both a and b were set equal to 1, and secondly, the values of a and b were varied subject to $a + b = 1$ (five other alternative sets were adopted) (Gal [1979]).

The specification of the parts/policy goals in AEPSOM has been similar to that of the Brookhaven model. The alternative policy objective function has two parts: the first part dealing with the real variables and specified in linear form (the policy objective function (1) as in (3.5)) and the second part relating to financial variables (taxes and subsidies) and specified in non-linear form. The first part involves the minimization of the use of oil, reduction of the import of oil and energy conservation. The second part of the policy objective function involves the minimization of the budget deficit (maximization of revenue) in the energy sector. The alternative policy objective function is of the following form (using the AES symbols):

$$\begin{aligned} \text{P.O.F.(2): } WL = & a[wG] - b\{((+T_1)Y + (+T_2)X + (+T_3)Z) \\ & - \{(-T_1)Y + (-T_2)X + (-T_3)Z\}\} \end{aligned} \quad (3.6)$$

where: $+T = \{+T_1, +T_2, +T_3\}$ = vector of three types of taxes, and $-T = \{-T_1, -T_2, -T_3\}$ = a vector of three types of subsidies.

In this alternative specification of the policy objective function, considerations of real and monetary or transfer effects (Harberger [1971]) of government energy policies have been incorporated. This specification of a policy objective function has important economic significance in formulating public policies. The importance of such considerations has been stated by Sparrow et al. ([1979], p. 181) as :

"Considerations of real versus monetary, or transfer

effects have long been recognised by economists as crucial to the evaluation of all forms of public activity: their application is usually very limited because of insufficient data."

In this specification, real effects of energy policies are measured in physical units (peta joules); monetary effects are measured in million A\$. The policy objective function embeds the choice that those government policies should be selected which cause minimum use of total energy, crude oil and imported oil in the economy and generate maximum revenue (minimize energy sector budget deficit) for the government.

In estimating the transfer effects of taxes and subsidies, it is assumed that the burden of taxes and subsidies is borne by those on whom they are imposed (Sparrow et al., [1979]).

It may be necessary to mention here that some of the elements of the π -T vectors are zero i.e., taxes and subsidies are only applicable to energy activities which are subject to government fiscal instrument control. A specific presentation of P.O.F. (2), including the AEPSOM symbols, is given in (3.18).

3.4.1.9 The Policy Objective Function : The Economic Perspective

Recently, the optimum intertemporal use of natural resources, both exhaustible and renewable, has been a major concern in economics. This is so since it has been alleged that profit maximizing multi-nationals and private enterprises are using the world's natural resources at a higher rate than they should. Also the environmental implications of the consumption and uses of resources by an exponentially increasing world population provides a pessimistic prediction. A large volume of economic literature has grown in this area to investigate the significance of natural resources in economic development, the economic implications of an

ever increasing use of natural resources and to determine the optimum use/economic use/minimum use of natural resources (Howe [1979]). A survey of the literature in this area is provided in Julius [1981]. From this growing volume of literature on the economic utilization of natural resources, one issue certainly does emerge: an efficient (intra- and inter-temporal) utilization of natural resources is essential. (Chapter Six of this study will deal with this issue in detail to highlight the economic implications of the issue and its resolution by the AEPSOM results.)

In the present specification of the policy objective function, this central issue of resource economics has played the prominent role since the physical target variables relate to the economic utilization of energy resources (specially, the use of total energy and crude oil).

The present specification of the policy objective function has also incorporated another major economic concern of the western industrialized countries : self sufficiency in oil. The economic problems experienced by these countries due to their dependence on imported oil have been stated before. It was clear from the discussion that the dependency on imported oil has been advocated as a major cause of the macro-economic problems experienced by these countries in the 70s, 80s and 90s. Therefore, the policy objective of minimization of import dependency has crucial economic implications for a country.

In addition, the policy objective function incorporates the implications of the monetary/budgetary implications of energy resource allocations and government policy intervention. As the resource sector has been a leading sector in the development in many resource rich countries including Australia, the policy

objective of the maximization of net revenue in the energy sector has an appropriate and wide economic perspective.

In this connection, it may be restated that these energy policy objectives are typical in the OECD countries. Energy policy studies in these countries have been undertaken with explicit recognition of these objectives (Webb and Ricketts [1980]). Also in some mathematical programming energy planning models, a similar set of energy policy objectives has been incorporated. The Brookhaven models, BESOM and MARKAL (Kydes op. cit.), which are very widely used energy models have incorporated a similar set of energy policy objectives (stated above) involving physical and monetary target variables/goals.

3.4.2 The Constraints of the Model

The objective of an energy planning exercise is to optimize the value of the policy objective function which is subject to some constraints. These constraints relate to the availability of resources, technological structure, consumers' choice, producers' behaviour and institutional and political set-up of the economy.

Since there are two types of decision makers who formulate their own optimum decisions, these constraints can be classified into two types: (a) the constraints on the optimizing behaviour of policy makers and (b) the constraints on that of economic agents: producers and consumer's of energy. (a) The constraints on the policy makers' decision making are in the form of limits on their budget expenditures, restrictions imposed on the policy instruments by the underlying socio-political system, and the nature of response of the economic agents to the policy measures of the policy makers (represented by the behavioural model in an MLP

model). (b) The economic agents' optimum decisions are also subject to some constraints: resource availability, technological structure, habit, existing productive capacity, market size, controls by the policy makers.

In the following sections, the specification of the two sets of constraints will be discussed.

3.4.2.1 Policy Constraints

Several alternative types of policy constraints have been specified in the MLP literature. (i) Constraints on the changes of the policy instruments: In Candler and Norton [1977], the policy instruments (such as subsidies on fertilizer, water taxation, price support etc.) were made subject to variations of a certain range (for example, subsidies on fertilizer had a range of zero to 50% of cost). In Bisschop et al. [1982], certain ranges of the policy instruments were also specified. (ii) Budget constraints: In Sparrow et al. [1979], the policy constraints were specified to make the transfer effects of policy instruments equal to zero (taxes equal subsidies). A quadratic policy constraint in the following form: government revenue - government expenditure $> -K$, was included in Fortuny-Amat's [1979] example of the large scale application of MLP.

While in the existing MLP literature, only one of these constraints is specified, in the present study, both the types of policy constraints are specified. The first type imposes limits on the variation of the taxes and subsidies. In the abstract model, equation (3.1.b) represents this type of constraint. A range of 0 to 20% of the cost on the variation of the taxes and

subsidies is specified:

$$0 \leq \pm t_j \leq 20\% \text{ of the cost of the respective variable } j.$$

In Australia, no literature exists dealing with this type of specification of the limits on the range of fiscal instruments.

This specification seems reasonable for Australia for a medium-term planning period of 10-15 years. The range is the maximum possible allowed variation of taxes and subsidies. An optimum policy solution may be obtained by only small changes (less than 20%) in many policy instruments and 20% changes (maximum 20%) in few policy instruments.

A second type of constraints is specified following the long established practice in economics in which economists have argued that the public programmes should be self-financing (taxes should equal subsidies and other government expenditure (Harberger [1971])). The constraint in the present model is specified to make the net revenue (taxes minus subsidies) of the government to be positive, so that other government expenditures can be met from the sectoral revenue (transfer effects are positive):

$$\{(+T_1)Y + (+T_2)X + (+T_3)Z\} - \{(-T_1)Y + (-T_2)X + (-T_3)Z\} \geq 0$$

(3.7)

This constraint takes care of the monetary (budgetary) implications of government policies and restricts the selection of a set of policy instruments which does not cause a budget deficit in the sector.

3.4.2.2 Behavioural Constraints: The Energy System Model¹

The other type of constraints in AEPSOM are the behavioural constraints which are represented by a behavioural model of the energy sector simulating the optimization behaviour of the energy producers and consumers. For surveys of the behavioural model in the agricultural sector, see Norton and Schiefer [1981] and of the energy sector models, see Hoffman and Wood [1976]). Chapter Two also contains a survey of existing single level energy sectoral behavioural models.

In MLP studies, a variety of different types of behavioural models have been specified: a non-linear agriculture sector model involving the optimization of the sum of consumer's and producer's surplus where the producers are risk averters (Candler and Norton [1977]), a cost minimization linear programming agriculture sectoral model (Bisschop et al. [1982]), and a mixed-integer programming model of the iron and steel sector (Sparrow et al. [1979]).

Since linear programming sectoral models replicate the optimizing behaviour of economic agents in a perfectly competitive market situation (Samuelson [1952]) and they are computationally easier in an MLP model, a linear programming cost minimization energy sector model has been specified as the behavioural model in AEPSOM. However, as taxes and subsidies appear in the objective

1. An energy system model is a mathematical model consisting of the various entities, elements or parts (supplies, fuels, technologies, processes, end-uses etc.) and their inter-relationships (demand, supply, intermediate balance etc. equations) of the energy sector. Alternatively, an energy system model is a mathematical model of the energy sector containing the sector-wide entities such as energy flows, costs, prices, conversion losses, processes, technologies etc.

function of the linear programming behavioural model in AEPSOM, the behavioural model becomes non-linear.

The constraints of AEPSOM (the equations 3.1.e to 3.1.j) form an energy system (ES) model of the Australian energy sector. So, to specify the behavioural constraints of AEPSOM, it is needed to specify an ES model for Australia as in (3.3).

For a detailed specification of the Australian ES model first the salient features of the Australian Energy System (AES) will be described (for a discussion of the general features of energy systems, see Meier [1984]). AES will provide us with the necessary information for specifying the ES model. In our analysis of AES, the variables, parameters, and coefficients which are included in the ES model will be defined.

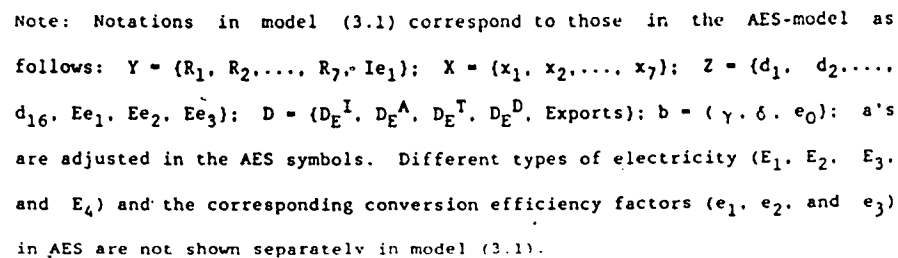
(I) AES

Figure 3.1 shows an aggregate AES. AES presents a network of flows of primary energy to the end-uses via several steps of conversion, transportation, transmission and distribution. The different steps shown in the AES figure such as extraction, refinery etc. are the different stages through which a particular primary energy flows until it reaches the end-users. AES is a multi-input (primary energy), multi-activity (technologies), multi-product (energy products) and multi-use (end-uses) energy production and consumption system.

Seven types of primary energy¹ are specified in AES: coal

1. Harder [1982] provides a comprehensive discussion of the definitions and descriptions of different forms of energy - their chemical and thermodynamic principles, technologies (supply,

AUSTRALIAN ENERGY SYSTEM 1979 - 1980



(R_1), crude oil (R_2), natural gas (R_3), hydro-electricity (R_4), biomass (R_5), solar (R_6) and uranium (R_7). These forms of energy are either converted into energy products or transported to the end-users.

At present coal is used either in electricity production (steam cycle)(E_1) or by the end-users in different sectors. There are two sources of crude oil: domestic production and imports. Crude oil is a compound of the methane group, containing carbon and hydrogen with a large number of atoms in their molecules. The refinery processes separate its components by primarily using a fractional distillation technique. Some of the other techniques used in the Australian refineries are: cracking, reformer and alkylation - for the extraction of lighter distillates and the purification of the petroleum products (naphtha, kerosene, light distillates, gasoline, cracker feedstock, LPG, motor spirit and lubricants). We have assumed that oil from these different sources is refined to produce petroleum products (x_2), that is we have aggregated all the fractions of the refinery outputs into a broad group. Refinery loss is represented by γ .

Natural gas is used for electricity generation (steam cycle and gas turbine) (E_3) and for end-uses (x_3).

The primary source of electricity is hydro electricity (R_4). Other sources of electricity are: coal E_1 , oil E_2 and natural gas E_3 . Total electricity generation is x_4 .

There are various sources of biomass (R_5) in Australia such as wood, bagasse, sugar-cane, crop residues and oil seeds, among others. Though they have the common characteristic of being composed of living matter, they differ substantially in their

chemical properties, resulting in different end products, such as methanol and ethanol. In spite of this heterogeneity in the chemical properties of these fuels, here they are classified as biomass fuel (x_5) since total use of these fuels in Australia is relatively low in comparison with other fuels.

Solar energy (R_6) is considered to be feasible only in the domestic sector using water heated in solar panels. Therefore solar energy goes to the final users (x_6) instead of being supplied to the national grids.

All uranium (R_7, x_7) is exported in the form of ore and triuranium octoxide (U_3O_8) (E_{e3}) since there is no present domestic use.

In AES, the important conversion losses are defined. The transmission and distribution loss of electricity, distribution loss of natural gas and conversion loss of refinery are the major forms of conversion losses included in AES. These are represented by the coefficients e_0 , δ and γ .

Four end-use sectors are identified in AES: manufacturing industry, agriculture (including mining), transport and domestic (including services). Not every energy product is used in every sector. A detailed listing of the uses of the fuels in all the end-use sectors is given below:

a. Manufacturing Industry (DE^I)

1. coal (d_1), 2. petroleum products (d_2), 3. natural gas (d_3), 4. electricity (d_4), and 5. biomass (d_5)

b. Agriculture (DE^A)

1. petroleum products (d_6), and 2. electricity (d_7)

c. Transport (DE^T)

1. petroleum products (d_8), and 2. electricity (d_9)

d. Domestic (including commercial sectors) (DE^D)

1. coal (d_{10}), 2. petroleum products (d_{11}), 3. natural gas (d_{12}), 4. electricity (d_{13}), 5. biomass (d_{14}), and 6. solar (d_{15})

e. Exports

1. coal (E_{e1}), 2. petroleum products (E_{e2}), and 3. uranium (E_{e3})

This background information about AES will be used to specify the constraints of the ES model.

(II) Constraints of the ES Model

There are five types of constraints in an ES the model: the demand constraints; the constraints that represent the intermediate energy balances and the supply balances (with separate specifications of the electricity and petroleum product sub-sectoral balances); and the resources and capacity constraints (for a discussion of the necessary constraints of an ES model, see Meier, [1984]). One feature of the present specification is that the end-uses are defined in terms of energy products, not in terms of the energy services as in Meier [1984]. The symbols used in specifying these constraints are identified in Figure 3.1. Symbols with bars on them indicate their fixed quantities in 1979-80.

(1) Demand Constraints

The demand constraints require that the energy supplies from different end-use flows must be greater than or equal to the total energy demand in each sector and exports. The following equations are formed by incorporating the sectoral flows of energy that are

defined in Figure 3.1. The demand constraints of the ES model are:

$$\begin{aligned}
 d_1 + d_2 + d_3 + d_4 + d_5 &\geq DE^I \\
 d_6 + d_7 &\geq DE^A \\
 d_8 + d_9 &\geq DE^T \\
 d_{10} + d_{11} + d_{12} + d_{13} + d_{14} + d_{15} &\geq DE^D \\
 E_{e1} &\geq \bar{E}_{e1} \\
 E_{e2} &\geq \bar{E}_{e2} \\
 E_{e3} &\geq \bar{E}_{e3}
 \end{aligned} \tag{3.8}$$

The first four constraints are the demand constraints in the four sectors of the economy. The last three constraints are export constraints.

(2) Intermediate Energy Balance Equations

The constraints ensure that the uses of different energy products in the different sectors must equal the total supply of the energy products. The constraints, which are formed by the flows of end-uses and energy products defined in AES, are:

$$\begin{aligned}
 x_1 &= d_1 + d_{10} + E_{e1} \\
 x_2 &= d_2 + d_6 + d_8 + d_{11} + E_{e2} \\
 (1/\delta_3)x_3 &= d_3 + d_{12} \\
 x_4 &= d_4 + d_7 + d_9 + d_{13} \\
 x_5 &= d_5 + d_{14} \\
 x_6 &= d_{15} \\
 x_7 &= E_{e3}
 \end{aligned} \tag{3.9}$$

(3) Supply Balance Equations

These equations ensure that the supplies of primary energy in Australia must equal the supplies of energy products plus the

conversion losses. The balance equations are:

(i) Petroleum Products Supply Balance Equation

$$E_2 + x_2 = R_2 + I_{e1} \quad (3.10)$$

(ii) Electricity Supply Balance Equation

$$(1/e_0)x_4 = e_1E_1 + e_2E_2 + e_3E_3 + E_4 \quad (3.11)$$

(iii) Other Supply Balance Equations

$$\begin{aligned} R_1 &= x_1 + E_1 \\ R_3 &= x_3 + E_3 \\ R_5 &= x_5 \\ R_6 &= x_6 \\ R_7 &= x_7 \end{aligned} \quad (3.12)$$

(4) Resource Constraints

In the ES model, all the primary energy supplies have been constrained to their supplies in 1979-80. The resource constraints of the model are:

$$\begin{aligned} R_1 &\leq \bar{R}_1 \\ R_2 &\leq \bar{R}_2 \\ R_3 &\leq \bar{R}_3 \\ R_5 &\leq \bar{R}_5 \\ R_6 &\leq \bar{R}_6 \\ R_7 &\leq \bar{R}_7 \end{aligned} \quad (3.13)$$

(5) Capacity Constraints

The capacity constraints require that the supplies of energy cannot be higher than that which can be produced by the capacity of the existing equipment, techniques and plants for mining, producing, converting, transporting and distributing, and end-uses of energy. We have specified only the constraints on electricity generation and petroleum refining since these are the major con-

straints.

The constraints are:

$$\begin{aligned} E_4 &\leq kHe \\ x_4 &\leq kTe \\ (1/\gamma)x_2 &\leq RK \end{aligned} \tag{3.14}$$

where:

He = hydro-electricity generation capacity

Te = total capacity of electricity generation

RK = total capacity of the refineries

k = capacity factors

γ = refinery losses

(6) User-Defined Constraints:

It is conventional to include some 'user-defined constraints' in ES models in addition to standard ones required for the normal presentation of the energy system. This is done to make the energy systems model to (Musgrove et al. [1983] p. 15)

"reflect the real life situation where relative prices will play an important role in the choice of technologies, but other factors may also be important".

Some of these factors are the upper, lower or fixed bounds on the investment, capacity and market penetration or share of a technology or end-uses. In MARKAL, a large number of such constraints were specified (Musgrove op. cit. p. 16).

The advantage of this type of user-defined constraints is that they make the ES model more realistic to represent the technical characteristics of the existing energy system and to forecast the short-term or medium term energy system accurately. However, they have the disadvantage that they make the energy system model restrictive, thus leaving not much freedom to choose.

In addition, this practice may not be suitable in a study designed for the formulation of optimum energy systems and policies since in such a study what is needed is not a positive forecasting of the future system, but a presentation of normative results showing the desired/optimum structure/directions of resource allocations and technological developments in the energy sector.

In AEPSOM, a 'compromise' situation was adopted as only one type of such user defined constraints was included in it. These constraints were in a form that restricted the model not to choose electricity uses in different sectors below their actual or predicted uses in 1979-80¹. These constraints limit the possibility of substitution of electricity by other fuels as there exists short-term technical non-substitutability in the power using industries (more discussion on pp. 207-208).

These constraints on the uses of electricity are as follows:

$$\begin{aligned} d_4 &\geq \bar{d}_4 \\ d_7 &\geq \bar{d}_7 \\ d_9 &\geq \bar{d}_9 \end{aligned} \quad (3.15)$$

(III) Behavioural Objective Function (B.O.F.)

The objective function of this ES model is a cost equation. A cost equation is specified so that the behavioural model repli-

1. It should be mentioned that these constraints (Musgrove et al. [1983], p.15)

"affect the output from the model and this must be borne in mind when analysing the optimum solution".

This point will be again referred to in Chapter Five. In Chapter Six, the AEPSOM results will be analysed for their policy implications, in particular, for their technological policy implications in this perspective.

cates the behaviour of an atomistic market consisting of cost minimizing producers and end-users (Samuelson [1952]). It consists of the following types of costs (net of taxes or subsidies): the cost of supplying primary energy (c_i), the cost of oil imports (c_m), the cost of conversion of primary energy to energy products (c_j), the cost of generation of electricity (c_e), and the cost of end-uses (c_k). Each type of cost consists of both fixed and variable costs (capital, labour, energy, and other operation and maintenance costs). Transportation and distribution costs of energy are included in the end-use costs.

By incorporating all the different types of costs, the cost equation can be defined as:

$$C = \sum_{i=1}^7 c_i R_i + c_m I_e + \sum_{j=1}^7 c_j x_j + \sum_{e=1}^4 c_e E_e + \sum_{k=1}^{15} c_k d_k \quad (3.16)$$

The costs are measured in terms of millions of \$ per petajoules of energy.

In AEPSOM, the objective function of the behavioural problem contains $\pm T$ (the tax and subsidy instruments). The above presentation of the objective function of the behavioural problem does not contain the tax and subsidy instruments. To specify the tax and subsidy instrument variables, we need to discuss the existing fiscal instruments which are now being applied in Australia. This will be done in the next section. However, the following is the form of the objective function of the behavioural problem containing existing taxes and subsidies in the Australian energy sector:

$$C = \sum_{i=1}^7 (c_i + T_i) R_i + c_m I_e + \sum_{j=1}^7 c_j x_j + \sum_{e=1}^4 c_e E_e + \sum_{k=1}^{15} (c_k - T_k) d_k \quad (3.17)$$

3.5 AEPSOM POLICY VARIABLES

The following listing and classification of the policy variables in AEPSOM is based on the hierarchical multi-goal multi-level energy policy system in Australia.

I. Policy Target Variables

The target variables were defined and specified in the previous section. These are reproduced here: 1. Import of oil; 2. consumption of oil; and 3. total consumption of energy.

II. Instruments and Strategies

Energy policy options/instruments are pursued to remove impediments of market failures to achieve the Pareto optimum resource allocation consistent with the other policy objectives in the energy sector such as the security of energy supply. A large number of policy instruments is available to the policy makers. The policy instruments set includes (1) physical controls or direct controls such as import quota, (2) technical efficient methods (determination of an intertemporal efficient energy system - fuel and technology mix), (3) determination of depletion and exploration rates, (4) fiscal instruments (taxes and subsidies), (5) direct investment, (6) price fixing, (7) expenditures and strategies related to research and development, education and information/public exhalation, (8) other non-quantitative policies such as monopoly purchasing, (purchases by state agencies) participation (providing capital and receiving profit) (Webb and Ricketts [1980], Munasinghe and Schramm [1983], Griffin and Steele [1980]). However, the task of choosing a set of policy instru-

ments is always determined by the policy objectives to be achieved. The choice will depend on the prevailing political, economic and technological conditions in a country.

A. Existing Policy Instruments and Strategies in Australia

In 1979-80 three types of instruments were used in Australia to achieve energy policy objectives (prices, taxes and subsidies, and government expenditures) in conjunction with other policy strategies.

(i) Pricing Instrument

The price of domestic crude oil is determined by the Commonwealth government.

(ii) Taxes and Subsidies

The taxes and subsidies are: (A) Primary energy: t_1 = a levy on coal, t_2 = resource rent tax on crude oil, t_3 = resource rent tax on natural gas; (B) End-uses: $-t_1$ = subsidy on the use of coal in the manufacturing industry sector; $-t_3$ = subsidy on the use of natural gas in the manufacturing industry sector; $-t_5$ = subsidy on the use of wood in the manufacturing industry sector; $-t_{10}$ = subsidy on the use of coal in the domestic sector; $-t_{12}$ = subsidy on the use of natural gas in the domestic sector; $-t_{14}$ = subsidy on the use of wood in the domestic sector, and $-t_{15}$ = subsidy on the use of solar energy in the domestic sector.

(iii) Government Expenditure

The major heads of government expenditures in the energy sector are research and development, conservation, education and

propaganda.

(iv) Energy Technological Strategy

The government announces the policy strategies related to the major forms of energy mainly for providing information to the private sector about the optimum or expected developments in the energy sector.

(v) Other Strategies

Other energy policies such as depletion policy and exploration policies are also pursued by the government.

3.6 AEPSOM: COMPLETE DESCRIPTION, MODEL SOLUTION OUTPUT

AND DATA:

3.6.1 A Complete Description of AEPSOM

1. Policy Objective Function: (a) Equation 3.5 or (b) Equation 3.6. The general statement of the policy objective function in (3.6) (the alternative specification) can now be restated by including the symbols used in AES as follow:

$$\text{Min } WL = Ie1 + CNo + TCe - \sum_{i=1}^7 +t_i R_i + \sum_{k=1}^{15} +t_k d_k \quad (3.18)$$

The specific $+t_i$ and $-t_k$ (specific $+T$) which were adopted by the Australian government in 1979-80 were reported in Section 3.5(II) above.

2. Constraints:

- (1) Behavioural objective function: Equation 3.17
- (2) Behavioural constraints set: Equations 3.8 to 3.15

(3) Non-negativity constraints: All the variables be ≥ 0 .

3.6.2 Data

The details of the estimations of these data are given in Appendix C.

A general note on the justifications and usefulness of the data used in this study is necessary at this point. There were several sources of data used in this study : government and academic publications. Various estimates of the same data were available from these sources, specially at different dates. For example, government energy publications have produced different estimates of energy data as more accurate and up-to-date information was available. Efforts were made at the primary stage of this research to adopt a set of consistent and accurate data (available at that time) for AEPSOM; alternative data available at later stages could not be incorporated. This problem may exist in other applied modelling work which has been pointed out by Hazell and Norton ([1986], p. 272) as:

"Building an applied model is a process, and the most successful models evolve through time to take account of new findings. There never is a definite version, but rather at any moment in time the model represents a kind of orderly data bank that reflects both the strengths and limitations of the available quantitative information."

As stated above, the set of data used in the present study, has been adopted partly from published sources and is partly estimated by the present author. Adaptation of the present set of data is not an indication of the refusal of the reliability or accurateness of other available data. Sources of data were selected in this study by the criteria of suitability and easy availability of the data necessary for AEPSOM.

3.7. SUMMARY

Australian energy model AEPSOM is a static model for 1979-80. The model is based on the framework of a price control MLP, the theory of economic policy and policy systems analysis. Justification and methods for the specification of the AEPSOM elements have been discussed in this chapter. Data for the model are either estimated from different published sources, or originally calculated by the author.

CHAPTER FOUR

MLP SOLUTION ALGORITHM: THE PARAMETRIC

PROGRAMMING SEARCH APPROACH

4.1 INTRODUCTION

In the previous chapters, the existing energy models were reviewed and the need for a new modelling approach was exposed. A theoretical energy planning model was developed and a numerical model - AEPSOM was specified. The next task in the modelling exercise is to address the issue of how AEPSOM can be numerically implemented to facilitate Australian energy policy studies.

It was stated in Chapter Two that multi-level programming¹ is a recently developed mathematical programming technique (Candler and Norton, [1977]). Although it is a powerful analytical technique for multi-level optimization, experiments, mostly at academic levels, are still going on to develop an algorithm to solve an MLP. In most of the existing MLP algorithms, some sort of transformation of the original problem is necessary. This makes the MLP solution relatively difficult, because the size of the transformed MLP becomes large in comparison with the original problem. Existing algorithms are usually not commercially available.

1. In this Chapter, only one special type of MLP which is bi-level programming is considered.

Therefore, as it was argued in Chapter Two, there is a general need for developing both MLP algorithm and software that are easily operational and readily available. The objective of this chapter is to develop an algorithm of that type to solve an MLP.

The present chapter is structured as follows: Section 4.2 provides some definitions. Section 4.3 discusses the PPS approach. Section 4.4 demonstrates how the present algorithm can solve an MLP, while an alternative specification of an MLP (including π in the upper level policy objective function) is given in Section 4.5. Some issues in the application of this algorithm are discussed in Section 4.6. Section 4.7 contains a brief summary of the steps of the algorithm. Computer programmes used or usable for implementing the algorithm in this study are stated in Section 4.8. Section 4.9 identifies the alternative types of policy planning studies that can be undertaken by solving an MLP model using the PPS algorithm, while Section 4.10 discusses the advantages and limitations of the proposed algorithm. Finally, Section 4.11 summarizes the discussions in this chapter, and tries to point out the usefulness of the proposed search method for solving MLP. While this Chapter deals with price control MLP (price control bi-level programming), uses of the PPS algorithm to solve different other types of MLP such as resource control, dynamic, and non-linear (behavioural model) MLP are discussed in Appendix D.

4.2 DEFINITIONS:

Some definitions are provided in this section¹.

A. Linear Programming:

The following is a linear programme (LP):

$$\text{Max } C = cX_{22}$$

$$\{X_{22}\}$$

s.t.

(4.1)

$$A_2X_{22} \geq R$$

$$X_{22} \geq 0$$

Assumptions :

- (1) A is an (M X N) matrix ; rank of (A) = M < N ;
- (2) $c, X_{22} \in E^N, R \in E^M$;
- (3) $S_1 = \{A_2X_{22} \geq R, X_{22} \geq 0\}$ is a non-empty, convex and compact set;
- (4) the objective function is linear and continuous;
- (5) the LP problem has a unique optimum solution².

Definitions :

- (1) Activities:

X_{22} is the vector of the activities of the model (4.1).

1. The main mathematical terms used in this chapter will be defined at the appropriate places. The mathematical dictionary of Skrapek et al. [1976] contains most other terms and concepts used in this chapter.

2. In large scale numerical linear programming models, this assumption is generally correct (Candler and Norton [1977]).

(2) Basic solution:

A basic solution to LP is a solution vector $X_{22} \in E^N$ (an extreme point) which is obtained through solving the LP for M variables by setting the remaining $N - M$ variables equal to zero.

(3) Basic feasible solution and optimum solution:

A basic solution vector $X_{22} \in E^N$ that satisfies the constraints : $A_2 X_{22} \geq R$ and $X_{22} \geq 0$ is defined as the basic feasible solution and the basic feasible vector that optimizes (in the present case maximizes) the objective function $C = cX_{22}$ is the optimum solution.

B. Parametric Programming.

If θ is the parameter of the variation of the objective function ($C = cX_{22}$), then a parametric programme can be defined as:

$$\text{Max } C = (c + \theta U)X_{22} \quad \{\theta_1 \leq \theta \leq \theta_p\}$$

$$\{X_{22}\}$$

s.t.

$$A_2 X_{22} \geq R$$

$$X_{22} \geq 0$$

where

$U = (u_1, u_2, \dots, u_n)$ is a constant vector of the units of the parametric variation; θ = a scalar parameter,

θ_1 = lower level of θ ; θ_p = upper level of θ .

Assumptions:

- (1) A is an $(M \times N)$ matrix
- (2) $c, X_{22} \in E^N, R \in E^M$;
- (3) $U \in E^N$

Solutions of a Parametric Programme

Parametric programming involves the determination of the region $K \subseteq E^1$ so that for each $\theta \in K$, $\theta \in E^1$ there is an optimum solution to the problem (4.3) and for $\theta \in E^1 - K$ (ie, outside the determined region), there is no solution to the problem. In the case of linear parametric programming, the solution procedure involves the generation of all the relevant extreme point optima in the region $K \subseteq E^1$ for each $\theta \in K$. Computationally, an algorithm for parametric programming involves the following two separate stages:

(a) finding the optimum solution vector with $\theta = 0$ (a basic optimum solution),

(b) a systematic generation of the alternative optimum solution vectors (generation of all pertinent adjacent extreme points/basic optimum solution) as θ varies from θ_1 to θ_p .

The first solution to the problem (4.2) is a usual solution to the linear programming problem with $\theta = 0$ using the simplex finds the optimum basic solution to the problem from the alternative basic solutions. In subsequent solutions, the objective function coefficients are changed parametrically as: $C = c + \theta U$ with $\theta > 0$. This yields new solutions to (4.2) which are the alternative optimum basic solutions. In other words, as the cost coefficients change by θU ($\theta_1 \leq \theta \leq \theta_p$), alternative basic solutions are chosen as the optimum basic solutions to the problem (4.2). So, parametric programming obtains the alternative optimum basic solutions as a result of the continuous changes in the coefficients of the objective function.

Conditions for the Generation of Alternative Parametric Solutions

To demonstrate the conditions for the generation of alternative parametric solutions (adapted from Taha [1976]), the variables and coefficients of the linear programme are classified as basic (with b subscript) and non-basic (with m subscript) as:

Objective function:

$$C = c_b X_{22b} + c_m X_{22m}$$

and the constraints:

$$A_{2b} X_{22b} + A_{2m} X_{22m} \geq R$$

The optimum solution to the linear programme is:

$$X_{22b} = A_{2b}^{-1} R$$

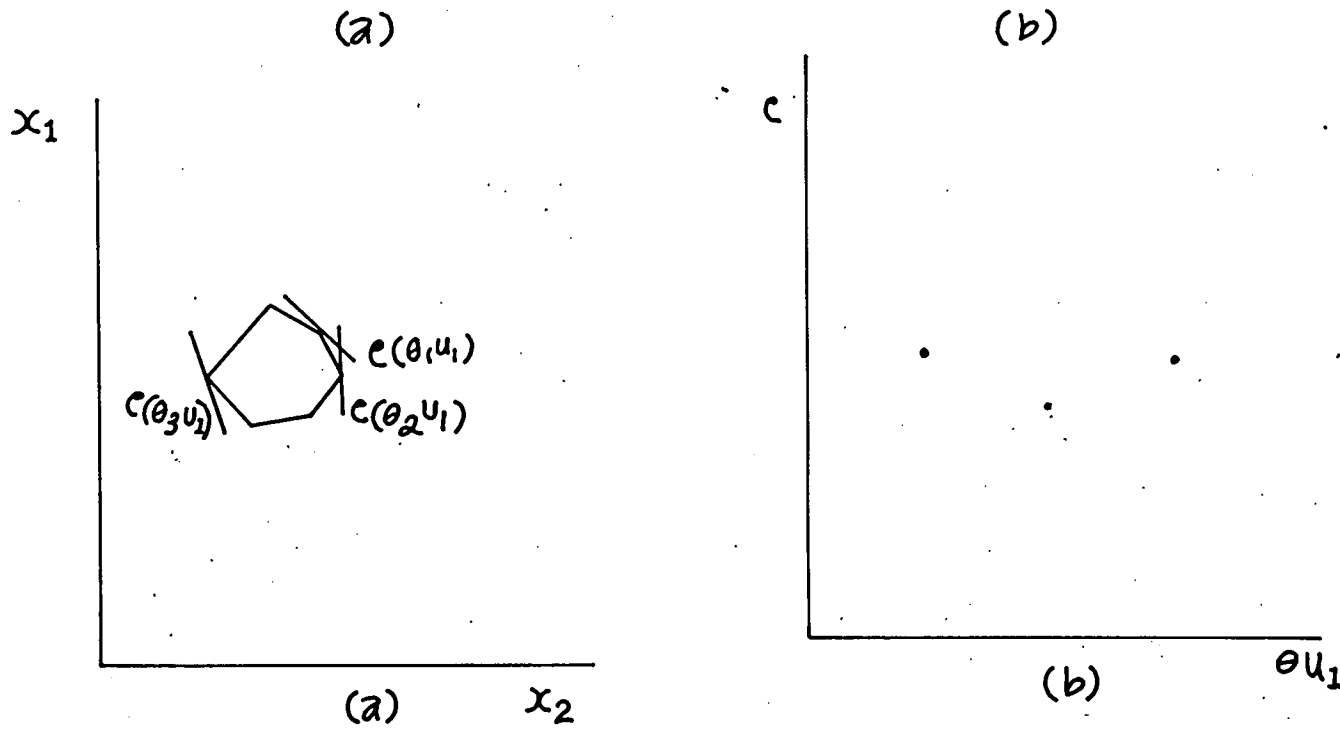
since at the optimum solution $X_{22m} = 0$. This optimum solution will occur when $\theta = 0$. Let it be defined as X_{22b}^0 .

The optimum solution X_{22b} will remain optimum as long as the condition $z_j^0 - c_j^0 \geq 0$ corresponding to this solution is satisfied for all j (where $z_j = c_b B^{-1} A_{2bj}$; A_{2bj} = jth elements of A_{2b}). When $z_j^0 - c_j^0 < 0$, there will be a critical value of θ which is θ_1 for which an alternative optimum solution X_{22b}^1 exists.

Figure 4.1 shows the solution to the parametric programming problem. In the first case (Figure 4.1.a), the coefficients of the objective function are varied parametrically (θ_1, θ_2 , and θ_3)

FIGURE 4.1

SOLUTION TO A PARAMETRIC PROGRAMMING PROBLEM



thereby producing three alternative solutions in parametric programming: l_1 , l_2 and l_3 . This implies that the optimum value of the objective function of a parametric programming problem is a function of parametric levels, as shown by Figure 4.1.b.

C. Multi-level Programming (Price Control Bi-Level Programming):

The following is a non-linear price control MLP model¹:

$$\text{Min WL} = wX_{11} \quad (4.3.a)$$

{ $\pm T$ } Policy/Upper level problem

s.t.

$$X_{11} = I \cdot X_{22} \quad (4.3.b)$$

$$T_1 \leq \pm T \leq T_p \quad (4.3.c)$$

$$\{(+T)X_{22} - (-T)X_{22}\} \geq 0 \quad (4.3.d)$$

$$\text{Min C} = (c \pm T) X_{22} \quad (4.3.e)$$

{ $X_{22} \mid \pm T$ } Behavioural/Lower level problem

s.t.

$$AX_{22} \leq R \quad (4.3.f)$$

$$X_{11}, X_{22} \geq 0 \quad (4.3.g)$$

Assumptions:

(1) The objective function (4.3.a) is linear and continuous,

(2) $S_1 = \{X \mid AX_{22} \geq R; X_{11} = I \cdot X_{22}; X_{11}, X_{22} \geq 0\}$

is a non-empty, convex and compact set,

(3) $S_2 = \{X \in S_1 \mid C = \text{Min} \{(c \pm T)X_{22} : (X_{22} \mid \pm T)\}$,

1. This is an abridged version of the model (3.1) in Chapter Three. In this formulation of MLP, the lower level objective function is being perturbed by $\pm T$. The upper level's constraints on and preferences for $\pm T$ are reflected (i) in the policy and budgetary constraints (4.1.c) and (4.1.d), and (ii) in the upper level objective function in model (4.21).

$X_{11} = I * X_{22}$, $T_1 \leq \pm T \leq T_p$, $\{((+T)X_{22} - (-T)X_{22}) \geq 0\}$ is compact, but other properties are not known since S_2 is not explicit¹,

(4) LP in the lower level problem has a unique solution.

Definitions:

Activities and Coefficients:

w = a vector of coefficients of the policy objective function

$(1 \times e)$,

X_{11} = a vector of policy target variables $(e \times 1)$,

X_{22} = a vector of sectoral behavioural variables $(m \times 1)$,

c, A = vector and matrix of cost and technological coefficients

$(1 \times m)$ and $(n \times m)$, in the lower level problem,

$\pm T$ = a vector of taxes and subsidies (t_1, t_2, \dots, t_m)

(if $T < 0$ are subsidies, and if $T > 0$ taxes),

I = a matrix of $(e \times m)$ coefficients for defining the target variables,

T_1, T_p = vectors of lower and upper limits of $\pm T$.

Multi-level Programming Solution:

The definition of an optimum MLP solution is as follows

(Fortuny-Amat, [1979]; Bialas & Karwan [1980]): A solution to an MLP will be considered as an optimum (local) solution to the MLP if the solution satisfies the following conditions:

(i) the solution is in the opportunity set of the behavioural

1. A deficiency of single level models is that they cannot define S_2 . For formulating an optimum policy S_2 is the relevant opportunity set (feasible region). Therefore single level models generate wrong results/policies (Candler and Norton [1977]).

problem/lower level problem (feasible solution to the behavioural problem, 4.3.e to 4.3.g);

(ii) the solution is optimum for the lower level problem (the behavioural optimum),

(iii) the solution satisfies the constraints on the policy problem: $T_1 \leq \pm T \leq T_p$; $\{(+T)X_{22} - (-T)X_{22}\} \geq 0$.

(iv) the solution is optimum for the policy problem (the optimum solution to the lower level problem that provides an optimum value for the objective function of the policy problem, (4.3.a.)) (the policy optimum/MLO optimum solution).

Optimum: Local and Global

An optimum over S may be defined as follows:

(i) Maximum :

\tilde{X}_{11} is a maximum solution vector of X_{11}

so that

$$f(\tilde{X}_{11}) \geq f(X_{11}), \text{ for all } X_{11} \in S$$

(ii) Minimum :

\tilde{X}_{11} is a minimum solution vector of X_{22}

so that

$$f(\tilde{X}_{11}) \leq f(X_{11}), \text{ for all } X_{11} \in S$$

(iii) Local optimum :

\tilde{X}_{11} is a local maximum or minimum solution vector of X_{11}

so that

$$f(\tilde{X}_{11}) \geq f(X_{11}), \text{ or } f(\tilde{X}_{11}) \leq f(X_{11}) \text{ for all } X_{11} \in N$$

where N is a neighborhood in S .

(iv) Global optimum: Maximum (or minimum) defined in (a) or

(b) above is a global optimum.

Feasible Regions:

An MLP has the following three feasible regions.

(i) Behavioural feasible region: The behavioural feasible region (S_1) is defined by the values that can be taken by the variables of the lower level problem (X_{22}), given the values of $\pm T$.

(ii) Policy feasible region: The region defined by the constraints 4.3.c and 4.3.d imposed by the underlying policy system and/or budgetary considerations.

(iii) Policy-behavioural feasible region: This region (S_2) is defined by the attainable values of the policy target variables (X_{11} or X_{22} as $X_{11} = I * X_{22}$) under different values of the policy instrument variables ($\pm T$).

4.3. PARAMETRIC PROGRAMMING SEARCH ALGORITHM

In the parametric programming search algorithm, the lower level sub-model (equations 4.3.e to 4.3.g) is solved as a parametric programming problem (involving a variation of a scalar (θ) in the cost coefficients). The parametric program generates alternative optimum solutions to the lower level sub-model for different levels of parametric variations. Then the solution to the complete multi-level programming problem (4.3.a to 4.3.g) involves finding that parametric solution to the lower level problem which yields the optimum value for the policy objective function (4.3.a) and satisfies the policy and budgetary constraints (4.3.c) and (4.3.d).

To elaborate the PPS approach the MLP in (4.3) is reformulat-

ed¹ as:

$$\text{Min WL} = wX_{11}$$

$$\{X_{11}\}$$

s.t.

$$X_{11} = I \cdot X_{22}$$

$$\theta_1 \leq \theta \leq \theta_p$$

$$\{(+\theta U)X_{22} - (-\theta U)X_{22}\} \geq 0$$

$$\text{Min C} = (c \pm \theta U)X_{22} \quad (4.4)$$

$$\{X_{22} \mid \pm \theta U = \pm T\}$$

s.t.

$$A_2 X_{22} \geq R$$

$$X_{11}, X_{22} \geq 0$$

The lower level problem of (4.4) is a parametric programming problem of the type shown in (4.3). Thus an MLP model can be reformulated as an MLP model with the lower level problem as a parametric programming problem.

Therefore, the steps of the PPS algorithm will be: first, to solve the lower level problem as a parametric programme. This defines the policy behavioural-feasible region (S_2) by θU and X_{22} or X_{11} , and second, to find the value of $\pm \theta U$ and corresponding X_{22} (a point in S_2) that yield the optimum value for the upper level

1. In MLP (4.4), equating $\pm T = \pm \theta U$ needs some clarification. In MLP model (4.1) $\pm T$ is a vector of variables, while $\pm \theta U$ is a vector of parameters. Since $\theta \pm T$ can be varied in a parametric programming along a ray generating different values of θU along that ray., similarly $\pm T = \pm \theta U$ is made in that sense. Adaptation of different values of U provides the possibility for varying θ along different rays ($U_1\theta, U_2\theta, \dots, U_n\theta$) and thus for considering a wide range of values (not all) of $\pm T$ (T_1, T_2, \dots, T_n) for finding optimum $\pm T$. This correspondence between $\pm T = \pm \theta U$ is maintained through the whole thesis.

objective function. It may however be mentioned that although in the algorithm the lower level objective function is being perturbed, the upper level is preferred.

The above points are illustrated in Figure 4.2.

