APPLICATIONS OF LINEAR MODELLING IN ENERGY ANALYSIS

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ABSTRACT

The primary objective of this study was to explore the use of classical linear models in Energy Analysis; so as to resolve some of the methodological problems associated with Energy Analysis, and to extend the scope and potential of Energy Analysis as a scientific discipline. This was undertaken in the form of two separate yet related discourses.

The first discourse provided a basis for resolving the energy quality problem encountered in Energy Analysis. A general equation was hypothesized and tested:

$$m_1 \sum_{i=1}^{i=j} (Y_1)_i + m_2 \sum_{i=1}^{i=j} (Y_2)_i + \dots m_n \sum_{i=1}^{i=j} (Y_n)_i$$

$$= n_1 \sum_{i=1}^{i=j} (X_1)_i + n_2 \sum_{i=1}^{i=j} (X_2)_i + \dots n_n \sum_{i=1}^{i=j} (X_n)_i$$

where: y = effective energy output of an end-use class (ΔH output), known

x = primary energy input (ΔH input), known

m = quality coefficient for an effective energy output (quality equivalents/ ΔH output), unknown

n = quality coefficient for a primary energy input (quality equivalents/ ΔH input), unknown

i = energy supply use pathways, j = number of pathways.

The matrix of simultaneous linear equations represented by this equation is usually overdetermined. Therefore, an appropriate solution method is a fitting procedure, such as regression. Further, in order to solve this general equation, one coefficient must arbitrarily be given a value equal to unity. Hence, all estimated coefficients are expressed in terms of multiples of that coefficient (termed quality equivalents).

The general equation was first tested for the 1976 New Zealand economy, so as to estimate 'actual' quality coefficients. Subsequently, the general equation was tested for a notional 'energy efficient' New Zealand economy, so as to estimate 'long run' quality coefficients, which reflected thermodynamic limits. Generally very accurate estimates of the coefficients were obtained. The solutions to the equations indicated that hydroelectricity was the highest quality primary energy source, followed by natural gas, oil, coal and then wood.

The second discourse examined the 'optimal' use of primary energy resources in the New Zealand food system, using the formalism of Linear Programming. A preliminary discussion concluded that the concept of 'optimality' had greater potency than the concept of 'efficiency' in evaluating the use of energy resources, particularly in food systems. For each food sector (Production, Processing, Export-Import, Distribution, Catering and Household), coefficient matrices were assembled, drawing on literature data. Various combinations of constraints and objective functions were applied, in different Runs. The main objective functions used were minimising energy inputs for providing a nutritionally adequate diet, or maximising net energy gain from exporting agro-food products. The most critical constraints were found to be land area and market demand constraints.

Detailed results of the Linear Programming runs are presented and discussed. An energetically 'optimal' diet was found to consist of large amounts of cereals, significant amounts of fresh fruit and vegetables and dairy products, and a very small amount of meat. Such a diet provided the Recommended Daily Allowances, for all nutritional elements, for the New Zealand population. Meat, Fish and Dairy products were found to have a particularly important function as commodities to be traded for imports of oil and energy intensive goods.

A final discussion reviewed the use of Linear Models in Energy Analysis, and future directions for growth and development in Energy Analysis.

PREFACE

This thesis is part of two research programmes being undertaken in the Food Technology Research Centre. The first research programme began in the early 1970's, and has attempted to introduce quantitative techniques (principally Linear Programming and Extensions) to product development and diet planning. This has resulted in a number of PhD dissertations (Edwardson, 1974; Anderson, 1975; Chittaporn, 1977; Ngarmsak, 1983). The second research programme was initiated in 1977, and has attempted to quantify energy use in the food system, and to identify energy conservation measures particularly applicable to the food processing sector. This research has been funded by the New Zealand Energy Research and Development Committee. The material for this thesis has been drawn from the findings of Contract 3123 "Energy Requirements for Food Supply in New Zealand".

Much of the details of surveys undertaken for Contract 3123 and used in this thesis have been published by the N.Z.E.R.D.C., under the author's name. Readers are recommended to refer to these reports for further details:

(1) Patterson, M.G. and Earle, M.D. 1982. Energy Use in the Catering Industry. N.Z.E.R.D.C. Report P66. (Appendix F).

(2) Patterson, M.G. and Earle, M.D. 1982. Total Energy Requirements of Shopping for Food. N.Z.E.R.D.C. Report P67. (Appendix G).

(3) Patterson, M.G. and Earle, M.D. 1982. Total Energy Requirements of the Wholesale Distribution of Foods. N.Z.E.R.D.C. Report P68. (Appendix H).

(4) Patterson, M.G. and Earle, M.D. 1982. Total Energy Requirements of the Household Preparation and Storage of Foods. N.Z.E.R.D.C. Report P69. (Appendix I).

(5) Patterson, M.G. and Earle, M.D. 1982. Total Energy Requirements of Food Retailing. N.Z.E.R.D.C. Report P70. (Appendix J).

(6) Patterson, M.G. and Earle, M.D. 1984. Energy Use in the New Zealand Food System. N.Z.E.R.D.C. Report (In Press).

Another paper that summarises much of Part A of this thesis, has also been published: Patterson, M.G. 1983. Estimation of the Quality of Energy Sources and Uses. Energy Policy 11:4 346-359 (this paper appears in Appendix A).

ACKNLOWEDGEMENTS

I wish to acknowledge that a thesis of this scale and scope could not be undertaken without the help, assistance and influence of a great number of people. Although it is impossible to specifically mention all of these people and the nature of their assistance, I do wish to sincerely thank them.

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An acknowledgement and a thank you, is also due to all of the people who provided technical assistance in the staffs of the Computer Centre, Food Technology Research Centre and the Library at Massey University. Vivienne Mair's and Trish Blandford's assistance in competently typing and word processing this difficult manuscript is especially appreciated.

I also wish to acknowledge that my ability to present this thesis for examination, depended on funding provided by the New Zealand Energy Research and Development Committee to Massey University under contract 3123. Much of the data and information gained from work on this contract, formed the basis of this thesis. I therefore wish to thank the NZERDC for providing me with the opportunity to undertake this research, and subsequently use it as the basis for this thesis.

I am also grateful for the information and assistance, given to me by literally hundreds of people in government agencies, and in various business establishments. The data provided by these people, during several surveys, were particularly valuable.

Finally, my sincere thanks and indebtedness is given to my family and my wife Ann, for their continual encouragement and support. Without this, this thesis would have never reached fruition.

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