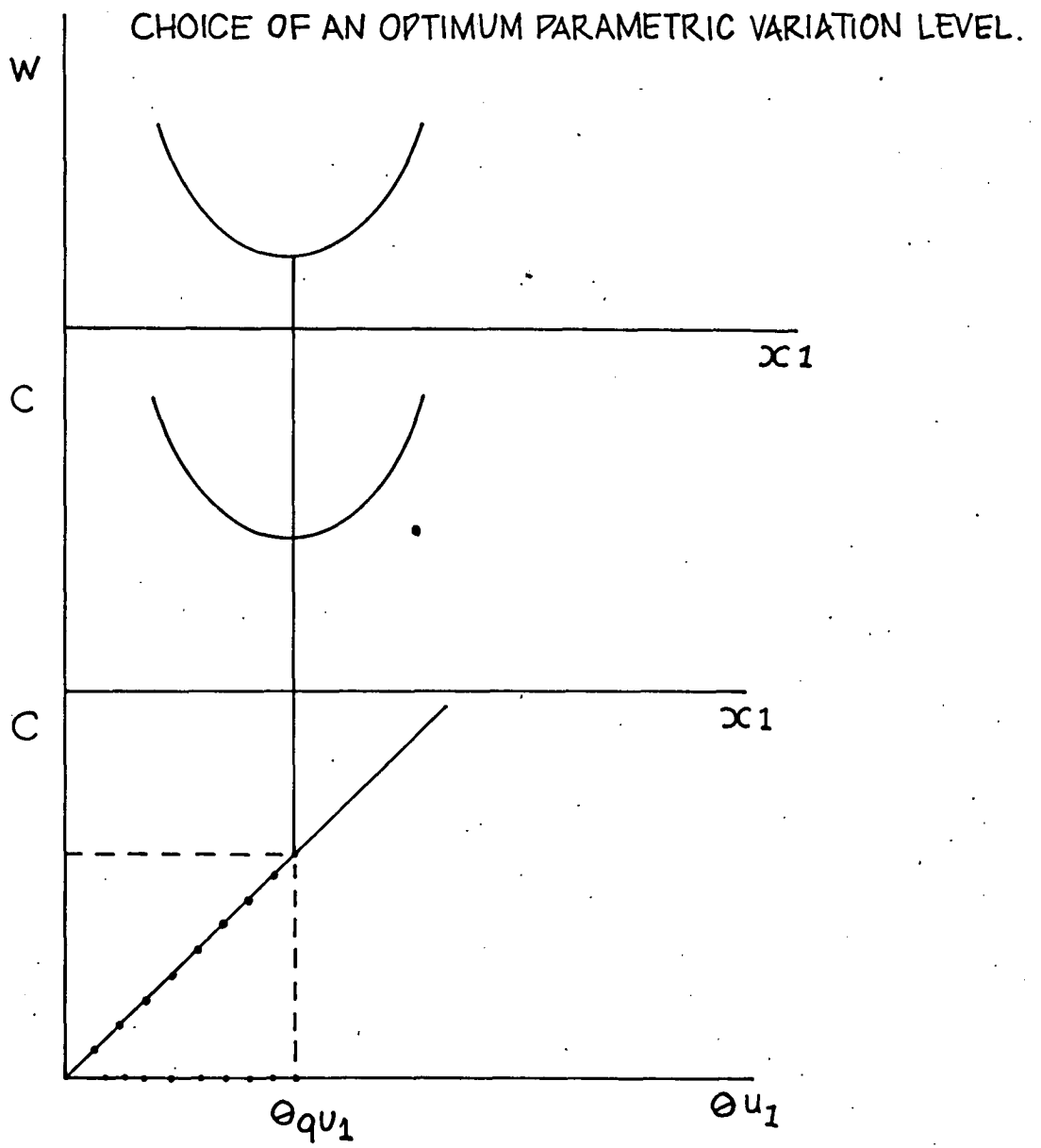
Figure 4.2 shows the different levels of parametric variations $(\theta_1 u_1, \theta_2 u_1, \dots, \theta_n u_1)$ and the different values of the lower level objective function (optimum values) together with the values of the policy objective function. Evidently therefore, the policy objective function attains its optimum value at the 9th level of parametric variation. Consequently, the optimum values (the optimum MLP solution) of x_1 and θu_1 , are $\bar{x}_{1(9)}$ and $\bar{\theta}_9 u_1$, and the optimum value of the policy objective function: $\bar{W}_L = w(\bar{x}_{1(9)})$.

To illustrate the algorithm, the following linear programming problem is used (Daellenbach et al. [1983], p. 43):

$$\begin{aligned}
 &\text{Max } F = 24x_1 + 20x_2 \\
 &\quad \{x_1, x_2\} \\
 &\text{s.t.} \\
 &\quad 0.5x_1 + x_2 \leq 12 \\
 &\quad x_1 + x_2 \leq 20 \\
 &\quad 0.06x_1 + 0.04x_2 \leq 1 \\
 &\quad 1200x_1 - 800x_2 \geq 0 \\
 &\quad x_1, x_2 \geq 0
 \end{aligned} \tag{4.5}$$

A parametric programming formulation of the above linear programming problem is as follows (Daellenbach op. cit., pp. 131-

FIGURE 4.2



132):

$$\text{Max } F = (24 + 24\theta) x_1 + 20 x_2$$

$$\{-1 \leq \theta \leq 100\}$$

$$u_1 = 24$$

s.t.

$$0.5x_1 + x_2 \leq 12$$

$$x_1 + x_2 \leq 20$$

(4.6)

$$1.5x_1 + x_2 \leq 24$$

$$1200x_1 - 800x_2 \geq 0$$

$$x_1, x_2 \geq 0$$

The following are the alternative solutions to the parametric programme within the θ range of -1 to 100.

- | | | | | |
|----|------------------|------------|-----------|-----------|
| 1. | $\theta = 0$ | $x_1 = 12$ | $x_2 = 6$ | $F = 408$ |
| 2. | $\theta = -1$ | $x_1 = 6$ | $x_2 = 9$ | $F = 324$ |
| 3. | $\theta = -7/12$ | $x_1 = 12$ | $x_2 = 6$ | $F = 240$ |
| 4. | $\theta = 1/4$ | $x_1 = 16$ | $x_2 = 0$ | $F = 384$ |

The initial solution with $\theta = 0$ is the usual solution to the linear programming problem (4.5), in other words, it is the optimum solution to the linear programme in (4.6). In the parametric programme, as the cost coefficient was varied parametrically by θ , the alternative optimum solutions 1 to 4 were found.

An MLP¹ can be defined by incorporating the linear programming of (4.5) in (4.3) as follows:

$$\text{Max } W = 2x_1 + x_2$$

1. To keep the example simple, it is assumed in this MLP model that only one tax (t_1) is imposed by the policy makers, and that only the policy constraint exists.

s.t.

$$-24 \leq t_1 \leq 2400$$

$$\text{Max } F = (24 + t_1)x_1 + 20x_2$$

s.t

$$0.5x_1 + x_2 \leq 12 \quad (4.7)$$

$$x_1 + x_2 \leq 20$$

$$1.5x_1 + x_2 \leq 24$$

$$1200x_1 - 800x_2 \geq 0$$

$$x_1, x_2 \geq 0$$

and by using its parametric programming reformulation (4.6) as:

$$\text{Max } W = 2x_1 + x_2$$

s.t.

$$-24 \leq 24\theta \leq 2400 \quad \{t_1 = 24\theta\}$$

$$\text{Max } F = (24 + 24\theta) x_1 + 20x_2 \quad \{u_1 = 24\}$$

s.t.

$$0.5x_1 + x_2 \leq 12 \quad (4.8)$$

$$x_1 + x_2 \leq 20$$

$$1.5x_1 + x_2 \leq 24$$

$$1200x_1 - 800x_2 \geq 0$$

$$x_1, x_2 \geq 0$$

In the PPS algorithm, the lower level problem in (4.8) is solved as a parametric programming problem in the same process as is used to solve model (4.5). In the present example, the alternative solutions were obtained: solution 1. $\theta = 0$; solution 2. $\theta = -1$; solution 3. $\theta = -7/12$, solution 4. $\theta = 1/4$.

The PPS algorithm searches these four alternative solutions to find the solution which provides the optimum value for the policy objective function, and satisfy the constraint that

$-24 \leq 240 \leq 2400$. The different values of the policy objective function for various parametric solutions are:

- (1) $W = 30$,
- (2) $W = 21$,
- (3) $W = 30$, and
- (4) $W = 32$.

It is evident that solution no.4 generated the maximum value for the policy objective function. Thus the PPS algorithm finds the parametric programming solution no.4 as the optimum solution to the MLP in (4.6 or 4.7) satisfying the constraint $-24 \leq 240 - 6 \leq 2400$ and $t_1 x_1 = 96$.

The relevant optimum results are:

- (1) policy objective function: $W = 32$;
- (2) tax: $t_1 = \theta u_1 = (0.25 \times 24) = 6$; and
- (3) activities: $x_1 = 16$, $x_2 = 0$.

4.4. MLP SOLUTION BY THE PPS ALGORITHM

4.4.1 MLP Solution and its Proof

The arguments stated so far become obvious looking at the structural similarities between a usual MLP (4.3) and a parametric programming embedded MLP (4.4).

A comparison of these models reveals that they are essentially similar. The only difference is in the objective functions of the lower level problems of these two models. In (4.4), the objective function is $C = (c \pm \theta U)X_{22}$, while in (4.3) it is $C = (c \pm T)X_{22}$. Since, these two models are the same (for some values of $\pm T$ determined by θU), it, therefore, follows that $\theta U = \pm T$. And

a comparison of the structural similarities between the models in (4.3) and (4.4) shows that $\pm\theta U$ can be interpreted as the values of taxes and subsidies (changes in the costs of different activities) imposed by the policy makers along a ray determined by $\pm U$. Therefore, the parametric programme can define S_2 by relating $\pm\theta U$ and X_{22} or X_{11} .

In the MLP stated in (4.3), the programming problem is to find a point in S_2 (which is S_1) or the values of $\pm T$ and X_{22} or X_{11} (within a certain range of $\pm T$) that optimize the value of the policy objective function. The programming problem as in (4.4) can be solved to find the values of $\pm\theta U$ and X_{22} or X_{11} (a point in S_2 (which is also in S_1)) (within a range of $\theta: \theta_1 \leq \theta \leq \theta_p$) that optimizes the policy objective function. Since the PPS algorithm can find $\pm\tilde{\theta}_1 U$ and \tilde{X}_{22} (or \tilde{X}_{11}), which are the optimum values of taxes and subsidies, and the activities of the lower level problem (the optimum values of X_{11} can be obtained from the relationship $X_{11} = I \cdot X_{22}$), the PPS algorithm can solve an MLP.

The structural similarities between (4.3) and (4.4) help to formulate the following theorem:

Theorem:

An MLP can be solved by solving the lower level sub-model as a parametric programming problem and by choosing the level of parametric variation (the level of policy instruments: $\pm T$) that optimizes the policy objective function, and satisfies the constraints in the upper level problem.

Proof:

Mathematical requirements of an MLP solution are satisfied by the solution obtained by the PPS algorithm. At this solution

point, the lower level problem has an optimum solution, that solution satisfies the upper level constraints and also that solution provides optimum value for the policy objective function. Therefore, the PPS algorithm can find a solution of an MLP (a policy optimum).

To illustrate the above points, an MLP is stated as:

$$\text{Min WL} = wX$$

s.t.

$$X = (X_{11}, X_{22}) \in S_2 \quad (4.9)$$

where:

$$S_2 = \{X \in S_1 \mid C = \text{Min} \{(c \pm T)X_{22} : (X_{22} \mid \pm T),$$

$$T_1 \leq \pm T \leq T_p, \{(+T)X_{22} - (-T)X_{22}\} \geq 0\}$$

$$\text{and } S_1 = \{X \mid A X_{22} \geq R; X_{11} = I * X_{22}; X_{11}, X_{22} \geq 0\}.$$

It was assumed that S_1 is a closed and bounded opportunity set of the lower level problem while the characteristics of S_2 cannot be determined.

The elements of the MLP solution may now be analysed with the framework of the MLP stated in (4.9). Condition (i) (Section 4.2.c) means that the solution to the lower level problem will be in S_1 . Condition (ii) implies that a solution will be at an extreme point of S_1 . Condition (iii) requires that the extreme point in S_1 will also be in the policy-behavioural opportunity set S_2 . Condition (iv) implies that the extreme point in S_1 that optimizes the upper level objective function is the optimum solution to MLP. Therefore, the optimum solution to an MLP is at an extreme point in S_1 that optimizes the objective functions of

the lower and upper level problems. This extreme point is the saddle point of MLP.

The implications for the solution of an MLP can now be analysed as follows: Since the lower level constraints are linear, S_1 is a convex set, and optimum solutions of the lower level problem will occur as one of the extreme points of S_1 . The search for the optimum solution to an MLP can be directed and limited to the extreme points of S_1 . Thus, to solve an MLP we need only make a search in S_1 to find out the extreme point in S_1 which will be in S_2 (the saddle point) that optimizes simultaneously the objective functions of the optimization problems at both levels. Parametric programme can uncover extreme points in S_1 (given θU) and the PPS algorithm can find the extreme point in S_1 which satisfies the upper level constraints and provide optimum value for the upper level objective function.

To show how a parametric search can solve MLP, a compressed MLP model with parametric programming at the lower level is formulated as:

$$\text{Min WL} = wX$$

s.t.

(4.10)

$$X = (X_{11}, X_{22}) \in S_2$$

where:

$$S_2 = \{X \in S_1 \mid C = \text{Min} \{(c \pm \theta U)X_{22} : (X_{22} \mid \pm \theta U)\},$$

$$\theta_1 \leq \theta \leq \theta_p, \{(+\theta U)X_{22} - (-\theta U)X_{22}\} \geq 0\}$$

$$\text{and } S_1 = \{X \mid A X_{22} \geq R; X_1 = I^* X_{22}; X_{11}, X_{22} \geq 0\}$$

The PPS algorithm (a) parametrically perturbs the objective function of the lower level problem ($C = c \pm \theta U$) and uncovers extreme points of S_1 as θU ranges from θ_1 to θ_p (satisfies MLP

solution elements i and ii), and (b) searches these extreme points to find the extreme point in S_1 that yields the optimum value for the upper level objective function (elements iv), and that also meets the policy and budgetary constraints 4.3.c and 4.3.d:

$(\theta_1 \leq \theta \leq \theta_p); \{(+\theta U)X_{22} - (-\theta U)X_{22}\} \geq 0$ (element iii)(ie, the extreme point be in S_2).

The theorem is proved. It, therefore, follows that the PPS algorithm can find an MLP optimum solution.

A parametric programming solution approach to a dual behavioural problem has been developed by Candler and Townsley [1982], a study that supports the present algorithm.

4.4.2 Economic Interpretations of MLP Solution by the PPS

Algorithm.

Economically, an MLP solution involves the finding of the values of $\pm T$ and activities X_{22} that satisfy the policy constraints and provide optimum value for the policy objective function. The policy makers have the choice of varying the value of $\pm T$ within a certain range (subject to some constraints) until a set of activities X_{22} is found which can generate an optimum value of the policy objective function.

The mathematical process of the PPS algorithm used to find the MLP solution is exactly the same as the economic principle discussed above. The parametric programme generates all the possible values of $\pm \theta U$ ($\pm T$) and the corresponding optimum solutions X_{22} s (on the ray determined by θU). These optimum solutions are the ones which can be obtained by the policy makers by adopting different values of $\pm T$. In other words, these alternative parametric solutions show the alternative outcomes of pursuing different

levels of $\pm T$. The PPS algorithm searches these optimum solutions for choosing the level of $\pm T$ and finding the corresponding optimum solution X_{22} which generate the optimum value for the upper level objective function (satisfying constraints in the upper level).

The PPS algorithm ensures the interdependence between the two sub-optimization problems (the upper and lower level problems) in the following way: $\pm T$ ($\pm \theta U$) introduced by policy makers intervenes in the decision making of economic agents the result of which is a set of alternative parametric solutions to the lower level problem (X_{22}). Therefore decisions of economic agents X_{22} are subject to interventions from the upper level ($\pm \theta$). These alternative optimum decisions of economic agents are judged in terms of the criteria embedded in the policy objective function and that decision of economic agents would be desirable to policy makers which will generate an optimum value of the policy objective function. Therefore, policy makers' choice of $\pm T$ ($\pm \theta U$) as the optimum policy is constrained by economic agents' reactions (X_{22}) to $\pm \theta U$. Thus, the choice of $\pm T$ ($\pm \theta U$) by policy makers is constrained by the upper level constraints and the reactions of economic agents (X_{22}) to such interventions and the decisions of economic agents (X_{22}) are also constrained by $\pm T$ ($\pm \theta U$) and other behavioural constraints. Therefore, in the PPS algorithmic representation of MLP, interdependence between two level decision makers is established. In other words, in the PPS algorithm, an MLP is solved interdependently (any sub-optimization problem is not solved independently).

4.4.3 Mathematical Properties of the MLP Solution.

(a) Existence, Uniqueness, and Global Optimality of MLP Solution:

The properties of the PPS algorithm solution need to be discussed at this point. Generally, the problems of existence, uniqueness and global optimality of MLP are still not resolved. For a discussion of the properties of an MLP model solution, we refer to the MLP representation given above.

The properties of S_2 are not known since it is not explicit (algebraically or numerically). S_2 will only be known when S_1 is known, which in turn will depend on the optimum decision of the lower level decision makers (economic agents). The undesirable possibilities are: S_2 may be empty, disjoint, and even non-convex. In the first two cases, there will be a solution existence problem; and in the third case, there is the problem of the determination of uniqueness and global optimum (Appendix D contains a demonstration of this problem).

Accepted views regarding these problems of policy existence, uniqueness and global optimality are as follows (Candler and Norton [1977]):

(a) in a large-scale real world problem, the problem of policy existence may not be encountered; and

(b) appropriate algorithms can be adopted to overcome the policy uniqueness problem and to find the global optimum of an MLP policy model.

(b) Existence, Uniqueness, and Global Optimality of MLP Solution

In the Case of the PPS Algorithm:

The PPS algorithm can find an optimum on the ray determined

by ΘU if S_1 is bounded, closed and convex (i.e., if a solution to the lower level problem exist).

It should be mentioned that the existence of an MLP solution (the validity of the theorem) depends on how the parametric programming of the lower level problem is terminated. There are three ways (Murtagh, [1981]) for parametric programming to be terminated and there are three alternative conditions of existence in the above theorem. In the first case, Θ will increase until the MLP problem becomes infeasible (for the values of Θ above a certain value, the linear programming solution goes unbounded). The optimum solution to MLP in this case may be within the range of Θ_1 to Θ_f of the value of Θ , where Θ_f is the upper value of Θ beyond which the solution to the problem becomes infeasible. If that is the case, then there will be no MLP solution existence problem. The second case is where Θ increases infinitely without changing the most recently found optimum solution to the parametric programming. Here, a solution to an MLP will exist but imposing an upper limit on Θ will be necessary. In the third case, Θ increases up to its pre-specified upper limit, if any, and an optimum solution will be found within the range Θ_1 to Θ_p of the value of Θ where Θ_1 and Θ_p are the lower and upper limits and determined exogenously. In the present form of specification of MLP as in (4.4), the existence problem which can be caused by different forms of termination of the parametric search does not arise since a range of the variation of Θ has been incorporated in the model. And the optimum solution will be within that range. Therefore, in all these situations, the PPS algorithm will not encounter the solution existence problem.

However, as the algorithm only searches along the ray deter-

mined by $\pm\theta U$ and finds an optimum in this ray, there is no guarantee that the PPS algorithm can find a global optimum.

The parametric search can be extended by changing the units, directions and range of the parametric variation and many alternative optima (on the rays determined by the parametric variations) can be examined to form an idea about the plausibility of the MLP solution obtained. Of course, it may be suggested to continue the search until further improvement in the policy objective function is not possible, but it may not be practical in real situations due to time and resource constraints. However, the non-determination of a global optimum may not be a very serious limitation of an algorithm if the algorithm finds some improved results since (Candler and Norton [1977], p. 37)¹:

'(a) there is question whether real world market equilibrium sometimes leads to local optimum,

(b) these results provide an improved plan over the base or original plan,

(c) improvement rather than optimality is sometimes considered as an objective of policy analysis (Kornai [1969]).'

4.5 AN ALTERNATIVE SPECIFICATION OF AN MLP MODEL

To make an MLP problem economically more meaningful and non-trivial, the MLP in (4.4) can be specified again including $\pm T$ in the policy objective function as² follows (next page):

1. Views of others on the usefulness of search methods, specially of the ones that cannot provide a guarantee for finding the global optimum, will be stated in the Conclusion Section (4.12).

2. A similar version of AEPsOM was specified in Chapter Three and will be reproduced in Chapter Five, model (5.2).

$$\text{Min WL} = awX_{11} \pm b(\pm T)X_{22}^1$$

$$\{\pm T\}$$

s.t.

$$X_{11} = I \cdot X_{22}$$

$$T_1 \leq \pm T \leq T_p \quad (4.11)$$

$$\text{Min C} = (c \pm T)X_{22}$$

$$\{X_{22} | \pm T\}$$

s.t.

$$AX_{22} \leq R$$

$$T, X_{11}, X_{22} \geq 0$$

This model is different from the original formulation in (4.4) because of a different specification of the policy objective function in this model.

The PPS algorithm can be applied to this specification of MLP as well. The same algorithmic principle applies, however, in model (4.11) alternative parametric solutions will be searched to find the optimum value of the new policy objective function.

4.6 SOME ISSUES IN USING THE PPS ALGORITHM:

The PPS algorithm searches the policy-behavioural region along a line determined by (1) the units, (2) the signs and (3) the direction and ranges of the parametric variation.

Therefore, discussions on the determination of the units, signs, and direction and range of the parametric variation is

-
1. This alternative policy objective function is similar to the ones in Equations (3.6) in Chapter Three and (5.2.a) in Chapter Five.

necessary.

(1) Units of Parametric Variation:

The determination of the appropriate units of parametric variations (including its sign): $\pm U$ is important in the PPS algorithm. $\pm 0U$ makes a search along a line in n -space. Therefore one particular $\pm U$ uncovers all the extreme point optima along the line determined by $\pm 0U$. The application of the PPS algorithm with a particular set of $\pm U$ can find global optima on a thin line. And by choosing another set of $\pm U$ another global optima on another line can be generated. Therefore, generation of the MLP optimum solution depends on the determination of the appropriate unit of parametric variation ($\pm U$). Therefore considerable attention needs to be given to the question of the choice of the units of parametric variation in the PPS algorithm since the units determine the range and direction of the search done by the PPS algorithm.

The question remains : How to find the appropriate $\pm U$? In single level parametric programming, the units of parametric variation are generally obtained from the information of the system/environment under study. For example, if a = production cost of a product at the base period, and 0 time, then the cost equation for any future period can be presented as $c = a + u0$. A numerical example of the cost equation is as follows: $c = 5 + 0.40$. The unit of parametric variation $u = 0.4$ can be obtained from market surveys, econometric estimates, trend analysis etc.

Therefore, in many single level parametric programming studies, finding the units of parametric variations may not be a problem. But that is not the case in parametric programs in MLP in the PPS algorithm.

In the present formulation of MLP, the following $\pm u_j$ is appropriate since this vector provides a direction of search towards the preference direction of the upper level objective function¹:

$\pm u_j = \pm h_j = -c_j \pm wI_j$, $j = 1, 2, \dots, n$ (I_j = j th elements of the matrix I . The elements of this matrix are either 1 or 0.)

The selection of $\pm u_j$ in the above procedures does not give any guarantee for the generation of global or even local MLP solution, since the search is along a line. There is a need, therefore, for trying other alternative units to make search along other lines in S_2 .

Generally, it will be prudent to vary the units (U) as much as possible starting with the units $\pm u_j = \pm h_j$. The following alternatives were tried in the present study :

- (1) To choose U so that its elements are either +1, 0, or -1.
- (2) To choose the units to equal $\pm c_j$ or 0 (c_j = cost coefficients; $j = 1, 2, \dots, n$).

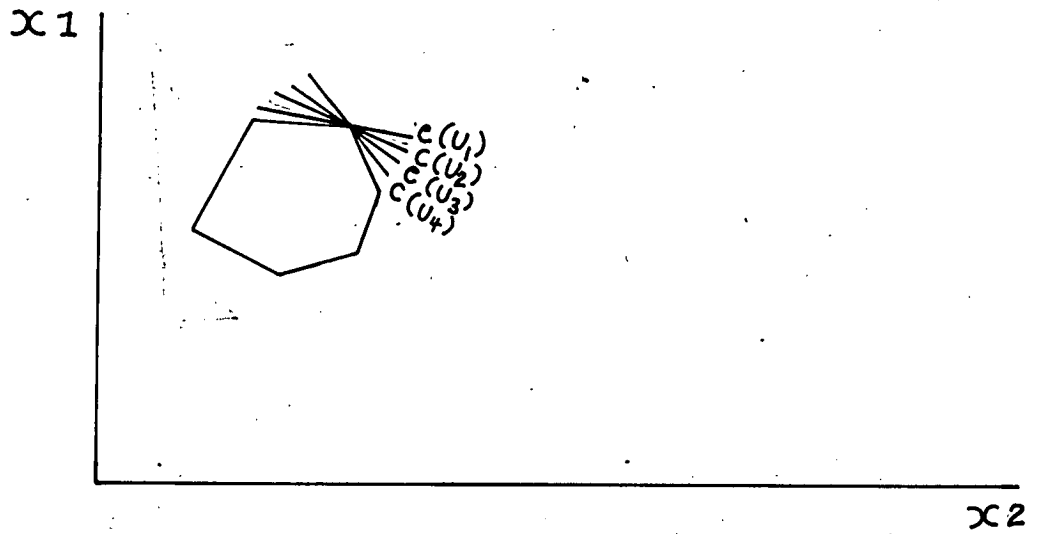
There is, of course, a general problem of multiple optima in the case of small variations in U . The problem can be illustrated in Figure 4.3 and is further discussed in Appendix D.

Figure 4.3 shows that changing the units of parametric variations of the behavioural objective function coefficients, which will move it as shown by $c(U_1)$, $c(U_2)$, $c(U_3)$, and $c(U_4)$, may not change the optimum solution to the lower level problem. Therefore, the optimum solution to the upper level problem will not change. So, in this case, we will find a range of values of the policy instruments (different values of parametric variations),

1. Suggested by an anonymous examiner.

FIGURE 4.3

CHANGES IN THE UNITS OF PARAMETRIC VARIATIONS



not a set of unique values of the policy instruments, that will provide the same value for the policy objective function.

(2) Signs of the Direction of the Coefficients Subject to Parametric Variations

The signs of the parametric variation of different cost coefficients (\pm) depend on the choice of taxes or subsidies applicable to different activities. If a tax is imposed on an activity, then the sign of the parametric variation of its cost coefficients will be +, in the case of a subsidy it will be -.

It may, however, be mentioned that the signs of parametric variations will be different in two types of policy studies:

(a) the policy study involving the determination of the optimum levels of existing taxes and subsidies and prices (if any price is under control), and

(b) the policy study that involves the determination of the optimum mix and levels of taxes and subsidies and prices.

(a) Existing Taxes and Subsidies:

In the first case, the lower level problem is solved by making the coefficients of the lower level objective function which are subject to existing taxes and subsidies, to vary parametrically (ie. the lower level problem is solved as a parametric programming problem). The optimum solution to the complete multi-level programme provides a set of optimum values for existing taxes and subsidies.

(b) Optimum Mix of Taxes and Subsidies:

In this case, at first the lower level sub-model should be solved as a linear programming problem with the lower level objective function contained within it (as a normal behavioural model):

$$\begin{aligned}
 &\text{Min } C = cX_{22} \\
 &\{X_{22}\} \\
 &\text{s.t.} \qquad \qquad \qquad (4.12) \\
 &\qquad A_2 X_{22} \geq R \\
 &\qquad X_{11}, X_{22} \geq 0
 \end{aligned}$$

The vector of the level of optimum activities is defined as X_{22}^B . Then the lower level sub-model should be solved with the policy objective function in it as follows:

$$\begin{aligned}
 &\text{Min } WL = wX_{11} \\
 &\{X_{11}\} \\
 &\text{s.t.} \qquad \qquad \qquad (4.13) \\
 &\qquad X_{11} = I * X_{22} \\
 &\qquad A_2 X_{22} \geq R \\
 &\qquad X_{11}, X_{22} \geq 0
 \end{aligned}$$

This model is termed a central control policy model. The solution to the central control policy model determines the optimum value of the policy objective function and the optimum set of activities. Let us define this vector of the activities as X_{22}^P .

The next step involves a comparison between the two sets of activities to identify the differences between the choices of the individual economic agents and the choices of the policy makers. So, the differences can be used as an indication for the mix and the direction of the policy instruments, taxes and subsidies,

necessary to influence the activities of individual economic agents. So the vector:

$$\pm u_j = -x_{22(j)}^P + x_{22(j)}^B$$

$$\text{or, } \pm u_j = -x_{22(j)}^P + x_{22(j)}^B$$

can be used to determine, signs and mix of the parametric variations in the following way:

$$\begin{aligned} u_j &< 0 \text{ if } x_{22(j)}^P > x_{22(j)}^B; \\ u_j &> 0 \text{ if } x_{22(j)}^P < x_{22(j)}^B; \\ u_j &= 0 \text{ if } x_{22(j)}^P = x_{22(j)}^B; \\ j &= 1, 2, \dots, n \end{aligned} \quad (4.14)$$

Table 4.1 contains an example of this method:

Table 4.1
Determination of Optimum Mix of Taxes and Subsidies

Activities	x_{22}^P	x_{22}^B	U	\pm
$x_{22(1)}$	20	10	10	-
$x_{22(2)}$	15	26	11	+
$x_{22(3)}$	21	21	0	0

For applying the PPS algorithm, cost coefficients c_1 and c_2 should be subject to parametric variations and the signs should be - and + respectively.

The numbers in Table 4.1 imply that a mix of tax on $x_{22(2)}$,

subsidy on $x_{22(1)}$, and nothing on $x_{22(3)}$ is the optimum mix of tax and subsidy in this example.

(3) Direction and Range of Parametric Variation

The direction of the parametric variation depends on the units and signs of the parametric variation which have been discussed above. There are other factors that will also have effects on the direction of the parametric variation: In an MLP model, if $\pm T$ is entered in the upper level objective function, this will provide the desired direction for the parametric variation. The policy constraint, determined on the basis of the underlying government policy environment, will determine the range of parametric variation. For example, if the policy feasible region is specified as $T_1 \leq \pm T \leq T_p$, then the desired parametric variation will be restricted only within this specified region.

4.7. A SUMMARY OF THE ALGORITHMIC STEPS:

(1) Choose a set of the units (U) of the parametric variations (Θ). There are several alternatives for that:

- (a) Units equal to $\pm c_j$, ($j = 1, 2, \dots, n$) or 0;
- (b) Units equal to +1, 0, or -1;
- (c) Units (u_j) as close as possible to $(-c_j \pm w_2 I_j)$,
 $j = 1, 2, \dots, n$.

(2) Determine which units will be equal to 0 and the directions (\pm) of the variations of the remaining parameters. The following are the alternatives:

- (a) Existing tax and subsidy regime: Identify the existing

taxes and subsidies. If a tax is imposed on a particular activity (fuel or energy), then the direction of the parametric variation of that activity should be positive; and if subsidy is given then it should be negative (for example if tax is imposed on x_{22j} , then the coefficient of the lower level objective function, c_j , should be subject to parametric variation in the positive direction $+u_j$, otherwise (for subsidy) in the negative direction, $-u_j$). The activities on which taxes and subsidies are imposed are the ones of which the cost coefficients are subject to parametric variation.

(b) Optimum tax and subsidy choice: Solve the lower level sub-model in model (4.4) twice :

(i) As a linear programme, as in (4.12) and

(ii) again with the upper level objective function in it as in model (4.13) to find two alternative sets of

optimum activities: X_{22}^B and X_{22}^P .

(iii) Find the differences between these two sets of activities as

$X_{22}^B - X_{22}^P$ and choose the signs of the units ($\pm U$) to

equal the sign of $\pm(X_{22}^B - X_{22}^P)$ or set $U = 0$ if the difference is equal to 0.

(iv) Choose the signs according to $\pm U$.

(3) Determine the range of the parametric variation by studying the underlying policy system.

(4) Solve the lower level problem of an MLP as the parametric programming problem specified following Steps 1 and 3.

(5) Search the alternative (parametric) solutions to the lower level problem generated in Steps 1 to 4 to find out the

solution which provides the optimum value for the upper level objective function and satisfy the policy and budgetary constraints.

(6) Continue Steps 1 to 5 until no further improvement in the upper level objective function is possible.

(7) In the case that all the possible combinations of the units and directions of parametric variations can not be tried to solve an MLP, any solution to an MLP will be a reasonable approximate solution to an MLP (i) if it generates a value of the upper level objective function fairly close (as close as possible) to the value of the policy objective function of the central control model specified from an MLP (in the same way as in model (4.13)), and (ii) if the value of the policy objective function of MLP is lower then the value of the policy objective function calculated from the values of X^B_{22} determined by the behavioural model (4.12). In this case, the MLP solution provides an improved plan over the original plan or no plan.

4.8 SOFTWARE

The main software for implementing the PPS algorithm in this study was the linear programming package (with parametric programming facility) of Pearse and Hardaker [1984]. The software can solve the lower level problem as a parametric programming problem. Two alternatives for searching these parametric solutions to find an optimum MLP solution are discussed below:

(a) For an MLP as in (4.3) without (4.3.c) and (4.3.d), two sub-programmes were developed by Gatenby [1986] in consultation with

the present author to find the MLP solution. The first sub-programme (Appendix E) searches the alternative parametric solutions to find the MLP solution. The second sub-programme changes the units of parametric variations (Appendix D, Section D.3). The combined package, consisting of the above three programmes and named POLICY PROGRAMME, can be used to solve an MLP.

(b) In the case of MLP as in (4.3) including (4.3.c) and (4.3.d) and as in the alternative specification in Section 4.5, the Policy Search Programme as in (ii) below is to be replaced by Lotus 1-2-3. Lotus 1-2-3 can be used to calculate the values of the policy objective function in (4.11) and the constraints (4.3.c) and (4.3.d) to find the optimum value (maximum or minimum) through an iterative procedure from the results of the parametric solutions to the lower level problem.

The POLICY PROGRAMME has the following operation sequence:

(i) Parametric Linear Programming package yields

$X_{22}(1), X_{22}(2), \dots, X_{22}(n)$

and $\theta_1 U, \theta_2 U, \dots, \theta_n U$

(ii) Policy Search Programme (two sub-programmes)/ Lotus 1-2-3

searches the outputs of (i) and finds $W = w(\bar{X}_{22})$,

\bar{X}_{22} and $\bar{\theta}U$, the optimum values of the upper level objective-function, activities, and taxes and subsidies

(iii) Output of (i) should be checked on whether $\theta_1 U, \theta_2 U, \dots$

$\dots, \theta_n U$ are within the range $\theta_1 \leq \theta \leq \theta_p$

(iv) Lotus 1-2-3 can calculate the values of the budgetary constraints from the output of (i) to determine the solutions

$X_{22}(1), X_{22}(2), \dots, X_{22}(n)$ which satisfy these constraints.

4.9 USE OF THE PPS ALGORITHM IN DIFFERENT TYPES OF POLICY STUDIES

The PPS algorithm can be used in two types of policy studies, which is already evident from the previous discussion on the units of parametric variations (a) the policy study involving the determination of the optimum values of existing taxes and subsidies (and prices if any price is under control) along with other energy policies, and (b) the policy study that involves the determination of the optimum mix and level of taxes and subsidies and prices along with other energy policies¹.

4.10 ADVANTAGES AND LIMITATIONS OF THE PPS ALGORITHM

4.10.1 Advantages

(1) To solve MLP with the PPS algorithm, it is not necessary to make a transformation in the original MLP. The size of the transformed MLP in some existing algorithms may become a problem, as discussed previously.

(2) Parametric programming software is commercially available (Pearse and Hardakar [1984]). Lotus 1-2-3 is also commercially available. The additional sub-programmes required to solve an MLP can easily be developed.

(3) The PPS algorithm can be used to solve large scale MLP

1. In Chapter Five, further discussion on these two types of policy studies will be provided.

models.

(4) The algorithm has favourable operational characteristics. These relate to the accuracy and efficiency of the algorithm, and to the cost and efficiency in extending and transferring it.

(a) Accuracy : As no other algorithms or models were available to test the accuracy of the results provided by the PPS algorithm, results obtained in this study were used to make a judgment. It can be seen in Chapter Five (p.176, 210) that the value of the policy objective function in MLP solution is (a) 8.2% different from that of a central control policy model¹, and (b) an improvement by 44.46% over the behavioural model.

(b) Efficiency: Since different models were solved by the PPS algorithm, there were different CPU times in cases of different models. However, the CPU time needed for solving AEPSOM (with existing taxes and subsidies) was: 40 seconds.

(c) Cost and Efficiency in Extension and Transfer : For implementing the PPS algorithm the major computer programme needed is parametric programming software. The other two sub-programmes are relatively smaller. The alternative programme Lotus 1-2-3 is commercially available. The whole computer programme can easily be transferred. If parametric programming software is available then the other two sub-programmes can be

1. If it is accepted that the central control policy model solution is an ideal basis for the determination of policy directions, then a solution which is only 8.2% different from the ideal situation may be considered reasonably accurate. By increasing the range of search it would be possible to obtain better results.

written by somebody having reasonable knowledge of computer programming or Lotus 1-2-3 can be used. Therefore, the complete computer software for solving an MLP model, is relatively simple to obtain, develop, or transfer.

4.10.2 Limitations

(1) One limitation of the PPS algorithm discussed above is that the parametric search is limited to a single line, determined by the units and signs of the parametric variations ($\pm U$). Therefore, it is not possible to guarantee that the algorithm can find a global optimum. But, as it was stated before, the units of the parametric variations can be changed to extend the search in the policy-behavioural set.

(2) An important methodological issue is whether or not macro-economic constraints can be included in an MLP model, if a solution is sought by the PPS algorithm. For analyzing the issue, let us give a condensed statement of an MLP model with macro-economic constraints as:

$$\text{Min } W_1 = w_1 X_{11} + w_2 X_{22}$$

$$\{\pm T\}$$

$$\text{s.t.}$$

$$p_1 X_{11} + p_2 X_{22} = R_1$$

$$\text{Min } C = (c \pm \Theta U) X_{22} \quad (4.15)$$

$$\{X_{22} \mid \pm \Theta U = \pm T\}$$

$$\text{s.t.}$$

$$A_2 X_{22} \geq R_2$$

$$X_{11}, X_{22} \geq 0$$

where:

X_{11} = a vector of macroeconomic variables ($m \times 1$),

X_{22} = a vector of energy variables ($n \times 1$),

w_1, w_2 = vectors of the policy objective function
coefficients,

c = a vector of the behavioural objective function
coefficients,

R_1, R_2 = vectors of the RHS constants.

A statement of the above problem with macroeconomic constraints in the lower level of the MLP problem is as follows:

$$\text{Min } W_1 = w_1 X_{11} + w_2 X_{22}$$

$\{+T\}$

s.t.

$$\text{Min } C = (c \pm \theta U) X_{22}$$

$$\{X_{22} \mid \pm \theta U = \pm T\}$$

s.t.

(4.16)

$$A_2 X_{22} \geq R_1$$

$$P_1 X_{11} + P_2 X_{22} = R_2$$

$$X_{21}, X_{22} \geq 0$$

The question is whether both the above problems are similar. If they are similar, then Model (4.15) can be solved by the PPS algorithm. Experiments may be undertaken to test the problem in future work. However, the author's view is that the above two specifications will give the same values as the optimum solution, even though these two specifications are structurally distinct.

4.11 SUMMARY AND CONCLUSION

In the PPS algorithm, the lower level problem of a complete

MLP problem is solved as a parametric programming problem. . . Alternative optimum (basic) solutions to the lower level problem are searched to find the one which is optimum for the upper level problem. The algorithm can be used to solve different types of MLP problems including a dynamic MLP. There are some unresolved methodological issues which may be investigated in further studies.

The PPS algorithm is a heuristic search method. Like any other heuristic method for solving an MLP, it has the disadvantage that it can not be guaranteed that a global optimum is found. The real evaluation of the usefulness of an iterative procedure, specially in the context of the problems of solving MLP (see Candler, Fortuny-Amat and McCarl, [1981]), has been stated as follows (Hazell and Norton [1986], p.323):

"Conceptually the main drawback of the iterative procedure is that the determination of the true optimum solution can not be guaranteed. However, in practice, large numbers of solutions may provide the analyst with reasonable confidence that the true optimum solution is found."

McCarl and Spreen [1980] have also emphasized the usefulness of search methods as:

..."these algorithms¹ are rather cumbersome and demanding in terms of computer capacity. Informal iterative or search methods also may be used in the quest for optimum policy."

Having developed an algorithm to solve an MLP, the next task is to apply this algorithm for solving AEPsOM to undertake the desired Australian policy studies. This will be done in the next two chapters.

1.The MLP non-search algorithms discussed in Chapter Two (the present author's note).

CHAPTER FIVE

THE RESULTS OF THE AUSTRALIAN ENERGY PLANNING MODEL

5.1 INTRODUCTION

The numerical implementation of AEPSOM is supposed to provide information useful and adequate for the formulation of a multi-level energy plan. In this chapter, the AEPSOM results, which indicate the model's capability in producing useful numerical output, will be reported and discussed. The chapter is structured as follows: How AEPSOM was solved, what type of output it produced, the policy uses of these results and the alternative AEPSOM solutions - these topics are reported in Section 5.2. A general discussion of all the relevant results produced by AEPSOM is provided in Section 5.3 while the sensitivity analysis is reported in Section 5.4. Validation tests on the results of AEPSOM are stated in Section 5.5 to determine the reliability of these results for policy prescription. This discussion of the validation of results will prepare the background for the use of these results in policy formulation in the next chapter.

5.2 AEPSOM SOLUTIONS AND OUTPUT

5.2.1 Model

An abstract representation of the two types of the specifications of AEPSOM from Chapter Three is reported here to facilitate the understanding of the outputs of AEPSOM and their policy uses.

Specification 1¹.

$$\text{Min WL} = wG \\ \{+T\}$$

(a) Policy objective
function (P.O.F(1))

s.t.

$$G = I_1Y + I_2X + I_3Z \quad \text{(b) Definitional equations}$$

$$T_1 \leq +T \leq T_p \quad \text{(c) Policy constraints}$$

$$\{(+T_1)Y + (+T_2)X + (+T_3)Z\} - \{(-T_1)Y + (-T_2)X + (-T_3)Z\} \geq 0$$

(d) Budget constraints

(5.1)

$$\text{Min C} = (c_1 \pm T_1)Y + (c_2 \pm T_2)X + (c_3 \pm T_3)Z$$

$$\{Y, X, Z \mid +T\}$$

(e) Behavioural objective
function

s.t.

$$Z \geq \bar{D} \quad \{\alpha\}$$

(f) Demand constraints

$$Z = aX \quad \{\delta\}$$

(g) Intermediate energy balance
constraints

$$X = bY \quad \{\mu\}$$

(h) Energy supply balance
constraints

$$Y \leq \bar{Y} \quad \{\Gamma\}$$

(i) Resource constraints

$$X \leq \bar{X} \quad \{\beta\}$$

(j) Capacity constraints

$$G, Y, X, Z \geq 0$$

(k) Non-negativity constraints

where: WL = value of P.O.F.

w = vector of coefficient of the policy objective
function (i x e);

G = vector of energy target variables (e x 1);

Y = a vector of primary energy (p x 1);

1. This model is a reproduction of the model (3.1) in Chapter Three. Symbols used in both models are the same.

X = a vector of energy products ($n \times 1$);

Z = a vector of end-uses of the energy products
($m \times 1$);

D = a vector of end-uses in different sectors ($q \times 1$);

c_1, c_2, c_3 = costs of supplying, converting
and using energy $\{(p \times 1), (n \times 1), (m \times 1)\}$;

$\pm T_1, \pm T_2, \pm T_3$ = vectors of different taxes
and subsidies $\{(p \times 1), (n \times 1), (m \times 1)\}$
(lower case t's are the elements);

a, b = matrices of technological coefficients
 $\{(m \times n), (n \times p)\}$;

I 's = matrices elements of which are either 1 or 0;

Y = a vector of the fixed amount of available
primary energy ($p \times 1$);

X = a vector of the fixed level of capacities
($n \times 1$);

$M = \{\alpha, \delta, \mu, \Gamma, \beta\}$ = shadow prices related to different
constraints (these shadow prices are specified
in model (B.1) in Appendix B).

Specification 2.

$$\text{Min WL} = wG -$$

$$[\{(+T_1)Y + (+T_2)X + (+T_3)Z\} - \{(-T_1)Y + (-T_2)X + (-T_3)Z\}]$$

$\{\pm T\}$

(a) Policy objective

function¹ (P.O.F.2)

s.t.

$$G = I_1 Y + I_2 X + I_3 Z \quad \text{(b) Definitional equations}$$

$$T_1 \leq \pm T \leq T_p \quad \text{(c) Policy constraints} \quad (5.2)$$

$$\text{Min } C = (c_1 \pm T_1)Y + (c_2 \pm T_2)X + (c_3 \pm T_3)Z$$

$$\{Y, X, Z \mid \pm T\} \quad \text{(d) Behavioural objective function}$$

s.t.

$$Z \geq \bar{D} \quad \text{(e) Demand constraints}$$

$$Z = aX \quad \text{(f) Intermediate energy balance constraints}$$

$$X = bY \quad \text{(g) Energy supply balance constraints}$$

$$Y \leq \bar{Y} \quad \text{(h) Resource constraints}$$

$$X \leq \bar{X} \quad \text{(i) Capacity constraints}$$

$$G, Y, X, Z \geq 0 \quad \text{(j) Non-negativity constraints}$$

5.2.2 Solution

The optimum solution of AEPSOM was obtained by applying the PPS algorithm developed in the previous chapter. The reader can recall that an optimal solution to an MLP involves finding the optimum basic solution to the behaviour model of AEPSOM. A solution of the above type that satisfies the constraints on the policy instruments and provides the optimum value for the policy objective function is the optimum solution for an MLP. To be able

1. This alternative specification of the policy objective function was introduced in Chapter Three, Equation (3.6).

to apply the PPS algorithm, the following issues related to the techniques of solving AEPSOM as a price control MLP needed to be resolved:

- i) Development of a formula to find the units of parametric variation to solve AEPSOM; and
- ii) Development of a procedure for applying AEPSOM to two types of policy studies i.e., (a) for finding the optimum values of the existing taxes and subsidies and (b) for finding the optimum mix and optimum values of taxes and subsidies.

Since these were discussed in detail in Chapter Four, only their applications to AEPSOM will be discussed in Sections 5.2.7 and 5.2.8 below.

5.2.3 Optimum Solution

As AEPSOM was solved by the PPS algorithm, there was no guarantee that the global optimum was found. However, the AEPSOM results can be considered optimum for the reasons discussed in Chapter Four.

(i) Identification of Optimum Solution¹

Conventionally, the following two criteria are adopted to determine the optimum policy : Pareto optimality and the optimum value of the policy objective function. These two criteria were applied to identify the optimum solution of AEPSOM. The optimum solution was determined by the lowest value of the policy objective function, which is the normal mathematical criterion used for

1. The identification and interpretation of the AEPSOM optimum solution should be made within the context of the MLP solution discussed in Chapter Four: The AEPSOM optimum is an optimum along a ray determined by parametric variations.

determining a minimum. The AEPSOM optimum also has economic implications. The AEPSOM optimum solution corresponds to the Pareto optimum in the energy sector in the sense that at the optimum the value of no target variable can be reduced further without increasing the values of one or more target variables in the Australian energy sector¹.

5.2.4 Output

In the case of AEPSOM being solved using the PPS algorithm, its optimum solution generates the following results²:

- (a) the optimum value of the policy objective function (WL),
- (b) the optimum value of the behavioural objectives function (C),
- (c) the optimum values of taxes and subsidies ($+T = +OU$)
- (d) the optimum values of the activities (X, Y, Z),
- (e) a set of shadow prices or dual variables (defined below) $M = (\alpha, \delta, \mu, \Gamma, \beta)$ ³ corresponding to the energy demand, conversion,

1. For an analysis of the Pareto optimum implication of an MLP model solution, see Hazell and Norton ([1986], p.323).

2. The unit of real and monetary variables are petajoules (PJ) and million Australian dollars.

3. The shadow prices are the dual variables of a linear programme. For example if the general linear programming (primal) problem is as follows :

$$\text{Min } C = cX_{22}$$

$$\{X_{22}\}$$

s.t.

$$A_{22}X_{22} \geq R$$

$$X_{22} \geq 0$$

supply balance, and supply and capacity constraints of the primal problem (5.1 and 5.2), and

(f) Reduced costs (R_c) (defined below) showing the amount of required cost reduction in the energy activities which will cause that activity to appear in the optimum solution.

5.2.5 Uses of Results for Multi-Level Energy Planning¹.

In the previous MLP studies, model results have been used mainly to (a) determine the optimum values of existing taxes and subsidies (b) make explicit the policy - behavioural feasible region and (c) to formulate technology policies (Candler and Norton [1977], Bisschop et al. [1982], Ballenger [1984], Sparrow et al. [1979]). The present MLP study has extended the scope of

...Continued...

The dual problem to the above primal problem is:

$$\begin{array}{ll} \text{Max } Z = MR & \{M \text{ is a row vector}\} \\ \{M\} & \end{array}$$

s.t.

$$MA_{22} \leq c^T$$

$$M \geq 0$$

There are some important primal-dual relationships (see Intriligator [1971]). However, the shadow prices are the dual variables M such that $cX^*_{22} = M^*R$.

1. From the outset of the study, policy formulation problems in market economies have been discussed with different levels of economic controls. Therefore, it is obvious that the model will be applicable to both developed and underdeveloped market and mixed economies.

An MLO model can also be applied to fully controlled economies. In these economies most of the resources are controlled and distributed by the government, but the objectives of the central policy makers and the operation level policy makers may be different. The nature of control of the activities of the operation level decision makers by the central level policy makers may also range from some tax and subsidy measures to the direct controls of price and resources. This type of policy system can also be modelled by an MLO model.

applications of MLP model results by undertaking the types of policy studies (specially by adopting $\pm T$ in conjunction with shadow prices and reduced cost in policy studies) discussed in this section.

The uses of the AEPSOM results are discussed below.

(a) Policy Systems Analysis:

The values of the policy objective function and behavioural objective function and also the values of $\pm T$ provide insights into the characteristics of the underlying policy system.

(b) A Multi-Level Energy Plan:

(i) An Optimum Energy System: The optimum values of X , Y , Z constitute the elements of the optimum energy system.

(ii) An Optimum Energy Policy Plan: The results of the model can be used to formulate a comprehensive set of energy policies. The behavioural objective function does not have any policy uses, but it is informative in the sense that the aggregate reactions of the individual economic agents to government policies can be studied from various values of the behavioural objective function.

AEPSOM results can be used for formulating the following policies:

(a) $\pm T$ for Tax and Subsidy Policy: The value of the taxes and subsidies selected by the model will be the optimum values of the tax and subsidy instruments. If an MLO model is solved by the PPS algorithm (discussed in Chapter Four), the values of the parametric variations (ΘU) of the coefficients of the lower level objective function become the values of taxes and subsidies.

Therefore, the optimum value of $\pm T$ is determined in the present study by $\pm \theta U$ since the PPS algorithm has been used to solve AEPSOM. Details of the meaning and the mechanism of determination of $\pm \theta U$ have been discussed in Chapter Four.¹

(b) P for Pricing Policy: For the purpose of government pricing policy formulation (when prices are fixed by the government), the opportunity cost approach to pricing is adopted. In this approach, the price of energy should be equal to the value of the cost of the next best alternative available. In a mathematical programming energy model, shadow prices calculated by the model reflect the scarcity costs or opportunity costs of activities, and these shadow prices are adopted to formulate energy prices.

It may however be mentioned that, although the above is the normal practice, in an environment where prices are not directly fixed by the government, but are controlled by taxes or subsidies or other regulations (as in price control MLP), prices can be calculated by the formula (5.3) or (5.4) below, since these prices will be the market prices which are equal to production costs plus government taxes or minus government subsidies. Prices in this study were determined by using the following formula (shown by (5.1.e)):

$$P_1 = c_1 \pm T_1, P_2 = c_2 \pm T_2, P_3 = c_3 \pm T_3 \quad (5.3)$$

where P_1, P_2, P_3 = prices of different forms of energy

1. If a resource control MLP model is solved by the PPS algorithm, the model solution will also provide the optimum values of activities which are under direct government control. These optimum values can be used to identify government investment policies in the energy sector.

c_1, c_2, c_3 = average cost of the activities

$\pm T_1, \pm T_2, \pm T_3$ = taxes or subsidies

If the PPS algorithm is applied to solve an MLP model, prices can be calculated as follows:

$$P_1 = c_1 \pm \theta U_1, P_2 = c_2 \pm \theta U_2, P_3 = c_3 \pm \theta U_3 \quad (5.4)$$

where P_1, P_2, P_3 = prices of different forms of energy

θ = level of parametric variation

U_1, U_2, U_3 = unit of the parametric variations of c_1, c_2 and c_3 .

However, shadow prices were used in this study to formulate other forms of energy policies (discussed below).

(c) X, Y, Z for Technology Policy: The optimum values of the activities in the energy model (energy supplies, products and end-uses) determine what may be called the optimum energy system. The optimum energy system indicates the efficient resource allocation, i.e. the optimum pattern of activities in the energy sector. A comparison of the optimum energy system with the existing energy system can provide guidelines for the formulation of energy technology policies. In an economy where government investment in the energy sector exists, these values of the activities also show the desired pattern of public sector investment. In a market economy, the values of activities are used only to formulate energy technology policies as guidelines for government energy department operations and to provide information to the private sector to help in making investment decisions.

(d) X,Y,Z for Investment Policy¹: The optimum set of energy activities shows the optimum pattern of output of energy in the economy. Incremental capital-output ratios related to energy activities can be used to calculate the levels and structure of investments necessary to attain all of these energy outputs.

(e) $\alpha, \delta, \mu, \Gamma, \beta$ for Conservation Policy, Education and Information Policy; and Research and Development Policy:

Shadow prices can be used to determine priorities for the allocation of government funds for policy actions in such areas as conservation, research and development, and education and information. As shadow prices of end-use constraints indicate the effects of reduction in unit per energy consumption, these shadow prices are useful for the formulation of energy conservation policies. α ($= \alpha_1, \alpha_2, \dots, \alpha_n$) shows the relative priority areas for energy conservation.

The relative shares of each type of constraints of the total values of the shadow prices indicate the priorities in the allocation of funds for research and development, and education and information.

(f) R_c for Research and Development Policy: If one energy supply or technology is not viable in the market at the moment, that activity will not be in the simplex tableau of the optimum solution. The reduced cost of that activity indicates the cost reduction which will result in the penetration of the market by

1. In Australia, the state governments invest in the electricity sector. Since there is no need for a national investment policy, and as AEPsOM is not regionally segregated, no investment policy for the Australian energy sector has been formulated in this study.

that activity (Bradley, Hox and Magnanti [1977]). On the basis of this information government can undertake research and development policies or develop a more efficient technology or find cost-saving methods in that energy operation.

5.2.6 Two Types of Model Specifications

The two types of AEPsOM were solved separately.

5.2.7 Three Types of Units of Parametric Variations

In Chapter Four, three types of units of parametric variations were proposed which were applied to solve AEPsOM. These three types of units are:

- (1) $U = C$ = elements are selected to either equal c_j or 0;
- (2) $U = K$ = elements are either +1, 0 or -1;
- (3) $\pm u_j = H = -c_j \pm wI_j$; $j = 1, 2, \dots, n$.

In alternative cases, AEPsOM was solved by adopting those three units of parametric variation.

5.2.8 Two Types of Policy Studies

It was stated in Chapter Four (pp. 145-146) that an MLP model (AEPsOM) can be used to undertake two distinctively separate policy studies if it is solved by the PPS algorithm:

- (1) to find the optimum values of the existing taxes and subsidies in an economy (existing $\pm T$) and
- (2) to find the optimum combination of taxes and subsidies and their optimum values (optimum $\pm T$).

Methods for solving an MLP model by the PPS algorithm for these two types of policy studies were stated in Chapter Four. These methods were applied to solve AEPsOM, and to obtain results

suitable for the two types of policy studies. In the next section, AEPSOM results will be reported separately for these two policy regimes. In each of the policy studies, the above mentioned three units of parametric variation were adopted to solve AEPSOM.

5.3 PRESENTATION AND DISCUSSION OF THE AEPSOM RESULTS

This section will report the major results of AEPSOM and will discuss the results¹.

The important results produced by AEPSOM which were stated before are the (optimum) values of (a) the policy objective function, (b) the behavioural policy objective function (c) the taxes and subsidies (d) prices (e) activities (energy supply, production and end-uses), (f) shadow prices and (g) reduced costs. Sensitivity studies with AEPSOM also show the effects of changes in the energy sectoral variables and coefficients on the above mentioned results, especially on the policy objective function, and thus provides a comparative static framework for policy analysis.

The optimum AEPSOM solution with descriptions of the main characteristics of the model solution is given in Table 5.1. A listing of the various AEPSOM solutions is given in Appendix F.

1. In MLP studies, numerical findings are generally used for two purposes (i) to study the characteristics of the multi-level decision making, and (ii) to analyse and/or formulate policies (for example, Candler and Norton, [1977]). The same approach has been adopted in this study. Comparative accounts of the findings of the present study, and previous MLP and other studies will be provided throughout the whole chapter for an relative evaluation of the findings of the present study.

Table 5.1

OPTIMUM MODEL SOLUTIONS:AEPSOM with Policy Constraints(Feasible Optimum Solutions).

Model No.	Brief Description	Type of Policy	U	Policy Constraints	RESULT
					Optimum value P.O.F (1)* (PJ)
Model No. 5	AEPSOM 1979-80 data	Optimum set	U = C	$0 \leq \pm T \leq 20\%$ $B=3777.91 > 0$	6,733.70 ($\pm T \mid 0$)

*P.O. F (1) $W = Ie_1 + CNo + TCo$, with the policy constraints:

(1) $0 \leq t_j \leq 20\%$ of $j \quad j = 1, 2, \dots, 37$ (For 1989-90,

$j = 1, 2, \dots, 43$)

(2) $B = \sum_{i=1}^{37} (+t_j)x_j - \sum_{j=1}^{37} (-t_j)x_j \geq 0$

This model corresponds to AEPSOM in (5.1), Specification 1.

Detailed results of all these solutions are not reported here. Only those which are significant for the present study will be reported in the tables in the next sub-sections. In those tables, several model results are reported in addition to the optimum AEPSOM solution (model solution no. 5) for comparison purposes.

5.3.1 Some Elements of the Numerical Policy System

5.3.1.1 The Policy Objective Function

The optimum values of the policy objective function in the cases of two model specifications are reported in Table 5.1.

In the case of specification 1, only Model No.5 produced results satisfying the initial policy constraints $0 \leq \pm T \leq 20\%$. The optimum values of the policy objective function (1) are the same in the case of model solution 5 and 6 (Appendix F), although these have different upper level constraints on the policy range, while model solution 13 produces a very much lower value of the policy objective function.

To trace the relationships between the values of the policy objective function and the variations in $\pm T$ (or $\pm \Theta U$), Table 5.2 was prepared containing the values of the policy objective function and levels of Θ under both specifications of the policy objective function. It is evident from Table 5.2 that with the different levels of parametric variation, the values of the policy objective functions do not show any increasing or decreasing trend. This implies that the problem of finding the optimum value of $\pm T$ can not be solved by simply increasing or decreasing $\pm T$ steadily. Therefore, careful study is needed to find the optimum values of $\pm T$.

Table 5.2

Levels of Parametric Variations and the
Values of the Policy Objective Functions

Model No. 4

Q	W1*	W2**	W3***
0.0000	7031.66	0.00	7031.66
0.1300	7032.16	8142.39	-1110.23
0.5012	6734.20	24455.52	-17721.32
0.5900	6734.20	9202.55	-2468.35
2.2486	7037.22	26514.73	-19477.51
2.6850	7037.22	21432.75	-14395.53

Model No. 5

Q	W1*	W2**	W3***
0.0000	7031.66	0.00	7031.66
0.0771	6733.70	3777.91	2955.79
0.1158	6897.83	5226.25	1671.58
0.2899	6897.83	3460.04	3437.79
0.2918	7036.72	3798.89	3237.83
0.3137	7036.72	2889.04	4147.68
0.3149	7037.22	2863.57	4173.65

Model No. 6

Q	W1*	W2**	W3***
0.0000	7031.66	0.00	7031.66
0.0791	6733.70	3859.65	2874.05
0.1042	7110.58	4702.72	2407.86
0.1150	6898.33	5190.08	1708.25
0.2222	7773.20	2717.27	5055.93
0.2937	7912.09	3476.58	4435.51
0.3164	7912.09	2540.03	5372.06

*W1 = P.O.F.(1)

**W2 = The second part of P.O.F.(2)

***W3 = P.O.F.(2)

5.3.1.2 The Values of the Behavioural Objective Function

The optimum solutions to some behavioural models of AEPSOM (the single level linear programming model of the energy sector without $+T$ in it or when $+T = 0$) are reported in Table 5.3. Optimum solutions to the same behavioural models when these models are solved as the lower level of an MLP (AEPSOM) (i.e., optimum value for the behavioural problem determined by the MLP solution) are also reported in the Table.

It appears from Table 5.3 that optimum solutions to the single level behavioural model are not the same as the optimum MLP solutions to the behavioural model. In other words, the optimum value of the behavioural objective function without government intervention is different from when there is government intervention. In most of the solutions of which six are reported in Table 5.3 the former value has been lower than the latter.

Different values of the behavioural and policy objective functions are also reported in Table 5.3. It is apparent from the Table that in the cases where optimum model solutions involve $+T = 0$, the value of the behavioural objective function of AEPSOM is higher than the value of the behavioural objective function of the cost-minimizing linear programming model of the energy sector (single level behavioural model, in Model 7). This implies that to achieve the optimum value of policy objectives, the energy sectoral total costs have to increase. Alternatively, AEPSOM does not choose the energy sector behavioural optimum solution (without government intervention) as optimum solution for the MLP model.

These results clearly demonstrate the different/conflicting interests of the private and public sector. The public sector decision criteria select that private sector performance which is

Table 5.3.

Optimum Values of the Behavioural and Policy Objective Functions

Model number	B.O.F. (1)*	B.O.F. (2)**	P.O.F. (1)	$\pm T$
1	229336.34	229336.34	7031.68	$\pm T=0$
2	229336.34	229336.34	7031.66	$\pm T=0$
3	229336.34	229336.34	7031.40	$\pm T=0$
4	229336.34	230668.43	6734.20	$\pm T \neq 0$
5	229336.34	245047.03	6733.70	$\pm T \neq 0$
6	229336.34	251442.69	6733.70	$\pm T \neq 0$

*The value of the objective function of the single level linear programming model.

**The value of the objective function of the behavioural model of AEPSOM. It does not include taxes or subsidies.

different from the private sector's own chosen optimum performance.

This does not, however, mean that policy intervention will always raise the level of energy sector costs, as can be seen from Table 5.4. In Model Solution 13, increased value of the parametric variation has actually at some time reduced the value of the behavioural objective function. For example at $\theta = 9.112$, the value of the behavioural objective function of AEPSOM is 255748.56 which is less than the value generated by the single level linear programming model.

One important aspect of the AEPSOM optimum solution should be discussed here. If the optimum values of P.O.F(1) in Model Nos 7 and 5 are compared (Table F.1 in Appendix F), it will reveal that the optimum value determined by the single level behavioral model (Model No.7) : 7031.68 is higher than that of the MLP model - AEPSOM (Model No. 5).

Table 5.4

Different Values of θ and Three Objective Functions

Model No.5

θ	B.O.F.(1)	B.O.F.(2)	P.O.F.(1)
0.0000	229336.34	229336.34	7031.66
0.0771		245047.03	6733.70
0.1158	-	252385.15	6897.83
0.2899	-	284808.63	6897.83
0.2918	-	285150.94	7036.72
0.3137	-	289020.25	7036.72
0.3149	-	289237.88	7037.22

Model No.13

θ	B.O.F.(1)	B.O.F.(2)	P.O.F.(1)
0.0000	275179.50	275179.50	8427.01
0.1000		275412.38	4680.03
0.1625		275361.06	9476.85
0.1867		275341.19	9476.85
0.5413		275048.94	9477.45
1.0000		274505.13	9477.45
1.7092		273371.75	9476.14
1.9159		272993.06	9494.46
1.9442		273940.12	9494.46
2.2645		272224.38	9494.46
9.1118		255748.56	9494.46

B.O.F.(1) and B.O.F. (2) as defined before.

In Figure 5.1, optimum values of different target variables generated by Model No. 5 and the single level behavioural model are shown. The bar diagrams of $Ie1(B)$, $CNo.(B)$ and $TCe(B)$ show the values of target variables ($Ie1$, CNo and TCe) generated by the behavioural model which are higher than their values generated by the MLP model ($Ie(M)$, $(No(M)$, and $TCe(M)$)).

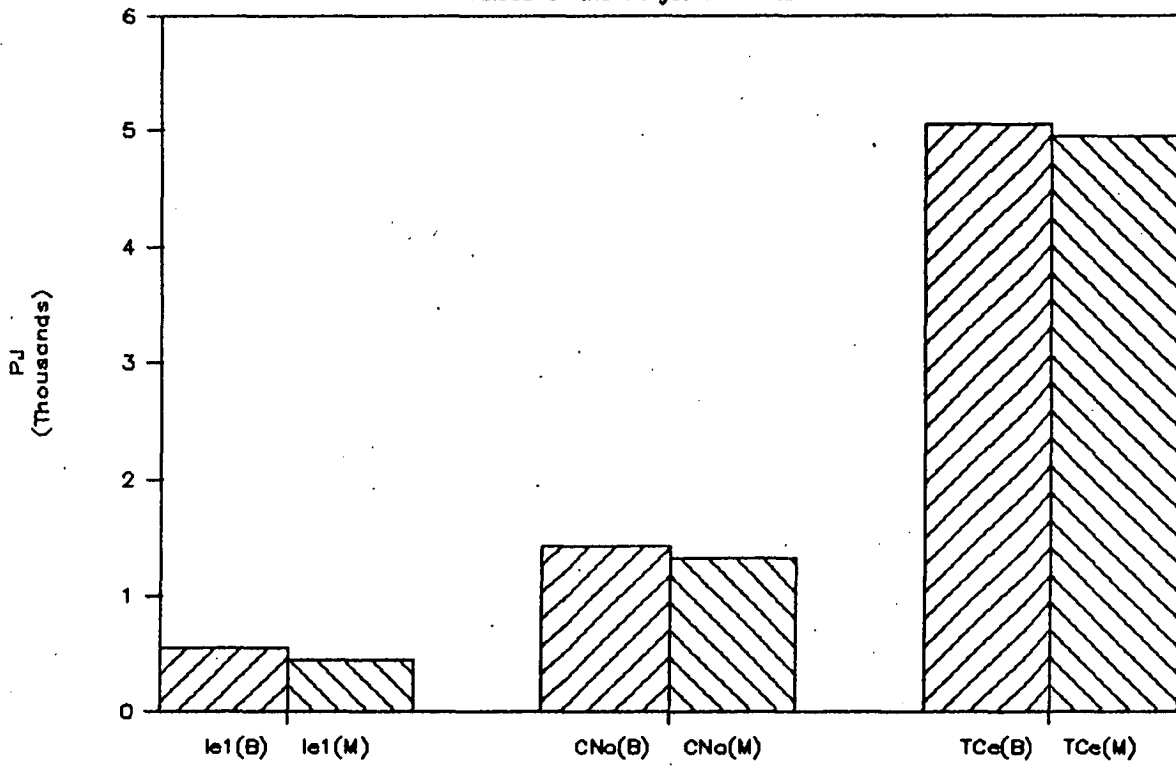
5.3.1.3 A Multi-level Policy System Analysis

In Appendix B, some analytical characteristics of multi-level decision making are stated. The AEPSOM results can be used to highlight some numerical characteristics of the multi-level policy system, the characteristics which exist analytically in model (B.1) in Appendix B. The AEPSOM results demonstrate the following numerical characteristics of the policy system in the Australian energy sector.

(a) Goal Interdependence:

The first characteristic is goal inter-dependence: an indirect goal inter-dependence exists in the energy sector (i.e., objectives of the policy makers are dependent on the objective of economic agents as well as on the energy system (which are represented by the behavioural objective function and the energy sector constraints)). The optimum value of the policy objective function is the value of the (multi) goals that the policy makers sought to achieve by making a rational decision. The optimum value of economic agents' goals is reflected in the value of the behavioural objective function (Table 5.3). It is evident from Tables 5.3

Figure 5.1
Values of the Target Variables



and 5.4 that the achievement of goals at each level of decision making is interdependent (indirect goal inter-dependence): the optimum values of the policy and behavioural objective functions are interdependent. It was also found that the two level decision makers have conflicting interests (Table 5.4), and the optimum solution to the system results is a compromise situation providing the attainment of optimum goals for the decision makers at each level (saddle point, optimum solution in Table 5.4 (model No. 5) at $\theta = 0.771$).

(b) Intervention:

In the above mentioned policy system context, the adaptation of policies ($+T$ intervention) by the policy makers results in improved performance of the policy system (lower level of social energy goals). This is evident from Table 5.1 since the optimum solution to AEPSOM (Model No. 5) is in the case where $+T \neq 0^1$.

In other studies, Candler and Norton ([1977], p. 27) and Ballenger [1984]) also found that the behavioural optimum is

1. In the terminology of game theory (for a discussion of game theory, see Intriligator [1971], Fortuny-Amat [1979]), AEPSOM results show that the policy system in the Australian energy sector is characterized by a two-person, nonzero-sum, cooperative game situation. In this situation the policy makers and economic agents (two persons) are engaged in their own decision making, but the outcome of one's decision (the value of the policy objective function or behavioural objective function) does not depend only on his decision or strategy but also on the other person's decision (i.e., the optimum value of the policy objective function is dependent on the optimum value of the behavioural objective function and vice versa, Table 5.3 and 5.4). Both type of decision makers mutually gain from their decisions of the game (nonzero-sum game) in the sense that the optimum solution to the game results in a lower value of the policy objective function (Table 5.1). There is also the possibility of mutual cooperation. The optimum policy outcome is attained at the saddle point in the policy-behavioural feasible region ($g(G, +T, X, Y, Z) = 0$) in the cases of models (5.1) and (5.2).

inefficient compared with the multi-level programming optimum in the sense that "the behavioural optimum lies . . . further inside the policy-behavioural frontier" in a policy maximization case.

This brings in the issue of the desirability of the government intervention in achieving the objectives of the society. AEPSOM results indicate the possibility for attaining a lower level of policy goals by the government policy intervention in the energy sector.

5.3.2 Appropriateness of the AEPSOM Results

It was argued in Chapter Two (Section 2.4.3) that the single level (both positive/behavioural and normative/central control policy) models misrepresent the underlying multi-level decision making process. Therefore, their numerical results may generate wrong prediction or optimum policies. AEPSOM results can be used to evaluate these arguments regarding the appropriateness of single level mathematical programming models.

For that purpose, these two types of models are specified from AEPSOM as follows:

(a) Single-Level Positive/Behavioural Model

$$\text{Min } C = (c_1 \pm T_1)Y + (c_2 \pm T_2)X + (c_3 \pm T_3)Z$$

{Y,X,Z}

(a) Behavioural objective function

s.t.

$$Z \geq D$$

(b) Demand constraint

$$Z = aX$$

(c) Intermediate energy balance constraints

$$X = bY$$

(d) Energy supply balance constraints

$$Y \leq Y$$

(e) Resource constraints

$$X \leq \bar{X}$$

(f) Capacity constraints

$$G, Y, X, Z \geq 0$$

(g) Non-negativity constraints

(b) Single-Level Normative/Central Control Model

$$\text{Min WL} = wG$$

(a) Policy objective function

$$\{Z, Y, X\}$$

(P.O.F.(1))

s.t.

$$Z \geq D$$

(b) Demand constraint

$$Z = aX$$

(c) Intermediate energy balance constraints

$$X = bY$$

(d) Energy supply balance constraints

$$Y \leq \bar{Y}$$

(e) Resource constraints

$$X \leq \bar{X}$$

(f) Capacity constraints

$$G, Y, X, Z \geq 0$$

(g) Non-negativity constraints

Definitions of the symbols are the same as in model (5.1).

In Table F.1 (Appendix F), Model No. 7 and Model No. 9 are the single level energy sector positive and normative models. Model No.7 has determined a lower level of policy goals compared to an MLO model, Model No.5. On the other hand, Model No. 9 has determined a lower optimum policy goal level, but that can only be attained by central controls of the energy sector (not by indirect controls as in the market economy). Therefore, both the single level mathematical models (Model Nos 7 and 9) produce erroneous results for the energy sector (the optimum value of the policy objective function as well as the optimum values of other

model results: prices, taxes and subsidies, shadow prices and reduced costs). Consequently, it may be argued that an accurately specified and implemented MLO model (Model No 5) can generate appropriate numerical results for optimum energy policy planning in a market economy.

From the evidence of past studies (Candler and Norton [1977]) stated in the previous sub-section and also from the present work, it can now be concluded that an MLP model can represent the multi-level decision making system appropriately, and therefore, generates accurate energy model results (forecasts or policies).

5.3.3 Taxes and Subsidies

As it was stated before, within the structure of existing $\pm T$, improvement in policy goals is not possible compared to a situation of market performance. Therefore, optimum values of $\pm T$, in the cases of existing $\pm T$, are 0.

If the policy system is allowed to choose the optimum mix and values of $\pm T$, then the model solution finds $\pm T \neq 0$ optimum solution to AEPsOM. These values of optimum mix and optimum values of $\pm T$ are reported in Table 5.5.A.

A comparison of the optimum mix of $\pm T$ and the existing $\pm T$ reveals that the optimum mix of $\pm T$ suggested by AEPsOM is different from existing $\pm T$ (see Table 5.5.B.).

5.3.4 Prices

The calculated prices of different energy supplies, products and end-uses are reported in Tables 5.6.A. and 5.6.B. Although all these prices are reported here, not all energy prices are under government control in Australia.

Table 5.5.A.

Optimum Mix and Levels of Taxes and Subsidies: 1979-80
(\$M/PJ)

Energy Type (1)	Model No. 5		Model No. 6		Model No.13	
	+T on energy Types(2)	% (3)	+T on energy Types	% (3)	+T on energy Types	% (3)
R ₁	0.0000	0.0000	0.0000	0.0000	0.0280	3.8889
R ₂	0.2313	4.6260	0.2373	4.7460	0.3000	6.0000
Ie ₁	0.1272	2.4003	0.1305	2.4625	0.0000	0.0000
R ₃	0.0000	0.0000	0.0000	0.0000	0.0120	1.5385
R ₄	0.0000	0.0000	0.0000	0.0000	0.1000	0.5189
R ₅	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R ₆	-0.0871	-67.0177	-0.0894	-68.7562	0.0000	0.0000
R ₇	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
E ₁	1.0779	7.7100	1.1058	7.9100	0.0000	0.0000
E ₃	-1.7209	-7.7100	-1.7655	-7.9100	0.0000	0.0000
E ₄	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
x ₁	-0.0794	-7.7100	-0.0815	-7.9100	0.0000	0.0000
x ₂	0.1773	12.7576	0.1819	13.0885	0.0000	0.0000
E ₂	-1.4410	-7.7100	-1.4784	-7.9100	0.0000	0.0000
x ₃	0.1033	7.7100	0.1060	7.9100	0.0000	0.0000
x ₄	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
x ₅	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
x ₆	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
x ₇	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₁	0.2120	7.7100	0.2175	7.9100	-0.2750	-10.0000
d ₂	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₃	0.0948	7.7100	0.0973	7.9100	-0.1230	-10.0000
d ₄	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₅	0.0000	0.0000	0.0000	0.0000	-0.0250	-10.0000
d ₆	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₇	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₈	18.27270	7.6918	18.7467	7.8914	0.0000	0.0000
d ₉	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₁₀	0.1002	7.5932	0.1028	7.7902	-0.1320	-10.0000
d ₁₁	0.0000	0.0000	0.0000	0.0000	-0.3390	-34.5918
d ₁₂	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₁₃	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₁₄	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
d ₁₅	-0.5012	-7.4910	-0.5142	-7.6854	-0.9450	-14.1256
Ee ₁	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ee ₂	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ee ₃	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

- (1) Definitions of these energy types (both for 1979-80 and 1989-90) are given in Table 5.5.A.(Appendix) below.
- (2) +T is a column of taxes and subsidies suggested by AEPsOM. The second entry in the column is tax on the second type of energy (oil). That is how T column relates to different energy forms.
- (3) (i) Taxes and subsidies as percentages of costs: $(T + C) \times 100$.
(ii) Taxes subsidies, and costs are measured in million Australian dollars per petajoules (\$M/PJ).

Table 5.5.B

Existing and Optimum Set of $\pm T$ 1979-80
Model No.5

Energy Type	Set of Existing $\pm T$	Optimum Mix of $\pm T$
R ₁	+	0
R ₂	+	+
Ie ₁	0	+
R ₃	+	0
R ₄	0	0
R ₅	0	0
R ₆	0	-
R ₇	0	0
E ₁	0	+
E ₃	0	-
E ₄	0	0
x ₁	0	-
x ₂	0	+
E ₂	0	-
x ₃	0	+
x ₄	0	0
x ₅	0	0
x ₆	0	0
x ₇	0	0
d ₁	-	-
d ₂	0	0
d ₃	-	+
d ₄	0	0
d ₅	-	0
d ₆	0	0
d ₇	0	0
d ₈	0	+
d ₉	0	0
d ₁₀	-	+
d ₁₁	0	0
d ₁₂	-	0
d ₁₃	0	0
d ₁₄	-	0
d ₁₅	-	-
Ee ₁	0	0
Ee ₂	0	0
Ee ₃	0	0

Table 5.5.A. (Appendix)

**List of the Activities of the Behavioural Model:
Energy Supplies, Production and End-uses**

AEPSOM: 1979-1980 Activities /Energy Type	AEPSOM: 1989-1990 Activities of /Energy Type
A. Primary Energy Resources	A. Primary Energy Resources
R ₁ = coal	R ₁ = coal
R ₂ = crude oil	R ₂ = crude oil
Ie ₁ = imported crude oil	Ie ₁ = imported crude oil
R ₃ = natural gas	R ₃ = natural gas
R ₄ = hydro electricity	R ₄ = hydro electricity
R ₅ = biomass	R ₅ = biomass
R ₆ = solar	R ₆ = solar
R ₇ = uranium	R ₇ = uranium
B. Intermediate Energy	B. Intermediate Energy
E ₁ = electricity from coal	RR ₁ = synthetic oil from coal
E ₃ = electricity from natural gas	E ₁ = electricity from coal
E ₄ = hydro-electricity	E ₃ = electricity from natural gas
x ₁ = coal	E ₄ = hydro-electricity
x ₂ = petroleum products	x ₁ = coal
E ₂ = electricity from petroleum products	x ₂ = petroleum products
x ₃ = natural gas	E ₂ = electricity from petroleum products
x ₄ = total electricity production	x ₃ = natural gas
x ₅ = biomass	x ₄ = total electricity production
x ₆ = solar	x ₅ = biomass
x ₇ = uranium	x ₆ = methanol
	x ₇ = solar
	x ₈ = uranium
C. Energy End-uses	C. Energy End-uses
i. Manufacturing Industry Sector:	i. Manufacturing Industry
d ₁ = coal	d ₁ = coal
d ₂ = petroleum products	d ₂ = petroleum products
d ₃ = natural gas	d ₃ = natural gas
d ₄ = electricity	d ₄ = electricity
d ₅ = biomass	d ₅ = biomass
ii. Agricultural Sector:	ii. Agricultural Sector:
d ₆ = petroleum products	d ₆ = petroleum products
d ₇ = electricity	d ₇ = electricity

Table 5.5.A. (Appendix) (Continued)

List of the Behavioural Model Activities/Energy Types

AEPsOM: 1979-1980 Activities of the Behavioural Model/Energy Type	AEPsOM: 1989-1990 Activities of the Behavioural Model/Energy Type
iii. Transport Sector	iii. Transport Sector
d ₈ = petroleum products d ₉ = electricity	d ₈ = coal d ₉ = petroleum products d ₁₀ = natural gas d ₁₁ = electricity d ₁₂ = methanol
iv. Domestic and Other Sectors	iv. Domestic and Other Sectors
d ₁₀ = coal d ₁₁ = petroleum products d ₁₂ = natural gas d ₁₃ = electricity d ₁₄ = biomass d ₁₅ = solar	d ₁₃ = coal d ₁₄ = petroleum products d ₁₅ = natural gas d ₁₆ = electricity d ₁₇ = biomass d ₁₈ = solar
v. Exports	v. Exports
Ee ₁ = coal Ee ₂ = petroleum products Ee ₃ = uranium	Ee ₁ = coal Ee ₂ = petroleum products Ee ₃ = natural gas Ee ₄ = uranium

Table 5.6.A
Optimum Energy Pricers in 1979-80

Model No. 5

Energy Type	$\pm T$	C	P (M\$/PJ)*
R ₁	0.0000	0.72	0.7200
R ₂	0.2313	5.00	5.2313
I _{e1}	0.1272	5.30	5.4272
R ₃	0.0000	0.78	0.7800
R ₄	0.0000	19.27	19.2700
R ₅	0.0000	1.18	1.1800
R ₆	-0.0871	0.13	0.0429
R ₇	0.0000	0.13	0.1300
E ₁	1.0779	13.98	15.0579
E ₃	-1.7209	22.32	20.5991
E ₄	0.0000	0.00	0.0000
x ₁	-0.0794	1.03	0.9506
x ₂	0.1773	1.39	1.5673
E ₂	-1.4410	18.69	17.2490
x ₃	0.1033	1.34	1.4433
x ₄	0.0000	6.00	6.0000
x ₅	0.0000	0.00	0.0000
x ₆	0.0000	0.00	0.0000
x ₇	0.0000	0.00	0.0000
d ₁	0.2120	2.75	2.9620
d ₂	0.0000	1.42	1.4200
d ₃	0.0948	1.23	1.3248
d ₄	0.0000	2.30	2.3000
d ₅	0.0000	0.25	0.2500
d ₆	0.0000	2.00	2.0000
d ₇	0.0000	0.20	0.2000
d ₈	18.2727	237.56	255.8327
d ₉	0.0000	228.40	228.4000
d ₁₀	0.1002	1.32	1.4202
d ₁₁	0.0000	0.98	0.9800
d ₁₂	0.0000	3.39	3.3900
d ₁₃	0.0000	6.17	6.1700
d ₁₄	0.0000	0.00	0.0000
d ₁₅	-0.5012	6.69	6.1889

$$* P = c \pm T$$

c = Cost coefficient vector (cost of different forms of energy)

$\pm T$ = Tax or subsidy vector (taxes or subsidies on different forms of energy)

P = Price vector (prices of different forms of energy)

Taxes, subsidies, costs and prices are measured in million Australian dollars per petajoules.

Table 5.6.B

Optimum Energy Prices in 1979-80

Model No. 6

Energy Type	$\pm T$	c	P (M\$/PJ)*
R ₁	0.0000	0.72	0.7200
R ₂	0.2373	5.00	5.2373
Ie ₁	0.1305	5.30	5.4305
R ₃	0.0000	0.78	0.7800
R ₄	0.0000	19.27	19.2700
R ₅	0.0000	1.18	1.1800
R ₆	-0.0894	0.13	0.0406
R ₇	0.0000	0.13	0.1300
E ₁	1.1058	13.98	15.0858
E ₃	-1.7655	22.32	20.5545
E ₄	0.0000	0.00	0.0000
x ₁	-0.0815	1.03	0.9485
x ₂	0.1819	1.39	1.5719
E ₂	-1.4784	18.69	17.2116
x ₃	0.1060	1.34	1.4460
x ₄	0.0000	6.00	6.0000
x ₅	0.0000	0.00	0.0000
x ₆	0.0000	0.00	0.0000
x ₇	0.0000	0.00	0.0000
d ₁	0.2175	2.75	2.9675
d ₂	0.0000	1.42	1.4200
d ₃	0.0973	1.23	1.3273
d ₄	0.0000	2.30	2.3000
d ₅	0.0000	0.25	0.2500
d ₆	0.0000	2.00	2.0000
d ₇	0.0000	0.20	0.2000
d ₈	18.7467	237.56	256.3067
d ₉	0.0000	228.40	228.4000
d ₁₀	0.1028	1.32	1.4228
d ₁₁	0.0000	0.98	0.9800
d ₁₂	0.0000	3.39	3.3900
d ₁₃	0.0000	6.17	6.1700
d ₁₄	0.0000	0.00	0.0000
d ₁₅	-0.5142	6.69	6.1759

$$* P = c \pm T$$

c = Cost coefficient vector

$\pm T$ = Tax or subsidy vector

P = Price vector

5.3.5 Shadow Prices

It was mentioned before that in this study shadow prices will not be used for pricing policy purposes, but to determine the priorities in conservation programmes, research and development, and education and information policy. Shadow prices have been reported here for these uses. The proportions (Z) of the shadow prices related to different types of constraints have also been reported here since these proportions indicate the relative priorities for various policy measures. Two types of shadow price proportions are calculated: (1) shadow price proportions of different sectoral end-use constraints and (2) shadow price proportions of all types of constraints in the model: energy end-uses, intermediate balance, supply balance, resource constraints and capacity constraints.

These two types of shadow prices and their proportions are reported in Tables 5.7.A and 5.7.B for Model No.5. Proportions of sectoral end-use constraints reflect the priorities for conservation programmes, while the proportions of shadow prices related to all the constraints reflect priorities for government expenditure for research and development, and education and information policies.

5.3.6 Optimum Activities

One important result of AEPsOM is a set of optimum values of the activities in the Australian energy sector. This set of optimum activities (numerical values of the flows of primary energy, secondary energy and end-uses of energy as well as various technologies) constitutes the optimum energy system for Australia.

Table 5.7.A

Proportion of Shadow Prices, 1979 - 1980

Model No. 5

Constraints/Symbols*	Shadow Prices \$/PJ	Proportions(%)
1. Demand Constraints (α) (5.1.f)	521.4165	0.6947
2. Intermediate Balance (δ) (5.1.g)	177.1009	0.2359
3. Supply Balance (μ) (5.1.h)	31.9612	0.0426
4. Resources Constraints (Γ) (5.1.i)	6.5168	0.0087
5. Capacity Constraints (β) (5.1.j)	3.6875	0.0049

* These constraints were specified in Model 5.1 or 5.2

Table 5.7.B

Shadow Prices Related to Different Demand Constraints (r)

Model No. 5

Demand Constraints (5.1.f)	Shadow Prices \$/PJ	Proportions
Manufacturing Industry	5.1628	0.0098
Agriculture/Primary Industry	9.2059	0.0177
Transport	236.0849	0.5046
Domestic and Commercial	4.0107	0.0077
Electricity Manufacturing	80.3937	0.1542
Electricity Primary Industry	74.2146	0.1423
Electricity Domestic Sector	85.3799	0.1637

In Table 5.8.A. the optimum set of activities suggested by three model solutions along with the 1979-80 actual energy production and uses is shown. In Table 5.8.B. a similar set of figures for 1989-90 is shown. When the demand and supply of energy are constrained to their actual values in 1979-80 (as in Model 5 and 6) the optimum set of activities is somehow close to their actual values. However, when the constraints were relaxed by 20%, the structure of the optimum set of activities changes due to greater flexibility and substitutability among different fuels. In both cases, model results indicate different structures and values of energy activities than the 1979-80 actual figures.

In the 1989-90 energy system, the model solution suggests a set of optimum activities which is different from the 1989-90 actual figures and government projections. The differences between the 1989-90 actual energy activities and the model results (produced by an MLP model specified to determine an optimum energy policy system for Australia) clearly indicate a different profile for the energy sector growth. Some new developments in the 1989-90 AES are the uses of town gas in the domestic sector, and natural gas and coal in the mining sector (Jones et. al., [1991]).

Therefore, both the 1979-80 and 1989-90 model results suggest optimum energy systems for Australia different from those that have been considered to be ideal and possible by the government and the private sector.

5.3.7 Reduced Costs

The reduced costs of the 1979-80 and 1989-90 AEPSOM are reported in Table 5.9.A and 5.9.B. Although different model solu-

Table 5.8.A
Optimum Activities, 1979 - 1980
(PJ)*

Energy Type	1979 - 80 Actual **	Model Results		
		Model No.5	Model No.6	Model No.13
R ₁	2448.81	2448.8101	2448.8101	2938.5703
R ₂	874.87	874.8701	874.8701	0.0000
Ie ₃	435.34	453.3918	453.3918	1709.4453
R ₃	364.18	364.1799	364.1799	437.0100
R ₄	50.23	86.6099	86.6099	103.9300
R ₅	138.14	138.1399	138.1399	165.7600
R ₆	0.50	0.0000	0.0000	0.0000
R ₇	586.04	586.0400	586.0400	703.2400
E ₁	845.57	351.6301	351.6301	864.0101
E ₃	87.91	364.1799	364.1799	0.0000
E ₄	50.23	86.6103	86.6103	103.9304
x ₁	493.95	2097.1797	2097.1797	2074.5601
x ₂	1188.82	1063.2300	1063.2300	1275.9099
E ₂	50.23	265.0317	265.0317	433.5352
x ₃	251.16	0.0000	0.0000	437.0100
x ₄	293.02	288.8400	288.8400	346.6000
x ₅	138.14	138.1399	138.1399	165.7600
x ₆	0.50	0.0000	0.0000	0.0000
x ₇	586.04	586.0400	586.0400	703.2400
d ₁	83.72	590.2200	590.2200	271.2700
d ₂	192.56	0.0000	0.0000	0.0000
d ₃	175.81	0.0000	0.0000	437.0100
d ₄	108.84	108.8400	108.8400	130.6000
d ₅	71.16	138.1399	138.1399	165.7600
d ₆	96.28	117.2000	117.2000	140.6800
d ₇	25.12	25.1200	25.1200	30.1000
d ₈	807.90	812.0798	812.0798	974.4897
d ₉	4.19	0.0000	0.0000	0.0000
d ₁₀	4.19	234.4200	234.4200	281.2600
d ₁₁	87.91	0.0000	0.0000	0.0000
d ₁₂	58.60	0.0000	0.0000	0.0000
d ₁₃	154.88	154.8800	154.8800	185.9000
d ₁₄	66.98	0.0000	0.0000	0.0000
d ₁₅	0.50	0.0000	0.0000	0.0000
Ee ₁	1272.54	1272.5400	1272.5400	1522.0300
Ee ₂	133.95	133.9500	133.9500	160.7400
Ee ₃	581.85	586.0400	586.0400	703.2400

* Energy is measured in Petajoules (PJ) in Table 5.8.A and 5.8.B.

** Source: Department of National Development and Energy [1983].

Table 5.8.B

Optimum Activities: 1989-90

(PJ)

Energy Type	1989-90 Actual*	Forecast**	Model Solution	
			Existing \pm T Model Solution No. 19	Optimum \pm T Model Solution No. 23
R ₁	4688.0	4198.56	4198.5596	4198.5596
R ₂	1182.6	1159.52	0.0000	649.5796
I _{e1}	449.0	326.51	648.8518	0.0000
R ₃	797.7	933.48	933.4800	933.4800
R ₄	53.2	58.60	86.6100	86.6100
R ₅	176.3	171.63	171.6301	171.6301
R ₆	3.0	1.00	1.0000	0.0000
R ₇	4291.4	4299.02	4299.0195	4299.0195
RR ₁	0.0	0.00	0.0000	0.0000
E ₁	1291.8	1272.54	769.2666	768.2666
E ₃	160.0	133.95	0.0000	0.0000
E ₄	53.2	58.60	86.6100	86.6100
x ₁	193.0	594.42	3429.2935	3430.2935
x ₂	1316.3	1172.08	360.0001	360.0002
E ₂	37.0	8.37	288.8523	289.5797
x ₃	497.0	523.25	933.4800	933.4800
x ₄	475.0	447.90	330.2300	330.2300
x ₅	176.3	171.63	171.6301	129.7701
x ₆	0.0	0.00	0.0000	41.8600
x ₇	3.0	1.00	1.0000	0.0000
x ₈	1921.4	4299.02	4299.0195	4299.0195
d ₁	175.3	125.61	909.3228	910.3228
d ₂	150.9	96.28	0.0000	0.0000
d ₃	296.8	318.14	698.5671	697.5671
d ₄	182.6	171.63	100.0000	100.0000
d ₅	101.5	104.65	0.0000	0.0000
d ₆	89.6	123.58	255.3500	255.3500
d ₇	42.0	41.86	0.0000	0.0000
d ₈	3.5	4.19	0.0000	0.0000
d ₉	995.3	891.62	0.0000	0.0000
d ₁₀	0.4	0.00	41.8599	0.0000
d ₁₁	6.6	4.19	0.0000	0.0000
d ₁₂	0.0	0.00	0.0000	41.8600
d ₁₃	4.0	4.19	0.0000	0.0000
d ₁₄	27.0	66.98	0.0000	0.0000
d ₁₅	97.0	125.58	95.4399	138.2999
d ₁₆	233.7	230.23	230.2300	230.2300
d ₁₇	77.0	66.98	171.6301	129.7701
d ₁₈	3.0	0.00	1.0000	0.0000
Ee ₁	2982.5	2519.97	2519.9702	2519.9702
Ee ₂	159.0	104.65	104.6500	104.6500
Ee ₃	109.6	246.97	246.9700	246.9700
Ee ₄	1749.8	4299.02	4299.0200	4299.0200

*Source: Jones et al. [1991]

**Source: Department of National Development and Energy [1983]

Table 5.9.A
Reduced Costs 1979-80
 (\$M)

Energy Type	Model No. 5 (Rc)	Model No. 6 (Rc)	Model No. 13 (Rc)
R ₁	0.0000	0.0000	0.0000
R ₂	0.0000	0.0000	0.0000
Ie ₁	0.0000	0.0000	0.0000
R ₃	0.0000	0.0000	0.0000
R ₄	0.0000	0.0000	0.0000
R ₅	0.0000	0.0000	0.0000
R ₆	0.1200	0.0406	0.1300
R ₇	0.0000	0.0000	0.0000
RR ₁	0.0000	0.0000	0.0000
E ₁	0.0000	0.0000	2.8553
E ₃	0.0000	0.0000	0.0000
E ₄	0.0000	0.0000	0.0000
x ₁	0.0000	0.0000	0.0000
x ₂	0.0000	0.0000	0.0000
E ₂	0.0000	0.0000	0.0000
x ₃	0.0000	0.0000	0.0000
x ₄	0.0000	0.0000	0.0000
x ₅	0.0000	0.0000	0.0000
x ₆	0.0000	0.0000	0.0000
x ₇	0.0000	0.0000	0.0000
x ₈	3.4991	3.3794	1.1377
d ₁	0.0000	0.0000	0.0000
d ₂	0.0000	0.0000	0.0000
d ₃	0.0000	0.0000	0.0000
d ₄	0.0000	0.0000	0.0000
d ₅	0.0000	0.0000	0.0000
d ₆	0.0000	0.0000	0.0000
d ₇	48.5300	47.3786	70.8436
d ₈	0.0000	0.0000	0.0000
d ₉	4.1752	4.0473	1.9847
d ₁₀	3.1813	3.1706	3.2310
d ₁₁	0.0000	0.0000	0.0000
d ₁₂	0.8661	0.8579	0.9620
d ₁₃	2.1635	2.4224	0.3357

Table 5.9.B
Reduced Costs 1989-90
(\$M)

Energy Type	Model No. 19 (Rc)	Model No. 23 (Rc)
R ₁	0.0000	0.0000
R ₂	981.8057	0.0000
Ie ₁	0.0000	0.6192
R ₃	0.0000	0.0000
R ₄	0.0000	0.0000
R ₅	0.0000	0.0000
R ₆	0.0000	0.0802
R ₇	0.0000	0.0000
RR ₁	13.3173	10.9377
E ₁	0.0000	0.0000
E ₃	3.1608	3.1876
E ₄	0.0000	0.0000
x ₁	0.0000	0.0000
x ₂	0.0000	0.0000
E ₂	0.0000	0.0000
X ₃	0.0000	0.0000
x ₄	0.0000	0.0000
x ₅	0.0000	0.0000
x ₆	11.0793	0.0000
x ₇	0.0000	0.0000
x ₈	0.0000	0.0000
d ₁	0.0000	0.0000
d ₂	2.1473	2.7005
d ₃	0.0000	0.0000
d ₄	0.0000	0.0000
d ₅	0.3742	0.4948
d ₆	0.0000	0.0000
d ₇	82.5036	78.0598
d ₈	51.7197	42.2602
d ₉	37.6223	29.4883
d ₁₀	0.0000	2.9175
d ₁₁	109.0059	96.4279
d ₁₂	0.0000	0.0000
d ₁₃	55.3883	11.0223
d ₁₄	0.00000	0.0000

tions suggest different magnitudes of reduced costs for these activities, the values of reduced costs are fairly similar in the cases of Model Nos 5 and 6. This is plausible since Model 5 and 6 were specified within a given structure of the energy sector. This certainly provided a possibility for a different technological pattern and thus calculated different reduced costs which indicate that different cost savings are required for market penetration of those activities.

5.4 SENSITIVITY ANALYSIS

To test the robustness of the results of AEPSOM, the sensitivities of model solutions to changes in some crucial variables, parameters and policies were tested. These variables, parameters and policies were chosen for sensitivity analysis because of either their strategic importance in the energy sector or uncertainty regarding them.

A complete list of the model solutions reflecting the changes in the policies and parameters of the Australian energy sector, effects of which have been studied, is given in Table F.1. More or less the same changes are assumed in the models in the cases of existing taxes and subsidies and optimum mix of taxes and subsidies. These changes and the models in which these changes were incorporated are as follows:

- (1) introduction of taxes on imported oil (Model No.12),
- (2) relaxation of constraints (demand and supply) by 20% and 100% respectively (Model No's.13, and 14),
- (3) limiting petroleum import (import quota) (Model No.15),

- (4) introduction of some new technologies in the 1979-80 Australian energy system (1979-80 AEPSOM) (coal conversion technologies, methanol production, electric railway etc. (Model No.16)),
- (5) administering import parity prices of all domestic crude oil (Model No.17),
- (6) a doubling of the 1979-80 supply of energy resources while the demand level of 1979-80 remains the same (Model No.18),
- (7) development and solution of AEPSOM for 1989-90 (Model no.19 and 23), and Appendix G),¹
- (8) and different weights attached to the two components of policy objective functions (P.O.F. (2)) (Table 5.10),
- (9) Different weights attached to the three policy target variables in policy objective function P.O.F.(1) (Table 5.11). It should be noted here that none of the sensitivity studies has generated an optimum solution satisfying policy constraints.

However, these sensitivity studies are reported here to study the effects of these changes on the policy objectives.

(i) Sensitivity Study (1) and (3):

The issue of energy security has dominated policy discussions in Australia for a decade. Consequently, one of the energy policy objectives has been the security of energy supply. It was stated in Chapter Three that because of the heavy dependence of Australia on imported oil, security of energy supply has synonymously been used with self sufficiency in oil. In Australia, the

1. Appendix G contains a description of the specification of and the data used in the 1989-90 AEPSOM.

objective of the security of energy supply or self-sufficiency of oil has been pursued by adopting policies such as diversification of energy supplies and energy conservation, specially oil (Department of Primary Industries and Energy [1988]).

However, the diversification of energy sources and energy conservation are only two policy options from a host of other policy strategies. These are: direct control of oil imports, suitable oil contracts, reserve standby capacity, international sharing arrangements among friendly countries, oil storage and fiscal and monetary policies designed for overall restructuring of the economy (Griffin and Steele, [1980]. Considerable controversies have developed regarding the relative efficacy and desirability of import controls and import tariffs¹. Because of the superior allocative effects of import tariffs over import controls, tariffs on imported oil have been considered to be an effective policy instrument for achieving oil self-sufficiency.

Therefore, tax on the importation of oil has been introduced into the set of policy options to study the effects of this policy instrument (Sensitivity Study (1)). It may be mentioned that in Australia, tax is not imposed on the importation of oil. So this sensitivity study was considered as crucial since it should reveal the implications of introducing a tax on the importation of petroleum.

1. A discussion on the alternative instruments of commercial policy and their relative effects in the domestic economy is covered in Ethier [1988]. A political economic perspective on this topic is provided in Ethier [1988] and in Todaro [1981]. In this study, only two instruments, import control and import tariff are covered since these are the widely used instruments applied to the importation of energy in the developed market economics.

The alternative policy instrument, direct control of oil imports, was also introduced into the Australian optimum policy system to compare the effects of this instrument (Sensitivity Study 3).

Effect: In the case of sensitivity study (1), the model solution suggests $+T \neq 0$ (Model solution 12). Compared to the base solution, this sensitivity study also shows an improvement in the optimum level. The policy objective function (2) had a lower value compared to the policy objective function (1). However, when a limit of the 1979-80 import level was imposed on the energy system (Sensitivity study (3)), a feasible solution to AEPSOM did not exist.

(ii) Sensitivity Study (2) and (6):

As optimum energy system and policy are clearly dependent on the relative and absolute scarcity of different energy resources (reflected in AEPSOM in the resource constraints), relaxation of the constraints of AEPSOM were introduced in various solutions. This was aimed at studying the effects of the constraints on both optimum energy system and policy. In one type of sensitivity studies, the demand and supply constraints were relaxed by 20% and 100% of the 1979-80 supplies respectively (Sensitivity Study 2). In another study, the demand RHS's were at the 1979-80 level, and supplies were increased by 100% of the 1979-80 level (Sensitivity Study 6).

Effects: In the case of sensitivity study (2), the optimum $+T \neq 0$, while $+T = 0$ in the case of sensitivity study (6). This implies that a goal improvement is possible in the situations reflected in sensitivity study (2), but not in the case of sensitivity study (6). It is worth mentioning that out of

all the model solutions, model solution 13 which is a study of sensitivity study (2) generated the lowest value for the policy objective function.

(iii) Sensitivity Study (4):

Developments in energy technologies, particularly in new and renewable technologies, which will result in reduced energy costs and increased energy supplies, make the energy industry competitive, diversify the sources of supplies, while increased technological efficiencies are considered to be an effective way to achieve the energy policy objectives, i.e., to solve energy problems. In view of this, some new technologies (stated before) were introduced in the 1979-80 AEPsOM to study how these new technologies affect the Australian energy system and policies.

Effects: The introduction of new technologies in the 1979-80 energy system has predicted an improved level of social goals. The optimum $\pi^* = 0$ implies the desirability of government intervention in the economy.

(iv) Sensitivity Study (5):

Controversies have circulated regarding the introduction of import parity pricing of domestic crude oil in Australia, particularly in its scope and time phasing. As efficient resource allocation is considered to be a problem of efficient pricing of resources (Griffin and Steele [1980] Chapter 2 and 3), should it be either in terms of domestic market mechanism or measured in international prices (a controversy to be discussed shortly), the effects of import parity pricing of domestic crude oil need to be understood. The Australian government had followed a policy of

phasing the introduction of import parity pricing by segregating off-shore and onshore oil. The study of the energy system and policy implications of the import parity pricing of all domestic oil has been the objective of this sensitivity analysis.

Effect: The introduction of the import parity pricing of crude oil did not provide any improvement in the optimum solution; the optimum $\pm T = 0$.

Actually the values of the policy objective functions (1) and (2) in this case were higher than the base model solution under existing $\pm T$.

(v) Sensitivity Study (7):

The base year AEPSOM was specified for 1979-80 (i.e., 1979-80 data were used). Since AEPSOM is a static model, AEPSOM was also specified for 1989-90 (for existing $\pm T$, Model No. 19; for optimum $\pm T$, Model No. 23). The algebraic description of the 1989-90 AEPSOM and the data used in it are reported in Appendix G.

The purpose of developing the 1989-90 AEPSOM was to study the future directions of the Australian energy sector and policies, and to compare the implications and prescriptions of the 1979-80-AEPSOM results with its results. This would, of course, provide some time dimensions in the analysis and formulations of optimum energy policies and can be regarded as safeguard against myopic suggestions of a static model.

Effects: The 1989-90 specification of AEPSOM shows also an improvement in the optimum solution through government intervention: $\pm T$ (i.e. optimum $\pm T \neq 0$).

(vi) Sensitivity Study (8)

Different weights were given to the two components of policy objective function (2).

It was stated in Chapter Three that one of the alternatives for attaching weights to different components of a multi-criteria objective function is to make the sum of the weights equal to 1 and to vary the weights within this restriction. In this study this approach was used. In the initial specification as well as in the results reported so far in Table 5.1 for policy objective function (2), the weights of the two components of the policy objective function were 1 and 1 (see note (ii) in Table 5.1). However, in sensitivity study (8) the weights were changed keeping the sum of weights equal to 1 and results were calculated for the policy objective function (2) (Table 5.10); solution Nos 2 to 6).

Effects: The results of these models including different weights showed that these alternative weights did not change the optimum solution to AEPSOM.

Table 5.10

Different Weights to the Two Parts of P.O.F.(2).

Model No. 5

Solution	Weights		Optimum Solution	
NO.	Part 1	Part 2	Θ Level	P.O.F.(2)
1	1.00	1.00	0.115	1671.58
2	0.20	0.80	0.115	4473.01
3	0.30	0.70	0.115	3260.61
4	0.40	0.60	0.115	2048.20
5	0.60	0.40	0.115	-376.62
6	0.70	0.30	0.115	-1589.03

(vii) Sensitivity Study (9):

In this study different weights were attached to the three policy target variables in policy objective function (1). Initial weights were 1,1, and 1 for three variables of the policy objective function: import of energy (Ie1), consumption of oil (CNo) and total consumption of energy (TCe). Two other sets of weights were also specified (2,1, and 1 ; 3,2, and 1) for determining the sensitivity of the model solution to the weights of the policy objective function. The results are reported in table 5.11. It is evident from the table that for all these types of weights, optimum solution was found at the same level of the parametric variation. In other words, different weights did not change the optimum solution to AEPSOM (optimum values of taxes, subsidies, prices, activities, etc). However, the optimum value of the policy objective function has changed in different cases because of different weights given to different variables. This leads us to conclude that the optimum solution to AEPSOM is not sensitive to

Table 5.11

Sensitivity of the Optimum Solution to Different
Weights in the Policy Objective Function

Model No. 5

Solution NO.	Weights - (P.O.F.(1))			Optimum Solution	
	Ie1	CNo	TCe	Level of θ	Values of P.O.F.(1) (PJ)
1	1	1	1	0.077	6733.70
2	2	1	1	0.077	7187.09
3	3	2	1	0.077	8968.74

different weights specified in AEPSOM and therefore the initially specified weight set can be considered acceptable.

5.5 RELIABILITY OF THE RESULTS: MODEL VALIDATION

In this section, the reliability of the results of the AEPSOM, and thus the reliability of the policies will be tested. For this purpose, the usual model validation criteria will be adopted.

It was stated in Chapter Two that model validation is one of the important steps of an optimization study. It refers to the correspondence of the model to the underlying processes/systems that are being modelled (Labys [1982]) or to the reliability of the model.

Hazell and Norton ([1986], p.269) have described model validation and its purposes as :

" Validation of model is a process that leads to (1) a numerical report of the models fidelity to the historical data, (2) improvements of the model as a consequence of imperfect validation, (3) a qualitative judgment on how reliable the model is for its stated purposes, and (4) a conclusion (preferably explicit) for the kinds of uses it should not be used for."

Several criteria are used to test the validation of a model (Labys [1982], Taha [1976] Hazell and Norton [1986]). In Chapter Two it was stated that there are three levels of validation tests: descriptive, analytical and experimental and there are three types of validation criteria which are applied to these three levels of validation tests (Kresge [1980]). The first type of criteria includes: (A.1) the attainment of the objectives of the model

(A.2) the appropriateness of the model structure (relates the first model evaluation criteria discussed in Chapter Two); (A.3) the plausibility of results (corresponds to criterion 3 in Chapter Two). The second type of criteria applied to the analytical level includes (B.1) the characteristics of the model solution, (B.2) the robustness of the results. The third type of criteria is related to the usability of the model and includes the following: (C.1) methodological tests related to: (C.1.a) model documentation, (C.1.b) cost and efficiency in model transfer and extension, and (C.2) tests related to model execution such as : (C.2.a) accuracy and efficiency of the execution, (C.2.b) cost of and efficiency in the software transfer and extension.

The above list contains almost a complete set of model validation criteria which can be used in modelling studies. It may, however, be mentioned that hardly ever all these criteria are used in a modelling study. Hazell and Norton ([1986], p.269) have stated the range of applications of these tests in the following form :

"Validation begins with a series of comparisons of model results with the reported actual values of the variables. Most often, simple comparisons are made..... However, more complete tests are possible and have been done ".

It should, however be noted that the validation tests, specially the statistical tests, of macro-econometric systems models (for examples of such models see Powell [1980]) and mathematical programming systems models are not exactly same (Labys [1982]).

In this study, a set of tests will be done, though not the complete set of tests.

A discussion on the applications of these model validation criteria to AEPSOM is provided below.

(A.1) Attainment of the Objectives of the Model: Greenberger and Richels ([1979], p.486) state:

"The validity of a model is most meaningfully examined in the context of purpose for which the model was constructed or to be used."

A judgment about the uses (of the results) of the model (to obtain enough information) to attain the stated modelling objectives is, therefore, necessary. AEPSOM has provided the information (Chapters Five and Six), necessary for studying the characteristics of the underlying policy and energy systems, and the formulation of a comprehensive multi-level energy plan.

(A.2) Appropriateness of Model Structure: Priori Justification About the Model Structure: By this criterion, a judgment is made on how good the model is in representing the underlying system to solve a problem or to meet the purposes for which the model is developed. In Chapter Two, it was argued that an MLP energy planning model is appropriate for multi-level energy planning. AEPSOM is formulated within the desired framework. Therefore, the results of the AEPSOM could be considered appropriate on a *priori* grounds.

(A.3) Plausibility of Results: The accuracy of the results of a model need to be checked. In this process, the relevance of the optimal solution provided by the model to the expected results or the reported actual values or the historical data set is verified. Several methods can be used for this purpose; (a) intuitive judgment, (b) comparison of results (i) with some past data or (ii) the ability to predict the future performance of the system or (iii) with similar studies; (c) statistical tests such as the mean

absolute percentage error or the mean squared error (Labys [1982], p.165); and (d) self auditing, third party auditing etc.

The statistical methods of auditing were not applied in this study. The tests A.3.b i and A.3.b.iii were not considered suitable for this study since these tests are not appropriate for normative models (like AEPsOM) of 'new' or significantly altered systems and major structural changes (Greenberger and Richels [1979], p. 486). A third party auditing could not be undertaken since only the author (first party) was involved in this study. The statistical tests (A.3.c) were not conducted as the differences between the actual and optimum values were not judged to be useful for validating AEPsOM for the reasons stated above. However, Criteria A.3.a and A.3.b were applied.

(a) Intuitive Judgment: The results of AEPsOM reported in this chapter seem to be in the expected directions. What AEPsOM has suggested is an ideal/optimum system/result. Policies are formulated to move the existing system as close as possible to the ideal system. From that point of view, AEPsOM results reflect the optimum situation in the energy sector which can only be attained by full implementation of the policies suggested by the model and to the extent that the real life energy sector characteristics are close to the ones assumed in AEPsOM and they remain unchanged as they were assumed in AEPsOM.

A note on the results of optimum activities is specially needed here which will put the AEPsOM results in proper perspective for energy planning studies: AEPsOM has selected some technologies from the available alternatives on the basis of the relative costs and prices of different technologies within the frame-

work as determined by (a) the technical characteristics and constraints of the energy sector, and (b) the underlying policy system in the energy sector as reflected in the energy policy objectives and instruments. The forms of these elements of energy sector technical and policy systems have influenced the AEPSOM solution.

The reasons for which some end-uses appeared to be zero are (a) the aggregated character of the model (see Appendix C), and (b) the non-inclusion of the non-zero lower bounds ($Z \geq Z$) on most of the end-uses of fuels in various sectors. It was discussed in Chapter Three that in linear programming energy sector models, some user defined constraints of the above form are specified to impose lower limits below which end-uses are restricted not to drop in the optimum solution. These limits reflect the underlying technical non-substitutability among different fuels at the end-use level (Julius, [1981]; Hall, [1983]) (some fuels in some sectors cannot be completely substituted by alternative fuels). This was done in MARKAL. The present author was informed by a MARKAL author (Musgrove, [1987]) that many user defined constraints, specifically fuel margins were specified in MARKAL to reduce this type of zero corner solutions to the end-uses.

In AEPSOM, constraints on the electricity uses in the different sectors to meet certain minimum electricity demands were specified (Chapter Three, Section 3.4.2). But inter-fuel substitution up to a high degree among other fuels (perfect substitutability in the neo-classical form) was allowed to meet the total energy demand in each sector. This might have produced a zero-corner type of optimum solution results for end-uses. This type of zero-corner solutions could be reduced by imposing more lower

bounds on the end-uses of fuels in various sectors. Greater possibility of inter-fuel substitution was allowed in AEPSOM to determine the eventual optimum end-use pattern indicating the directions of increases or decreases in the uses of energy resources compared to their present pattern in the economy, should sufficient time and perfect technical substitutability be allowed and exist. Again, this was for evolving an ideal (optimum) technological pattern, probably at the cost of some realism. Justification for this effort was discussed in Chapter Three, Section 3.4.2. It was also stated there that an energy model output should specially be discussed keeping the user-defined constraints in mind.

Since a compromise between the immediate/existing technical non-substitutability and the long run potential of inter-fuel substitutability was made in AEPSOM, the AEPSOM optimum end-use pattern should be viewed as the long term desired broad directions in the allocation of resources and technological developments in the energy sector.

Therefore, a normative view of the reported model results will be taken to formulate energy technology policies, as the optimum values and other AEPSOM results were generated for normative uses rather than positive/forecasting purposes.

(b) Comparison of Results: The criterion 3.b.iii is stated by Kresge ([1980], p. 185) as :

"... the plausibility of the results will be judged through comparison with the results produced by other related pieces of analysis".

The problem in applying this criterion in the present study is that no other MLP energy model exists in Australia. There-

fore, comparison of the results of the present model with the results of another similar model is not possible. But it can be stated that the results in this study are not unrealistic or non-operational in the context of the Australian energy sector. Since AEPSOM is a systems optimization study, the AEPSOM results indicate optimum systems (energy and energy policy systems). These optimum systems have been found to be different, at least partly, from the existing systems. This does not imply that model results are not plausible. It means that existing systems are not the optimum systems due to the market imperfections which prevent the existing system to attain the optimum system specified in the model (Norton and Schiefer [1980]).

However, the following test of the accuracy of results was undertaken in the present study. Accuracy of an MLP model can be tested by comparing the values of policy objective functions of the following three models:

- (A) A Central Control Policy (Model Nos 9 (and 10))
- (B) A behavioural model of the energy sector (Model Nos 7 and 8)
- (C) An MLO model of the energy sector (Model Nos 5 and 27).

The closer the results of (B) and (C) are to the result of (A), the more accurate the results of (B) and (C) can be considered to be.

To demonstrate the efficiency of MLP results in the present study, the optimum values of the policy objective function of AEPSOM (opt. $\pm T$) in the above three formulations have been reported in Table 5.12.

Table 5.12
Comparison of Different Model Solutions

Model Type & No.	A (9)	B (7)	C (5)	difference between A and B in % of A	difference between A and C in % of A
Value of P.O.F.(1)	5101.51	7031.68	6733.20	37.80	31.90

The values of the policy objective functions in Table 5.12 clearly demonstrate a higher value of the policy objective function suggested by the behavioural model. Compared with the central control (single level) policy model (Solution A) the multi-level programming and single level behavioural model solutions (Model C and Model B) show a deviation of 31.9% and 37.80% respectively. Other MLP models results (for example Model No.13) are even less deviated. The P.O.F.(1) value of Model No.13 is 4,680.03 which gives a deviation of only 8.2% from Model A(9). Therefore, the multi-level programming (C) model provides accurate (close to solution (A)) results¹.

An existing multi-level programming publication (Candler & Townsley [1982], p. 27) shows that a multi-level programming policy model provides better results than a single level mathematical programming model. It was found in that study that the value of the policy objective function calculated in the above procedure is deviated 31% from the expected 'optimum value'.

The true value of the policy objective function in a decentralized market economy with indirect government control provided by

1. By increasing the number of iteration, it is possible to find a solution very close to the global/true optimum solution (See the Conclusion Section, Chapter Four).

model C will be between the levels of value determined by models (A) and (B). As this is the case in the present study and since the optimum of the policy objective function of AEPSOM (Model No.5/Model C) is deviated by 31.9 % from the Central Control Policy Model, it may be concluded that AEPSOM has produced (approximate) optimum results for the Australian energy sector.

(B.1) Mathematical Properties of the Model Solutions

In Chapter Four it was stated that the PPS algorithm would provide an optimum solution to an MLP, although there would be no guarantee that the solution would be a unique global optimum. It was also mentioned that any plan (solution) improvements over base or original plan can be considered acceptable. As it has been observed that AEPSOM ($\pm T$) has generated results/plans which are improvement over the single-level model results or existing $\pm T$ case results, we may be content with the AEPSOM results (see Candler and Norton [1977] for justifications for such an argument).

In heuristic search methods like the PPS algorithm, the possibility of finding a global optimum increases if the number of searches is increased. Three units of parametric variations used in solving AEPSOM extended the search by the algorithm. More units could be tried. Since AEPSOM optimum results were found satisfactory, as discussed in the previous section, and further searches would have proved to be expensive (in terms of time and resources) without any definite possibility of obtaining better results (closer to the central control policy model results), no more searches were undertaken.

(B.2). Robustness of the Results

Results of the sensitivity analysis of AEPSOM (the optimum mix of $\pm T$ case) were reported in Table F.1. From Table F.1, it is revealed that the model solutions were not very sensitive to small changes such as the changes in the form of the introduction of tax on imported oil (Model No. 12), import parity pricing (Model No. 18) and in the coefficient of the policy objective function (Table 5.10 and 5.11).

(C.1). Methodological Tests:

With regard to the criteria (C.1), the relevant information about AEPSOM has been reported in Chapter Three. From the presentation of the AEPSOM set there, it can be argued that AEPSOM can easily be transferred and extended.

(C.2). Model Execution Related Tests:

The criteria (C.2) were discussed in Chapter Four. It was found that the PPS algorithm satisfied the relevant criteria.

To summarise, the tests A.3.b i and A.3.b.ii were not considered suitable for this study¹ since such tests were not appropriate for normative models, like AEPSOM, of 'new' or significantly altered systems (Greenberger and Richels [1979], P. 486). Since these tests were not suitable for the present study, more emphasis was given to other criteria such as A.1, A.2, A.3.a. Justification for an emphasis on these tests have been stated as (Greenberger and Richels

1. Non-availability of historical data and time constraints sometimes prohibit undertaking any validation tests of models (for example, Jaforullah [1988])

[1979], P. 486 - 487) follows:

"In general, historical validation is inappropriate for models of 'new' or significantly altered systems, or for proposed major structural changes. A more suitable form of validation in these cases is face (or content) validation, where the assessors subjectively evaluate the degree to which the models elements and structure correspond to their perceptions about the actual phenomena that the model is meant to represent."

All other criteria: B.1, B.2, C.1 and C.2 were, however, applied.

5.6 CONCLUSION

This Chapter has presented the results of AEPSOM. The major reported results include optimum values of the policy and behavioural objective functions, some elements of the energy policy system and energy system, taxes and subsidies, market prices, shadow prices and reduced costs.

These results have established some analytical aspects of the multi-level decision making process at the sectoral level in a market economy such as the need for the determination of the optimum level of policy intervention ($+T$), the possibility of the formulation of an improved plan by the government, and the conflicting interests of the government and private sector economic agents.

This Chapter has also examined the credibility of the sector programming model by applying a standard set of model validation criteria. In spite of the difficulties in applying these validation tests to an applied model and although no consensus on the exact procedures for validating has yet been reached in the profession (Hazell and Norton, [1986], p. 266), a wide range of tests were

performed to validate AEPsOM.

CHAPTER SIX

AN AUSTRALIAN OPTIMUM MULTI-LEVEL ENERGY PLAN

6.1 INTRODUCTION

Effects of the events in the international energy market have been considerable in Australia. Consequently, several energy policy problem areas have generated in the Australian economy. Some of these energy problem areas are: self-sufficiency in energy, appropriate pricing of energy, choice of a set of fiscal instruments, equitable distribution of the benefits created in the energy sector, conservation of energy, specially fossil fuels, finding measures appropriate for dealing with supply disturbances, optimum depletion of fossil fuels, determination of the exact boundary of energy policies etc.

To deal with these energy policy issues, there are several options available to the government for each type of issue. This necessitates the formulation of an energy plan by the Australian government so that the relevant issues and options are considered simultaneously and a resolution of these issues and options is possible. Formulation and implementation of such an energy plan will help solve energy problems of Australia.

These factors had provided the motivation of this study: the formulation of a comprehensive multi-level energy plan¹ consist-

1. Solution to AEPSOM has provided values of energy policy instruments as taxes and subsidies, prices, expenditure priorities for conservation, research and development, and education and information. The results also included values of the activities and

ing of (a) an optimum energy system, and (b) a set of energy policy instruments. This chapter deals with that essential task of the study, although within a framework which has the following limitations.

As the work for the study started in the early 1980s, the AEPSOM base year model was specified for the year 1979-80 using 1979-80 actual energy statistics. AEPSOM has, however, been developed for the year 1989-90 for projection purposes - incorporating 1989-90 projection data. As the 1989-90 data are available now, they have been incorporated in Table 5.8 and their energy system and policy implications are discussed below.

Because of the emphasis of the study on the specification of an MLP energy sector model and the application of the model results to formulate a set of energy policies for Australia, a comprehensive treatment on the numerous developments in the energy market and policy initiatives, during the period of 1980-1990 and beyond has not been provided in the thesis. The above limitation of the study could have been avoided if the thesis was dealing with a single or a small number of energy policy issue(s) (not all the energy sectoral issues and options) in which case a systematic and comprehensive account of the historical and analytical aspects of an energy policy issue could have been provided.

However, the post-1980 developments and changes in the Australian energy system (Sections 5.2.6. and 6.2.), taxation poli-

...Continued...

reduced costs which gave the necessary information to formulate energy depletion, exploration and development, and technology policies. In this chapter, the policy implications of the AEPSOM results will be studied to suggest a multi-level energy plan for Australia. Various energy policy problem areas will be discussed separately. Issues and options in each problem area will be highlighted and how AEPSOM results can resolve those issues will be discussed.

cies (Section 6.3.1), pricing policies (Section 6.3.2), energy conservation strategies (Section 6.3.5), energy technology strategies (Section 6.3.8), and the achievement of energy policy objectives (Section 6.4) are discussed below and have been related to the policy implications and conclusions drawn from the results.

It has been stated at several places in the thesis (Chapter Two, Chapter Three (pp. 66-67), and Appendix B) that the effects of relative prices on the allocation of resources and adjustments in the energy market can be specified in a mathematical programming model (Musgrave et al. [1983], p. 15). An integrated approach to the factors influencing the formulation of energy policies to achieve energy policy objectives will be given in Section 6.4.3. In addition, Sections 6.3.5, 6.3.6, 6.3.7 discusses the influences of relative prices in the implied energy policies.

However, the effects of relative prices are not as prominent in the structure of a mathematical programming model as it is in an econometric model (as in a CGE model with CES or translog functions (Chapter Two)). The effects of relative prices are not generally specified in a sophisticated and more realistic way in mathematical programming models (specially in MLP) due to computational problems associated with such models.

In addition to prices, there are many other factors (Musgrave et al. op. cit., p. 15) which influence the energy market and policy. Other factors which have influenced the choice of solutions in the study are discussed in Chapter Three (pp. 66-67), Chapter Five (pp. 206-208) and Chapter Six (pp. 218-219). The roles of relative prices and other non-price factors in the choice of technology have been stated by Musgrave et al. [1983, p.15] as

follows:

"The nature of a linear programming solution is such that when using minimum cost as the objective function, the 'cheapest' technology will be implemented until some constraint is reached. This may not accurately reflect the real world situation where relative prices will play an important role in the choice of competing technologies, but other factors may also be important. Consumers, for example, may choose a particular device for reasons of convenience, safety, or preference for some type of fuel. A new process entering the market-place will be unlikely to take over the entire available market before it has been fully proven. Moreover, lack of knowledge concerning the alternatives can be an important factor in limiting the market growth of technologies."

Therefore, in discussing the policy implications of the AEPSOM results, some of these factors will be considered along with relative prices in desirable proportions required for the developments of the policy implications. AEPSOM's choice of activities is dependent on the following factors, among others: price, technology, resource constraints, substitutability of inputs in energy production, distribution and end-uses, efficiency, budgetary considerations, and government policy objectives, instruments and constraints.

The structure of this chapter is as follows: The optimum Australian energy system specified by the AEPSOM results is reported and discussed in Section 6.2. The policy implications of the AEPSOM results are discussed in Section 6.3. An integration of the various types of policies is needed to formulate a comprehensive set of policies for the energy sector. An integrated comprehensive set of Australian energy policies is formulated in Section 6.4 while the conclusions are stated in Section 6.5.

6.2 AN OPTIMUM ENERGY SYSTEM PLAN

Different model solutions provided various numerical optimum energy systems for Australia. Numerical values of the flows of primary energy, secondary energy and end-uses of energy as well as various technologies, which are the components of the optimum energy systems, are shown in Table 5.8. The major characteristics of the technological pattern of AES implied by the AEPSOM results are discussed below. Intuitive justifications of these results were discussed in Chapter Five, Section 5.5.

On the energy supply side, imported crude oil (Ie_1) appears more attractive than domestic crude oil (R_2). Solar energy (R_7) was not found viable in 1979-80 although it appears viable in 1989-90.

In the area of energy conversion technologies, natural gas (x_3) for end-uses was not found viable in Model Solution 5 and 6 although its use for electricity production (E_1) was justified. Natural gas appears in Model No.13. For 1989-90, natural gas (x_3) use increased substantially to an amount of PJ 933.48 - which is much higher than the actual (PJ 437.0) for 1989-90.

The following end-uses were not chosen by AEPSOM Solution 5 for 1979-80: petroleum products (d_2) and natural gas (d_3) in the manufacturing industry sector, electricity (d_9) in the transport sector, and petroleum products (d_{11}), natural gas (d_{12}), biomass and solar energy (d_{13}) in the domestic and commercial sector. Results are the same in Model No.6 while in Model No.13 natural gas use in the manufacturing industry sector appears viable.

For 1989-90, the situation changes substantially. Some of the technologies which were not viable in the 1979-80 model solutions appear viable in the 1989-90 models, while some other 1979-80 viable technologies were not found viable in the 1989-90 models. For example, solar energy was not viable in 1979-80, however it was viable in 1989-90. In 1989-90, relatively, more use of natural gas was suggested by the Model unlike for 1979-80 when more coal use was evident. Biomass was not in the 1979-80 Model Solution, while it appeared in the 1989-90 solution.

Different combinations of end-uses of energy have been selected by different models depending on the assumptions made about the policy interventions, costs, technological and resources conditions and availability, time horizon etc. Table 5.8.A and 5.8.B for the years 1979-80 and 1989-90 reveal that the following end-uses were not selected by any of the five models:

- (i) petroleum products in the manufacturing industry sector,
- (ii) electricity in the transport sector,
- (iii) petroleum products in the 'domestic and other sectors.'

For the intuitive justifications of these end-use results of AEPSOM the following points may be noted (other points were discussed in Chapter Five):

- (i) Regarding end-uses in the manufacturing sector, as progressive reduction of the use of oil has been a major objective of Australian energy policy, substitution of petroleum products in different sectors by alternative fuels is a desirable policy outcome. These findings have also been established by the MARKAL model (Musgrove et al. [1983] pp. 82-83). A cost saving of 3.49 M\$/PJ through any improvement in technical efficiency can make the use of petroleum in the manufacturing sector viable. The major

competing fuels in the manufacturing sector will be different forms of coal (fluidised bed and conventional boilers), natural gas (conventional boiler) and wood and bagasse (boiler).

(ii) Electricity use in the transport sector has not been chosen by AEPSOM. One possible justification is that the relative technical convenience and economy of alternative fuels such as methanol and coal (Musgrove et al. [1983], pp. 82-83) have made electricity use in the transport sector a non-viable technology.

This result is consistent with MARKAL (Musgrove et al. [1983], pp. 82 - 83) forecasts for electricity use in the transport sector. The following transport sector's electricity uses (in peta joules) were predicted by MARKAL: 2.6 in 1980, and 3.5 in 1990. These figures were quite insignificant compared to the total energy-uses in the transport sector which were (in peta-joules) 799.1 in 1980 and 894.4 in 1990. If the transport sector was disaggregated in different transport modes (such as road, rail etc) in AEPSOM then the model would probably have selected some use of electricity (for further discussion on the aggregation issue in this study, see Section C.3. in Appendix C).

Technical improvements in the transport sector, specially in rail transports, which can reduce cost 48.53 M\$/PJ (Table 5.9.A) will make the use of electricity in the transport sector viable.

(iii) MARKAL predicted an oil-use of 55.5 (PJ) in the domestic and commercial sector in 1980, while this figure was predicted by MARKAL to be reduced to only 8.00 (PJ) in 1990.

6.3 OPTIMUM ENERGY POLICIES¹

Although the implications of all the reported model solutions were considered while formulating the set of policies, the results of Model No.5 were mainly adopted and analysed for the following policy studies.

6.3.1 Taxes and Subsidies

In a market economy like that of Australia the major forms of government instruments to control the energy sector are the fiscal instruments (taxes and subsidies). Per unit taxes and subsidies may be imposed to correct market failures due to external effects in production, conversion and end-uses and the presence of monopoly, so that the economic agents observe the desired marginal conditions for the efficient allocation of resources. Lump sum taxes and subsidies are effective in bringing about a desired income distribution (Musgrave [1959], Henderson and Quandt [1980]).

The specific objectives for which taxes and subsidies have been applied in the Australian energy sector are : conservation of energy, promotion of exploration, optimum depletion of energy, inter-fuel substitution and equity in income (Smith (ed.), [1979], Groenewegen [1984]).

Various forms of taxes which are generally used are ad valorem taxes, severance taxes, property taxes, company resource rent tax and capital gain tax (Webb and Ricketts [1980]). In Australia, a combination of these taxes in various degrees is in existence.

1.This section demonstrates the policy steering aspect of AEPSOM.

Several forms of subsidies either to the producers or to the consumers are also in existence : considering capital cost as a current cost for tax purposes, accelerated depreciation allowance, depletion allowance, exploration expenditure allowance and ad valorem sales subsidy (Webb and Ricketts [1980], Groenewegen [1984]).

The issues that have been discussed to formulate an efficient set of fiscal instruments in the Australian energy sector (Smith (ed.) [1979], Lloyd (ed.) [1984], Branon (ed.) [1975], Gruen and Hillman [1981]) are (A) the determination of the appropriate mix and rates of different taxes and subsidies, and (B) the suitability of the resource rent tax (defined below). The last issue has received serious academic and government considerations (Groenewegen [1984]) for several reasons: the need for the diffusion of windfall gains from energy explorations over the whole community, existence of several types of taxes and charges imposed by both commonwealth and state governments creating fiscal system management problems, and probably, over-taxation of mining energy. While the first issue is still being discussed, the government introduced resource rent tax, first by introducing it only to the offshore oil industry in 1983, then progressively to the whole oil industry.

Implications of the AEPSOM results in the context of these issues are discussed below.

(A) Regarding the first issue, AEPSOM results can be used to adequately address the issue. The optimum mix of taxes and subsi-

dies¹ suggested by AEPSOM² is reported in Table 5.5.A Table 5.5.B shows a comparison of the existing taxes and subsidies and the optimum mix of taxes and subsidies.

The supply side intervention by taxation is usually used as an instrument to change market prices so that they reflect the opportunity costs of various energy forms (for example, by internalizing external costs), and to bring about an efficient allocation of primary energy resources, and optimum intertemporal allocations of energy resources (optimum depletion of exhaustible resources) and encouragement for exploration activities. As noted before AEPSOM results have suggested the following supply side taxes and subsidies: taxes on domestic crude oil, imported crude oil, and subsidy on solar energy.

Demand side taxes (excise taxes) and subsidies are justified because of the existence of merit-want market failures (Musgrave [1959]). This type of market failure is caused by the 'irrational' or short sighted preference of consumers. In the energy market, merit want appears since it is argued that consumers are variational because they waste this scarce resource. Also, in the situation that a possibility of a trade embargo exists, excise taxes on various forms of energy, which are subject to a

1. It should be mentioned that the choice of $\pm T$ in this study has been determined by the criteria of attainment of the energy policy objectives and efficient allocation of (minimum cost) energy resources. Other criteria for determining a "good" tax system were not applied. Such criteria include equity in the distribution of income and tax burden, suitability for achieving economic stabilization objectives, easy administrability and understandability, imposition of minimum excess burden (Musgrave and Musgrave [1984], p. 225).

2. The plausibility of the suggested taxes and subsidies in the context of energy policy objective will be discussed in Section 6.4.

potential trade embargo can accommodate contingencies of such an embargo in the consumers' behaviour. Moreover, excise taxes on energy end-uses may cause inter-fuel substitution, and thus may help the development of cheap new and renewable energy.

AEPSOM results have suggested the following excise taxes or subsidies : taxes on coal and electricity in the manufacturing industry sector, on electricity in the transport sector, and on coal in the domestic and commercial sector; subsidies on none.

In addition, the model results have implied the following taxes or subsidies on energy conversion technologies: taxes on coal-burnt electricity, petroleum products and natural gas; subsidies on petroleum products and natural gas-burnt electricity¹, and coal (distribution).

(B) An important issue in energy economics is the determination of an appropriate taxation scheme for taxing economic rent (resource rent) generated in the energy sector because of the limited supplies of fossil fuels (excluding normal profit).

There are several alternative measures for taxing economic rent in the energy sector, such as company income taxes, competitive bidding and royalties, and progressive resource rent tax.

1. In 1989-90, a subsidy on electricity production from petroleum is suggested by the model. This result is the outcome of the existence of many factors in the energy sector (pp. 205-208). To meet the demand for electricity there was a need for more electricity production from oil compared to 1979-80 production, since the uses of coal in the manufacturing and domestic sectors were comparatively more attractive than the use of coal in electricity production (Table 5.6.A and 5.6.B). The supply of the increased electricity in the market would have been possible only through a subsidization of petroleum in electricity production. However, model results suggest that the amount of subsidy to petroleum in electricity production is smaller than the government revenue from the possible tax (suggested by the model) on the use of coal in the domestic sector, a technological alternative which required the subsidization of electricity from oil.

Every taxing scheme has its merits and demerits and in many cases a combination of some of them is suggested for taxing economic rent (Webb and Ricketts [1980], Marks [1986]).

However, resource rent tax (Smith [1979]) has very often been advocated because of its neutral effect on supply decisions and its effects on equity. The possible problems of the determination of the exact economic rent or surplus, and the adverse effects of the resource rent tax on exploration activities, have limited its application.

AEPSOM results have indicated taxes on various energy supplies, without any indication of what type of tax would be appropriate in these cases. The issue remains what would be the appropriate form of tax in these cases.

Since the selection of the right type of taxation to extract economic rent from producers depends on many economic and non-economic considerations, a combination of several taxes, probably of severance taxes (specific or ad valorem), royalties and resource rent tax, that would move the post-tax energy prices to the levels demonstrated in Table 5.6.A is suggested.

6.3.2 Pricing Policy

Price is used here as the quantity of money to be paid for exchanging one unit (PJ) of energy¹.

Determination of energy prices has been a crucial issue in

1. There are, however, other connotations of price such as an accounting unit and a measure of absolute value (Blaug [1985]). Price has been interpreted here as relative price, and therefore, other issues related to the definition and function of price have not been considered in formulating pricing policies.

energy policy analysis because of the influence of prices in efficient allocation of energy resources, public ownership of many energy industries, and the effect of prices on the depletion rate of exhaustible energy resources.

A general rule which is followed in the determination of the price of a particular good is that the price will cover (or will be based on) cost. But controversies exist regarding the concept of cost that should be used for pricing purposes. The two concepts of cost are : opportunity cost (opportunities or alternatives forgone in order to achieve something) and outlays (total money expenditure).

An example for determining energy prices in Australia on the basis of opportunity cost is the import parity pricing of domestic crude oil (i.e. setting the price of domestic oil equal to its next alternative-the price of imported oil). Arguments for determining the energy price equal to its international price (import price or export price) follow from the economic principle that efficiency in domestic production will be achieved when marginal cost of domestic production equals its international price (Little and Mirrlees [1974]). In spite of doubt about the rationale of this principle on the ground that the economic structure of a foreign country is different from the domestic country (which implies different relative price structures in the two countries), setting the price to its international price has been advocated in Australia not only for oil, but also for other forms of energy including coal, natural gas, and even electricity (Saddler [1981], Treasury [1984]).

Pricing of energy on the basis of outlays has two main principles: average cost pricing and marginal cost pricing. In the

average cost pricing method, which is primarily an accounting method, the price is set equal to the average cost of production.

The marginal cost pricing method, although the most powerful method and increasingly being practiced, yet the most often criticized one, can be formalised by adopting the following welfare maximizing model:

$$\begin{aligned} & \text{Max } \int_0^T \text{NB} \cdot \exp(-rt) \cdot dt \\ & \text{s.t.} \end{aligned} \quad (6.1)$$

$$K(t) \geq q(t) \geq 0$$

$$I(t) \geq i(t) \geq 0$$

$$\text{and } i(t) = K(t) + sK(t)$$

where

$$\text{NB} = \int_0^Q p(q,t) \cdot dq - c(q,k,t) - i(t)$$

T = time

p = consumers' willingness to pay for energy

q = energy output

c = production cost

K = capacity level

r = discount rate

i = investment rate

I = rate of capital depreciation

By applying Pontryagin's maximum principle, the following optimum price can be determined (see Munasinghe and Schramm [1983] pp 142 - 143 for its derivation):

$$\tilde{P}(t) = (\delta c / \delta q) - m_1 + m_2$$

where m_1 and m_2 are the new capacity and resources supply costs.

It is argued that marginal cost pricing can yield a welfare optimum since under this rule net social surplus will be maxi-

mized. Of course, this argument is valid in a perfectly competitive market situation and in the absence of significant externalities (economies or diseconomies).

The arguments against marginal cost pricing are also very powerful. The arguments are as follows:

(1) In the case of increasing returns to scale, marginal cost pricing will result in loss to the firm or industry.

(2) The marginal cost has no unique definition (Lewis, [1949]) since marginal cost will depend on the level of output. Therefore it cannot be used as a basis for pricing.

(3) Administration of marginal cost pricing rule is comparatively difficult (compared to accounting cost method).

(4) There may be multiple energy pricing policy objectives such as equity (interpersonal and interregional), and industrial development, in addition to the objective of efficient allocation of energy resources. In that case, marginal cost pricing will not be appropriate.

(5) If the marginal cost pricing principle is not met in all industries, practicing this rule in an industry may result in welfare loss rather than welfare gain (the second best theory¹, Lipsey and Lancaster [1956-57]).

In spite of the above objections, the marginal cost pricing principle has gained wide acceptance. However a compromised principle is practiced in real life, which may be stated as follows:

1. In spite of this objection from the theory of second best this study has adopted a partial equilibrium analysis of the energy sector for the reasons discussed in Chapter Two. Consequently, the principle of marginal cost pricing will be used for formulating energy pricing policy.

(a) set price equal to marginal cost

(b) make adjustment for equity, industrial development and other social - political considerations.

In Australia, the commonwealth government controls oil price. Electricity prices in the states are set by the state governments while prices of natural gas, and coal are determined by the providing industries. Several issues have dominated this area: whether the government should control energy prices in Australia or not; if government control is permitted what are the prices which should be controlled by the government and what principles would be followed in determining energy prices.

Several justifications have been put forward for government control of energy prices, particularly of oil prices, such as: prices can be used to take advantage of any monopoly position in the world energy market, prices should be fixed so that they will earn revenue for the government, the users will pay for the infrastructure development and ensure self-sufficiency in energy, specially in oil (Edwards [1983], Marks [1986]).

While the marginal cost principle is adopted in determining electricity prices by the state governments, setting energy prices (oil, natural gas, electricity, coal) at their world levels has been advocated (Treasury [1984]) and implemented (for example import parity prices of domestic crude oil (Marks [1986])). Pricing on the basis of the shadow prices of an energy sector programming model has also been advocated and illustrated (Musgrove et al. [1983]). Therefore, different approaches to energy pricing are adopted for pricing different types of energy in

Australia¹.

The guidelines AEPsOM results provide in resolving the above three energy pricing issues are discussed below:

(a) The present study has demonstrated the desirability of government intervention in the energy sector to achieve the energy policy objectives. These interventions include the imposition of taxes and subsidies implying the indirect control of energy prices.

(b) As taxes and subsidies influence price, the energy prices which should be under government influence have been shown in Table 5.6. The model results suggest that, at the supply level, the prices of crude oil and imported oil, at the secondary energy level, those of coal burnt electricity, petroleum products, and natural gas, and at the end-use level, those of coal and electricity in the manufacturing sector, electricity in the transport sector, coal in the domestic and commercial sector, should increase in the market. The model results also suggest that the prices of solar energy, natural gas burnt electricity, coal, and electricity from petroleum products should decrease.

(c) Following the dominating view that the energy price should reflect the opportunity cost to ensure efficient allocation of energy resources in an economy, it can be argued that prices of domestic energy, specially the energy forms which are traded, should be equal to their international prices. This suggests that the energy prices should be controlled or influenced by the government to move these prices to their international levels, in

1. The same practice will be followed in this study.

the case that domestic market prices are different from the international prices - (either by direct price control or by imposing taxes or subsidies).

The model results, however, support indirect control of energy prices through taxes and subsidies (deregulation of prices) rather than direct control of them. This is preferred, even above the administration of import parity pricing of crude oil by the government. This is evident from the sensitivity study (5), which demonstrated that the introduction of import parity price in the model did not improve the value of the policy objective function, instead it diminished that level. But, if energy price is deregulated there may be a reduction in government revenue (Marks, op. cit.) and it would be difficult to ensure that resource rents accrue to Australians which is an important motivation for price control in Australia as government may have to resort to some type of crude oil levy. What is needed is a policy package which would result in deregulation and at the same time ensure accruing resource rents to Australians.

It is important to note that the optimum market price for domestic crude oil (1979-80), suggested by the model, is \$M 5.23/PJ which is close to its import parity price of \$M 5.30/PJ. These results suggest that the energy policy objectives including efficiency in the energy resource allocation in Australia can be achieved by choosing an appropriate or politically acceptable form of energy taxation (alternatives are discussed above). This also implies that the administration of an import parity pricing policy by the government may not be necessary. A relevant tax can be imposed on the domestic crude oil and the market be left to adjust its price to somewhere close or equal to its import parity price.

The outcomes of this strategy would be the determination of the price of domestic crude oil equal or close to its import parity price (through the market by imposing tax without direct control by the government), and the guarantee that all resources rents accrue to Australians. This strategy has the advantage that this would help achieve the objectives of price control such as the earning of government revenue etc. mentioned above, in addition to the equity effects of such a policy).

The possible justification for this approach to oil pricing may be derived from the arguments that when there is the possibility of an oil embargo or supply uncertainty, this external cost is not internalized in the discretionary behaviour of economic agents. In the situation of such a trade embargo, there will be costs contingent in the supplies of energy. And the policy implication of this situation has been stated by Gruen and Hillman ([1981], P 114) as :

" As the adjustment costs are associated with the need to change the composition of domestic output, the theory of optimal policy indicates the form of intervention should aim directly at product, that is, a producer tax or subsidy".

Also as one of the energy policy objectives in Australia has been the reduction of the use of oil (due to any anticipated trade embargo), raising the price of domestic crude oil somewhere close to its international level through intervention in the product market by taxation can be the optimal policy for Australia.

For similar reasons (i.e., in the context of energy problems and energy policy objectives) electricity prices in 1979-80 suggested by the model solution (6.00 \$M/PJ) can be considered optimum prices for electricity.

6.3.3 Depletion Policy

Depletion policy relates to the issue of optimum resource use over time (the rate at which resources should be depleted). This is a problem of intertemporal allocation of exhaustible resources.

This policy issue is very important in view of the finite stock of exhaustible energy resources and because of the fact that any use today will leave less for future generations (the question of equity in intergenerational distribution of natural resources).

In Australia, this issue of optimum depletion policy has been discussed (Saddler [1981], Gruen and Hillman [1981]). However, no definite optimum depletion rate has been prescribed, neither has the present depletion rate(s) been evaluated.

Desirability of a depletion policy in the Australian context has been discussed by referring to the existing market form in the energy supply sector (Gruen and Hillman [1981]) i.e. by relating to the question whether the Australian energy suppliers are competitive or monopolistic. The argument is that if the energy supply market is monopolistic, then government policy is desirable, since a monopolistic market does not deplete resources at a social optimum rate. It may, of course, be necessary to mention that such a straight forward generalization of monopolistic elements in the market and depletion policy intervention is not possible, since competitive and monopolistic firms appear to be over conservationist or under conservationist depletors, depending on demand, price, and supply related conditions (Howe [1979]).

The AEPsOM does not directly address the issue of optimum depletion rate, but the result of the model can be used to provide some guidelines for an energy depletion policy in Australia. A comparison of the required energy supplies in 1979-80 and 1989-90

suggested by the model can be an indication of the rate of depletion of various types of energy.

If the 1979-80 actual supplies of coal, crude oil and natural gas are compared with their optimum values chosen by Model Solution 13 (in this case there was the possibility of flexibility in the supply of these energy forms), then it appears that the optimum result suggests more supplies (depletion) of coal and natural gas and less supplies of crude oil than their actual uses in 1979-80. These results are consistent with the reserve position of these fossil fuels in Australia.

6.3.4 Exploration Policy

Exploration plays a significant role in the allocation of exhaustible resources over time. A finite stock of resources can be extended by supplementing the stock through exploration activities.

AEPSOM structure implies that if the resource supply constraints in AEPSOM are binding, that will be an indication for positive shadow prices. And if these supply constraints are relaxed, it would result in reduced energy system cost. Numerically the Model Solution 13 where the supply constraints are relaxed by 20 % has provided the minimum value of the policy objective function from all the solutions (Table 5.1.). The results show the importance of an increased energy supply in the Australian energy system. Increased energy supply on a sustained basis is possible through further exploration activities.

To accelerate exploration activities, a government can follow several strategies:

- (a) subsidize exploration activities by accelerated tax

allowances for exploration expenditure, immediate or accelerated exploration expenditure write off etc., and

(b) direct involvement in exploration, possibly through an exploration company. Because of moral issues related to providing subsidies to the private sector companies and because of the common property nature of exploration activities, sometimes government participation in the exploration activities is suggested (Saddler, [1981]). However, as such a policy is not consistent with the political strategies of current governments in power, the policy can not be implemented.

Therefore, the encouragement of exploration activities of the private sector through various fiscal, pricing and legislative measures is recommended.

6.3.5 Conservation Policy

The objective of energy conservation has been a focal point of discussion in recent political economics (Eichner, [1979]). Despite the political economic implications, energy conservation has some technical dimensions.

A whole range of energy conservation instruments can be adopted to achieve the conservation objective of energy policies. The strategy of conservation programmes is to choose a level of consumption of energy and energy mixes to maximize social welfare by eliminating waste and low welfare uses.

The pricing methods are adopted to influence the consumers' and producers' decisions to allocate funds for the energy budget. The pricing methods include price fixation and control, and taxes on fuels (Btu taxes) and energy using equipment.

The non-price methods of conservation include direct quantity

rationing, instituting fuel efficiency standards such as setting minimum mileage standards for new vehicles and standards for residential insulation and energy-use efficiency, expenditure for research and development, and education and information.

In Australia, an active energy conservation programme has been pursued since the beginning of energy policy initiatives. However, due considerations have not been given to the social desirability and welfare implications of these programmes (ESCAP [1979], Department of National Development [1979], Endersbee et al. [1980], Department of Primary Industries and Energy [1988]).

The Australian government has adopted the following policies to ensure energy conservation: (1) control or influence energy prices to reflect their long run costs, (2) taxes and subsidies to increase efficient and non-oil energy use, (3) increase energy use efficiency in the industry, commerce and transport sectors by improved 'housekeeping', modifications to existing operations and improved maintenance of existing energy systems, and by research and development, demonstration, advisory and legislative measures for an increasing introduction of new efficient technologies.

In this study, the proportions of shadow prices in Table 5.7.B. indicate the transport sector to be the major area for conservation, followed by electricity demands in different sectors. This result is consistent with the situation in the energy sector in Australia where the transport sector is the major user of liquid fuel which is the scarcest energy resource in the economy.

This emphasis in the area of conservation indicated by shadow prices is also supported by the other AEPsOM results: pricing or taxes and subsidies. The model results (Table 5.5.B) have suggested tax on the petroleum product use in the transport sector (tax on

d₈). This is consistent with the present energy pricing policy, as stated above, in which energy price influence through taxes or subsidies is suggested to reduce oil use.

Therefore, it can be argued that the conservation of oil in the transport sector by an excise tax (which will internalize the adjustment cost of oil disruption) and other technological changes and improvements (such as the use of methanol (suggested by the model)) is clearly the priority area in energy conservation in Australia. Since other shadow prices were not zero, the model results also suggested conservation programmes in other sectors of the economy. Endersbee et al. [1980] has identified the major conservation measures and technologies in all sectors of the Australian economy. Measures suggested in Endersbee et al. [1980] can be adopted in Australia.

Historically, conservation programmes in Australia have passed through various phases with initial emphasis on public awareness, subsequently by awareness of the industrial and commercial users, and the transport sector (Marks, [1986]). The Government has realized that the conservation in the transport sector is a vital area for conservation of energy in Australia. This is also a policy strategy suggested by AEPsOM.

6.3.6 Education and Information Policy

In spite of the controversy on the effectiveness of public policies in the form of education and information in energy management, historical experiences show that these policies can be quite effective. In many national emergencies, such as war, public policies in the form of education and information may be more effective than economic policies such as taxes, subsidies, control

of money supply etc. (Griffin and Steele [1980]).

In the energy sector, these policies are considered to be effective because of :

(a) the popular appeals of energy problems, and

(b) ignorance on the part of the general public about the role they can play in solving the energy problem through better management of energy.

Education and information policies are designed to increase community-wide understanding of the energy problem so that the general public will adopt methods for better management of the energy supply, its production and its end-uses and thus conserve energy.

In Australia, an emphasis has been given to education and information policy. Programmes have been undertaken in the form of publicity campaigns, conferences, posters, etc.

AEPSOM priorities for education and information policies are indicated by the proportions of shadow prices in Table 5.7. For the obvious reason of liquid fuel security in the Australian context, the community should be made aware of this problem, specially about the possibility and methods for conservation of liquid fuel in the different sectors of the economy. This emphasis is reflected by the highest proportion of shadow prices related to the energy demand constraints in Table 5.7.A. AEPSOM results also suggest education and information priorities in the conversion technology area (the second highest proportion of shadow prices for the intermediate balance constraint).

This highest priority for education and information activities for energy conservation is consistent with the Australian energy policies. The relative priorities in education and information

policies as suggested by the AEPSOM results should also be incorporated in Australian energy policies.

6.3.7 Research and Development Policy

Both basic research (without commercial objective) and applied research and development (turning research into a practical output or process) are vital to modern industrial development because of their effects on innovation, an engine of industrial development (Schumpeter [1934]).

The question has frequently been debated: why should the government undertake research and development work? Since research and development work has substantial externalities i.e. one firm's findings will benefit other firms and the social rate of return for research and development is higher than its rate of return in the private sector, government undertaking of research and development is considered to be justified.

Research and development in the energy sector have been geared in the past towards an increasing energy supply and inter fuel competitiveness through reduction in the cost of production of energy. However, a recent shift in the emphasis is noticeable with more concentration of efforts in the areas of energy conservation and increasing efficiency of new energy sources to substitute fossil fuel. In other words, the energy research and development programme is being designed to increase energy production (by finding more energy deposits and extracting existing reserves more efficiently), increase efficiency in the energy supply, its conversion and its end-uses and reduce energy use in the economy.

In Australia, there has been doubt whether Australia will pursue an energy research and development programme, substantial

in size, on its own, or buy the results from other developed countries like the U.S.A. Japan and the U.K. However, the Australian governments had an active research and development programme to develop expertise in the important technologies, and to stimulate research in the technologies appropriate for Australia in terms of its resource base and export prospects. The government's research and development programme also emphasizes the involvement in international research programmes and the study of the social, legal, and institutional aspects of energy sector programmes to find the appropriate strategies to develop the energy sector (Department of National Development, [1979]).

AEPSOM results suggest that priority for research and development for energy conservation technologies and strategies, in comparison with other areas such as supply expansion and conversion technologies, is desirable (highest shadow price proportion for the energy demand constraints in Table 5.7.A.). The base model solutions and sensitivity studies indicate this emphasis in policy. These results are also consistent with existing policy strategies in Australia.

It has been mentioned above that although higher emphasis in the research and development policy was generally given in the past to energy conversion technologies such as the technologies for synthetic oil production. However, a shift in emphasis towards energy conservation as suggested by AEPSOM results is desirable. This is also officially being recognised. This will be evident from the shift in the government research and development policy emphasis towards conservation (Department of Resources and Energy, [1985], chapter 11). However, AEPSOM results also imply higher priorities for research and development in conversion technologies

(the second highest proportion of shadow prices for the intermediate balance equations).

Research and development in the conservation area may be aimed at

(a) finding new technologies¹

(b) institutional development for education and information to popularize conservation programmes.

In the energy conversion area, research and development activities will be directed towards development of fuel-efficient and economic conversion technologies using less and less liquid fuels.

6.3.8 Energy Technology Policy

A choice of an appropriate energy technology policy has several dimensions:

(a) determination of appropriate factor proportions in the energy supply, production and end-use techniques (Sen [1968]),

(b) determination of the appropriate size and nature of forms of industry (centralized or decentralized/soft nature of the energy system) (Meadows et al. [1972]), and

(c) selection of an efficient energy system i.e. choice of a mix of appropriate energy forms, processes or techniques (Griffin and Steele [1980]) that can supply the energy required in the economy at minimum cost.

1. Some of the areas where research and development activities can be undertaken are : increasing efficiency of single energy processes, promotion of co-generation of electricity and heat, possibility for improvement in energy husbandry, introduction of increased industrial energy recovery etc. (Endesbee et al. [1980], Harder [1982]).

Resolution of these issues, for the formulation of an appropriate energy technology policy is important. The approach adopted here to determine an optimum technology in the energy sector is that the market should determine such a system, which is of course, subject to government interventions.

Resolution of these issues need deliberate government policy formulation, mainly to provide information to the private sector. The purpose of providing information about energy technologies to the private sector is to influence expectations in the energy market to achieve the socially desired allocation of resources (static and intertemporal). This is so because the future energy market does not exist and the choice of appropriate energy technology policy involves the determination of adoption of some forms of energy technology which are not in the present market.

For the future sustainable energy system, the International Institute for Applied System Analysis has predicted a gradual transitionary process through various stages (Häfele [1981]). First stage : from now up to 2030 - a transition from the present carbon-based energy system to a different carbon based energy system characterized by a short supply of fossil fuels but a gradual market penetration of coal gasification and liquefaction technologies and a considerable build-up of nuclear and solar power. Second stage : after 2030 - in this stage hydrogen will become the dominant energy form which will result in what is called the hydrogen economy.

Although the future is not well known, it is for sure that the energy system is in transition. The whole inventory of new and renewable energy technologies are being considered for adoption in the near future. Some of these technologies are the following

:liquid and gaseous fuel conversion from coal and oil shale, nuclear energy (burner, breeder and fusion reactors), solar energy (direct use, solar cells and solar panel), wind energy, ocean energy (tidal and wave), biogas, geothermal energy, combined cycles in electric power generation (magnetohydrodynamics, thermionics and potassium turbines), and hydrogen as source of energy.

In Australia, public policy has clearly recognised the fact that new and renewable technologies will be making an increasing contribution to the Australian energy sector. The government, in association with the private sector, is providing funds for research and development, and for demonstration of new and renewable energy. Relative emphasis has been given to, and optimism has been expressed about the potential market penetration of solar energy and liquefaction and gasification of coal in the near future.

In the previous chapter, the optimum technological pattern in the Australian energy sector as reflected by the optimum selection of activities, was shown in Table 5.8. Some of the energy technology policies implied by the optimum energy system determined by AEPSOM are as follows:

(1) Increased market penetration of some renewable energy (solar energy, methanol and biomass) over time is desirable. AEPSOM results clearly support the Australian energy technological strategy of increased market penetration of new and renewable energy (such as solar, biomass and methanol). Although the synthetic fuel production is not suggested as viable, the policy implication of this result would be to direct more research and development in this area to reduce cost and develop more efficient techniques. The reduced cost (Table 5.9.B) of the activity repre-

senting synthetic oil production from coal indicates the magnitude of cost saving necessary for penetration of the market by this technology (M\$/PJ 11 to 13). Actions should be pursued to achieve this cost saving.

(2) Regarding the issue of self-sufficiency in oil to-day or tomorrow by suggesting a gradual adjustment in the system through inter-fuel substitution, conservation etc. is required. This will help AES for smooth transition to the post-oil era.

(3) Progressively more uses of natural gas and coal, specially in the manufacturing industry, and domestic and commercial sectors, in comparison with the use of other conventional energy are necessary.

(4) Eventual complete import independence is possible and, therefore, should be identified as a target of energy policies.

(5) Gradual reduction in the use of petroleum products, specially in the manufacturing industry sector is needed.

(6) As the production of synthetic oil from coal was not found viable, efforts should be directed to reduce the cost of this process so that the technology penetrates the market. Some strategies for cost saving would be to consider all the alternative coal liquefaction processes such as Fischer-Tropsch, SRC2, Flash Pyrolysis, Exxon Donor Solvent (Musgrove et al. [1981]). A reduction in coal price may also foster market viability of local liquefaction technologies.

A comparison of the prices/costs (Table 5.6.A) of the fuels and technologies suggested by the model results will reveal that the model selection of fuels and technologies has been based on their relative prices (other factors were stated in Section 6.1). The selection of the technological policy implication No. (1)

above has been influenced in the model solution by the fact that prices of solar energy (0.04 m\$/PJ) and biomass (1.18 m\$/PJ) at the supply level are lower than other marginally competing energy forms such as domestic crude oil (5.24 m\$/PJ) and hydro-electricity (19.27 m\$/PJ). The policy suggestion No. (3) has been influenced by the fact that coal and natural gas are cheaper than petroleum products and electricity in the two sectors mentioned above. For justifying the policy strategy No. (5), it can be mentioned that petroleum products are certainly more expensive in the manufacturing industry, agricultural and domestic and commercial sectors compared to other fuels used in these sectors. Regarding policy suggestion No. (6), it can be argued that coal conversion technologies are still expensive. The assumed cost for the conversion of coal to oil (see Table G.3) is 15.67 m\$/PJ. If the costs at the end-users' level are considered, this technology would appear to be more expensive compared to other alternatives.

The energy sector, being a dynamic and innovative sector in the economy, has experienced technological changes involving inter-fuel substitution, conservation and development of new and renewable energy technologies during the modelling period. The 1989-90 actual energy figures imply the following changes/developments (Jones et al. [1991]), among others, to the 1979-80 AES: increased use of solar energy and biomass, increased use of natural gas, reduced use of petroleum products in the manufacturing industry sector, and almost the same level of oil import. A similar technological pattern has also been implied by the AEPsOM results (discussed above). The 1989-90 actual energy supply, production and end-uses figures shown in Table 5.8.B are, therefore, consistent with the technological pattern suggested by

AEPSOM.

6.4 AN ENERGY POLICY PLAN FOR AUSTRALIA

The discussion of each energy policy separately has prepared the background for presenting a comprehensive set of integrated energy policies. In this Section such a set of energy policies for Australia will be prescribed.

6.4.1 Australian Energy Policy Objectives

In spite of recent formalization of Australian energy policy activities, the objectives of Australian Energy policies have taken a distinct shape by this time. The energy policy objectives which are commonly found in most of the official government documents and academic work and the ones which were stated in Chapter Three are as follows: security of energy supply/import independence, conservation of energy, specially oil, efficient allocation of energy resources and equity in income and uses of resources in the energy sector.

6.4.2 A Set of Optimum Energy Policy Instruments and Strategies

Debate on the determination of a set of energy policies is getting serious, and the need for resolving the controversial issues in the Australian energy sector is becoming increasingly pressing. The following section summarizes the energy policy implications of the AEPSOM by providing some empirical evidence in resolving the existing controversies in the energy sector an

area characterized by the existence of conflicts and non-compatibilities in issues and options.

(1) Pricing Policy: AEPsOM results have clearly demonstrated the need for changes in the relative price structure in the energy sector, although the model suggests deregulation of the energy market.

(2) Taxes and Subsidies: AEPsOM results also indicated the need for rearrangement of fiscal instruments in the energy sector. Taxation of 4.63 % of cost of domestic crude oil is possible by pursuing a package of fiscal instruments consisting of resource rent tax, royalties and competitive bidding. Import duty on imported crude is necessary. Some other excise taxes and subsidies will complete the energy sector fiscal instruments.

(3) Depletion Policy: Although AEPsOM results do not directly provide evidence to formulate an energy depletion policy according to the principle suggested by the optimum depletion model presented above, they do imply a higher rate of extraction of coal and natural gas and lower rate for crude oil compared to their present rates.

(4) Exploration Policy: An active government exploration policy, to be pursued through fiscal instruments, will help increase reserves of energy resources and thus will make the country more energy import independent.

(5) Conservation Policy: In view of the scarcity of liquid fuels and the problems related to their import, highest priority to the conservation activities in the transport sector followed by the priorities in the agriculture and manufacturing industry sectors will appear to be a rational prioritization of the conservation policy in Australia.

(6) Education and Information Policy: As the lack of information is a source of market failure in the energy sector, dissemination of information about energy problems, technologies and prospects, specially about conservation measures, should be one of the strategies within the government energy policies.

(7) Research and Development Policy: As a market may fail to allocate socially desirable resources for research and development, government research and development activities directed towards energy conservation prospects can play an important role.

(8) Energy Technology Policies: In addition the need for accelerated recovery from existing non-oil fossil fuel reserves, the prospects for progressive reduction of the use of petroleum products and the market penetration of renewable energy should be stressed in government's energy policies. From the potential inventory of Australian energy resources and technologies, the exploration of the possibilities of cost savings in new technologies, specifically in producing liquid fuel from coal (and natural gas) should be given priority.

6.4.3. The Post-1980 Developments and the Evaluation of the Suggested Policies

The following discussion will conclude the presentation of the policy implications of AEPsOM by highlighting the effectiveness of the suggested policies to achieve the desired objectives in the context of historical developments in the energy sector.

(1) Security of Energy Supply/Self-sufficiency in Liquid Fuels.

Historical energy figures show that energy self-sufficiency has increased in Australia over the period of 1979-80 to 1989-90.

In 1979-80, oil import was 50% of the total domestic production of oil, while it is 38% in 1989-90, which is a 12% reduction in oil import.

In spite of various interpretations of the meaning and implications of security of energy supply, in the Australian context, it has the connotation of self-sufficiency in liquid fuels. An optimum set of policies to deal with this externality consists of: optimum pricing, taxes and subsidies, conservation of energy, specially liquid fuels, increasing the production of domestic crude oil, import control adjustments in the economy through macro-economic policies to reduce dependence on the imported fuels, and emergency measures including reserve standby capacity, oil storage, international sharing agreement's and diversification of import sources (Griffin and Steele, [1980]).

The policy prescriptions of AEPsOM contain a selected set of instruments and strategies, which are consistent with each other and that can achieve the objective of energy security/self-sufficiency in liquid fuels. Raising the price of domestic crude oil equal or close to its import price has made the domestic oil price competitive and thus, has reduced unnecessary wastage and uses of oil. This can also be done by including a risk premium (due to the possibility of oil embargo) with the price of domestic crude oil. Since the imported price of oil as it is in the market does not include the externality of the social cost of an oil embargo, a tariff on the imported oil, as suggested by AEPsOM, can add an adequate security premium to the market price (Griffin and Steele, [1980], p. 346). AEPsOM has rejected direct import control as the sensitivity study with a constraint on the imported oil (sensitivity study no.3) produced a non-feasible solution.

Other taxes and subsidies are also directed towards a reallocation of energy resources to reduce import dependency. Relatively slow extraction of oil will provide its future security. Conservation of oil in the transport sector, encouragement of further exploration of oil, publicity of energy information, research and development activities for oil conservation and cost savings in new technologies, and methanol use - energy policy strategies suggested by AEPSOM - will also make the economy more self-reliant in liquid fuels. As AEPSOM does not address emergency energy policy issues, the emergency measures stated before may also be adopted in conjunction with other policies implied by AEPSOM.

(2) Conservation of Energy, Specifically of Oil.

From the observation of historical data it appears that although energy intensity in the Australian economy had declined over the period of 1979-80 to 1985-86, it has remained almost constant for the period 1985-1986 (Jones et al. [1991]). From Table 5.8 it will also appear that the actual total energy consumption in 1989-90 is more than its forecast made earlier. This means that energy has not been conserved much in recent years. Jones et. al. (op. cit., p.37) have stated it as follows:

"Australian energy consumption has grown strongly in recent years, and this trend is expected to continue in the medium term."

The possible reasons for this may be the developments in the international energy markets, especially a reduction in oil price and probably a slower response of the economy to energy conservation programmes and policies pursued by the Government during this period.

Several policy alternatives are available to achieve this

energy policy objective, such as: fuel taxes and subsidies, taxes and subsidies on equipment, efficiency standard, development of fuel efficient energy supply, conversion and end-use technologies, public exhortation, influencing the rate of depletion of scarce fuels by taxes and subsidies, finding the appropriate substitutes of fuels of limited supply and direct quantity rationing (Griffin and Steele, [1980]).

AEPSOM has selected a set of policies which will help achieve the conservation objective in Australia. Taxes on the fuel supplies and subsidies on non-oil equipment/end-uses are appropriate measures. The relative price structure of various fuels indicated by AEPSOM is favourable for conservation, since the model has predicted a rise in the prices of those fuels which should be conserved. AEPSOM has also suggested a specific nature of other conservation policy measures such as: slower depletion of oil, education and information policies, specially for conservation programmes, development of new technologies (solar and substitute technologies (methanol)). The adjustments in Australian energy policies implied by the above strategies will help achieving energy conservation.

(3) Efficient Allocation and Utilization of Energy Resources.

It is often argued that the problem of efficient allocation of resources is essentially a rational pricing (static or dynamic) problem (Griffin and Steele [1980]). This argument seems to have extreme neo-classical bias, and may not hold true in an economy with fixed or less flexible prices and wages (output and input prices). Therefore, supplementary policies to pricing policies are necessary.

AEPSOM has formulated a set of energy prices which will reallocate energy resources in the socially desirable directions. Other policies, such as the previously mentioned taxes and subsidies, conservation programmes, and development of new technologies will also help to supplement and implement the pricing policies implied by the model.

It may, however, be mentioned that the principles of pricing policy formulation in this study have been of the second-best type. It means that instead of determining the best (pricing) policy in a single fuel market, the model has determined a set of second-best energy prices by considering the externalities in all the fuel markets.

(4) Equity in the Ownership/Uses of Energy Resources.

In Chapter Three, the position taken in this study regarding the equity objective was stated. Following the dominating view about the equity objective in the energy sector, this study adopted the approach that the equity policy should be studied separately from the efficiency related study after the efficiency considerations have been dealt with¹. Therefore, the main emphasis of this study has been on the efficient (socially desirable) allocation and utilization of energy resources.

It may, however, be mentioned that the prices, taxes and subsi-

1. Many government policy interventions, specially taxes and subsidies, in the economy may affect existing pattern of ownership of wealth and factor endowments, and the supply of factors, and thus the existing pattern of distribution of wealth and income. Adjustments in the pattern of distribution of income is possible by suitably chosen tax, expenditure and income policies which may involve an efficiency loss. This fundamental contradiction in public policies in a market economy needs careful considerations in formulating an equity policy in the Australian energy sector.

dies, depletion policy and technology policy formulated by AEPSOM will have equity implications. However the equity implications of the AEPSOM results may be analysed in further studies and appropriate policy instruments such as a system of income transfers and taxes, social security or minimum income schemes, inheritance laws etc. (Groenewegen [1984], Webb and Ricketts, [1980], pp. 108-109) can be derived in that study. This approach is certainly different from that of Graaff who stated 'that tinkering with the price mechanism may be considered one of the more feasible and satisfactory ways of attaining what ever distribution of income and wealth is desired by the society' (Graaff [1957]). Recent developments in welfare economics in the determination of optimum equity in income and wealth (Blaug [1985]) may be helpful in formulating the equity policy in the energy sector.

6.5 CONCLUSION

The energy policy studies pursued in this chapter have demonstrated the application of an MLO model to formulate a multi-level energy plan. AEPSOM has attempted to address the problem of the determination of the optimum energy policy in Australia. As the developments in the energy sector in 1989-90 indicate that some energy policy objectives have not yet been achieved satisfactorily (Jones et al. [1991]), a set of reformulated energy policies is needed. The set of optimum energy policies suggested by AEPSOM indicates the directions for the reformulation of a comprehensive integrated set of energy policies for Australia.

CHAPTER SEVEN

MAJOR FINDINGS:

SUMMARY, LIMITATIONS, AREAS FOR FURTHER RESEARCH, AND CONCLUSIONS

To end this multi-level energy planning study, this chapter provides a summary and overview of the study, points out its limitations, suggests agenda for further research and draws some conclusions.

7.1 SUMMARY AND OVERVIEW

7.1.1 Background: Problems, Issues and Policy Modelling.

Energy has played a significant role in man's pursuit of a better standard of living. Events in the world energy market in 1973, 1979-80 and 1990 have certainly created a wider understanding and recognition of the problem: Achieving an efficient and socially desirable allocation of resources in the energy sector to solve the so-called energy problem. Identification of market failures leads to the prescription of government interventions and to the promotion of economic efficiency and development in the energy sector (issues). For the reasons stated previously, models are useful tools in energy planning. Therefore, a large number of energy models has been developed. Since the relevance and usefulness of energy plans depend on the appropriateness of the model used in the policy study, the quest for an appropriate energy planning model, or, in its wider sense, an appropriate energy planning approach, may be justifiable.

7.1.2 ML0 Approach: Justification and Theoretical Formulation

Since market failures justify energy planning by the government, the energy policy system is characterized by the existence of two separate sub-problems: optimum policy formulation by the government (policy problem) and optimum production and end-use decisions of economic agents (behavioural problem). Although energy models have been developed to replicate the competitive market mechanism to reflect the decision making of individual economic agents, a clear and complete representation in these models of the policy interactions between the government and economic agents, resulting in what is called multi-level multi-goal hierarchical policy systems, is lacking. Consequently, existing energy models cannot provide results pertaining to the decision making process, and may not be satisfactorily applied to formulate multi-level energy planning. In addition, necessary articulation of the policy planning problem in the form of classified model variables as the target and instrument variables has not been made. Also the existing energy models can produce results adequate only for a partial set of energy policies: the mathematical programming models provide mainly energy technological policies and shadow prices, while the macro-econometric models can produce results for taxes, subsidies and other economic policies. No existing energy model can produce results adequate for the formulation of a comprehensive set of energy policies consisting of those energy technological and economic policies.

These deficiencies of existing energy models in their use in multi-level energy planning studies necessitate the adoption of an ML0 approach to multi-level energy planning. In this approach, the energy planning problem is modelled to optimize a policy

objective function subject to (a) the constraints on the policy options and their consequences, and on the ranges of choice and (b) the constraints imposed by the behavioural sub-model on the degrees of freedom of the policy makers. The operational technique for multi-level optimization is called multi-level programming (MLP). An MLP model has four main components: a) A weighted policy objective function containing the objectives of the policy makers, b) the constraints on the choice of policy instruments, c) the objective functions of economic agents, and d) the constraints on the behaviour of economic agents. MLP is considered as a collection of nested optimization problems at different levels.

The energy planning modelling approach developed in this study is also structured within the framework of Tinbergen's theory of economic policy planning since this theory of economic policy planning provides an operational framework suitable for policy planning. To understand and identify the exact characteristics of the underlying policy planning problem, an analysis of the underlying policy system and its incorporation in the policy planning model are also necessary.

Any energy planning model developed within this approach will have several advantages:

(a) It represents exactly and explicitly the underlying policy planning problem (i.e. hierarchical multi-level multi-goal policy system). Therefore, this approach (i) produces improved results/plans, (ii) generates some analytical results related to the underlying policy system in the form of nature of intervention and interdependence, (iii) makes explicit the policy-behavioural feasible region which is implicit in other types of models and (iv) can be used to study some welfare economic implications of

government intervention.

(b) It can provide a comprehensive set of energy policies consisting of energy technological and economic policies.

Considering the fact that multi-level energy planning in a market economy requires an MLO model and an integrated (technical and economic) comprehensive (as comprehensive as possible) set of energy policies, the present multi-level energy planning approach appears to be an improvement over the existing single level optimization energy planning models/approaches.

7.1.3 The Australian Model : AEPSOM.

A journey from theory to practice is always fraught with problems and difficulties, and in many cases the rigour of a theoretical model is lost in its real life applications.

To give an empirical content to the theoretical approach, an Australian energy planning model AEPSOM was developed. AEPSOM was developed on the basis of the following specification of the Australian energy policy planning problem.

(1) Energy Policy Objectives

The major objectives of the Australian energy policy are: reduction in oil imports, reduction in the use of oil, conservation of energy, and efficient allocation of resources.

(2) Energy Policy Instruments

The possible energy policy instrument alternatives in Australia are the following: (a) Indirect Control: (i) Taxes and subsidies; (ii) Government expenditures for energy conservation, research and development, and education and information. (b) Direct

Control: (i) Pricing of domestic crude oil.

(3) Energy Policy Strategies/Policy Guidelines: (a) Technological strategy, (b) depletion policy, (c) exploration and development strategy.

AEPSOM is a price control MLP model based explicitly on the energy policy and energy systems in Australia. The policy objective function incorporates minimization of oil imports, total oil use and total energy use as well as minimization of the energy sectoral government budget deficit. The policy constraints of the model impose limits on the taxes and subsidies imposed by the government in the energy sector, and require the sectoral budget to be self-financing. The behavioural objective function of AEPSOM replicates the cost minimization behaviour of the energy producers and end-users. The constraints of the behavioural model represent the structure and operation of the Australian energy system/sector.

AEPSOM is specified to capture the hierarchical multi-level (two-level) energy policy formulation process in Australia. In AEPSOM, decision making of the policy-makers and economic agents are integrated in a single model and hierarchically placed in the modelling structure. Solution to AEPSOM determines the optimum policy targets configuration in the energy sector attainable under the present political regime and the behavioural and technical constraints in the energy sector.

The base year of AEPSOM was specified for the year 1979-80 and for sensitivity studies another one for 1989-90. Some of the data were estimated by the author and others were obtained from published sources.

An energy sector MLP model can have several applications. It

can be applied to a market economy, a mixed economy or a controlled economy. It can be utilised to determine the optimum values of the existing taxes and subsidies or the optimum mix and values of taxes and subsidies necessary for attaining the sectoral energy policy objectives. In addition, it provides results needed for the determination of other energy policies such as pricing policy, conservation policy, research and development policy, education and propaganda policy and technological policy in both the above cases.

Although MLP models have potentials for wide and useful policy applications, MLP model specifications have so far been restrictive. AEPSOM is capable of including real life policy from a wider perspective and hence is applicable to different types of policy studies.

7.1.4 Solution Algorithm : The PPS Approach.

The real test of an empirical model development is its numerical implementation. AEPSOM was numerically implemented by the PPS algorithm. The main difficulty with an MLP model is its implementation by an algorithm. Algorithms either are not commercially available or cannot solve large MLP models. Search for appropriate algorithms and software is still ongoing with an uncertain prospect. The present PPS algorithm solves an MLP model by solving first the behavioural model and then searching the behavioural model solution that optimizes the policy objective function and satisfies the policy constraints. Optimum results produced by the PPS algorithm are close to the expected optimum results. Other criteria such as efficiency in CPU time, and cost and efficiency in extension and transfer of the algorithm were

applied to test the algorithm.

7.1.5 Results : Validation Tests and Policy Implications.

The main outcome of a modelling work is a set of results which can be used to provide guidelines for the formulation of policies. AEPSOM results provided a set of information for an analysis and understanding of the Australian energy policy problems. The results were capable of addressing energy policy issues in the following areas: energy taxes and subsidies, pricing, energy technology, conservation, education and propaganda, research and development, optimum depletion of exhaustible resources, and exploration and development activities of the government.

To test the reliability of the AEPSOM results, some conventional validation tests were performed. These tests included a *priori* justifications about the relevance of the model, the underlying problems or systems, usefulness of output for achieving the objectives of the modelling study, accuracy of results, comparison of the model results with results of other studies and intuitive judgments.

AEPSOM generated a numerical policy system in the Australian energy sector which has provided some insights into the characteristics of multi-level multi-goal hierarchical policy formulation in the energy sector.

AEPSOM results have been used to formulate a multi-level optimum energy plan for Australia: (1) AEPSOM has determined an optimum energy system for Australia. The numerical optimum energy system has been reported in Table 5.8. (2) A set of optimum energy policy instruments and strategies for Australia has been

formulated. In addition to the required changes in the pricing and fiscal instruments areas, details of the desirable optimum pattern of energy supply, conversion, and end-use technologies were shown by the energy flows produced by AEPSOM. Increased production and use of coal is necessary. Progressive reduction in the use of natural crude oil is desirable. The introduction of coal conversion technologies will substitute naturally occurring crude oil, this requires improvement in its efficiency. Also, increased production and harnessing of hydro-electricity and solar energy are desirable and will reduce the use of fossil fuels, particularly crude oil, for electricity generation. Other Australian energy policy studies have suggested similar technology policy (Endersbee et. al. [1980]). Increased supply of primary energy and expansion of capacities will have a significant effect on Australian energy systems in the future. But currently emphasis, needs to be given to other energy policies such as an appropriate mix of $\pm T$, conservation programmes, and appropriate technology with a long-term strategy for increasing the supply of domestic energy resources.

7.2 LIMITATIONS

The limitations of this study have been discussed and presented at different places of the thesis. These include the assumption of linearity in most of the relationships in the model, the impossibility of capital and labour substitution, the limited framework in which the effects of relative prices on energy variables and policies are specified, the partial equilibrium character of the model, the unavailability of, thus non-incorporation of the 1989-90 data in the forecast model, and the limited discussion of

the data used in the model¹.

But the major limitation that may be raised is the non-incorporation of energy macro-economic interactions in AEPSOM. As discussed before, the present partial equilibrium approach has the advantage of giving emphasis on the energy sectoral technological and economic issues and options more comprehensively and integrated compared to a general equilibrium model where energy sectoral technological and system operation details are not adequately captured. In addition to this, the emphasis of the present study has been on the multi-level policy interactions in the energy sector, rather than on the energy macro-economic interactions. After multi-level policy interactions in the energy sector have properly been modelled and studied, energy macro-economic interactions and multi-level policy interactions in the energy sector can be simultaneously studied.

The other limitation of this study that was also pointed out previously is the solution of the model by an iterative algorithm. Because of the existing problems of solving an MLP model, development of new algorithms is necessary. In spite of the drawbacks of the PPS algorithm, it has some good features and the results of AEPSOM solved by this algorithm were found to be acceptable.

7.3 AREAS FOR FURTHER RESEARCH

Further research should be directed at the following

1. This was brought about by the main emphasis of the study (discussed in Chapter One).

areas: (i) The rigorous treatment of the theory of multi-level optimization of the energy sector (ii) The implementation of an MLP energy model (static or dynamic) with macro-economic and policy constraints (iii) Further experiments with the PPS algorithm in the following directions: (a) Solution of a non-linear MLP model; (b) Comparison of the results of a model solved by the PPS algorithm with the results obtained by another algorithm; (c) Solution of an MLO energy planning model which includes macro-economic and policy constraints by the PPS algorithm; (d) Specification of an MLP model involving two separate optimization problems - maximization or minimization - at two levels of the MLP problem; and (e) Further theoretical investigations of the properties of the results of an MLP model solved by the PPS algorithm, in addition to the ones undertaken in Chapter Four, Section 4.4, such as the existence, uniqueness, and global optimality of model solution.

The first type of research will help to provide analytical insights into the interactions of the two-levels of decision making. The second type of research will help to investigate the characteristics and implications of energy-macroeconomic interactions for optimum energy policies. The third type of research should make the PPS algorithm more useful, widely usable and acceptable.

7.4 CONCLUSIONS

Although various conclusions from this study were drawn at different parts of the thesis, they can be summarized here at the end of the study as follows (next page):

(a) Desirability of MLO Approach

The energy planning model proposed and developed in this study can represent the energy policy system of a market economy accurately. One characteristic of such a policy system revealed by the AEPSOM results ie., the conflicting interests of the government and economic agents, reinforces the need for an MLO approach to energy planning with explicit specification of the objective functions of these decision makers.

AEPSOM has predicted an improved energy plan in the case of optimum $\pm T$ compared to a single level behavioural model and to the case of existing $\pm T$ (base or original plan¹). If energy policies were formulated on the basis of results of a single level energy sector model (the behavioural model) the policies would be erroneous. Therefore, the MLO model can determine the value of the policy objective function and select a set of optimum other re-

1. This result would seem to be of some significance in applied welfare economic study, since it provides some empirical evidence in resolving the continued controversy over the determination of an appropriate government role in energy and resource management. In Chapter Six, it was stated that this result provided evidence in justifying a point in normative economics regarding the efficiency of decentralized market behaviour in achieving societal objectives.

Views of Candler [1991] on a finding of an improved plan in an MLP study was communicated to the present author in this form:

"Provided that you have shown that you have found a better policy than the existing one, this may be enough to qualify as 'a contribution to knowledge', depending on (a) the size of improvement, and (b) a clear acknowledgement that it cannot be proven to be global, and (c) some explanation that computational costs of finding the global optimum (or proving the present solution to in fact be optional) would be excessive."

(The above issues: (a), (b), and (c) arising in the present study were discussed in Chapters Four, Five and Six).

sults which is different from the results of a single level model. In addition, this type of model can provide an integrated and comprehensive set of energy policies.

Also an optimum multi-level energy plan formulated by adopting an MLO approach can generate an optimum energy system plan and an optimum energy policy plan simultaneously.

In many cases, issues related to the desirability of government intervention in the energy sector, import parity pricing of energy, resource rent taxation, conservation, exploration and development, and deregulation of the energy market are addressed theoretically by applying economic principles. This study has produced results which could be used to address policy issues like those mentioned above by providing empirical evidence.

Therefore, the methodological conclusion of the study is that an MLO model can provide an alternative methodology and framework for optimum multi-level energy planning.

(c) Optimistic Prospects of MLP

Existing problems in MLP were highlighted at different parts of the thesis. In specifying AEPsOM, attempts were made to improve the state of the specification and use of an MLP model. The following points have emerged from this study:

(i) An MLP can be used to undertake normative studies in the energy sector (desirability of energy policies).

(ii) An MLP model can be adopted to undertake a policy system analysis to reveal numerically the characteristics of the underlying policy system.

(iii) It is possible to solve a fairly large MLP model representing a sector in reasonable detail.

(iv) It can produce a comprehensive integrated set of energy policies; not +T or technology policies separately.

(v) It also provides an appropriate policy modelling framework since it can explicitly be based within the framework of the theory of economic policy planning.

(vi) An MLP can be used to formulate an optimum mix of +T after investigating whether the existing set of +T is desirable or not.

(vii) The PPS algorithm can be used to find an optimum solution to an MLP. Although the PPS algorithm is an iterative search method, the algorithm can find an improved energy plan.

These extensions in the specification, implementation and applications of MLP models were made in the present study with the intention of generating the optimism that meaningful MLP models can be specified, numerically implemented and adopted for policy studies.

(d) Existence of Multi-level Hierarchical Policy System

The numerical policy system analysis has demonstrated the existence of a multi-level, multi-goal, hierarchical policy system in the Australian energy sector.

(e) Possibility of Changes in AES

The Australian energy system is expected to undergo some significant changes in the long run, if the policies suggested in this study are implemented and the assumptions made remain valid.

(f) Changes in Australian Energy Policies

AEPSOM has provided the following insights, guidelines and

directions in Australian energy policy planning and issues: the necessity for deregulation of energy prices, reorganization of the existing taxes and subsidies in the energy sector, priority for conservation, education and propaganda, and research and development policies, emphasis on the exploration and depletion policies, and the need for cost savings necessary for market penetration of new and renewable technologies.

The formulation of a comprehensive energy policy plan would, perhaps, be of some interest in the Australian energy policy context, because of the country's on-going search for a set of integrated comprehensive energy policies (Saddler [1981], Hall [1985], Marks [1986]). There is a need for a comprehensive set of quantitative energy policies studied and formulated in an integrated, comprehensive, consistent and optimum set-up (by applying an optimization model). It will, therefore, be of use if the suggested policies can open new perspectives for further dialogue on the Australian energy policy issues.

SELECTED BIBLIOGRAPHY

Al-ali, H.M. (1979), "Input-output Analysis of Energy Requirements: An Application to the Scottish Economy in 1973", Energy Economics, October, PP. 211-218.

Allen, G.R. (1976), The Graduate Students' Guide to Thesis and Dissertations, Jossey-Bass Publishers, London.

Allen, E.L. et al., (1976), U.S. Energy and Economic Growth, Institute for Energy Analysis, Oak Ridge Associated Universities, Oak Ridge, Tennessee.

Anthony, J.D. (1977), National Energy Policy, Commonwealth Australia, Canberra.

APEX III, Reference Manual, Control Data Corporation.

Arrow, K.J. (1951), Social Choice and Individual Values, Wiley, New York.

Arrow, K.J. and M.D. Intriligator (eds.) (1981), Handbook of Mathematical Economics, Vol.1. North-Holland Publishing Company, Amsterdam.

Asian and Pacific Development Centre (1985), Integrated Energy Planning: A Manual, 3 Volumes, Kuala Lumpur.

Australian Bureau of Statistics (1984), Australian National Accounts: Input-Output Tables 1978-79, Canberra.

Australian Bureau of Statistics (different volumes), Australian Year Book, Canberra.

Australian Institute of Energy/Institute of Engineers, Australia, (1983), Energy 83: Towards an Energy Policy for Australia, Position Papers, Sydney.

Ball, R. J., and C.J. Bowers, (1983), "Distortions Created by Taxes which are Options on Value Creation: the Australian Resources Rent Tax Proposal," Australian Journal of Management Vol 8, pp 1-14.

Ballenger, N.S., (1984), Agricultural Policy Analysis for Mexico: Sectoral and Macro Impacts, Ph.D. dissertation, University of California, Davis, cited in Hazell and Norton (1986), op.cit.

Bannock, G., R.E. Baxter and R. Rees (1984), The Penguin Dictionary of Economics, 3rd Edition, Penguin, New York.

Bard, J. F. (1983a), "An Efficient Point Algorithm for a Linear Two-stage Optimization Problem", Operations Research, V.31, No. 4.

Bard, J. F. (1983b), "An Algorithm for Solving the General Bilevel Programming Problem", *Mathematics of Operation Research*, V.8, No.2, PP. 260 - 723.

Bard, J. F. (1984a), "Optimality Conditions for the Bilevel Programming Problem", *Naval Research Logistics Quarterly*, V.31, pp 13-26.

Bard, J. F. (1984b), "An Investigation of the Linear Three Level Programming Problem", *IEEE Trans. on Systems, Man and Cybernetics*, v. SMC-14, N.5, pp. 711 - 717.

Bard, J. F. (1985), "Geometric and Algorithmic Developments for a Hierarchical Planning Problem", *European Journal of Operations Research*, 19 pp. 372-83.

Bard, J. and J. Falk (1982), "An Explicit Solution to the Multi-level Programming Problem", *Computer and Operations research*, Vol.9, No.1, pp.77-100.

Berndt, E.R. and Wood, D.O. (1975), "Technology, Prices, and Derived Demand for Energy", *Review of Economics and Statistics*, vol. 57(3), pp. 259-268.

Barnett, D. W. (1979) *Minerals and Energy in Australia*. Cassell, Sydney.

Basu, D.R. (1981), *Future Energy Policies for the UK: An Optimal Control Approach*, The Macmillan Press Ltd, London.

Bator, F., (1958), "The Anatomy of Market Failure", *Quarterly Journal of Economics* vol. 72.

Baughman, L. (1972), *Dynamic Energy System Modelling: Inter-fuel Competition*, Ph.D. thesis, School of Engineering, M.I.T., Mass.

Bayraktar, et. al. (ed)., (1981), *Energy Policy Planning*, Plenum Press, New York.

Behling, D.J., W. Marcuse, J. Luckachiuski and R. Dullien (1977), "The Long Term Economic and Environmental Consequences of Phasing Out Nuclear Electricity" in C.J. Hitch (ed.), *Modelling Energy Economy Interactions: Five Approaches*, Resources for the Future, Washington D.C.

Behling, D.J., W. Marcuse, M. Swift and R. Tessmer, (1975), "A Two-level Iterative Model for Estimating Inter-fuel Substitution Effects", presented at Summer Computer Simulation Conference, San Francisco, California, July 21-23.

Bensousan, A. et. al. (1974), *Management Applications of Modern Control Theory*, North-Holland Publishing Company, Amsterdam.

Bialas, W.D. & M.H. Karwan (1980), *Multi-level Optimi-*

zation : A Mathematical Programming Perspective, Dept. of Industrial Engineering, State University of New York, Buffalo.

Bialas, W.F. and M.H. Karwan (1982) "On Two-level Optimization" Transactions on Automatic Control, v. AC-27, N.I., pp. 211-14.

Bialas W.F. and M.H. Karwan, (1984) "Two-level linear Programming", Management Science, Vol.30, N8, pp 1004-1019.

Bialas, W., M. Karwan, and J. Shaw, (1980), "A Parametric Complementary Pivot Approach for Two-Level Linear Programming", Research Report, Department of Industrial Engineering Operations Research Programme, State University of New York, Buffalo.

Bisschop, J., W. Candler, J.H. Duloy, and G.T. O'Mara (1982), "The Indus Basin Model: A Special Application of Two-Level Linear Programming," Mathematical Programming Study, Vol. 20 pp. 30-38.

Black. J. ed. (1982) Liquid Fuels in Australia: a Social Science Research Perspective, Pergamon, Sydney.

Blaug, M., (1985), Economic Theory in Retrospect, Fourth Edition, Cambridge University Press.

Bracken, J. & J.T. McGill (1973), "Mathematical Programmes with Optimization Problems in the Constraints", Operations Research, Vol.21, pp.37-44.

Bradley, S.P., A.C. Hox and T.L. Magnanti, (1977), Applied Mathematical Programming, Addison-Wesley Publishing Company, Reading.

Brain, P. and G. Schuyers (1981), Energy and the Australian Economy, Longman Cheshire, Sydney.

Branon, G.M., ed., (1975), Studies in Energy Tax Policy, Ballinger Press, Cambridge, MA.

Brock, H.W. and D.M. Nesbitt (1977), Large Scale Energy Planning Models: Methodological Analysis, Stanford Research Institute, Menlo Park, C.A.

Brosowski, B & F. Deutsch (1985), Parametric Optimization and Approximation, Birkhauser Verlag, Boston.

Bullard, C.W., & A.V. Sebald (1975), "A Model for Analysing Energy Impact of Technological Change", presented at the Summer Computer Simulation Conference, San Francisco, California.

Candler, W. (1989, 1990, 1991), Personal Communication, World Bank, New York.

Candler, W. and R. Norton (1977), "Multi-level Pro-

gramming and Development Policy", Bank Working Paper No. 258, World Bank, Washington D.C.

Candler, W. and R. Townsley (1982), "A Linear Two-level Programming Problem", Computers and Operations Research Vol.9, N.1, pp 59-76.

Candler, W., J. Fortuny-Amat, and B. McCarl (1981), "The Potential Role of Multi-level Programming in Agricultural Economics", American Journal of Agricultural Economics, Vol. 63, August, pp.521-531

Carey, M, et. al. (1976), "The UK Energy Sector: A Cost Minimizing Model with Fixed Demands", Discussion Paper, Faculty of Commerce and Social Sciences, Birmingham University, Birmingham.

Carter, A.P. (1974), "Energy, Environment and Economic Growth", Bell J. of Economy and Management Science, Vol.5, pp.578-592.

Cassing J.H. and A.L. Hilman, (1982) "State-Federal Resource Rivalry: the Queensland Railway and the Federal Export Tax," Economic Record, Vol. 58: pp 235-41.

Centre for Applied Economic Research, (1985), Energy Modelling in Australia, University of NSW, Sydney.

Cherniavsky, E.A. (1981), "Multiobjective Energy Analysis", pp. 399 - 420, in Bayraktar et. al. (ed.) (1981) op. cit.

Christensen, L. R. et. al. (1973), "Transcendental Logarithmic Production Frontiers", Review of Economics and Statistics, Vol. 55, No.1 (February), pp. 28-45.

Christensen, L. R., et. al. (1975), "Transcendental Logarithmic Utility Functions," American Economic Review, Vol.65, No. 3 (June), pp.367-383.

Clarke. R. J, P.R. Hartley, D.M. Hocking, J. Jordan, D.C.L. Nellor, et. al., (1982), Energy Pricing Issues in Victoria, Centre Policy Studies, Monash University, Melbourne.

Common, M., (1988), Environmental and Resource Economics: An Introduction, Longman, New York.

Considine, D.M. (1977), Energy Technology Handbook, McGraw-Hill Book Company, New York.

Cook, P.L. & A.J. Surrey (1977), Energy Policy, Martin Robertson.

Corbett, A.H, (1976), Energy for Australia, Penguin, Harmondsworth.

Crossley, D. J., J. Dick, and J.D. Mardon, (1980), "De-

veloping Energy Strategies for Australia", Search Vol 11 (4), pp 98-108.

Daellenbach, H.G., J.A. George, D.C. McNickle, (1983), Introduction to Operations Research Techniques, Allyn and Bacon, Inc., London.

Daintith, J. (1981), Series Editor, Dictionary of Mathematics, J.M. McGregor Pty Ltd, Sydney.

Dale, M.B., (1970), "Systems Analysis and Ecology", Ecology 51, No. 1:3.

Dantzig, G.B. (1974), "On the Reduction of an Integrated Energy and Interindustry Model to a Smaller Linear Program", Technical Report SOL 74-20, System Optimization Laboratory, Stanford University, Stanford.

Dantzig, G.B. & P. Wolf (1961), "The Decomposition Principle for Linear Programs", Econometrica, October, pp.767-778.

Dantzig, G. B. et al. (1978), Stanford Pilot Energy/Economic Model, Stanford University, Palo Alto.

Debanne, J.G. (1975), "Towards a Network Representation of Total Energy Supply-Distribution Systems", presented at the Summer Computer Simulation Conference, op. cit.

Defrano, M.E. and J.B. Nugent, (1967), "The Effects of Long-Run and Short-Run Planning Goals on Economic Policy Instruments", paper presented to the Econometric Society, D.C., December, 28, Washington.

Debrue, G., (1959) The Theory of Value, Wiley, New York.

DeLucia, R., and H. Jacoby, (1982), Energy Planning for the Developing Countries : A Study of Bangladesh, Johns Hopkin University Press, Baltimore.

Department of National Development, (1979), Australian Energy Policy - A Review", Australian Government publishing Services, Canberra.

Department of National Development and Energy, (1981), Australian Energy Statistics, AGPS, Canberra.

Department of National Development and Energy, (1982), Energy Demand and Supply Australia 1960-61 - 1980-81, Australian Government Publishing Services, Canberra.

Department of Primary Industries and Energy, (1988), Energy 2,000: A National Energy Policy Paper, Australian Government Publishing Service, Canberra.

Department of Resources and Energy, (1983), Forecast of Energy Demand and Supply in Australia: 1982-83 to 1991-

92, AGPS, Canberra.

Department of Resources and Energy (undated, probably 1984), "Recent Development in Energy Policy", AGPS, Canberra.

Department of Resources and Energy, (1985), A Modified Free Market for Indigenous Crude Oil, Canberra.

Department of Resources and Energy, Australian Energy Statistics, several issues, AGPS, Canberra.

Derrick, S.D., D. McDonald, and P. Rosendale, (1981), "The Development of Energy Resources in Australia: 1981 to 1990," Australia Economic Review 3rd Q., pp 13-55.

Diesendorf, M.O., ed. (1979) Energy and People: Social Implications of Different Energy Futures, Society for Responsible Society, Canberra.

Dixon, L.C.W. and G.P. Szego (1980), "Numerical Optimization of Dynamic Systems :A Survey" in Dixon, L.C.W. & G.P. Szego (eds), Numerical Optimization of Dynamic Systems. North-Holland Publishing Company, Amsterdam.

Dixon, P.B., B.R. Parmenter, J. Sutton, and D.P. Vincent, (1982), ORANI A Multisectoral Model of the Australian Economy, North-Holland Publishing Co., Amsterdam.

Donnelly, W.A. (1984), "Energy Model for Australia", Centre Resources Environmental Studies Working Paper No.1984/4. CRES, ANU, Canberra.

Downs, A. (1957), An Economic Theory of Democracy, Harper and Row, New York.

Dudley, N. (1981) "Towards Optimal Decisions on Oil Stockpiling in Australia," Centre for Applied Economic Research Paper No. 11. University of NSW, Sydney.

Edelman, D.J. (1978), "Recent Energy Models A Review of Methodologies", Journal of Environmental Systems, Vol.7(3), pp. 279-292.

Edwards, G.W.(1983), "Economic Aspects of Energy Policy", in Australian Institute of Engineers, Energy 83: Towards an Energy Policy for Australia, Position Papers, Institute of Engineers, Sydney.

Edwards, G. W., and M.W. Thorpe, (1978), "Energy policy for Australia." Aust. Q 50 (2): 22-38.

Eichner, A.S., (1979), A Guide to Post-Keynesian Economics, The Macmillan Press Ltd.

Emerson, C., and P.J. Lloyd, (1983), Improving Mineral Taxation in Australia, Economic Record, Vol. 59,

pp.232-44.

Endersbee, L. A. Baxter.P., Butters..J. W. Corbett, A. H. Dembecki, J. A. et al. (1980), "An Energy Policy for Australia." Energy, Vol.5, pp. 295-323.

Energy Victoria, (1984), Victoria Energy Plan: Progress Report on Energy Planning, Department of and Minerals Energy, Melbourne.

Enthoven, A. (1962), "Operations Research at the National Policy Level", (Unpublished transcript of an address at the Operations Evaluation Group Biannual Conference, Washington, D.C., May), quoted in C.T. Whitehead (1967) USCS and Limitations of System Analysis, Rand Corporation, Santa Monica, California.

Ethier, W.J,(1988), Modern International Economics, Second Edition, W.W. Norton 2 Company, New York.

ESCAP, (1979), Proceedings of the Working Group Meeting on Energy Planning and Programming and of the Committee on Natural Resources, ERDS No. 20, UN, New York.

Esso Australia Ltd, (1984), Australian Energy Outlook, Sydney.

Falk, J. (1987), A Personal Communication, Department of Operations Research, The George Washington University, United States of America.

Fane, G., and B Smith, (1986), "Resource Rent Tax" in Hocking et al.(ed) op. cit., Australian Energy Policies in the 80s, Ch. 7, pp 209-241. Allen & Unwin, Sydney.

Fishbone, L.G. and H. Abilock (1981), "MARKAL - A Linear Programming Model for Energy System Analysis: Technical Description of the BNL Version", Energy Research, Vol.5, pp.353-375.

Folie, G. M. and A.M. Ulph (1976), "An Outline of an Energy Model for Australia", CRES Working Paper R/WP5, Australian National University, Canberra.

Folie, G. M. and A. M. Ulph (1977), "The Role of Energy Modelling in Policy Formulation, "CRES Working Paper CRE/WP7, Australian National University, Canberra.

Folie, G.M. and A.M. Ulph (1979), "Self-Sufficiency in Oil: An Economic Perspective on Possible Australian Policies", CAER Paper No.6. University of New South Wales, Sydney.

Folie, M. and A. M. Ulph (1982), "Energy Policy for Australia" in L.R. Webb & R.H. Allen (eds), Industrial Economics: Australian Studies, George Allen & Unwin, Syd-

ney.

Forrester, T.W. (1961), *Industrial Dynamics*, John Wiley and Sons, New York.

Fortuny-Amat, J. (1979), *Multi-Level Programming*, Ph.D. Thesis, Department of Industrial Engineering, Purdue University, United States of America.

Fortuny-Amat, J. and B. McCarl (1981), "A Representation and Economic Interpretation of a Two-Level Programming Problem", *Journal of Operational Research Society*, Vol. 32, pp 783-792.

Fox, K.A., J.K. Sengupta & E. Thorbecke (1973), *The Theory of Quantitative Economic Policy with Applications to Economic Growth, Stabilization and Planning*, North-Holland Publishing Co., Amsterdam.

Frisch, R. (1976), *Economic Planning Studies*, D. Reidel Publishing Company, Dordrecht-Holland.

Gal, T., (1979), *Postoptimal Analyses, Parametric Programming, and Related Topics*, McGraw-Hill Inc., New York.

Galligan, B. (1983), "National Energy Policy in Canada and Australia", *Australian Canadian Studies* Vol 1, pp 14-29.

Garnaut, R., and A. Clunies Ross, (1984), "Uncertainty, Risk Aversion and the Taxing of Natural Resource Projects." in Lloyd, P.S. (ed) (1984), *Mineral Economics in Australia*, Allan and Unwin, Sydney, pp. 98-115.

Gatenby, H. (1986a), "Two Sub-programmes for Finding Policy Optimum," University of Tasmania, Australia.

Gatenby, H. (1986b), "Two Sub-programmes for Doing the Searches as is Proposed in Heaps (1986) and for Finding Policy Optimum", University of Tasmania, Australia.

Goreux, L. M. and A. S. Manne (1973), *Multi-level Planning: Case Studies in Mexico*, North-Holland, Amsterdam.

Graaff, V. de V., (1957), *Theoretical Welfare Economics*, Cambridge University Press, London.

Graycar, A., (ed) (1983), *Retreat from Welfare State*, George Allen and Unwin, Sydney.

Gregory, R.G. (1984), "Some Implications of the Growth of the Mineral Sector," in Lloyd, P.J. ed (1984) *Mineral Economics in Australia*. Sydney: Allen & Unwin, Sydney, pp. 285-310, first published in *Australian Journal and Agricultural Economics* vol 20, August 1976 pp. 71-91.

Greenberger, M and R. Richels (1979), *Assessing Energy*

Models: Current State and Future Directions, Annual Review of Energy, vol.4, pp.467-500.

Griffin, J.M. and H.B. Steele, (1980), Energy Economics and Policy, Academic Press, London.

Groenewegen, P (1984), Public Finance in Australia, Second Edition, Prentice-Hall of Australia, Sydney.

Gross, P. & R. D. Smith (1976), Systems Analysis and Design for Management, Dun-Donnelley Publishing Corporation.

Gruen, I.H. & A.L. Hillman (1981), "A Review of the Issues Pertinent to Liquid Fuel Policy", Economic Record, June, pp.111- 127.

Häfele, W. (1981), Energy in a Finite World: Paths to Sustainable Future, Ballinger Publishing co., Cambridge, Massachusetts.

Hall, V.B. (1984), "Some Thoughts on Energy Modelling and Policy in Australia," Economic Society of Australia Economic Papers 3(1), pp 21-36.

Hall, V. B. (1985), "Updated Thoughts on the State of Energy Modelling in Australia", Centre for Applied Economic Research, (1985) Energy Modelling in Australia, CAER, University of NSW, Sydney.

Hallet, A.H. & H.Rees (1983), Quantitative Economic Policies and Interactive Planning: A Reconstruction of the Theory of Economic Policy, Cambridge University Press.

Hansen, B. (1958), The Economic Theory of Fiscal Policy, Harvard University Press, Cambridge, Massachusetts.

Harberger, A. (1971), "Three Basic Postulates of Applied Welfare Analysis," Journal of Economic Literature, Vol. 1 X (3), September, PP 785-797.

Harder, E.L. (1982), Fundamentals of Energy Production, John Wiley & Sons, New York.

Harris, S.F. (1981) Energy and Equity: What is the Market's Place?" Proceedings of the 51st ANZAAS Congress, Sect. 24 (Econ.), Presidential Address Brisbane.

Hazell, P.B.R. and R.D. Norton (1986), Mathematical Programming for Economic Analysis in Agriculture, Macmillan Publishing Co., London.

Heaps, T. (1985), 'A Formula to Determine Some Alternative Combinations of the Units for Parametric Variations'. Dept.of Economics, Simon Fraser University, Canada, (Personal Communication).

Heliwell, J.F. (1984), "Natural Resources and the Aus-

tralian Economy", in *The Australian Economy: A View from the North*, R. E. Caves L. R. Krause. (eds) pp. 81-126. Washington DC.

Henderson, J.F. & P.M. Norman (1975), "The Equations of the RBA1/74 Model of the Australian Economy", Reserve Bank of Australia, Research Discussion Paper 7504, Sydney.

Henderson, J.M. & R.E. Quandt (1980), *Microeconomic Theory*, 3rd edition. McGraw-Hill Inc., London.

Hevenden, R.A. (1974), "Use of Input-Output Analysis to Determine the Energy Cost of Goods and Services" in M.S. Macrakis (ed.), *Energy Demand, Conservation and Institutional Problems*, MIT Press, Massachusetts.

Higgins, C.I. and V.W. Fitzgerald (1973), "An Econometric Model of the Australian Economy", *Journal of Econometrics*, Vol.1, pp.229- 65.

Hildebrandt, T. (undated), "Evolution and State of the Art of Energy Modelling in Europe", *System Research and Technological Development*, Nuclear Research Centre, Julich.

Hitch, C.J. (ed.) (1977), *Modelling Energy-Economy Interactions: Five Approaches*, Research Paper R.5. Resources for the Future, Washington, D.C.

Hocking, D.M (1975), "Do We Need a National Energy Policy?" background paper prepared for conference on Energy Resources Policy: The Australian Prospect Sydney University Extension Board, Sydney.

Hoffman K. C. (1974), "A Unified Framework for Energy System Planning", in *Energy Modelling, Special Issue of Energy Policy*, IPC Science and Technological Press, Surrey U.K.

Hoffman, K.C. and D. Jørgenson (1977), "Economic and Technological Models for Evaluation of Energy Policy", *Bell Journal of Economics* 8(2), Autumn, pp.444 -446.

Hoffman, K.C. and D.O. Wood (1976), "Energy System Modelling and Forecasting" in *Annual Review of Energy*, Vol.1. Annual Reviews Inc., Palo Alto, pp423-454.

Hogan, W. W. and A. S. Manne, (1977), "Energy-Economy Interactions: The Fable of the Elephant and the Rabbit?" In Hitch ed., op. cit.

Hogan, W. W. and P. Weyant, (1980), "Combined Energy Models", *Energy and Environmental Policy Centre*, John F. Kennedy School of Government, Harvard University, Mass.

Hotelling, H. (1931), "The Economics of Exhaustible Resources", *Journal of Political Economy*, Vol 39, pp. 137-175.

Howe, C. W. (1979), *Natural Resources Economics*, John Wiley and sons, Inc. New York.

Hudson, E.A. & D.W. Jorgenson (1974), "U.S. Energy Policy and Economic Growth 1975-2000", *Bell Journal of Economics and Management Science*, Vol.5, pp 461-514.

Hunt, V.D., (1979), *Energy Dictionary*, Van Nostrand Reinhold Company, New York.

Hudson, E.A. & D.W. Jorgenson (1976), "Tax Policy and Energy Conservation" in D.W. Jorgenson (ed.), *Econometric Studies of U.S. Energy Policy*, North-Holland Publishing Co., Amsterdam.

Idrus, N. & N. Islam (1992), *Development Changes, Environmental Implications and Adjustments in Policy Measures in the South Pacific Economies*, a paper presented at the National Conference "on Environmental Engineering" titled *The Global Environment - Australian Implications*, Gold Coast, The Institution of Engineers Australia, National Conference Publication No. 92/5.

International Energy Agency, (1986), *Energy Policies and Programmes of I.E.A Countries*, OECD, Paris.

Intriligator, M.D. (1971), *Mathematical Optimization and Economic Theory*, Prentice-Hall Inc., N.J.

Islam, N. (1983a) "An Optimum Economic Policy Framework for the Energy Sector," paper presented to the 12th Conference of Economists, 28 August - 1 September, Hobart.

Islam, N. (1983b), "Energy Project Planning: Methodological Issues, Applications and Perspectives," *Administrative Science Review*, National Institute of Public Administration, Dhaka.

Islam, N. (1987a) "Energy Systems and Policy Planning: A Multi-level Optimization Study and Its Implications for Papua New Guinea," *Proceedings the First National Seminar on Renewable Energy for Rural Development*, 22-26 June, Department of Minerals and Energy, Port Moresby.

Islam, N., (1987b), "Energy Planning and Economic Development Strategy for Providing Housing for the Poor in Papua New Guinea, proceedings, the Regional Workshop "Housing Actions Towards Shelter in Asia and Pacific, University for Technology, September 19-22, Lae.

Islam, N. (1988a), "Training for Energy Planners in Developing Countries: A Case Study of Papua New Guinea," Proceedings, the First World Congress on Engineering Education and Training, November 13 - 15, Nepal.

Islam, N. (1988b), "An Energy Systems Model for Australia: A Tool for Formulation of Energy Policies," Departmental Working Paper No. 2/88, University of Technology,

Lae.

Islam, N., (1988c), "The Future of Australian Energy System: Forecasting by a Dynamic Energy Systems Model", Departmental Working Paper No: 2/88, University of Technology, Lae.

Islam, N., (1989a), "Planning for Renewable Energy Projects: A Methodology for Papua New Guinea," Proceedings of the Second National Seminar on Renewable Energy for Rural Development, Dept. of Mechanical Engineering, University of Technology, 1-3 November, Lae, pp. 137-151.

Islam, N. (1989b), "Multi-level Programming: An Algorithm", Departmental Working Paper No.2/89, University of Technology, Lae.

Islam N. (1989c), "Multi-level Programming: On the Problems of Existence, Uniqueness and Global Optimality", Seminar on Mathematics and Mathematics Education, University of Technology, Lae, 28-29 August, (Proceedings pp. 56-67).

Islam, N. (1991a), "Mathematical Properties of Multi-level Programming", the PNG Journal of Mathematics, Vol.2 (I), adapted from (1989d).

Islam, N., (1991b), "Resource Control Multi-level Programming: A Parametric Programming Search Algorithm", the PNG Journal of Mathematics, Vol.2 (2).

Islam, N., (1991c), "The Role of Renewable Energy in the Australian Energy System: An Issue in the Philosophy of Renewal", a paper presented at the Conference of Economists, 30 September - 3 October, University of Tasmania, Hobart.

Islam, N., (1991d), Energy Policies in Papua New Guinea: An Appraisal, the Journal of the Society of the Professional Engineers, Vol. II, 1991 (a different version presented at the ANZAAS Congress, February 15-16, 1990, Hobart, Australia).

Jaforullah, M. (1988), Energy Modelling in a General Equilibrium Framework with Alternative Production Specifications, unpublished Ph.D. thesis, the University of Adelaide, Adelaide.

James, D., (1983), Integrated Energy-Economic-Environment Modelling with Special Reference to Australia, Dept of Home Affairs and Environment, Canberra.

James, D., (1984), "Energy, Economics and Environment: Systems Modelling in Australia", Centre for Environmental and Urban Studies, Macquarie University, Paper Presented at the 54th ANZAAS Congress, May 1984, Canberra.

James, D. (1987), A Personal Communication, Macquire University, Australia.

James, D., A.R. Musgrove and K.J. Stocks, (1986), "Integration of an Economic Input- Output Model and a Linear Programming Technological Model for Energy System Analysis", *Energy Economics*, April, pp. 99-112.

Johansen, L. (1960), *A Multi-Sectoral Study of Economic Growth*, North-Holland Publishing Company, Amsterdam.

Johansen, L. (1974), "Establishing Preference Functions for Macroeconomic Decision Models - Some Observations on Ragnar Frich's Contributions", *European Economic Review*, 5, pp.41-66.

Jones, B., S. Bush., Kanakarathnam, A., M. Leonard, and P. Gillan, (1991), *Projections of Energy Demand and Supply: Australia 1990-91 to 2004-2005*, Australian Bureau of Agricultural and Resources Economics, Canberra.

Julius, D. (1981), *Energy Pricing in the Developing Countries : A Review of Literature*, World Book Energy Department Paper No.1. Washington D.C.

Just, J.E. (1974), "Impacts of New Energy Technology Using Generalized Input-Output Analysis" in M.S. Macrakis (ed.), op. cit.

Kaldor, N (1939), "Welfare Comparisons of Economics and Interpersonal Comparisons of Utility", *Economic Journal* vol. 49, pp. 549 - 552.

Karunaratne, N.D. (1981), "An Input-Output Analysis of Australian Energy Planning Issues", *Energy Economics*, Vol.3(3), pp.159-168.

Kasper, W. (1982), *Australian Political Economy*, Macmillan Company of Australia Ltd, Melbourne.

Kornai, J. (1969), "Man-Machine Planning", *Economics of Planning*, Vol.9, No.3, pp.209-234.

Kresge, D. (1980), " An Approach to Independent Model Assessment", in S.I. Gass (ed), *Validation and Assessment Issues of Energy Models*, National Bureau of Standards Special Publication 569, Washington D.C.

Kydes, A. (1978), *The Brookhaven Energy System Optimization Model - its Variants and Uses*, Brookhaven National Laboratory, BNL- 50873, Upton, N.Y.

Labys, W.C, (1982), "Measuring the Validity and Performance of Energy Models," *Energy Economics*, July 1982 pp. 159-68

Leontief, W. W. (1966), *Input-Output Economics*,

Oxford University Press.

Lewis, A. (1949), Overhead Cost, London.

Lipsey, R.G., and K. Lancaster (1956-1957), "The General Theory of Second Best," Review of Economic Studies, vol. XXIV (1), pp. 11-32.

Little, I.M.D., and J.A. Mirrlees, (1974), Project Appraisal and Planning for Developing Countries, Heinemann Educational Books, London.

Lloyd. P.J., ed (1984), Mineral Economics in Australia, Allen & Unwin, Sydney.

Lotus Development Corporation, Lotus 1-2-3.

Malinvaud, E. (1967), "Decentralized Procedures for Planning" in Malinvaud and M.O.L., Bacharach (eds), Activity Analysis in the Theory of Growth and Planning, Macmillan, London.

Malone, R. and A. Reisman (1978), "Less Developed Countries Energy System Network Simulator : LDC ESNS", BNL-58036, Brookhaven National Laboratory, N.Y. Cited in Meier (1984).

Manne, A. S. (1977), "ETA-MACRO A Model of Energy-Economy Interactions" in C. J. Hitch, (ed), Modelling of Energy-Economy Interactions; Five Approaches, Resources for the Future, Washington D.C.

Manne, A. S. and L. M. Goreux (eds.) (1973), Multi-level Planning: Case Studies in Mexico, North Holland Publishing, Amsterdam.

Marcuse, W. & L. Bodin (1975), "A Dynamic Time Dependent Model for the Analysis of Alternative Energy Policies", presented at the Summer Computer Simulation Conference, op. cit.

Marks, R. (1986), "Energy Issues and Policies in Australia," Annual Review of Energy, 11, pp. 47-75.

Marshall, A. (1920), Principles of Economics, Macmillan, London (originally published in 1890).

McCarl, B.A. & T.H. Spreen (1980), "Price Endogenous Mathematical Programming as a Tool for Sector Analysis", American Journal of Agricultural Economics, 62, pp.87-102.

McColl, G. D. (1982), "Changes in the International Energy Situation and their Implications for Australia", CAER Paper No.15, Centre for Applied Economic Research, The University of New South Wales, N.S.W., Australia.

Meadows, D. L et. al. (1972), The Limits to Growth, Universe Book, Washington D.C.

Meier, P. (1984), *Energy System Analysis in the Developing Countries*, Springer-Verlag, New York.

Meier, P. (1986), *Energy Planning in Developing Countries: An Introduction to Analytical Methods*, Westview Press, Inc, Colorado.

Mendelsohn, R., (1983), *Australian Social Welfare Finance*, George Allen and Unwin, Sydney.

Mesarovic, M.D., J.L.Sanders, and C.E. Sprogue, (1973), "An Axiomatic Approach to Organisations from a General Viewpoint" in S.L. Optuer (ed.) (1973), *System Analysis*, Penguin Books, Middlesex.

Mishan, E.J. (1981) *Introduction to Normative Economics*, Oxford University Press, Oxford.

Mork, K. A. (ed). (1981), *Energy Prices, Inflation and Economic Activity*, Ballinger Publishing Company, Mass.

Mubayi, V. and P. Meier (1981), *Energy Models for Developing Countries : A Comparative Assessment*, Brookhaven National Laboratory, BNL-51446, Upton, N.Y.

Mumford, G. (1985), "Headaches from Falling Oil Reserves, *Australian Financial Review*, November.

Munasinghe, M. & G. Schramm (1983), *Energy Economics, Demand Management and Conservation Policy*, Van Nostrand Reinhold Company, New York.

Murtagh, B.A. (1981), *Advanced Linear Programming*, McGraw-Hill, New York.

Musgrave, R.A., (1959), *The Theory of Public Finance*, McGraw-Hill Book Co., New York.

Musgrave, R.A and P.B. Musgrave (1984), *Public Finance in Theory and Practice*, McGraw - Hill Book Co., New York.

Musgrove, A.R., (1987), personal communication.

Musgrove, A.R., J.K. Stocks, P. Essam, D. Le, and V.J. Hoetzl, (1983), *Exploring Some Australian Energy Alternatives using MARKAL*, Division of Energy Technology, Technical Report TR2, CSIRO, Lucas Heights, New South Wales.

National Academy of Sciences (1976), *System Analysis and Operation Research : A Tool for Policy and Programme Planning in Developing Countries*, Washington, D.C.

National Energy Advisory Committee (1978), "Some Aspects of Energy Modelling in Australia", Canberra.

National Energy Advisory Committee, (1983) "Trade in Energy". Report No. 21. Canberra: NEAC.

Naylor, T. H. and J. M. Vernon, (1969), *Microeconomics and Decision Models of the Firm*, Harcourt, Brace and World Inc., New York.

Neil, R. F. (1977), *Managing the Energy Transition. A System Dynamics Search for Alternatives to Oil and Gas*, Ballinger Publishing Company, Mass.

Nemetaz, P.N., I.B. Vertinsky, P. Vertinsky, and V. Kanetkar, (1984), "Threat in Opportunity and Opportunity in Threat: Energy Prospects for Australia and New Zealand," *Journal of Energy Development*, Vol.9, pp. 263-88.

Norton, R.D. and G.W. Schiefer (1980), "Agricultural Sector Programming Models: A Review", *The European Review of Agricultural Economics*, Vol.7, No.3, pp. 229-264.

Nykamp, and P. W.H. Somerneyer (1971), "Explicating Implicit Social Preference Functions", *Economics of Planning*, 11(3), pp.101- 119.

Optner, S.L. (ed.) (1973), *System Analysis*, Penguin Books, Middlesex.

Oser, J. and S.L. Brue, (1988), *The Evolution of Economic Thought*, Fourth Edition, Harcourt Brace Jovanovich, New York.

Pareto, V., (1971), *Manual of Political Economy* (Originally published in 1906), A.M.Kelly, New York.

Park, S. H. (1982), "An Input-Output Framework for Analysing Energy Consumption", *Energy Economics*, April, pp.105-110.

Park, S. H. and Kubursi, A. A. (1983), "The Energy Constraints and Development; Consistency and Optimality Overtime", *Energy Economics*, January, pp. 9-15.

Pearce, D.W. and C.A. Nash, (1981), *The Social Appraisal of Projects: A Text in Cost-Benefit Analysis*, Halstead Press, New York.

Pearse, A.R. and J.B Hardaker, (1984), "A Program for Solving Linear Programming Problems", *Miscellaneous Publication No.8*, Department of Agricultural Economics and Business Management, University of New England, Armidale, Australia University Press, Cambridge.

Planco Inc. (1979), *Survey of the Research into Energy-Economy Interactions*, 2 Volumes, Dallas, TX.

Powell, A.A. (1974), *Emprical Analytics of Demand Systems*, Lexington Books, D.C. Heath and Company, Mass.

Powell, A.A. (1980), "The Major Streams of Economy-Wide Modelling: Is Rapprochement Possible?", In J. Kmenta

J.B. Ramsey (eds.), Large Scale Econometric Models: Theory and Practice, North-Holland, Amsterdam.

Preston, A.J., and A.R. Pegan, (1983), The Theory of Economic Policy, Cambridge University Press, Cambridge.

Propoi, A. (1980), "Dynamic Linear Programming," in L.C.W. Dixon and G.P. Szego (eds), Numerical Optimization of Dynamic Systems, North-Holland Publishing Company, Amsterdam.

Propoi, A. and I. Zimin (1981), "Dynamic Linear Programming Models of Energy Resource, and Economic Development Systems," RR-81-44, International Institute for Applied System Analysis, Laxenburg, Austria.

Rath-Nagel, St and A.Voss (1981), "Energy Models for Planning and Policy Assessment", European Journal of Operation Research, Vol. 8, pp 99-114.

Riaz, T., (1984), Pakistan: The Energy Sector, Ferozsons Ltd, Lahore.

Richards, W. (1982), "The Energy Policy Framework: a State- Bargaining Approach," Journal of Australian Political Economy, 12/13, pp 110-28.

Richards, W. and H.D.W. Saddler, (1981), "Petroleum Pricing: Equity Versus Efficiency? Petroleum Industry Research Project Background Paper, Centre for Resources and Environmental Studies, Australian National University, Canberra.

Saddler, H.D.W, (1981), Energy in Australia: Politics and Economics, Allen and Unwin, Sydney.

Samuelson, P.A. (1952), "Spatial Price Equilibrium and Linear Programming", American Economic Review, Vol.42, pp.283-303.

Schumpeter, J.A. (1934), The Theory of Economic Development, Harvard University Press, Cambridge.

Schuyers, G:P. (1979), New Energy Technologies in Australia, Ph.D. thesis, University of Melbourne.

Sen, A.K. (1968), Choice of Techniques: An Aspect of the Theory of Planned Economic Development, Third Edition, Basil Blackwell, Oxford.

Sen, A. (1973), "Behavior and the Concept of Preference", Economica, pp.241-259.

Sengupta, J.K. & K.A. Fox (1969), Economic Analysis and Operation Research Optimization Techniques in Quantitative Economic Models, North-Holland Publishing Co., Amsterdam.

Shaw, J.P. (1980), A Parametric Complementary Pivot Approach to Multilevel Programming, M.Sc. Thesis, State University of New York at Buffalo.

Shumway, C.R. and A.A. Chang (1977), "The Linear Programming versus Positively Estimated Supply Functions: An Empirical and Methodological Critique", American Journal of Agricultural Economics, Vol.59, pp.344-357.

Skrapek, W.A., B.M. Korkie, T.E. Daniel, (1976), Mathematical Dictionary for Economics and Business Administration, Allan and Bacon Inc. Boston.

Smill, V. and T. Kuz (1976), "European Energy Elasticities", Energy Policy, pp.171-175.

Smith, B., (ed), (1979) Taxation of the Mining Industry, CRES, ANU, Canberra.

Sparrow, T., D. Pilati, W. Marcuse, (1979), "A Programming Model for Industrial Energy Conservation Policy", Resources and Energy, Vol.2, pp. 179-199.

Stancescu, I.D. (1985), Energy and Nuclear Power Planning in Developing Countries, International Atomic Energy Agency, Vienna.

Stewart, G.A., H.A. Nix, G. Gartside, W. Rawlins, R. Gifford, J. Siemon (1979) The Potential for Liquid Fuels from Agriculture and Forestry in Australia, CSIRO, Australia.

Swan, P.L. (1984a), "Resource Rent Tax: the Issues," Economic Paper (Vol.3): pp 1-10.

Swan, P.L. (1984b), "Real Rates of Return in Electricity Supply: New South Wales, Tasmania, and Victoria," paper presented at Conference Economic Electric Power System, May 2-3, University of New South Wales, Sydney.

Swanson, L.W. (1980) Linear Programming: Basic Theory and Applications. McGraw-Hill Kogakusha Ltd, Tokyo.

Sweeney, J. L., (1981), "Energy and Economic Growth: A Conceptual Framework", in I. Kavrakoglyu, (ed). Mathematical Modelling of Energy Systems, Sijthoff & Noordhoff International Publishers B.V., The Netherlands.

Taha, A.H. (1976), Operations Research: An Introduction, 2nd Edition, Macmillan Publishing Company INC., New York.

Takayama, A. (1974) Mathematical Economics, Holt, Rinehart & Winston, New York.

Takayama, T. and G. G. Judge (1964), "Equilibrium Among Spatially Separated Markets: A Reformulation," Econo-

metrica, Vol.32.

Tengrove, C.D (ed), (1986), Australian Energy Policies in the 80's, Allena and Unwin Australia, Sydney.

Tessmer, R.G. & K.C. Hoffman (1975), "Coupled Energy-System- Economic Models and Strategic Planning" in Computers and Operations Research, Vol.2. Pergamon Press, Oxford.

Theil, H. (1956), "On the Theory of Economic Policy", American Economic Review, Papers and Proceedings, XLVI, May, pp.360-366.

Theil, H. (1970), Economic Forecasts and Policy, Third Printing, North-Holland Publishing Company, Amsterdam.

Tinbergen, J. (1952), On the Theory of Economic Policy, North- Holland Publishing Co., Amsterdam.

Tinbergen, J. (1954), Centralization and Decentralization in Economic Policy, North-Holland Publishing Co., Amsterdam.

Tinbergen, J. (1956), "Determination of an Optimum Economic Policy", Econometrica, XXVIII, pp.1-10.

Todaro, M.P. (1971), Development Planning Models and Methods, Oxford University Press, Nairobi.

Todaro, M.P., (1981), Economic Development in the Third World, Longman, New York.

Todd, J. (1983), "Some Comments on Australian Fuelwood Use", keynote address, Firewood Forum, Institute of Foresters Australia Inc., 29-30 April 1983, Canberra.

Treasury, (1984), "Energy Markets: Some Principles of Pricing", in Lloyd P.J., (ed.) (1984) Mineral Economics in Australia, Allen & Unwin, Sydney.

Trehan, R.K., J.G. Leigh and W.R. Park, (1979), Energy and Development: A Preliminary Analysis for Less Developed Countries. The Mitre Corporation, McLean, Virginia.

University of Tasmania (1986), Degree of Doctorate of Philosophy Handbook, Hobart.

Unlu, G (1987), "A Linear Bilevel Programming Algorithm Based on Bicriteria Programming," Computers Operation Research, V.14, No.2, pp. 173-179.

Van Dugteren. T. ed. (1980) Oil and Australia's Future: the Economic, Social and Political Aspects, Hodder & Stoughton, Sydney.

van Eijk, C.J. & J. Sandee (1959), "Quantitative Determination of an Optimum Economic Policy", *Econometrica*, XXVII, pp. 1-13.

Vincent, D.P. et al. (1979), The Short-term Effect of Oil Price Increases on the Australian Economy with Special Reference to the Agricultural Sector, Paper presented to the Australian Agricultural Economics Society, Twenty-third Annual Conference, Canberra. (Cited in Brain & Schuyers, 1981)

Vincent, D.P., P.B. Dixon, B.R. Parmenter, D.C. Sams, (1980), "Implications of World Energy Price Increases for the Rural and Other Sectors of the Australian Economy," in K.M.W. Howers, et. al. (eds), *The Impact of Changes in Energy Costs on the Rural Sector of the Australian Economy*, C.S.I. R.O. Division Land Resources and Management, Perth.

Walras, L (1954), *Elements of Pure Economics*, translated by W. Jaffe, Allen and Unwin, London. (Original publication in 1987).

Webb, M.G. (1967), *Pricing Policies for Public Enterprises*, MacMillan, London.

Webb, W.G. & M.J. Ricketts (1980), *Economics of Energy*, Macmillan Press, London.

Wells, G.M. (1977), "Optimal Economic Policies in Australia", Ph.D. thesis, Department of Economics, University of Tasmania.

Wen, U. (1981) *Mathematical Methods for Multi-level Programming*, Ph. D. Thesis, State University of New York, New York.

Wen, U. and W.F Bialas (1986), "The Hybrid Algorithm for Solving the Three-level Linear Programming Problem," *Computers and Operation Research*, Vol. 13, No.4, pp 366-377.

Wright. A. W. (1978) "The Case of the United States: Energy as a Political Good", *Journal of Comparative Economics*, Vol.2, pp 144-70.

Yotopoulos, P.A. & J.B. Nugent (1976), *Economics of Development: Empirical Investigations*, Harper & Row Publishers Inc., New York.

APPENDIX A

A SURVEY OF THE DEVELOPMENTS IN MLP : DIRECTIONS FOR FURTHER DEVELOPMENTS

A.1 CURRENT STATE OF MLP DEVELOPMENTS

Since the development of MLP in 1977 (Candler and Norton [1977]), there has been a considerable number of studies on MLP. These studies have been done in two areas of MLP: (1) model development and application; and (2) solution algorithm, with the main emphasis on the specification of an appropriate solution algorithm.

A.1.1 Model Development and Application

MLP models have been developed to represent and study the multi-level hierarchical decision making system, particularly at the sector levels. These model specification studies may be broadly grouped into two types: illustrative models and actual real world models.

(a) Illustrative Models:

These models are specified to demonstrate examples of MLP for developing algorithms to solve those types of models. Some of these models are very small, consisting of three or four variables. Other models have a dozen or so variables and equations. Although these

models represent underlying systems, they are not large enough to capture the salient features of the underlying systems with their necessary details (for example Fortuny-Amat and Mccarl, [1981]).

(b) Real World Models:

Some of the MLP studies have been undertaken to develop real world models of the underlying systems, for example Candler and Norton [1977], Bisschop et al. [1982], Sparrow et al. [1979], and Ballenger [1984].

Candler and Norton [1977] have specified a price control MLP model for the Mexican agricultural sector formed of 309 variables and 46 constraints. The policy target variables in the model are: employment, income, the levels of maize and wheat productions, and the size of the government budget. The policy instruments which are included in the model are water taxation, subsidy, government expenditure, prices and a share of crop purchased by the government. Ballenger's [1984] study is similar to that of Candler and Norton, since both of these models are used mainly for tracing out the policy feasible space.

Bisschop et al.'s [1982] model is much larger than the Candler and Norton model. It is a price and resource control MLP model, with the maximization of net farm income being the objective of the government and the public sector, while taxes, subsidies and the allocation of water resources are the available policy instruments.

The model of Sparrow et al. [1979] is a public-private sector interactive model for the formulation of a conservation policy in the iron and steel industry. The objective of the public sector is to maximize real benefits, measured in terms of the energy

saved while the objective of the private sector is to minimize cost of production in the industry. The model solution provides the mix of research and development expenditures, both public and private, and the taxes and subsidies that optimise the policy objective function.

A.1.2 Solution Algorithms

Because of space limitations, a brief survey of the existing algorithms for solving MLP is provided here. More elaborated surveys are done in Candler, Fortuny-Amat and McCarl [1981] and Wen [1981], among others.

(a) The Replacement Method:

In the first approach, which is termed the Replacement Method, the lower level problem is replaced by its Kuhn-Tucher conditions (Bard and Falk [1982], Bialas, Karwan and Shaw [1980], and Fortuny-Amat and McCarl [1981]). The transformed MLP problem thus becomes a single level mathematical programming problem although a non-convex one. This is caused by the complementary slackness conditions of the lower level problem.

Fortuny-Amat and McCarl [1981] solve this non-convex programming problem as a mixed integer programming problem by replacing the complementary slackness conditions by zero one integer constraints. Bard and Falk [1982] solve the transformed MLP by an algorithm which is based on branch and bound methods. Another method termed as the parametric complementary pivot approach is developed by Shaw [1978]. In this approach, the objective function of the upper level problem is placed in the set of constraints which includes the complementary slackness conditions. A restricted basis entry simplex procedure is

used to obtain a solution to the resultant problem. The objective function of the upper level problem is varied parametrically until all the feasible complementary basis are enumerated.

In the Bisschop et al. [1982] Model, the objectives of both levels of the two level programme are the same i.e., minimization of the cost of the agricultural sector. The principle of the algorithm in this model has been to determine the shadow prices and optimum values of the activities from the model ignoring the lower level objective followed by the placement of these values to the lower level problem to solve the optimum values of the lower level activities.

In the Candler and Townsley [1982] approach, the dual behavioural problem of resource control MLP is solved as a parametric programme to explore all the feasible basis to find the global optimum of the policy problem.

(b) Other Solution Algorithms

The most important of the other remaining approaches is based on the Sequential Unconstrained Minimization Technique (SUMT). With this approach, the constraints of the lower level problem of MLP are replaced by their penalty functions and the problem is transformed to an unconstrained optimization problem. The lower level problem can be optimized by the INSUMT algorithm (SUMT in the lower problem), and the simultaneous optimization of the two problems can be performed by a combined program: SUMT-INSUMT.

Another approach is to solve multi-level programmes iteratively/heuristically. The basic principles of the iterative algorithm have been stated by Fortuny-Amat [1979]. In this ap-

proach, 'some reasonable levels' of the policy instruments are exogenously determined and the lower level problem is then solved for all these levels of policy instruments. That level of policy instrument is chosen which produces the optimum value for the upper level objective function.

The essence of the algorithm is the exogenous selection of a finite number of values within a finite range of intervals of the policy instruments by adopting one of the methods for explicating the preferences of policy makers. Then, it is necessary to solve the behavioural model for each combination of the values of the policy instruments and to consider the value of the policy objective function for each set of values of policy instruments and to choose the one with the optimum value.

From the above discussion of the MLP algorithms, it appears that some sort of transformation of the original problem is necessary in most of the algorithms. This makes the solution of MLP relatively difficult. Also, in most cases the size of the transformed MLP becomes large in comparison with the original problem. Again, the algorithms are not usually commercially available. APEX III is the only commercially available software for MLP that requires easy transformation of an MLP model to be solved by it.

Therefore, there is a general need for developing both algorithm and software that are easily operational and readily available.

The development of an alternative algorithm in the present study was motivated by the general necessity for development of a new algorithm as well as by the hitherto non-availability of software for the problem under study.

A.2 A CRITICAL EVALUATION AND THE DIRECTIONS FOR FURTHER RESEARCH:

The limitations of existing MLP studies are as follows:

(1) The illustrative MLP models cannot be used for any real policy studies since these models are not capable of representing the necessary details of the systems under study.

(2) The limitations of the large scale models are that (i) the policy planning problem characterized by the classification of variables as targets and instruments is not included in these models, and (ii) in some studies, the emphasis has been on the analysis of the reactions of economic agents to the changes in the public policies rather than on the formulation of a set of optimum policies that can achieve the government objectives.

(3) The general difficulty with some of the existing algorithms is that they can find only an approximate solution to MLP through an iterative process. In these cases, it is not possible to determine the global optimality of the solution.

The algorithms which find the exact MLP solution by simultaneous solution of a complete MLP, can not be used to solve large scale MLP models due to several reasons including the computer space problem.

The needed directions for further research are as follows:

(a) Large MLP models should be developed representing the details of the underlying systems for undertaking useful policy studies.

(b) Algorithms need also be developed that can solve large MLP models exactly, preferably not iteratively, with minimum computer space and CPU time requirements and those should be available commercially.

In view of this needed research in MLP, attempts are made in this study to develop an approach that can overcome some of the limitations of existing MLP models.

APPENDIX B

SOME ADDITIONAL TOPICS OF THE PROPOSED MLO MODEL

In this appendix, some additional information about the theoretical MLO model developed in Chapter Two is provided. This includes (a) a discussion of the characteristics of the present modelling approach, and (b) a demonstration on the type of analytical insights that a theoretical MLP model can provide on the characteristics of multi-level decision making in the energy sector (such numerical results are discussed in Chapter Five).

B.1 SOME FEATURES OF THE PRESENT ENERGY PLANNING STUDY/APPROACH

Some of the important characteristics of the multi-level energy planning approach developed above are stated below.

(i) Applied Welfare Economic Study:

The present approach is adoptable to applied welfare study since it deals with the principles of maximization of social welfare in the energy sector. Therefore, this study is following the established steps of an applied welfare economic analysis: (i) to define a social welfare criterion, (ii) to identify the factors that may prohibit the achievement of the optimum level of welfare and (iii) to suggest a set of policy actions, the adaptation of which will maximize social welfare (Oser and Brue [1988]).

(ii) Multi - Level Optimization Approach:

As the objective of this study is to formulate an optimum

energy plan, this requires an optimization approach. The present multi-level energy planning approach recognizes the existence of and is explicitly based on the two-level decision making system existing in the energy sector (the upper level decision maker - the government and the lower level decision makers - producers and consumers). In this MLO approach, it is assumed that both the government and economic agents engage in optimizing behaviour for making decisions (rational choice). The assumption that the government engages in optimizing behaviour is implied by the theory of economic policy of Tinbergen (Tinbergen [1952]) and the assumption of the optimizing behaviour of economic agents is implied by the neoclassical economic theory. The government attempts to maximize social welfare, while economic agents optimise their well being (Oser and Brue [1988])¹. Such a two level decision making system requires a two-level optimization approach for modelling the energy sector planning problem.

(iii) Multi-Disciplinary Character:

The present approach is multi-disciplinary in character. Energy planning and modelling (Meier [1984]) involves the utilization of the knowledge of mathematics, operations research, economics and energy engineering to develop computerised models to address energy planning and policy issues.

(iv) Partial Equilibrium Model:

The energy sector planning may address only the energy sectoral issues and options (partial equilibrium approach) or it may

1. Although the Chicago School does not believe that the government optimizes social welfare.

incorporate energy macro-economic interactions and policy issues (general equilibrium approach). Both of these approaches have advantages and disadvantages.

Economic planning is generally considered in a general/multi-market (sector) equilibrium context because of the welfare implications of general equilibrium analysis. As a result, a general equilibrium planning approach in which simultaneous interrelationships between different sectors of the economy are considered is usually to be preferred. The disadvantage of this approach is that in this type of models, the details of the energy sector, specially the technical details, can not be incorporated, and computational difficulties may arise.

However, the partial equilibrium approach to energy sector planning is well established and accepted in the profession following the Marshallian approach to partial equilibrium analysis (Marshall, [1920]). It is true that such an approach can not capture the secondary benefits/losses of the interrelated markets. But the partial equilibrium approach is justified by arguing that the optimum welfare in a partial equilibrium setting will also result in optimum welfare in a general equilibrium framework (Griffin and Steele [1980]). The theory of second-best (Lipsey and Lancaster [1956-1957]), however, advocates a different view: in a situation where some markets are not perfect, achievement of optimum conditions in one market may lead to overall welfare loss in the economy, rather than welfare gain. This theory may be true under some restrictive situations such as the strong substitutability and complementarity of goods, and markets characterized by ineliminable distortion. Generally, these conditions are not met and the partial equilibrium analysis is considered to have optimum welfare

implications (Härberger, [1971], Griffin and Steele, [1980]).

There are several other advantages of partial equilibrium analysis of the energy sector or energy sector planning: it allows consideration of special characteristics of each industry within the sector, it is computationally simple, it requires minimum data, and it provides an aggregated viewpoint in the appraisal of individual projects by presenting detailed information about the processes etc. (Riaz, [1984], p. 26).

The real choice of the scope for energy sector planning hinges on some factors such as the objective and nature of the planning studies, adopted methodology, and computational facilities (availability of algorithm, software and hardware). Ignoring any computational problem, a partial equilibrium approach to energy planning will be found desirable if the objective of an energy planning study is to focus mainly on the detailed economic, technical and policy issues in the energy sector. The emphasis of such studies is on the (Munasinghe and Schramm [1983], p. 85)

" .. detailed analysis of each sub-sector with special emphasis on interactions among them, substitution possibilities, and the resolution of any resulting policy conflicts...."

As the emphasis of this study is on the detailed and comprehensive sectoral policy issues and options, the partial equilibrium approach (micro-energy planning) is adopted in this study.

(v) Multi-Level Energy Planning: Energy System and Policy Planning:

The energy planning may involve the planning of the energy system (determination of the optimum energy demand-supply combination, technological pattern and activities), together with the formulation of a set of optimum energy policies or either of them

separately. In the present study, energy planning refers to multi-level energy planning: the planning of the energy system and policy simultaneously.

(vi) Quantitative Energy planning:

Energy planning may refer to some qualitative energy policies such as the determination of the appropriate energy market regulation policy, institutional restructuring, control of ownership etc. It also may refer to quantitative policy such as pricing policy, taxation policy etc. In this study, only the quantitative energy policies are incorporated and studied.

(vii) Long-Term Energy Planning

Folie and Ulph [1977] have classified major energy policy issues in three groups: short, medium and long-term. The short-term energy policies are addressed to energy problems which arise from the instability in the energy market (supply, demand and price). The medium-term energy policy issues relate to the possibility of supply increases and inter-fuel substitution in energy supply, production and end uses within the structure of the existing energy system. The long-term energy policy issues deal with the problems of finding alternative, not readily adoptable, supplies of energy resources, and production and end-use technologies. This is only possible within a new structure of the energy system.

In the present study, the medium and long term energy policy and planning issues involving substantial structural changes will be addressed. Therefore, these policy studies (Chapter Five) will have a time horizon of 10-15 years in terms of their implementation and implications.

(vii) Energy Sectoral Model

In any sector model, the energy sector is considered as an economic unit (Hazell and Norton [1986], Chapter 7) such as the household, firm or government. A sector model should have several elements such as: (1) descriptions of producers' and consumers' economic behaviour, (2) production conditions, (3) resource endowments, (4) market conditions (perfect competition in the present study) and (5) policy system. In the proposed MLO model, all these elements are present. The behavioural model represents the elements (1) to (4) and the complete MLO model represents (5).

B.2 CHARACTERISTICS OF MULTI-LEVEL DECISION MAKING: SOME ANALYTICAL RESULTS

In this section, some analytical aspects of multi-level decision making embedded in the MLO model will be discussed. These analytical aspects are reflected in the processes of reactions and adjustments in various decision variables and relationships of different types of decision makers and the resultant equilibrium in the policy system in the model. Similar aspects of multi-level decision making revealed by AEPsOM results will be discussed in Chapter Five.

(a) Optimum Policy in an MLO Model

In the theory of economic policy, developed on the basis of a single level optimization model, the optimum values of the instruments are the policies that optimise the policy objective function. But in a multi-level optimum energy-economic policy framework, the optimum policy instruments are those for which the objective func-

tions of different level policy makers attain their optimum values.

The optimum policies in the framework of MLP model can be provided by the complete MLP model with the Kuhn - Tucker conditions of the behavioural model (with $\pm T$) as follows:

$$\text{Max } W = wG \quad (a)$$

$$\{G, \pm T_1, \pm T_2, \pm T_3, Y_p\}$$

s.t.

$$T_1 \leq \{\pm T_1, \pm T_2, \pm T_3\} \leq T_p \quad (b)$$

$$G = I_1 Y + I_2 X + I_3 Z \quad (c)$$

$$Y_p \leq Y_c \quad (d)$$

$$\{-(+T_1)Y - (+T_2)X - (+T_3)Z +$$

$$(-T_1)Y + (-T_2)X + (-T_3)Z\} \geq 0 \quad (e)$$

$$c_1 \pm T_1 - b\mu - \Gamma \geq 0 \quad (f)$$

$$c_2 \pm T_2 - a\delta - \mu - \beta \geq 0 \quad (g)$$

$$c_3 \pm T_3 - \alpha - \delta \geq 0 \quad (h)$$

$$Z - D = 0 \quad (i)$$

$$Z - aX = 0 \quad (j)$$

(B.1)

$$X - bY = 0 \quad (k)$$

$$Y + Y_p \leq \bar{Y} \quad (l)$$

$$X \leq \bar{X} \quad (m)$$

$$(c_1 \pm T_1 - b\mu - \Gamma)Y = 0 \quad (n)$$

$$(c_2 \pm T_2 - a\delta - \mu - \beta)X = 0 \quad (o)$$

$$(c_3 \pm T_3 - \alpha - \delta)Z = 0 \quad (p)$$

$$(Z - \bar{D})\alpha = 0 \quad (q)$$

$$(Y + Y_p - \bar{Y})\Gamma = 0 \quad (r)$$

$$(X - \bar{X})\beta = 0 \quad (s)$$

$$G, Y_p, Y, X, Z, \alpha, \delta, \Gamma, \mu, \beta \geq 0 \quad (t)$$

(b) Selection of Energy-Economic Policies by the Government

Selection of levels and mix of tax and subsidy will depend on the condition of whether an equation is binding or not. If an equation is binding, then policy will be to employ $+T$ (taxes) and if an equation is not binding the policy will be to employ $-T$ (subsidies). This is how a selection of optimum $\pm T$ is made in MLP.

But the ultimate choice of $\pm T$ and their optimum values will depend on the policy objective function. If an equation is binding, and the corresponding activity is preferred by the policy makers, then the selection will be $+T$. If $+T$ is chosen, then other energy policies will be undertaken by the government to reduce the tightness of the constraint. Other policies will be chosen because if the constraint is binding, it will have non-zero shadow prices (defined in Chapter Five) and will attract other policy attentions.

Y_p is usually exogenously determined. If Y_p is endogenous in the model, it will be determined in such a way that it will control the energy resources available for economic agents so that the policy objective function attains its optimum value.

(c) Conditions for Optimum Decisions of Economic Agents

In an energy system without government tax and subsidy intervention, the energy sector equilibrium conditions represent the equalities between the market costs and the imputed costs. With government intervention, equilibrium conditions change. In the latter case, the energy sector equilibrium conditions are perturbed by the government controls: $\pm T$ and Y_p .

In an energy policy regime, the conditions for optimum decisions (choice of a set of optimum behavioural variables) for the economic agents are shown by the equations B.1.n to B.1.s. The

decisions of economic agents regarding energy supply, conversion, and end-uses are guided by the following rules: Equation B.1.n implies that market costs (fixed and variable costs) of the primary energy supplies plus net tax must be greater than or equal to the imputed value of the fixed energy resources (Ricardian rent), and to the imputed value arising from the allocation of these resources to different energy conversion technologies (user's cost). Equation B.1.o implies that the costs of secondary energy conversion technologies plus net tax must be greater than or equal to imputed costs to different conversion technologies (operation and capacity costs) less the user's cost attributed to allocation of resources to different technologies. Equation B.1.p implies that the costs of end-use technologies plus net taxes must be greater than or equal to the imputed costs of the end-uses plus imputed costs of the end-use technologies.

Equations B.1.q to B.1.s imply that different forms of primary and secondary energy will be supplied and used in cases where the market costs plus net $\pm T$ and imputed costs of different forms of energy will be equal.

APPENDIX C

AEPSOM: DATA: SOURCES AND METHODS OF ESTIMATION

C.1 A DISCUSSION OF THE GENERAL ASPECTS

(a) Data Need

For a numerical specification of AEPSOM, the following types of data are needed: (1) weights of the policy target variables; (2) average costs per unit of each type of energy and technologies; (3) the efficiency rates of the conversion and end-use technologies; (4) the values of the right hand side parameters of the constraints.

(b) Units of Measurement

The energy variables and coefficients are measured in peta-joules. Cost coefficients are given in 1980 Australian dollars (millions).

(c) Sources of Data

Sources of data are indicated in different tables. Tables/data without an indication of source are the authors' estimates based on the available information, mainly from Musgrove et al. [1983].

C.2 DATA FOR AEPSOM

C.2.1 Policy Objective Function

The base case weights of the policy target variables were : Iel:1, CNo:1, and TcE:1. Sensitivity analyses were also undertaken

by changing the coefficients in different combinations (Table 5.12 in Chapter Five).

C.2.2 Policy and Budgetary Constraints

The policy constraints were specified numerically in the text of Chapter Three. There is no need for any data to be specified in the budgetary constraints.

C.2.3 Behavioural Objective Function

The MARKAL estimates of costs of supply, imports, secondary energy conversion, electricity generation and end-uses for the year 1979-80 were a major source of data for the AEPSOM behavioral model. Many other complementary data were used to calculate the reported figures. These five types of costs will be discussed separately.

(1) Supply Costs

The supply and import costs of the primary energy are:

Table C.1

Supply Costs of Energy

Energy	m\$/PJ
coal (R_1)	0.72
imported crude oil (Ie_1)	5.00
domestic crude oil (R_2)	5.30
natural gas (R_3)	0.78
wood (R_6)*	1.18
uranium (R_7)	0.13

*(Source: Todd [1983])

(2) Costs of Secondary Energy Conversion and ElectricityGeneration

Some costs in this category relate to the secondary energy flows and some relate to individual technologies. In some cases where secondary energy is the same in primary and secondary form such as coal, natural gas and wood, no conversion costs exist, and so no secondary energy conversion costs of these types of energy have been used in the model.

Costs of the relevant secondary energy and conversion technologies are as follows:

Table C.2

Costs of Conversion Technologies

Conversion Technologies/Flows	Costs m\$/PJ
refinery cost (x_2)	1.39
hydro-electricity generation (E_4)	19.27
electricity generation from coal (E_1)	13.98
electricity generation from petroleum products (E_2)	18.69
electricity generation from natural gas (E_3)	22.32

These costs are sums of the investment, operating and maintenance costs of the conversion technologies or flows.

It is difficult to calculate the aggregate refinery cost of petroleum products. A modern refinery consists of many types of units to provide facilities for different types of processing of crude oil. To avoid these difficulties, total aggregated costs of all the processes was adopted to use as the average cost of refineries.

Cost of electricity generation from hydro, petroleum products and natural gas have been adopted from MARKAL. The cost of electricity generation from coal has been estimated on the basis

of the weighted average of the different types of coal used in 1979-80 in electricity generation.

(3) The Costs of the End-uses

The end-use costs are based mainly on the estimates of end use costs in MARKAL. Two main types of costs have been used to estimate the average costs of the end-uses: delivery costs where appropriate, and investment, operation and maintenance costs.

(a) Delivery Cost

The delivery charges of energy have been adopted from MARKAL. The weights for estimating average delivery costs of energy in the present model are the actual quantities of fuels/energy used in different sectors, and are adopted from Department of National Development and Energy [1982].

Calculated average delivery and other costs of different forms of energy are as follows:

Table C.3

Delivery Costs of Energy (m\$/PJ)

	Manufacturing Industry	Agriculture	Transport	Domestic
coal	0.45 (d_1)			1.32 (d_{10})
petroleum products	0.35 (d_2)	0.35 (d_6)	1.45 (d_8)	1.40 (d_{11})
natural gas	1.00 (d_3)			2.19 (d_{12})

(b) Investment, Operation and Maintenance Costs

Calculation of the cost of aggregated end-use

technologies/flows is more difficult than aggregated cost estimates in the other cases. This is so since a substantial amount of investment, operating and maintenance costs are not involved in all end-use technologies. For example, there are different technologies in the manufacturing sector that use coal. However, not all these technologies involve substantial amounts of investment, operation and maintenance costs. Therefore, aggregation of the costs of all these technologies may not give a representative figure for aggregated end-uses. Also there was a lack of information about all these end-use technologies except for the use of coal in the industrial boiler, so that the average cost of using coal in the manufacturing sector has been adopted as typical of technology costs.

The costs of using different forms of energy to raise steam in the manufacturing sector are:

Table C.4

Boiler Costs

Energy	Costs m\$/PJ
Coal(d_1)	2.02
Petroleum Product (d_2)	1.42
Natural Gas (d_3)	1.23

Table C.5

Investment, and Operation and Maintenance

Costs of Other Energy in Manufacturing Industry Sector

Energy	Cost (M\$/PJ)
Electricity (d_4)	2.30
Wood (d_6)	0.25

The cost of a heavy mobile plant has been used as the cost of end-use of energy in the agricultural sector. The cost is as follows:

Table C.6

Heavy Mobile Plant Costs

Energy	Costs m\$/PJ
petroleum products (distillate)(d ₆)	71.93

Calculation of the cost of end-uses of energy in the transport sector is complicated by the fact that there are various types of end-use technologies (vehicles) which use different types of energy. The weighted average costs of the end-uses were calculated. The weights are the actual uses of the particular energy by different types of vehicles 1979-80 (source of the weights: Musgrove et al. [1983], Department of National Development and Energy, [1982]). Calculated investment, operation and maintenance costs of the end-use energy flows are given in Table 3.6.

Table C.7

Investment, and Operation and Maintenance

Costs of End-uses of Energy in the Transport Sector:

Energy	Cost m\$/pj	Transport Type
petroleum products (d ₈)	237.56	railway
electricity (d ₉)	220.40	railway

The investment, and operation and maintenance costs of the energy uses in the domestic sector are given in Table C.8.

Table C.8

Investment, and Operation and Maintenance Costs of Energy Uses
in the Domestic Sector

Energy	Cost m\$/PJ
coal (d ₁₀)	1.32
petroleum products (d ₁₁)	0.98
natural gas (d ₁₂)	3.39
electricity (d ₉)	6.17
solar (d ₁₅)	6.69

C.2.4. The Behavioural Constraints

(1) Demand Constraints

Data necessary for these constraints are only the amounts of energy demanded in each of the sectors.

The following figures for the end-uses of energy in different sectors are adopted from Department of National Development and Energy ([1982];p.18):

Table C.9

Energy End-Uses: 1979-80

Sectors	Energy PJ
Manufacturing (including mining) (DE ^I)	837.20
Agriculture (DE ^A)	142.32
Transport (DE ^T)	812.08
Domestic (DE ^D)	389.30
Demand for electricity in manufacturing industry (d ₄)	129.77
Demand for electricity in agriculture (d ₇)	4.19
Demand for electricity in domestic sector(d ₁₃)	154.88
Export	
Coal (E _{e1})	1272.54
Petroleum products (E _{e2})	133.95
Uranium (E _{e3})	581.85

(2) End-use Energy Flow Constraints

These constraints define the flows of energy uses in the different sectors. It has been mentioned that the flows are gross energy uses, so the efficiency factors have not been incorporated to calculate net energy uses in these equations. There is no need for any data to be specified in these equations.

(3) Secondary Energy Supply Constraints

Efficiency factors that have been derived in AEPSOM are shown in Table C.10.

Table C.10

Efficiencies of Different Technologies

Energy	Efficiency Factors
x_3	0.86
E_1	0.24
E_2	0.33
E_3	0.33
x_2	0.86
x_4	0.14

(4) The Primary Energy Balance Equations

There is no need for any data to be specified in these equations.

(5) Resource Constraints

The next set of numbers that we have adopted in our study represents the availability of resources in 1979-80. Total domestic supplies of coal, crude oil and natural gas are the upper

limits on the availability of primary energy resources in the model.

Table C.11

Primary Energy Resources: 1979-80

Energy	PJ
Coal (R_1)	2448.81
Crude oil (R_2)	874.87
Natural gas (R_3)	364.18
Wood (R_6)	138.14
Solar energy (R_7)	0.50*
Uranium (R_8)	586.04

(Source: Department of National Development & Energy, [1982], p.18)
 (*Solar energy supply level is adopted from MARKAL (MARKAL determines 0.50 PJ as the optimum level for 1979-80)).

(6) Capacity Constraints

The capacities of different technologies in 1979-80 are:

Table C.12

Capacities of Different Technologies: 1979-80

Energy	PJ
Hydro-electricity (E_4)	86.61
Total electricity (x_4)	411.11
Petroleum products (x_2)	1586.49

(Source: Department of National Development and Energy [1981], pp.24-29)

(*The electricity generation capacity and refinery capacity (MW and barrel/day) have been converted to PJ by the appropriate conversion factors. See Meier ([1984], Chapter Eight) for conversion factors that relate MW to MWh/year.)

C.3 METHODS AND PRINCIPLES OF ESTIMATION AND/OR AGGREGATION OF DATA IN AEPSOM

In MARKAL, almost all the possible existing and future individual energy supply, secondary and end-use conversion technologies are specified. For AES in the present work, the aggregated energy flows at different stages are mainly specified, except in some cases where a single technology has been specified. To make the MARKAL data consistent with the requirements of AEPSOM, the data have been aggregated with weights. The weights are the actual energy production and end-uses in 1979-80, adopted from Department of Energy and Resources [1982]. In some cases, actual energy flows corresponding to some individual technologies were not available. In these cases, optimum values of energy determined by the MARKAL solution were adopted.

APPENDIX D

SOME ADDITIONAL TOPICS ON THE PPS ALGORITHM

Chapter Four has discussed the PPS algorithm as it applies to a price control MLP in detail. In this appendix, some related topics such as (A) the general mathematical properties of an MLP such as existence, uniqueness and global optimality of the solution, and (B) the application of the PPS algorithm to other types of MLP (resource control, dynamic and non-linear behavioural model) are discussed. In addition, a formula for changing the units of parametric variations is presented.

D.1 EXISTENCE AND UNIQUENESS PROBLEM

To demonstrate the general problems of non-existence and non-uniqueness of MLP, we specify a non-numerical model of an MLP, which is specified as follows:

$$\begin{aligned} & \text{Max } W = x_1 x_2 \\ & \{t_1, t_2\} \\ & \text{s.t.} \\ & \text{Max } Z = p_1 x_1 + p_2 x_2^2 - c_1 x_1^2 - c_2 x_2^2 - t_1 x_1 - t_2 x_2 \\ & \{x_1, x_2 \mid t_1, t_2\} \\ & \text{s.t.} \\ & a_1 x_1 + a_2 x_2 = R \\ & x_1, x_2 \geq 0 \end{aligned} \tag{D.1}$$

For finding the optimum values of x_1 , and x_2 for any given t_1 and t_2 , it is required to differentiate partially the behavioural sub-problem's Lagrangean function and make it equal to zero:

$$L = p_1x_1 + p_2x_2 - c_1x_1^2 - c_2x_2^2 - t_1x_1 - t_2x_2 + \Gamma(a_1x_1 + a_2x_2 - R) \quad (D.2)$$

$$\frac{\delta L}{\delta x_1} = p_1 - 2c_1x_1 - t_1 + a_1\Gamma = 0$$

$$\frac{\delta L}{\delta x_2} = p_2 - 2c_2x_2 - t_2 + a_2\Gamma = 0 \quad (D.3)$$

$$\frac{\delta L}{\delta \Gamma} = a_1x_1 + a_2x_2 - R = 0$$

For solving this set of linear simultaneous equations, they are redefined in matrix form:

$$\begin{bmatrix} -2c_1 & 0 & a_1 & x_1 \\ 0 & -2c_2 & a_2 & x_2 \\ a_1 & a_2 & 0 & \Gamma \end{bmatrix} = \begin{bmatrix} t_1 - p_1 \\ t_2 - p_2 \\ R \end{bmatrix} \quad (D.4)$$

Solving the set of simultaneous equations by the Cramer's rule, the values of x_1 and x_2 are found:

$$x_1 = \frac{a_2^2 (p_1 - t_1) + a_1a_2(t_2 - p_2) + 2c_2a_1R}{2 [c_1a_2^2 + c_2a_1^2]} \quad (D.5)$$

$$x_2 = \frac{2c_1 (a_2R) + a_1 [a_2 (t_1 - p_1) - a_1^2 (t_2 - p_2)]}{2 [c_1a_2^2 + c_2a_1^2]}$$

The values of x_1 and x_2 are substituted in the policy objective function to find the optimum values of t_1 and t_2 . First, the policy objective function is differentiated with respect to t_1 and

t_2 , and the values are put equal to zero:

$$\frac{\delta W}{\delta t_1} = x_1 \frac{\delta x_2}{\delta t_1} + x_2 \frac{\delta x_1}{\delta t_1} = 0 \quad (D.6)$$

$$\frac{\delta W}{\delta t_2} = x_1 \frac{\delta x_2}{\delta t_2} + x_2 \frac{\delta x_1}{\delta t_2} = 0$$

By substituting the values of x_1 and x_2 , we get:

$$\begin{aligned} \frac{\delta W}{\delta t_1} = & \frac{a_1 a_2^2 [a_2 (t_1 - p_1) + a_1 a_2 (t_2 - p_2) + 2c_2 a_1 R]}{2 [c_1 a_2^2 + c_2 a_1^2]^2} \\ & + \frac{a_2^2 [2c_1 a_2 R + a_1 a_2 (t_1 - p_1) - a_1^2 (t_2 - p_2)]}{2 [c_1 a_2^2 + c_2 a_1^2]^2} \end{aligned} \quad (D.7)$$

$$\begin{aligned} \frac{\delta W}{\delta t_2} = & \frac{-a_2^2 [a_2^2 (t_1 - p_1) + a_1 a_2 (t_2 - p_2) + 2c_2 a_1 R]}{2 [c_1 a_2^2 + c_2 a_1^2]^2} \\ & + \frac{a_1 a_2 [2c_1 a_2 R + a_1 a_2 (t_1 - p_1) - a_1^2 (t_2 - p_2)]}{2 [c_1 a_2^2 + c_2 a_1^2]^2} \end{aligned}$$

To solve for t_1 and t_2 the two equations are rearranged as:

$$\begin{bmatrix} a_1 a_2^2 + a_2^4 & - (a_1^3 a_2 + a_1 a_2^3) \\ - 2a_1 a_2^3 & 2a_1^2 a_2^2 \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \end{bmatrix} \quad (D.8)$$

$$= \begin{bmatrix} a_1^2 a_2^2 (2c_1 R - p_1) - p_2 (a_1^3 a_2 + a_1 a_2^3) - p_2 (a_1^3 a_2 + a_1 a_2^3 + a_2^4 p_1) + 2a_1 a_2^2 c_2 R = F_1 \\ 2a_1^2 a_2^2 p_2 + 2c_1 a_2^3 R - 2a_1 a_2^3 p_1 - 2c_2 a_1^2 a_2 R = F_2 \end{bmatrix}$$

If the right hand side expressions are defined as F_1 and F_2 and the two simultaneous equations are solved, the results are;

$$t_1 = \frac{(2a_1^2 a_2^2)F_1 + (a_1^3 a_2 + a_1 a_2^3)F_2}{2a_1^4 a_2^4 + 2a_1^2 a_2^6 - 2a_1^4 a_2^4 - 2a_1^2 a_2^6}$$

and (D.9)

$$t_2 = \frac{(2a_1 a_2^3)F_1 + (a_1^2 a_2^2 + a_2^4)F_2}{2a_1^4 a_2^4 + 2a_1^2 a_2^6 - 2a_1^4 a_2^4 - 2a_1^2 a_2^6}$$

In both cases, the values of the denominators are zero, and thus the determinant of the coefficient matrix is zero. So any unique solution to the MLP cannot be determined.

D.2 APPLICATION OF THE PPS ALGORITHM TO DIFFERENT TYPES OF MLP

In Chapter Four, the principles of solving a price control MLP by the PPS algorithm was stated. In this sub-section, it will be demonstrated that the PPS algorithm can also be applied to other types of MLP, such as resource control, price and resource control, dynamic, and non-linear (behaviour model) MLP.

In a parametric programming problem, there can be three types of parametric variations: variations in the cost coefficients, variations in the right hand side parameters, and a simultaneous variation in both. The case of variations of coefficients of the objective function is already dealt with (price control MLP). A parametric programme with variations in the right-hand-side parameters can be used to solve a resource control MLP, and a

parametric programme with both types of variations can be used to solve a price and resource control MLP.

D.2.1 Solution to a Resource Control MLP

(i) Resource Control MLP

A resource control MLP (bi-level programming) is usually defined as:

$$\text{Min } W_1 = wX_{11}$$

$$\{X_{11}, X_{21}\}$$

s.t.

$$\text{Min } C = c_1X_{21} + c_2X_{22}$$

$$\{X_{22} \mid X_{21}\}$$

(D.10)

s.t.

$$A_1X_{21} + A_2X_{22} \geq R$$

$$X_{11} = I_1X_{21} + I_2X_{22}$$

$$X_{11}, X_{21}, X_{22} \geq 0$$

Here X_{11} and X_{21} , and X_{22} are the energy target and behavioural variables respectively.

It would be more appropriate to redefine the above MLP as an activity control MLP, since the upper level controls the activities (production and consumption) of the lower level, but - not the supply (domestic production or import) of resources.

If the above MLP is called an activity control MLP, then another type of MLP can be defined as a resource control MLP in the case where supplies of resources are controlled by the upper level decision makers. A resource control MLP can be stated as:

$$\text{Min } W_1 = wX_{11}$$

$$\{X_{11}, X_{21}\}$$

s.t.

$$\text{Min } C = c_2 X_{22}$$

$$\{X_{22} \mid X_{21}\}$$

(D.11)

s.t.

$$A_2 X_{22} \geq R + A_1 X_{21}$$

$$X_{11} = I_2 * X_{22}$$

$$X_{11}, X_{21}, X_{22} \geq 0$$

For solving this resource control problem, the parametric programming of the behavioural sub-model may be represented as:

$$\text{Min } C = c_2 X_{22}$$

$$\{X_{22}\}$$

s.t.

(D.12)

$$A_2 X_{22} \geq R + \theta B \quad (\theta B = -A_1 X_{21})$$

$$X_{22} \geq 0$$

where B = a vector of the units of parametric variations (b_1, b_2, \dots, b_n) , and θ = parametric variation.

The complete resource control MLP, with the parametric programme in the lower level problem, may be stated as:

$$\text{Min } W_1 = w X_{11}$$

$$\{X_{11}, \pm \theta B = \pm X_{21}\}$$

s.t.

$$\text{Min } C = c_2 X_{22}$$

$$\{X_{22} \mid \pm X_{21} = \pm \theta B\}$$

(D.13)

s.t.

$$A_2 X_{22} \geq R + \theta B$$

$$X_{11} = I * X_{21}$$

$$X_{11}, X_{22} \geq 0$$

Here $\theta_1, \dots, \theta_n$ are the marginal rates of substitution between the optimum value of the behavioural objective function

and the changes in the level of supply of resources. The reaction function $X_{22} \Phi(R \pm \Theta B)$ shows the changes in optimum responses of individual economic agents due to changes in levels of resource supplies or control of resources. Like a price control MLP, the solution to resource control MLP requires finding the value of ΘB (additional supplies of resources) and the corresponding values of X_{22} that provide the optimum values of the policy objective function.

The solution to a resource control MLP using parametric programming is illustrated in Figure D.1. In this case, the resource level varies with the different levels of parametric variations (shown in Figure D.1.c). Optimum solution to MLP occurs at the 9th level of parametric variation.

(ii) An Example

To demonstrate the applicability of the PPS algorithm to a resource control MLP, we refer to the following example:

The RHS parametric programming formulation of the linear programming problem in (D.13) is as follows (Daellenbach et al., 1983, P.140).

$$\text{Max } C = 24x_1 + 20x_2$$

S.t.

$$0.5x_1 + x_2 \leq 12$$

$$x_1 + x_2 \leq 20 \quad (D.14)$$

$$0.06x_1 + 0.04x_2 \leq 1 + \Theta \quad \{-1 \leq \Theta \leq +\infty\}$$

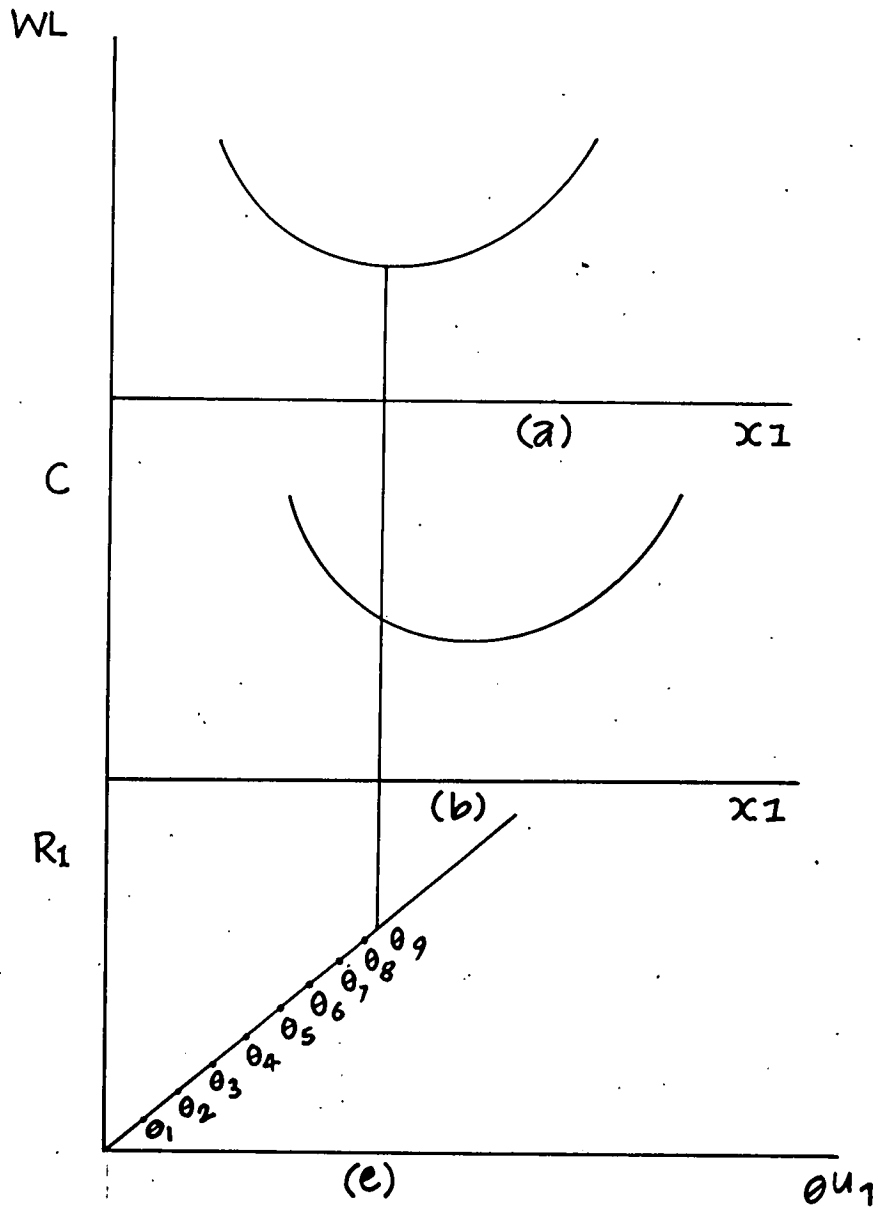
$$1200x_1 - 800x_2 \geq 0$$

$$x_1, x_2 \geq 0$$

In this example only one constraint is subject to the para-

FIGURE D.1

PPS ALGORITHM SOLUTION OF RESOURCE CONTROL MLP.



metric variation, but all the constraints can be subject to parametric variations.

The following are the results of the parametric solutions:

Solution 1: $\theta = 0$ $x_1 = 12$ $x_2 = 6$ $C = 408$

Solution 2: $\theta = 1$ $x_1 = 0$ $x_2 = 0$ $C = 0$

Solution 3: $\theta = 0.25$ $x_1 = 6$ $x_2 = 9$ $C = 324$

Solution 4: $\theta = 0.17$ $x_1 = 16$ $x_2 = 4$ $C = 464$

Solution 5: $\theta = 0.25$ $x_1 = 20$ $x_2 = 0$ $C = 480$

A resource control MLP formulation consisting of the above right hand side parametric programme is given below:

$$\text{Max } W = 2x_1 + x_2$$

s.t.

$$\text{Max } C = 24x_1 + 20x_2$$

s.t.

$$0.5x_1 + x_2 \leq 12 \quad (\text{D.15})$$

$$x_1 + x_2 \leq 20$$

$$0.06x_1 + 0.04x_2 \leq 1 + \theta \quad \{-1 \leq \theta \leq +\infty\}$$

$$1200x_1 - 800x_2 \geq 0$$

$$x_1, x_2 \geq 0$$

The application of the PPS algorithm involves searching of those five solutions and finding the one which provides the optimum value of the upper level objective function. The following is an illustration of how the PPS algorithm finds the optimum solution: The five parametric solutions to the programming problem provide the following values of the upper level objective function: Solution 1: $W = 30$, Solution 2: $W = 0$; Solution 3: $W = 21$, Solution 4: $W = 36$, Solution 5: $W = 40$. The PPS algorithm searches all these solutions and finds solution 5 as the optimum solu-

tion to the above resource control MLP. The optimum solution results are:

- (1) Upper level objective function $W = 40$,
- (2) Parametric variations: $\theta = 0.25$,
- (3) Activities: $x_1 = 20$, $x_2 = 0$.

(iii) Signs, Units, Direction and Range of Parametric Variations:

If there exists a resource control policy environment, the signs, directions and range of the parametric variations can be determined by studying the underlying policy system. For example, if the government policy is to increase the use of a resource, then the sign of the parametric variation would be + and if the policy is to decrease the supply then it would be -. Also the direction of the parametric variations can be determined by including the resource control variables in the policy objective function. The range of variations will certainly be specified from the information about the underlying policy system.

The units can be adopted in the following process. The policy and behavioural models are specified as:

$$\text{Min } W = wX_{11}$$

$$\{X_{21}\}$$

s.t.

(D.16)

$$A_1X_{12} + A_2X_{22} \geq R$$

$$X_{11} = I_1X_{22} + I_2X_{22}$$

$$X_{11}, X_{12}, X_{22} \geq 0$$

and $\text{Min } C = cX_{22}$

$$\{X_{22}\}$$

s.t.

(D.17)

$$A_2 X_{22} \geq R$$

$$X_{22} \geq 0.$$

Let optimum activity vectors of the models (D.16) and (D.17) be \bar{x}_{22}^P and \bar{x}_{22}^B respectively. The units of parametric variation then can be determined as:

$$U = \bar{x}_{22}^P - \bar{x}_{22}^B$$

If it is necessary to identify which activities are controlled, then the signs and units of the parametric variations should be as follows:

$$u_j > 0 \quad \text{if } \bar{x}_{22}^P(j) > \bar{x}_{22}^B(j)$$

$$u_j < 0 \quad \text{if } \bar{x}_{22}^P(j) < \bar{x}_{22}^B(j) \quad j = 1, 2, \dots, n.$$

$$u_j = 0 \quad \text{if } \bar{x}_{22}^P(j) = \bar{x}_{22}^B(j)$$

(iv) Algorithmic Steps:

When the signs, units, and range of parametric variations in a resource control MLP have been specified, steps 5 to 7 of the price control MLP solution algorithm in Section 4.7 (Chapter Four) can be followed to find an optimum solution.

D.2.2 Solution of a Price Control and Resource Control MLP

A price and resource control MLP¹ (bi-level programming) can

1. This model is similar to the model (2.21) in Chapter Two.

be defined as follows:

$$\text{Min } W_1 = wX_{11}$$

$$\{\pm T, X_{21}\}$$

s.t.

$$\text{Min } C = (c_2 \pm T)X_{22}$$

$$\{X_{22} \mid \pm T, X_{21}\}$$

(D.18)

s.t.

$$A_2 X_{22} \geq R - X_{21}$$

$$X_{11} = I_1 X_{21} + I_2 X_{22}$$

$$X_{11}, X_{21}, X_{22} \geq 0$$

The above MLP can be stated as an MLP problem with a parametric programming problem in the lower level :

$$\text{Min } W_1 = wX_{11}$$

$$\{\pm T, X_{21}\}$$

s.t.

$$\text{Min } C = (c_2 \pm \Theta U)X_{22}$$

$$\{X_{22} \mid \pm T = \pm \Theta U; X_{21} = \Theta B\}$$

(D.19)

s.t.

$$A_2 X_{22} \geq R \pm \Theta B$$

$$X_{11} = I_1 (\pm \Theta B) + I_2 X_{22}$$

$$X_{11}, X_{22} \geq 0$$

A comparison of the behavioural problem in (D.18) with the parametric programming problem in (D.19) reveals that they are similar (subject to the conditions discussed for the price control MLP). The behavioural problem in (D.19) is a parametric programming problem ; the main difference from the behavioural prob-

lem in (D.18) being that $R - X_{21}$ has been replaced by $R \pm \Theta B$ and $\pm T$ has been replaced by $\pm \Theta U$.

The algorithm for solving the MLP in (D.18) will be the same as it was in the previous cases.

D.2.3 Solution to a Dynamic MLP

To demonstrate the applicability of the PPS algorithm in solving a dynamic MLP (bi-level programming), the following dynamic MLP is specified:

$$\begin{aligned} \text{Min } W &= \sum_{i=1}^T \frac{w_i G_i}{(1+d)^i} \\ \{ \pm T_{1i}, \pm T_{2i}, \pm T_{3i}, Y_{pi} \} \end{aligned}$$

s.t.

$$G_i = I_1 Y_i + I_2 X_i + I_3 Z_i$$

$$Y_{pi} = Y_{ci}$$

$$T_1 \leq \{ \pm T_1, \pm T_2, \pm T_3 \} \leq T_p$$

$$\begin{aligned} \text{Min } C &= \sum_{i=1}^T \frac{(c_{1i} \pm T_{1i}) Y_i}{(1+r)^i} + \sum_{i=1}^T \frac{(c_{2i} \pm T_{2i}) X_i}{(1+r)^i} \\ &+ \sum_{i=1}^T \frac{(c_{3i} \pm T_{3i}) Z_i}{(1+r)^i} \\ \{ X_i, Y_i, Z_i \} \end{aligned}$$

s.t.

$$Z_i \geq \bar{X}_i$$

$$Z_i = a_i X_i$$

$$X_i = b_i Y_i$$

$$Y_i + Y_{pi} \leq Y_i$$

$$\sum_{i=1}^T X_i \geq \bar{X}_1$$

$$G_i, Y_{pi}, Y_i, X_i, Z_i \geq 0$$

(D.20)

$$i = 1, 2, \dots, t$$

where:

d = social discount rate,

r = market rate of interest rate,

w = vector of the coefficients of the policy objective

functions $(1 \times m_1) (1 \times k)$,

G = energy target variable vector $(k \times 1)$,

Y, X, Z = vectors of primary energy, secondary energy and
end-uses of energy: (1×1) , $(n \times 1)$, and $(p \times 1)$,

I_1, I_2, I_3 = matrices elements of which are either 1 or 0,

$\pm T_1, \pm T_2, \pm T_3$ = vectors of tax and subsidy related to Y ,

X , and Z : (1×1) , $(n \times 1)$, and $(p \times 1)$,

Y_p = amount of Y that is directly controlled,

$Y_c, \bar{Z}, \bar{Y}, \bar{X}$ = the right hand side constants of Y_p, Z, Y, X ,

i = time period 1, 2, . . . , n .

The above model can be condensed for convenience to the
following two period model:

$$\text{Min WL} = w_{1b}X_{11b} + w_d w_{1p} X_{11p} \quad (a)$$

$$\{\pm T_b, \pm T_p\}$$

s.t.

$$\text{Min C} = (c_b \pm T_b)X_{22b} + (c_d c_p \pm T_p)X_{22p} \quad (b)$$

$$\{X_{22b}, X_{22p} \mid \pm T_b, \pm T_p\}$$

s.t.

(D.21)

$$X_{22b}^1 + A_{11b}X_{22b} \geq R_b \quad (c)$$

$$X_{22p}^1 + A_{11p}X_{22p} \geq R_p \quad (d)$$

$$B_{11b}X_{22b} + B_{11p}X_{22p} \geq R_d \quad (e)$$

$$X_{11b} + X_{11p} = I_1 * X_{22b} + I_2 * X_{22p} \quad (f)$$

$$X_{11b}, X_{11p}, X_{22b}^1, X_{22p}^1, X_{22b}, X_{22p} \geq 0 \quad (g)$$

The b and p subscripts define the variables in the base year and the planning year respectively. wd and cd are discount factors, while X_{22b}^1 and X_{22p}^1 are the resource control variables.

A statement of the above dynamic MLP with a parametric programming version of the lower level problem is as follows :

$$\text{Min WL} = w_{1b}X_{11b} + wd w_{1p}X_{11p} \quad (a)$$

$$\{\pm T_b, \pm T_p, X_{22p}^1, X_{22b}^1\}$$

s.t.

$$\text{Min C} = (c_b \pm \theta U_1)X_{22b} + (cd c_p \pm \theta U_2)X_{22p} \quad (b)$$

$$\{X_{22b}, X_{22p} \mid \theta U_1 = \pm T_b, \theta U_2 = \pm T_p, \theta B_1 = X_{22b}^1, \theta B_2 = X_{22p}^1\}$$

$$\text{s.t.} \quad (D.22)$$

$$A_{11b}X_{22b} \geq R_b \pm \theta B_1 \quad (c)$$

$$A_{11p}X_{22p} \geq R_p \pm \theta B_2 \quad (d)$$

$$B_{11b}X_{22b} + B_{11p}X_{22p} \geq R_T \quad (e)$$

$$X_{11b} + X_{11p} = I_1^*X_{22b} + I_2^*X_{22p} \quad (f)$$

$$X_{11b}, X_{11p}, X_{22b}^1, X_{22p}^1, X_{22b}, X_{22p} \geq 0 \quad (g)$$

By applying the PPS algorithm, the optimum solution to the dynamic MLP can be obtained.

D.2.4 Solution to an MLP having a Non-Linear Behavioral Model:

A non-linear MLP (bi-level programming) is specified as:

$$\text{Min WL} = wX_{11}$$

$$\{\pm T, X_{11}\}$$

$$\text{Min C} = (c \pm T)X_{22}^2$$

$$\{X_{22} \mid \pm T\}$$

s.t.

(D.23)

$$A_2X_{22}^2 \geq R$$

$$X_{11} = I^*X_{22}$$

$$X_{11}, X_{22} \geq 0$$

A parametric programming version of the above non-linear MLP is as follows:

$$\text{Min } W_1 = wX_{11}$$

$$\{\pm T, X_{11}\}$$

$$\text{Min } C = (c \pm \theta U)X_{22}^2$$

$$\{X_{22} \mid \pm \theta U = \pm T\}$$

s.t.

(D.24)

$$A_2 X_{22}^2 \geq R$$

$$X_{11} = I \cdot X_{22}$$

$$X_{21}, X_{22} \geq 0$$

The linearized form of the above model is as follows:

$$\text{Min } W_1 = wX_{11}$$

$$\{\pm T_1, \pm T_2, \pm T_3\}$$

s.t.

$$\text{Min } C = (f_1 \pm \theta U_1)r_1 + (f_2 \pm \theta U_2)r_2 + (f_3 \pm \theta U_3)r_3$$

$$\{r_1, r_2, r_3 \mid \pm \theta U_1 = \pm T_1, \pm \theta U_2 = \pm T_2, \pm \theta U_3 = \pm T_3\}$$

s.t.

(D.25)

$$a_1 r_1 + a_2 r_2 + a_3 r_3 \geq R$$

$$X_{11} = I_1 r_1 + I_2 r_2 + I_3 r_3$$

$$X_{11}, r_1, r_2, r_3 \geq 0$$

where the r 's are the different grid points for linearization of the non-linear MLP. Notice that the model (D.25) and the linearization conditions on the grid points form a linear MLP which can be solved by the PPS algorithm. It may be mentioned here that non-linear parametric programming (Brosowski and Deutsch [1985]) can also be used to solve a non-linear lower level problem, and

the PPS algorithm can be used to find the parametric solution that yields the optimum value for the upper level objective function.

D.3. A FORMULA FOR EXTENDING THE PARAMETRIC SEARCH

The following formula (Heaps [1985]) can be adopted to change the units of parametric variation from 0 to 1 in the case where seven cost coefficients are subject to parametric variations:

```

DO 1001 I = 1, ..., N + 1
      u(7) = (I-1)/N
DO 1002 J = 1, N + 2-I
      u(6) = (J-1)/N
DO 1003 K = 1, N + 3 - I - J
      u(5) = (K-1)/N
DO 1004 M = 1, N + 4 - I - J - K
      u(4) = (M-1)/N
DO 1005 P = 1, N + 5 - I - J - K - M
      u(3) = (P-1)/N
DO 1006 Q = 1, N + 6 - I - J - K - M - P
      u(2) = (Q-1)/N
      u(1) = 1 - u(2) - u(3) - u(4) - u(5) - u(6) - u(7)

1006 CONTINUE
1005 CONTINUE
1004 CONTINUE
1003 CONTINUE
1002 CONTINUE
1001 CONTINUE

```


However, the application of this formula to AEPSOM produced results with multiple policy optima. Because of this non-uniqueness problem, in this study the formula was not adopted in implementing AEPSOM numerically.

POLICY PROGRAMME:
THE FIRST SUB-PROGRAMME FOR FINDING AN MLP SOLUTION

```

C
C      POLICY - POLICY OBJECTIVE FUNTION ROUTINE
C
C
C      CHARACTER*7 LAMBDA
C      CHARACTER INPUT(32)
C      CHARACTER*32 OUTP
C      REAL LMBA(123),X(123,123)
C      REAL Y,XLAM
C      REAL W(123)
C      INTEGER NVARNO(123)
C      REAL COEFS(123)
C
C      1001 FORMAT(32A1)
C
C      COMMON/XARRAY/X,LIX(123)
C
C      EQUIVALENCE(OUTP,INPUT)
C
C      CALL PBGPP
C
C      SET K, THE NUMBER OF TOTAL BASIC VARIABLES..
C
C      K=0
C      WRITE(1,*)'  WHAT IS THE BGPP OUTPUT FILE..'
C      READ(1,1001,END=9999)(INPUT(I),I=1,32)
C      OPEN(UNIT=7,FILE=OUTP,FILETYPE='FSU',STATUS='APPEND')
C
C      CALL READIN(LAMBDA,XLAM,LMBA,Y,KMAX,NOPT)
C      CALL PUTOUT(LMBA,KMAX,NOPT)
C
C      PROMPT FOR INPUT DETAILS.
C
C      MIN=0
C      MAX=0
C      NVAR=0
C      CALL INPUTS(MIN,MAX,COEFS,NVAR,NVARNO)
C
C
C      DETERMINE THE MINIMUM OR MAXIMUM.
C
C      IF (MIN.EQ.1) CALL GETMIN(COEFS,NVAR,NVARNO,LMBA,KMAX,NOPT,W)
C      IF (MAX.EQ.1) CALL GETMAX(COEFS,NVAR,NVARNO,LMBA,KMAX,NOPT,W)
C
C      9999 CONTINUE
C      CLOSE(UNIT=7)
C      STOP
C      END
C      SUBROUTINE READIN(LAMBDA,XLAM,LMBA,Y,KMAX,NOPT)
C
C      CHARACTER*7 LAMBDA
C      REAL XLAM,LMBA(123),X(123,123)
C
C      CHARACTER RECDIN(80)
C
C      COMMON/XARRAY/X,LIX(123)
C
C      1001 FORMAT(10X;A7,F16.4)

```

```

1002 FORMAT(12X,I2,1X,I2,1X,F16.4)
1003 FORMAT(80A1)
C
C
C   OPEN THE FILE, READ IT AND CLOSE AGAIN.
C
C   OPEN (UNIT=8,FILETYPE='FSU',STATUS='OLD',FILE='PBGPP.DATA')
C
C
C   I=0
C
C
C   DO 1500 I=1,123
C       LMBA(I)=0.0
C       DO 1500 J=1,123
C           X(I,J)=0.0
1500 CONTINUE
C
2000 CONTINUE
    NOPT=0
    KMAX=0
    K=0
C
C   DO 2500 I=1,123
C
C
C       READ(8,1003,END=9999,ERR=9998)(RECDIN(M),M=1,80)
C       GOTO 2100
9998 CONTINUE
    WRITE(1,*)'   ERROR IN READING BLANK RECORD'
    GOTO 9999
2100 CONTINUE
    READ(8,1001,END=9999,ERR=9997)LAMBDA,XLAM
    GOTO 2200
9997 CONTINUE
    WRITE(1,*)'   ERROR IN READING THE HEADER..'
    GOTO 9999
2200 CONTINUE
    IF (LAMBDA.NE.'LAMBDA=') GOTO 9996
    GOTO 2300
9996 CONTINUE
    WRITE(1,*)'   NO LAMBDA FOUND..'
    GOTO 9999
2300 CONTINUE
C
C
C       LMBA(I)=XLAM
C       WRITE(1,*)'   LAMBDA.. ',I
C       WRITE(1,*)LMBA(I)
C
C
C   DO 2400 J=1,123
C       READ(8,1002,END=9999,ERR=9995)NO,IX,Y
C       WRITE(1,1002)NO,IX,Y
C       GOTO 2410
9995 CONTINUE
    WRITE(1,*)'   ERROR READING THE VARIABLES..'
    GOTO 9999
C
2410 CONTINUE

```

```

C          X(I,NO)=Y
          LIX(I)=IX
          NOPT=I
C
          K=IX
          IF (K.GE.KMAX) KMAX=K
          IF (J.GE.IX) GOTO 2500
C
2400 CONTINUE
C
2500 CONTINUE
C
C
C
C
9999 CONTINUE
      CLOSE (UNIT=8)
C
      RETURN
      END
      SUBROUTINE INPUTS(MIN,MAX,COEFS,NVAR,NVARNO)
C
C
      INTEGER NVARNO(123)
      REAL COEFS(123)
C
C
C      PROMPT FOR NUMBER OF VARIABLES ..
C
2000 WRITE(1,*) ' HOW MANY VARIABLES FOR POLICY OBJECTIVE FUNCTION ?? '
      READ(1,*,END=9999,ERR=9991) NVAR
      GOTO 2100
9991 CONTINUE
      WRITE(1,*) ' ERROR.. MUST BE AN INTEGER..'
      GOTO 2000
2100 CONTINUE
      WRITE(1,*) ' WHAT ARE THOSE VARIABLE NUMBERS..? '
      READ(1,*,END=9999,ERR=9992)(NVARNO(I),I=1,NVAR)
      GOTO 2200
9992 CONTINUE
      WRITE(1,*) ' ERROR.. MUST BE ',NVAR,' INTEGER NUMBERS..'
      GOTO 2100
2200 CONTINUE
      WRITE(1,*) ' ENTER THE ',NVAR,' COEFFICIENTS.. ? '
      READ(1,*,END=9999,ERR=9993)(COEFS(I),I=1,NVAR)
      GOTO 2300
9993 CONTINUE
      WRITE(1,*) ' ERROR.. COEFFICIENTS MUST BE ',NVAR,' REAL NUMBERS'
      GOTO 2200
2300 CONTINUE
      WRITE(1,*) ' DO YOU WANT MINIMISATION.. ? '
      WRITE(1,*) ' 0 = NO , 1 = YES..'
      READ(1,*,END=9999,ERR=9994) MIN
      GOTO 2400
9994 CONTINUE
      WRITE(1,*) ' ERROR MUST BE 0 OR 1..'
      GOTO 2300
2400 CONTINUE

```

```

WRITE(1,*)' DO YOU WANT MAXIMISATION.. ?'
WRITE(1,*)' 0 = NO , 1 = YES..'
READ(1,*,END=9999,ERR=9995)MAX
GOTO 2500
9995 CONTINUE
WRITE(1,*)' ERROR.. MUST BE 1 OR 0'
GOTO 2400
2500 CONTINUE
9999 CONTINUE
C
RETURN
END
SUBROUTINE GETMIN(COEF5,NVAR,NVARNO,LMBA,KMAX,NOPT,W)
C
C
INTEGER NVARNO(NVAR)
REAL COEF5(123)
REAL X(123,123),LMBA(123)
C
REAL W(123)
REAL WMIN,LMIN
C
COMMON/XARRAY/X,LIX(123)
C
C
DO 2000 I = 1,NOPT
W(I)=0.0
DO 2000 J=1,NVAR
M=NVARNO(J)
W(I)=W(I)+(COEF5(J)*X(I,M))
2000 CONTINUE
C
C
DO 3100 I = 1,NOPT
WRITE(1,*)' MINIMUM.. ',W(I)
C
C
IF (I.EQ.1)WMIN=W(I)
IF (W(I).GT.WMIN) GOTO 3100
WMIN = W(I)
LMIN=LMBA(I)
3100 CONTINUE
WRITE(1,*)' RESULTANT MINIMUM IS ..',WMIN
C
WRITE(1,*)' CORRESPONDING LAMBDA IS ..',LMIN
WRITE(7,*)' LAMBDA FOR MINIMUM..',LMIN
WRITE(7,*)' THE MINIMUM..',WMIN
RETURN
END
SUBROUTINE GETMAX(COEF5,NVAR,NVARNO,LMBA,KMAX,NOPT,W)
C
C
INTEGER NVARNO(NVAR)
REAL COEF5(123)
REAL X(123,123),LMBA(123)
C
REAL W(123)
REAL WMAX,LMAX
C
COMMON/XARRAY/X,LIX(123)

```

```

C
DO 2000 I = 1,NOPT
  W(I)=0.0
  DO 2000 J=1,NVAR
    M=NVARNO(J)
    W(I)=W(I)+(COEFS(J)*X(I,M))
2000 CONTINUE
C
  WMAX=0.0
C
C
C
DO 3100 I = 1,NOPT
  WRITE(1,*)'  MAXIMUM... ',W(I)
C
C
  IF (W(I).LT.WMAX) GOTO 3100
  WMAX = W(I)
  LMAX=LMBA(I)
3100 CONTINUE
  WRITE(1,*) '  RESULTANT MAXIMUM IS ... ',WMAX
  WRITE(1,*) '  CORRESPONDING LAMBDA IS ... ',LMAX
  WRITE(7,*)'  LAMBDA FOR OPTIMUM IS ... ',LMAX
  WRITE(7,*)'  RESULTANT MAXIMUM IS ... ',WMAX
C
  RETURN
  END
  SUBROUTINE PUTOUT(LMBA,KMAX,NOPT)
C
  REAL LMBA(123),X(123,123)
C
  COMMON/XARRAY/X,LIX(123)
C
  WRITE(1,*)'  KMAX.. ',KMAX
  WRITE(1,*)'  NR OF OPTIMA.. ',NOPT
C
  WRITE(1,*)'  THE BASIC VARIABLE MATRIX..X'
  DO 1000 I=1,NOPT
    WRITE(1,*)(X(I,J),J=1,KMAX)
C
1000 CONTINUE
C
  WRITE(1,*)'  LAMBDA..'
C
C
  WRITE(1,*)(LMBA(I),I=1,NOPT)
  WRITE(1,*)(LIX(I),I=1,NOPT)
C
C
C
  RETURN
  END

```

APPENDIX F

A COMPLETE LIST OF AEPSOM SOLUTIONS

F.1. A LIST OF MODEL SPECIFICATIONS AND SOLUTIONS

The optimum AEPSOM specification and solution with descriptions of the main characteristics of model solutions was given in Table 5.1. A listing of the various AEPSOM solutions with necessary explanations is given in this appendix.

AEPSOM was solved for different units of parametric variations: K, C, H ; in two types of tax and subsidy policy regimes (existing mix and optimum mix); for the two types of specifications stated above; for the years of 1979-80 and 1989-90; and under varying conditions in the energy sector (sensitivity studies). In the first three solutions only existing taxes and subsidies were included in AEPSOM, while the optimum mix of taxes and subsidies were obtained and included in the next three Solutions (Solutions 4, 5, and 6). The behavioural model part of AEPSOM for 1979-80 and 1989-90 (without policy objective function, policy constraints and taxes and subsidies in the behavioural objective function) was also solved (Model Nos 7 and 8). The Central Control Policy Model (Models Nos 9 and 10, behavioural model with policy objective function instead of behavioural policy objective function in it) was also solved for these two time

TABLE F.1

A LIST OF MODEL SPECIFICATIONS AND SOLUTIONS

A. BASE SOLUTIONS: (WITHOUT POLICY CONSTRAINTS)

Model No.	Brief Description	Type of Policy	U*	Remarks: $\pm T=0, \pm T \neq 0$	RESULTS	
					Optimum value P.O.F. (1)** (PJ)	Optimum value of P.O.F.(2)**
Model No. 1	AEPSOM 1979-80 data	existing $\pm T$	U = I	$\pm T = 0$	7031.68 ($\pm T = 0$)	7031.68 ($\pm T = 0$)
Model No. 2	AEPSOM 1979-80 data	existing $\pm T$	U = C	$\pm T = 0$	7031.66 ($\pm T = 0$)	7031.66 ($\pm T = 0$)
Model No. 3	AEPSOM 1979-80 data	existing $\pm T$	U = H	$\pm T = 0$	7031.40 ($\pm T = 0$)	7031.40 ($\pm T = 0$)
Model No. 4	AEPSOM 1979-80 data	Optimum Set $\pm T$	U = I	$\pm T \neq 0$	6734.20 ($\pm T \neq 0$)	- 19 477.51 ($\pm T \neq 0$)
Model No. 5	AEPSOM 1979-80 data	Optimum Set $\pm T$	U = C	$\pm T \neq 0$	6733.70 ($\pm T \neq 0$)	1 671.58 ($\pm T \neq 0$)
Model No. 6	AEPSOM 1979-80 data	Optimum Set $\pm T$	U = H	$\pm T \neq 0$	6733.70 ($\pm T \neq 0$)	1 708.25 ($\pm T \neq 0$)

* U = Units of parametric variation

** (1) P.O.F. (1) $WL = Ie1 + CNo + TCo$ (the abstract model (5.1), but the policy constraints are not included in these solutions. The policy constraints are included in model solutions in Section E of this Table. The unit of measurement is petajoules (PJ)).

(2) P.O.F.(2) $WL = Ie1 + CNo + TCo - \sum_{j=1}^{37} (+t_j)x_j + \sum_{j=1}^{37} (-t_j)x_j, j = 1, 2, \dots, 37$

This specification corresponds to the abstract model (5.2)
(In the 1989-90 AEPSOM, $j = 1, 2, \dots, 43$).

Table F.1 (continued)

A.RESULTS: SINGLE LEVEL MODELS

Model No.	Brief Description	Type of Policy	U	Remarks: $\pm T=0, \pm T \neq 0$	RESULT	
					Behavioural objective function (PJ)	Optimum value P.O.F. (1) * (PJ)
Model No. 7	Behavioural model of AEPSOM, 1979-80 data (Single level model)	$\pm T$ not included	U not included	$\pm T = 0$	225,117.84	7,031.68
Model No. 8	Behavioural model of AEPSOM, 1989-90 data (Single level model).	$\pm T$ not included	U not included	$\pm T = 0$		10,988.46
Model No. 9	Central control policy model for 1979-80 data (Single level model).	$\pm T$ not included	U not included	U not included	U not included	5,101.51
Model No.10	Central control policy model for 1989-90 data (Single level model).	$\pm T$ not included	U not included	No result*	U not included	6,708.43

* Computed from the behavioural model results since there is no policy objective function in Model 7, 8, 9, and 10.

Table F.1 (Continued)

B. RESULTS: SENSITIVITY ANALYSIS: EXISTING $\pm T$ (WITHOUT POLICY CONSTRAINTS)

Model No.	Brief Description	Type of Policy	U	Remarks: $\pm T=0, \pm T \neq 0$	RESULT	
					Optimum value P.O.F (1) (PJ)	Optimum value of P.O.F (2)
Model No. 11	AEPSOM 1979-80 data	Existing $\pm T$ and t_3	U = H	$\pm T \neq 0$	6811.47 ($\pm T \neq 0$)	6 643.30 ($\pm T \neq 0$)
Model No. 12	AEPSOM 1979-80, introduction of t_3	Existing	U = H	$\pm T \neq 0$	7,131.66 ($\pm T = 0$)	7,063.86 ($\pm T = 0$)
Model No. 13	AEPSOM 1979-80, constraints relaxed by 20%	Existing	U = H	$\pm T \neq 0$	4,680.03 ($\pm T = 0$)	4,839.43 ($\pm T = 0$)
Model No. 14	AEPSOM 1979-80, constraints relaxed by 100%	Existing	U = H	$\pm T \neq 0$	14,045.27 ($\pm T = 0$)	9,877.63 ($\pm T \neq 0$)
Model No. 15	AEPSOM 1979-80, constraints on petroleum import	Existing	U = H		No feasible solution	
Model No. 16	AEPSOM 1979-80, introduction new technologies, 1979-80 cost for old technologies 1989-90 cost for new technologies	Existing	U = H	$\pm T \neq 0$	6,027.75 ($\pm T = 0$)	6,020.37 ($\pm T \neq 0$)

Table F.1 (Continued)

C. RESULTS: SENSITIVITY ANALYSIS: EXISTING $\pm T$ (WITHOUT POLICY CONSTRAINTS)

Model No.	Brief Description	Type of Policy	U	Remarks: $\pm T=0, \pm T \neq 0$	RESULT	
					Optimum value P.O.F (1) (PJ)	Optimum value of P.O.F (2)
Model No. 17	AEPSOM 1979-80, import parity price for domestic crude oil	Existing	U = H	$\pm T = 0$	7,131.66 ($\pm T = 0$)	7,131.66 ($\pm T = 0$)
Model NO. 18	AEPSOM 1979-80, supply double, but demand same as in 1979-80	Existing	U = H	$\pm T = 0$	6258.12 ($\pm T = 0$)	6258.12 ($\pm T = 0$)
Model No. 19	AEPSOM 1989 data, new technologies	Existing	U = H	$\pm T \neq 0$	10,988.46 ($\pm T \neq 0$)	9,879.25 ($\pm T \neq 0$)

Table F.1 (Continued)

D. RESULTS: SENSITIVITY ANALYSIS: OPTIMUM $\pm T$ (WITHOUT POLICY CONSTRAINTS)

Model No.	Brief Description	Type of Policy	U	Remarks: $\pm T=0, \pm T \neq 0$	RESULT	
					Optimum value P.O.F (1) (PJ)	Optimum value of P.O.F (2)
Model No. 20	AEPSOM 1979-80, constraints relaxed by 20%	Optimum	U = H	$\pm T \neq 0$	8,069.45 ($\pm T \neq 0$)	-6,387.54 ($\pm T \neq 0$)
Model No. 21	AEPSOM 1979-80, constraints relaxed by 100%	Optimum	U = H	$\pm T \neq 0$	13,449.34 ($\pm T \neq 0$)	-10,648.12 ($\pm T \neq 0$)
Model No. 22	AEPSOM 1979-80, supply double, but demand same as in 1979-80	Optimum	U = H	$\pm T \neq 0$	6,094.15 ($\pm T \neq 0$)	-6003.74 ($\pm T \neq 0$)
Model No. 23	AEPSOM 1989-90 data, new technologies	Optimum set	U = H	$\pm T \neq 0$	10,988.46 ($\pm T = 0$)	10,397.79 ($\pm T \neq 0$)

Table F.1 (continued)

E. ALTERNATIVE MODEL SOLUTIONS:
AEPSOM with Policy Constraints
(Feasible Optimum Solution).

Model No.	Brief Description	Type of Policy	U	Policy Constraints	RESULT
					Optimum value P.O.F (1)* (PJ)
Model No. 5	AEPSOM 1979-80 data	Optimum set	U = C	$0 \leq \pm T \leq 20\%$ $B=3777.91 > 0$	6,733.70 ($\pm T \neq 0$)
Model No. 6	AEPSOM 1979-80 data	Optimum set	U = H	$0 \leq \pm T \leq 54\%$ $B=3859.65 > 0$	6,733.70 ($\pm T \neq 0$)
Model No. 13**	AEPSOM 1979-80 data	Existing	U = H	$0 \leq \pm T \leq 61$ $B=-159.40 < 0$	4,680.03 ($\pm T \neq 0$)
Model No. 19	AEPSOM 1989-90 data	Existing	U = H	$0 \leq \pm T \leq 56\%$ $B=587.19 > 0$	10,988.46 ($\pm T \neq 0$)

* P.O. F (1) $W = Ie1 + CNo + TCo$

With the policy constraint:

(1) $0 \leq t_j \leq 20\%$ of j $j = 1, 2, \dots, 37$ (For 1989-90, $j = 1, 2, \dots, 43$)

(2) $B = \sum_{j=1}^{37} (+t_j)x_j - \sum_{j=1}^{37} (-t_j)x_j \geq 0$

These models correspond to the abstract

representation of AEPSOM in (5.1), Specification 1.

** Though Model No. 13 does not satisfy the second policy constraint

and the range of $\pm T$ is $0 \leq \pm T \leq 61\%$ of costs, its results are

reported here since this model solution produced lowest value of

P.O.F.(1) among all the model solutions.

periods to obtain the optimum mix of taxes and subsidies (Optimum $\pm T$) in 1979-89 and 1989-90. This type of policy problem was embedded in Model nos 4,5,6, and 11 to 23. For sensitivity studies, AEPSOM was solved in two different policy regimes (existing mix and optimum mix of taxes and subsidies) by incorporating the changes to be discussed in a later section on the sensitivity analysis.

(ii) Selection of the Appropriate Model Specification and Solution

It can be seen from Table 5.1. that in the case of Model 1, 2, and 3 (AEPSOM with existing $\pm T$), the optimum solution to AEPSOM was obtained when $\pm T = 0$. In other words, the behavioural optimum solution was also found to be optimum for the policy problem. This means that persuasion of existing $\pm T$ of any value does not improve the value of the policy objective function.

However, the situation changed in the case of the optimum $\pm T$ mix (Model Nos 4,5 and 6). In these solutions, optimum solution to AEPSOM was obtained with $\pm T \neq 0$. This implies that the behavioural optimum solution (with $\pm T = 0$) was not optimum for the policy problem and introduction of $\pm T$ influenced the allocation of resources in the economy, resulting in an improved value of the objective function.

Results of Model Nos 4, 5 and 6 were preferred for discussion of the AEPSOM results since these solutions generated a lower value of the policy objective function than those of Model Nos 1, 2 and 3.

Optimum solutions to AEPSOM are reported in Table F.1.D. These are the solutions which satisfy the policy and budget constraints

and attain the optimum value for the policy objective function (feasible optimum solution). Model Nos 5, 6, 13 and 18 satisfy the policy constraints to various degrees. From all these models specifications, Model No 5 will be mainly selected for policy studies since it produces a lower value of the policy objective function and satisfies the policy constraint ($0 \leq t_j \leq 20\%$ of the cost of the j -th activity) and the budget constraints. Other model results were also reported (Model Nos 6, 13 and 18) where necessary for comparison purposes.

It may be noticed that only Specification 1 generates optimum feasible solutions. Specification 2 did not generate an optimum feasible solution. Therefore, results for Specification 2 were not included in the optimum solution table and the results of the specification 2 were not adopted for policy studies. Moreover Specification 1 can be considered a realistic representation of the Australian energy policy system since the policy planning problem is really to achieve the three energy policy objectives by adopting a set of instruments which are subject to some constraints.

It is also worth mentioning that in some cases two specifications of AEPSOM generated the same solution to AEPSOM (for example Model Nos 17 and 18).

(iii) The Effects of the Units:

The effects of the units of the parametric variations on the optimum solution can be observed from Table 5.1. In Model 4, 5, and 6, the three units of parametric variations produced different optimum solutions to AEPSOM. It is obvious that the effects of the units of parametric variations on the solution of AEPSOM is

significant. In all the model specifications other than model 1, 2, 3, 4, 5, and 6, the units identified by H were adopted, because these units provide appropriate directions for search in the PPS algorithm. Since the PPS algorithm is an interactive method, application of different units increases the possibility of finding the true/global optimum.

F.2 THE POLICY OBJECTIVE FUNCTION

The optimum values of the policy objective function in the cases of various model solutions are reported in Table F.1. These values are reported for two types of policy studies, base cases and sensitivity studies separately. In every solution, optimum values of the policy objective function were calculated for the two types of specifications of the policy objective function shown in Table 5.1. (P.O.F. (1), and (2)). Definitions of the two P.O.F.s were presented in Chapter Five. The justification and significance of these alternative specifications were discussed in Chapter Three.

It was mentioned in the previous section that Model Nos 1, 2, and 3 did not produce any values of the policy objective function which were different from those of generated by the behavioural model. This applies to both the alternative specifications (1) and (2) of the policy objective function.

Model 4, 5 and 6 produce $\pm T \neq 0$ optimum values for the policy objective function of both specifications. Optimum values for the policy objective function (1) in these three solutions are close: 6734.20, 6733.70 and 6733.70. Optimum values for the policy

objective function (2) did not show the same pattern. The optimum values were numerically different from each other - 19,477.51, 1,671.58 and 1,708.25.

In the case of alternative specifications, only Model No.5 produced results satisfying the initial policy constraints $0 \leq +T \leq 20\%$. Two other solutions are also reported which satisfy the upper level of policy constraints of 54% and 61%. The optimum values of the policy objective function (1) are the same in the case of model solution 5 and 6, although these have different upper level constraints on the policy range, while model solution 13 produces a very much lower value of the policy objective function.

One striking result is that optimum model solutions are different in two alternative specifications of the policy objective function. For example, Model Solution 5 produces optimum values for the policy objective function (1) and (2) equal to 6733.70 and 1671.58 respectively while for the first component of the policy objective function (2) it is 6897.83. (First component of the policy objective function (2) is equal to the policy objective function (1)). It means that two alternative specifications of the policy objective function generate different optimum solutions to the model.

APPENDIX G

THE 1989-90 AEPSOM FOR SENSITIVITY STUDY

G.1 AEPSOM:1989-90 - MODEL SPECIFICATION

G.1.1 Preliminaries

(a) Assumptions

The assumptions made in AEPSOM:1979-90 are also valid for AEPSOM:1989-90. The additional assumption in AEPSOM:1989-90 is that the energy supply, demand, costs, and technologies for the year 1989-90 are known.

(b) Abstract Model

The abstract representation of AEPSOM:1989-90 is similar to AEPSOM:1979-80.

(c) Foundations

These are the same as in AEPSOM:1979-90.

G.1.2 Specification of AEPSOM

The principles and mechanism for the specification of AEPSOM:1989-90 are similar to those in AEPSOM:1979-80, therefore only a listing of AEPSOM 1989-90 equations will be provided here.

A. The Policy Objective Function

This is the same as in AEPSOM:1979-80.

B. The Constraint Set

(i) The Policy and Budgetary Constraints

They are the same as in AEP-SOM:1979-80.

(ii) The Behavioural Model of the Energy Sector

The behavioural constraints of AEP-SOM:1989-90 will consist of an ES model for 1989-90. Specification of the ES model: 1989-90 will be based on the Australian energy system for the year 1989-90. AES for 1989-90 is shown in Figure G.1.

The following new conversion technologies have been introduced in AES:1989-90:

1. coal liquefaction
2. methanol production from biomass

The following new end-uses were also introduced: coal, natural gas, and methanol uses in the transport sector.

(I) The constraints of ES model:1989-90

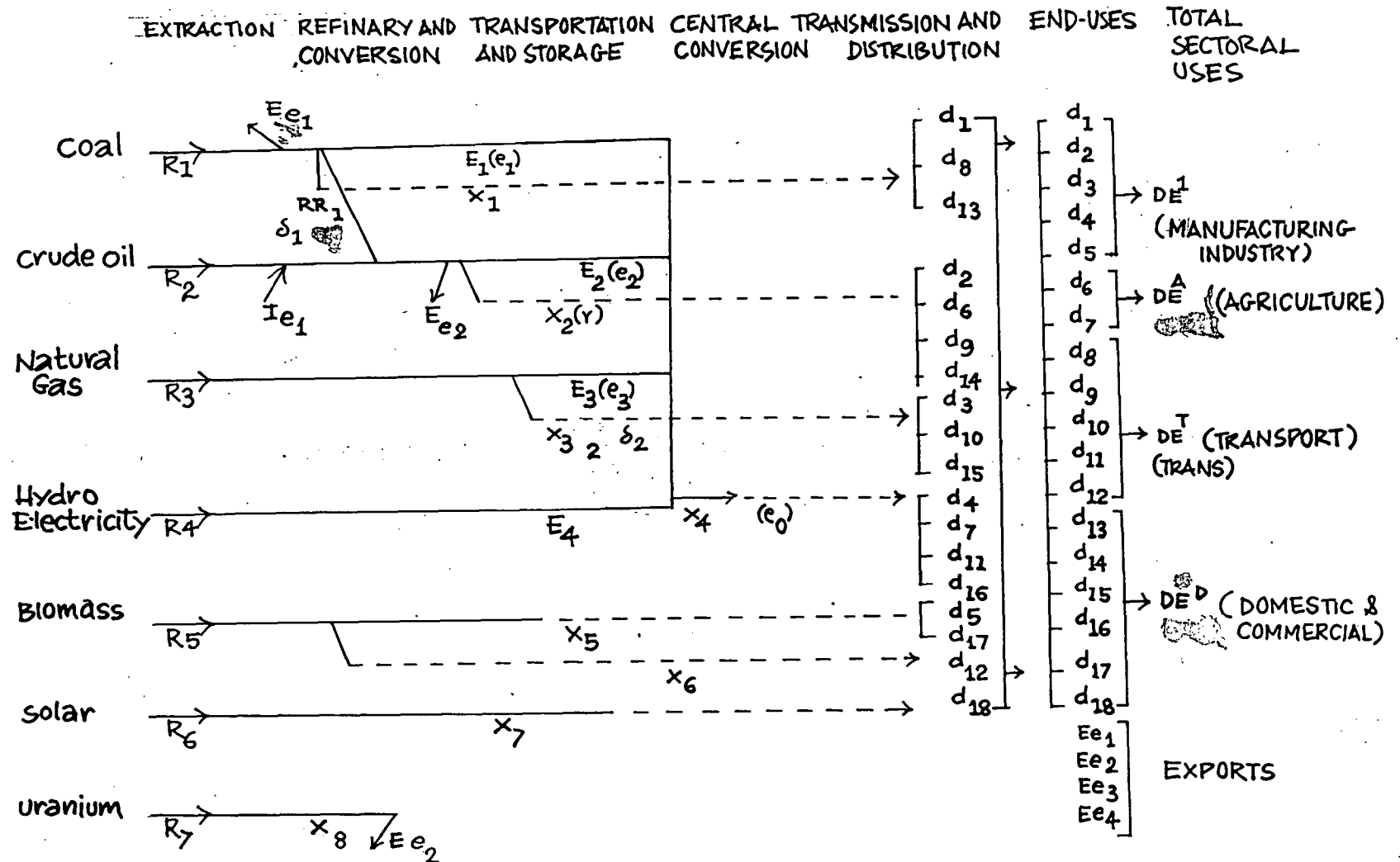
These are the same as those in the ES model:1979-80 in AEP-SOM:1979-80. So we shall not discuss in detail the specification of the constraints of the ES model:1989-90. The following is a list of the equations of the ES model: 1989-90.

1. Demand Constraints (including the export constraints)

$$\begin{aligned}
 d_1 + d_2 + d_3 + d_4 + d_5 &\geq DE^I \\
 d_6 + d_7 &\geq DE^A \\
 d_8 + d_9 + d_{10} + d_{11} + d_{12} &\geq DE^T \\
 d_{13} + d_{14} + d_{15} + d_{16} + d_{17} + d_{18} &\geq DE^D \\
 E_{el} &\geq \bar{E}_{el}
 \end{aligned}
 \tag{G.1}$$

FIGURE F.1

AUSTRALIAN ENERGY SYSTEM 1989-1990



$$E_{e2} \geq E_{e2}$$

$$E_{e3} \geq E_{e3}$$

$$E_{e4} \geq E_{e4}$$

2. Intermediate Energy Balance Equations

$$x_1 = d_1 + d_8 + d_{13} + E_{e1}$$

$$x_2 = d_2 + d_6 + d_9 + d_{14} + E_{e2}$$

$$(1/\delta_2)x_3 = d_3 + d_{10} + d_{15}$$

$$x_4 = d_4 + d_7 + d_{11} + d_{16}$$

$$x_5 = d_{17}$$

(G.2)

$$x_6 = d_{12}$$

$$x_7 = d_{18}$$

$$x_8 = E_{e3}$$

3. Supply Balance Equations

(i) Petroleum Products Supply Balance Equation

$$E_2 + x_2 = (1/\delta_1)RR_1 + R_2 + I_{e1}$$

(G.3)

(ii) Electricity Supply Balance Equation

$$(1/e_0)x_4 = e_1E_1 + e_2E_2 + e_3E_3 + E_4$$

(G.4.)

(iii) Other Supply Balance Equations

$$R_1 = x_1 + RR_1 + E_1$$

$$R_3 = x_3 + E_3$$

$$R_5 = x_5 + x_6$$

(G.5)

$$R_6 = x_7$$

$$R_7 = x_8$$

4. Resource Constraints

$$\begin{aligned}
 R_1 &\leq \bar{R}_1 \\
 R_2 &\leq \bar{R}_2 \\
 R_3 &\leq \bar{R}_3 \\
 R_5 &\leq \bar{R}_5 \\
 R_6 &\leq \bar{R}_6 \\
 R_7 &\leq \bar{R}_7
 \end{aligned}
 \tag{G.6}$$

5. Capacity Constraints

$$\begin{aligned}
 E_4 &\leq kHe \\
 x_4 &\leq kTe \\
 (1/e_2)E_2 + (1/\gamma)x_2 &\leq Rk
 \end{aligned}
 \tag{G.7}$$

6. User-Defined Constraints

$$\begin{aligned}
 d_4 &\geq \bar{d}_4 \\
 d_7 &\geq \bar{d}_7 \\
 d_{11} &\geq \bar{d}_{16}
 \end{aligned}
 \tag{G.8}$$

(II) Objective Function

The objective function of ES model:1989-90 is also similar to the objective function of ES model:1979-80 in AEPSOM:1979-80. However, the objective function of ES model:1989-90 is different in the following respects:

- 1) It contains costs of some additional activities.
- 2) The costs are 1989-90 costs in 1979-80 real prices.
- 3) Taxes and subsidies are for the year 1989-90.

The objective function of ES model: 1989-90 is as follows:

$$C = \sum_{i=1}^7 (c_i + T_i) R_i + c_m I_e \quad (G.9)$$

$$+ \sum_{j=1}^7 c_j x_j + \sum_{e=1}^4 c_e E_e + \sum_{k=1}^{18} (c_k - T_k) d_k$$

G.1.3. Output of AEPSOM:1989-90

Same as in AEPSOM:1979-80 for 1989-90.

G.2. DATA FOR AEPSOM: 1989-90¹

i. The Policy Objective Function 1

The weights in AEPSOM :1989-90 are : $I_{e1} : 1$, $C_{No} : 2$,
and $T_{Ce} : 1$.

ii. The Policy and Budgetary Constraints

Same as in AEPSOM 1979-80.

iii. The Behavioural Objective Function

The following real rates of increases and absolute increases
in the base year (1979-80) costs of fuels and new technologies

1. Sources of data: Tables/data without any source are the estimates of the present author.

were assumed (reasons are discussed below):

Table G.1

Increases in the Costs of Primary Energy

Energy	Per Annum Real Increases % (Cost m\$/pj)
coal (R_1)	2.9
domestic crude oil (R_2)	5.0
imported crude oil (I_{e1})	3.0
natural gas (R_3)	1.5
solar energy (R_5)	0.0
wood (R_6)*	0.0
uranium (R_7)	1.5

Table G.2

Increases in the Costs of Conversion Technologies

Conversion Technologies/flow	Real increases / Costs m\$/PJ
refinery cost (x_2)	1.5
hydro-electricity generation (E_4)	2.0
electricity generation from coal (E_1)	1.5
" " from petroleum products (E_2)	1.5
electricity generation from natural gas (E_3)	1.5

Table G.3

Costs of New Technologies

New conversion Technologies	Costs m\$/pj
conversion of coal to oil (RR_1)	15.67
conversion of wood to methanol (x_6)	43.60

Table G.4

Increases in the Cost of End-Use Technologies /
(Costs m\$ / pj)

	Manufacturing Industry	Agriculture	Transport	Domestic
Petroleum Products	2.00 (d ₂)	2.00 (d ₆)	2.00 (d ₈)	2.00 (d ₁₁)
Electricity		1.00		
Exports:				
coal	1.5			
natural gas	2.00			
uranium	1.5			

Some of the features of the cost structures of 1989-90 AES are: 1) Increases in the costs of primary fuels at different rates; 2) Increases in the cost of oil-based secondary energy conversion technologies but no increases in the costs of other secondary energy conversion technologies; 3) Increases in the cost of oil-based end-use technologies by 5% but no increases in the cost of other end-uses.

The reasons for assuming these types of increases in future energy costs are as follows: 1) Increases in primary energy costs are based mainly on the past increases; 2) No increases in cost of the non-oil-based secondary energy conversion technologies are assumed because it is expected that subsidies will be given to the non-oil-based technologies, and that there will be improvements in the efficiencies of these technologies (learning effects, see Schuyers, [1979], for a detailed study of these effects in the Australian energy sector). In contrast, oil-based technologies are expected to have no subsidies, and are predicted to have relatively fewer improvements in conversion efficiencies; thus their costs are expected to rise.

iv. The Behavioural Constraints

(1) Demand Constraints

The following figures for the end-uses of energy in different sectors are adopted from the Department of National Development and Energy ([1983], p.51):

Table G.5

End-uses of Energy: 1989-90

Sectors	Notations Energy PJ
Manufacturing (DE ^I)	1707.89
Agriculture (DE ^A)	255.35
Transport (DE ^T)	899.99
Domestic (DE ^D)	489.76
Export	
Coal (Ee ₁)	2519.97
Petroleum products (Ee ₂)	104.65
Natural gas (Ee ₃)	246.97
Uranium (Ee ₄)	4299.02
Demand for electricity in manufacturing industry (d ₄)	171.63
Demand for electricity in agriculture (d ₇)	41.63
Demand for electricity in domestic sector(d ₁₃)	230.23

(2) End-use Energy Flow Constraints

None needed.

(3) Secondary Energy Supply Constraints

The efficiency factors that have been derived for use are shown in Table G.6.

Table G.6

Efficiency of Different Technology, 1989-90

Fuel	Efficiencies
x_3	0.86
RR ₁	0.54
E ₁	0.22
E ₂	0.31
E ₃	0.32
x_2	0.90
x_4	0.86

(4) Primary Energy Balance Equations

We do not need any data to be specified in these equations.

(5) Resource Constraints

Table G.7

Primary Energy Resources: 1989-90

Energy	PJ
Coal (R ₁)	4198.56
Crude oil (R ₂)	1029.76
Natural gas (R ₃)	933.48
Wood (R ₆)	171.63
Solar energy (R ₇)	1.00
Uranium (R ₈)	4299.02

(Source: Dept. of National Development & Energy [1983]; p.51)

(6) Capacity Constraints

The following increases in the capacities of different technologies in 1989-90 were estimated(* next page):

Table G.8

Capacities of Different Technologies

Energy	PJ
Hydro-electricity (E ₄)	1.5
Total electricity (x_4)	5.00
Petroleum products (x_2)	4.00

* (The electricity generation capacity and refinery capacity (MW and barrel/day) have been converted to PJ by the appropriate conversion factors. The conversion factors that relate MW to MWh/year (for converting MW to PJ) may be seen in Meier [1984], Chapter Eight.)

APPENDIX H

SELECTED PUBLICATIONS FROM THIS RESEARCH WORK

Islam, N. (1983) "An Optimum Economic Policy Framework for the Energy Sector," paper presented to the 12th Conference of Economists, 28 August - 1 September, Hobart.

Islam, N. (1987) "Energy Systems and Policy Planning: A Multi-level Optimization Study and Its Implications for Papua New Guinea," Proceedings the First National Seminar on Renewable Energy for Rural Development, 22-26 June, Department of Minerals and Energy, Port Moresby, pp. 137-151.

Islam, N. (1988a), "An Energy Systems Model for Australia: A Tool for Formulation of Energy Policies," Departmental Working Paper No. 2/88, University of Technology, Lae.

Islam, N. (1988b), "The Future of Australian Energy System: Forecasting by a Dynamic Energy Systems Model", Departmental Working Paper No: 2/88, University of Technology, Lae.

Islam, N. (1989a), "Multi-level Programming: An Algorithm", Departmental Working Paper No.2/89, University of Technology, Lae.

Islam N. (1989b), "Multi-level Programming: On the Problems of Existence, Uniqueness and Global Optimality", seminar on Mathematics and Mathematics Education, Dept. of Mathematics and Statistics, University of Technology, Lae, 28-29 August, (in the Proceedings), pp. 56-67.

Islam, N. (1991a), "Mathematical Properties of Multi-level Programming", (adapted from 1989b), the PNG Journal of Mathematics, Vol.2 (I).

Islam, N., (1991b), "Resource Control Multi-level Programming: A Parametric Programming Search Algorithm", the PNG Journal of Mathematics, Vol.2 (2).

Islam, N., (1991c), "The Role of Renewable Energy in the Australian Energy System: An Issue in the Philosophy of Renewal", a paper presented at the Conference of Economists, 30 September - 3 October, 1991, University of Tasmania, Hobart.

(Most of these articles were adopted from the previous drafts of the thesis.)